APPENDIX A: RESOURCE EQUIVALENCY ANALYSIS

Background

There are two basic approaches to measuring the compensation for natural resources injuries. One is to focus on the demand side, the "consumer valuation approach"; the other is to focus on the supply side, the "replacement cost" approach. In the former, we seek to measure the monetary value that the public puts on the natural resources (i.e., how much the public demands the services of natural resources); in the latter, we seek to measure how much it costs to replace the natural resource services that the public loses as a result of the injury (i.e., how much it costs to supply natural resource services). See the Glossary for complete definitions of some of the terms used here.

FIGURE 1: Consumer Valuation versus Replacement Cost Approaches for Natural Resource Damage Calculation

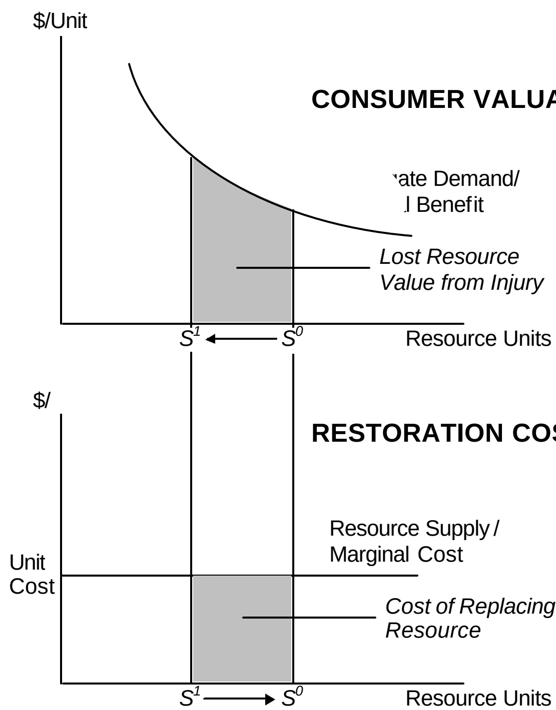

Figure 1 illustrates the difference between these two approaches. In both graphs, the supply of natural resources shifts from S^0 to S^1 as a result of an incident (e.g., oil spill, sediment discharge into a stream, illegal removal of vegetation). The shaded area in the top graph illustrates the dollar value of the resource loss as measured by the monetary payment that would make the public indifferent to the incident. For example, if each individual in a 30 million person society would need a $.05 payment (on average) to make them indifferent to the resource loss, the shaded area in the top graph would equal $1.5 million. Because the difficulty in observing market prices that reveal the level of cash payment that would compensate individuals for resource losses, the quantitative characteristics of the demand curve(s), and consequently the size of the shaded area in the upper graph, are difficult to measure. Contingent Valuation (CV) and other types of analyses are designed to estimate this dollar value. These methodologies typically involve large surveys and can be costly.

The lower graph illustrates a replacement cost approach. Beyond noting that the injured resource has value, the actual extent to which the public values it is not directly considered. Instead, the determination of adequate compensation depends on the level of natural resource provision (versus monetary payments) that compensates society for what it has lost as a result of the incident. The cost of providing this compensation becomes the estimate of damages. Resource Equivalency Analysis (REA) is the primary methodology for conducting this type of measurement in natural resource damage assessment. It is depicted by a resource supply shift in the lower graph from S^1 back to S^0. The shaded area is the total monetary cost of funding the supply shift. For example, if 2 acres of wetland enhancement are estimated to compensate for an incident that temporarily reduced the service value of 1 acre of wetland habitat, the cost of performing 2 acres of wetland enhancement becomes the estimate of damages.

It is clear from Figure 1 that the public's valuation of the resource (the shaded area in the top graph) is not necessarily equal to the total replacement cost (the shaded area in the bottom graph). This is especially true when unique resources or rare species are involved, as the slope of the aggregate demand curve (top figure) may be much steeper due to resource scarcity. This would result in a much larger monetary payment being necessary to compensate the public. In such a case, the replacement cost approach of REA may result in damages far less than the losses as valued by the public. However, because it is easier and less costly to measure the total replacement cost than the total public value, REA has an advantage over other methods, especially for small to medium-sized incidents with minimal impact on rare species.

Resource Equivalency Analysis

In this assessment, REA has been used to determining compensatory damages. This method is relatively inexpensive and relies primarily on biological information collected in the course of determining natural resource injuries caused by the spill. It is consistent with approaches recommended in the language of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Oil Pollution Act of 1990 (OPA).

REA involves determining the amount of "natural resource services" that the affected resources would have provided had it not been injured, and it equates the quantity of lost services with those created by proposed compensatory restoration projects that would provide similar services. The unit of measure may be acre-years, stream feet-years, or some other metric. The size of the restoration project is scaled to the injury first; the cost of restoration is then calculated after the scaling has been done. The cost of restoring a comparable amount of resources to those lost or injured is the basis for the compensatory damages. In this sense, REA calculates the *replacement cost* of the lost years of natural resource services.

Future years are discounted at 3% per year, consistent with National Oceanic and Atmospheric Administration recommendations for natural resource damage assessments. Discounting of future years is done based on the assumption that present services are more valuable than future services. When it comes to natural resources, the question of whether or not society should value the present more than future is a philosophical question (e.g., one can recall the "greenhouse effect" and the question of how much expense we should incur today to preserve the future). However, the question of how much society actually discounts the value of future natural resources is an empirical one. The 3% figure is currently the standard accepted discount rate for natural resource damage assessments.

REA involves three steps: 1) the debit calculation, 2) the credit calculation, 3) the computation of the costs of restoration. These calculations may be done in a variety of ways, but the most common are to estimate the injury and the restoration benefits in terms of area years of habitat or animal years.

Habitat Example

For example, suppose a 10-acre area is degraded due to an oil spill such that it supplies only 30% of its previous habitat services during the year following the incident. In the second year after the incident, the habitat begins to recover, supplying 90% of its baseline services. By the third year it is fully recovered. In this case, the lost acre years of habitat services would be 70% x 10 acres x 1 year + 10% x 10 acres x 1 year = 8 acre years of habitat services. Figure 2 illustrates this example by showing the recovery path of the habitat over time.

As stated above, future years are discounted at a 3% rate, thus the injuries in the second year count a little less. Incorporating this, 7.97 acre years of habitat services were lost. This difference appears minimal here, but becomes significant (due to compounding) if injuries persist many years into the future.

The credit calculation focuses on the gain in habitat services that result from a restoration project. Creating acre years of habitat services is a function of both area and time. Hypothetically, compensation could involve taking 7.97 acres of land with no habitat value (e.g., a parking lot) and turning it into productive habitat for 1 year. Alternatively, we could achieve compensation by creating 1 acre for 7.97 years. In reality, most restoration projects involve taking previously degraded habitat (at another nearby location) and restoring it over a number of years, and maintaining it into the future.

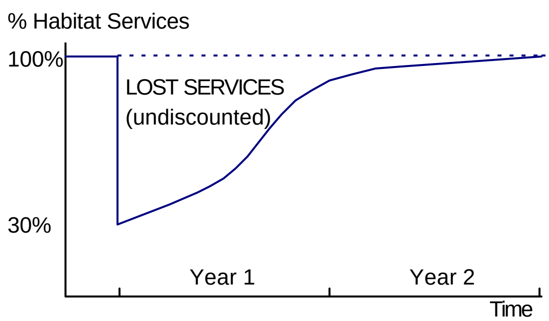

FIGURE 2: Biological Injury and Recovery

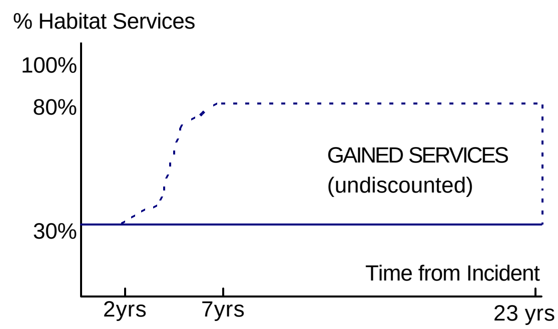

FIGURE 3: Restoration Trajectory/Credit

Suppose the restoration project improves the quality of a nearby degraded area, so that, if it previously provided only 30% of potential services, it would provide 80% of potential habitat services after restoration. Also suppose the project begins two years after the incident and it takes an additional 5 years for the 80% level to be achieved. Figure 3 provides an illustration of this restoration trajectory. In our hypothetical example, the project is expected to have a lifespan of 20 years. Note that, with future years discounted, the 20th year of the project (22-23 years after the incident) counts little; years after that are effectively completely discounted due to uncertainty regarding the future.

Mathematically, we seek to restore an area that will provide 7.97 acre years of services over the discounted 20-year phased-in life span of the restoration project. In this example, that would be an area of about 1.3 acres. That is to say, restoration of 1.3 acres for 20 years would compensate the public for the 7.96 lost acre years of habitat services due to the spill. Visually, the area identified in Figure 3 (multiplied by the affected acres and calculated to measure the present discounted value) should equal the area identified in Figure 4 (again, multiplied by the acres targeted for restoration and calculated to measure the present discounted value, thus discounting future years).

The percentage of habitat services lost (or gained, in the case of the restoration project) may be measured in a variety of ways. For our hypothetical oil spill case, three examples might include (1) the use of a habitat-wide evaluation index, (2) the use of one or more surrogate species, or (3) the use of an estimate based on the degree of oiling. Care must be taken when using a surrogate species to represent the entire affected habitat. Ideally, this surrogate is the population of one or more species that is immobile (that is, the animals do not move easily in and out of the affected area) and that has significant forward and/or backward ecological links to other species in the affected ecosystem. For example, the population of red crossbills, a bird that feeds primarily on pine cone seeds and migrates erratically from year to year, would be a poor surrogate for measuring injuries to a streambed. The aquatic macroinvertebrate community within the stream, however, provides an ideal surrogate, as they play a key role in the streambed food chain. Likewise, on the restoration side, care must taken when the project targets one or a few species rather than the entire habitat. Ideally, a project that seeks to restore the population of a key indicator species will also benefit the entire habitat and, thus, other species as well. Indeed, such projects typically focus directly on habitat improvements. However, it is important to verify that such a species-centered project is indeed benefiting the entire habitat.

Animal Example

When the injury is primarily to individual animals rather than a complete habitat, the REA may focus on lost animal-years. For example, suppose an oil spill causes negligible injury to a body of water, but results in the death of 100 ducks. Using information about the life history of the ducks (e.g., annual survival rate, average life expectancy, average fledging rate, etc.), we can estimate the "lost duck years" due to the spill. On the credit side, we can examine restoration projects designed to create duck nesting habitat and scale the size of the project such that it creates as many duck years as were lost in the incident.

Restoration Costs = Natural Resource Damages

Once the proposed restoration projects are scaled such that they will provide services equal to those lost due to the incident, the cost of the projects can be calculated. Note that this is the first time dollar figures enter the REA process. Until now, all the calculations of the "equivalency" have been in terms of years of resource services. The cost of the restoration projects is the compensatory damage of the incident.

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For another explanation of the REA methodology (in its more specific form for habitats), see "Habitat Equivalency Analysis: An Overview", prepared by NOAA. Copies of this document are available at http://www.darp.noaa.gov/library/pdf/heaoverv.pdf.

GLOSSARY

Aggregate demand

the demand of all consumers combined; e.g., if there are 20,000 people in a town and each person demands two pieces of bread each day, the aggregate demand is 40,000 pieces of bread per day.

Compensatory restoration

a restoration project which seeks to compensate the public for temporal or permanent injuries to natural resources; e.g., if a marsh is injured by an oil spill and recovers slowly over ten years, a compensatory project (which may be off site) seeks to compensate the public for the ten years of diminished natural resources.

Discount rate

the rate at which the future is discounted, i.e., the rate at which the future does not count as much as the present; e.g., a dollar a year from now is worth less than a dollar today; if the bank offers a 3% rate, whereby $1.00 becomes $1.03 in one year, the future was discounted at 3%.

Primary restoration

a restoration project which seeks to help an injured area recover more quickly from an injury; e.g., if a marsh is injured by an oil spill and would recover slowly over ten years if left alone, a primary restoration project might seek to speed the recovery time of the marsh and achieve full recovery after five years.

Replacement cost

the cost of replacing that which was lost; e.g., if fifty acre-years of habitat services were lost due to an oil spill, the cost of creating fifty acre-years of similar habitat services would be the replacement cost.

FINAL REPORT

Acute seabird and waterfowl mortality resulting from the *M/V Cosco Busan* oil spill, November 7, 2007

Prepared for:

California Department of Fish and Game
Office of Spill Prevention and Response

By:

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December 3, 2009

1.0 INCIDENT AND RESPONSE

Introduction
This report provides an estimate of total mortality from the *Cosco Busan* oil spill for all seabird and waterfowl species, both inside San Francisco Bay and on the outer coast. It includes background on the response with regard to bird observations and collection, details on several field studies conducted to understand the fate of beached birds, a description of the use of the Beached Bird Model used to estimate mortality, and the results of those calculations.

Shorebirds and landbirds are not addressed in this report, since very few of either of these groups were collected. The trustees conducted a separate estimation of shorebird mortality that is not included in this report.

Incident Description

At 8:30 am on the morning of November 7, 2007, the container ship *M/V Cosco Busan* struck the Delta Tower of the Bay Bridge in San Francisco Bay, California. The accident opened a large gash in the hull of the vessel, puncturing two port fuel tanks and reportedly releasing 58,000 gallons of bunker fuel oil onto a flood tide.

Oiling Pattern

The oil slick moved back and forth between the Golden Gate and the East Bay on successive tidal cycles, affecting shorelines along both the central Bay and the outer coast. In the East Bay, various degrees of shoreline oiling occurred from the San Rafael Bridge in the north to the Oakland Inner Harbor Channel in the south. In the northwest Bay, oiling was concentrated in the vicinity of San Quentin, the Tiburon Peninsula, Richardson Bay, Angel Island, and the Marin Headlands near the Golden Gate Bridge. In the southwest Bay (west side of the Bay south of the Golden Gate Bridge), sporadic oiling occurred on shorelines around Ft. Mason and the Embarcadero, as well as on Alcatraz and Yerba Buena Islands. Along the outer coast, shoreline oiling was detected from Limantour Spit in the north to Pillar Point Harbor in the south.

Beached Bird Search and Collection
The oil spill response was managed through a Unified Command established jointly by the United States Coast Guard, the California Department of Fish and Game's Office of Spill Prevention and Response (OSPR), and the responsible party. The response utilized the Incident Command System, which was comprised of a number of sections and branches and involved coordination with other state, federal, and local agencies, which is standard procedure during an oil spill response. The Wildlife Operations Branch within the Operations Section was responsible for conducting search and collection of live and dead oiled wildlife which consisted primarily of birds.

The search and collection effort was comprehensive and extensively documented. Teams organized by Wildlife Operations usually consisted of pairs of individuals from multiple agencies, including the Oiled Wildlife Care Network, International Bird Rescue Research Center, California Department of Fish and Game (Office of Spill Prevention and Response), United States Fish and Wildlife Service, and East Bay Regional Park District. Additional search and collection efforts were conducted by other agencies and organizations, as well as by members of the general public. Search and collection effort by other agencies, including Richardson Bay Audubon Society, BeachWatch (on the outer coast), Point Reyes Bird Observatory (in the Bolinas area), and Angel Island State Park (at Angel and Alcatraz Islands) were also used in the analysis.

Readily accessible beaches were searched one or more times per day between November 9 and 19, and then less frequently through early December. The spill response area covered about 300 km of coastline, including both accessible and inaccessible coastline inside and outside of the Bay. Figure 1 shows the length of coastline searched each day during the spill response.

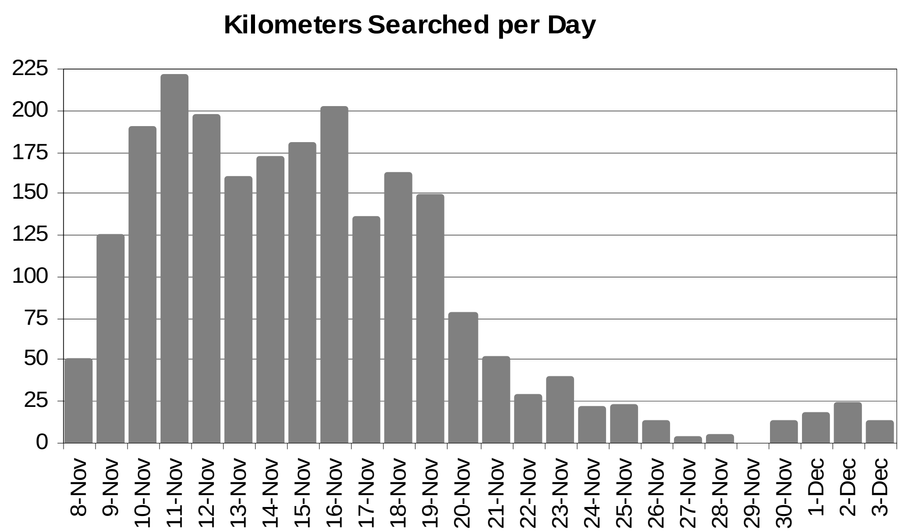

Figure 1. Coastline searched each day by Wildlife Operations search and collection teams, and by teams from Richardson Bay Audubon Society, BeachWatch, Point Reyes Bird Observatory, and Angel Island State Park.

Aerial Surveys of Birds at Risk

As part of the oil spill response, aerial surveys were conducted by the University of California, Santa Cruz (UCSC) wildlife survey team in the area affected by or likely to be affected by the oil spill. Observers flew in a Partenavia Observer aircraft using protocols described by Briggs et al. (1985) and Henkel et al. (2007). Two experienced observers, one on either side of the plane, continuously surveyed a 75-meter strip transect for seabirds and oil. A third person acted as navigator, recording spatial and ambient data onto a laptop computer connected to a Garmin 12XL GPS. The software program dLog2 (Ford 2004) was used to record the latitude, longitude, position, time, and other data at 5-

second intervals. Bird observations were recorded both on the logging computer and hand-held tape recorders. Surveys were flown at an altitude of 200 ft (~60m) and a speed of 90-100 kt (167 km/hr). All birds were identified to lowest possible taxon, and their behavior and time of observation noted.

Aerial surveys were flown on five different days, November 8, 9, 13, 15, and 21 (see Figure 2 below). The areas surveyed by day were:

November 8: Surveys were conducted from northern Monterey Bay to Point Reyes, and then from Point Reyes to the longitude of the Farallon Islands. Within the Bay, transects were conducted in the central Bay, from the Richmond-San Rafael Bridge to the San Francisco-Oakland Bay Bridge.

*November 9: S*urveys were conducted along the outer coast from Pillar Point to Point Reyes, and in San Pablo Bay, from the west shoreline to the NE corner of the Bay and south to the Richmond-San Rafael Bridge.

November 13: Surveys were conducted in Drakes Bay, from Chimney Rock to Limantour Beach, and from Half Moon Bay to Monterey Bay. Within San Francisco Bay, transects were flown from the Oakland Airport to the Dumbarton Bridge.

*November 15: S*urveys were conducted along the outer coast from the east end of the Point Reyes Headlands south to Point Bonita.

November 21: Surveys were again flown from the east end of the Point Reyes Headlands to Point Bonita. Within the Bay, Richardson Bay and the central Bay west of Alcatraz Island were surveyed.

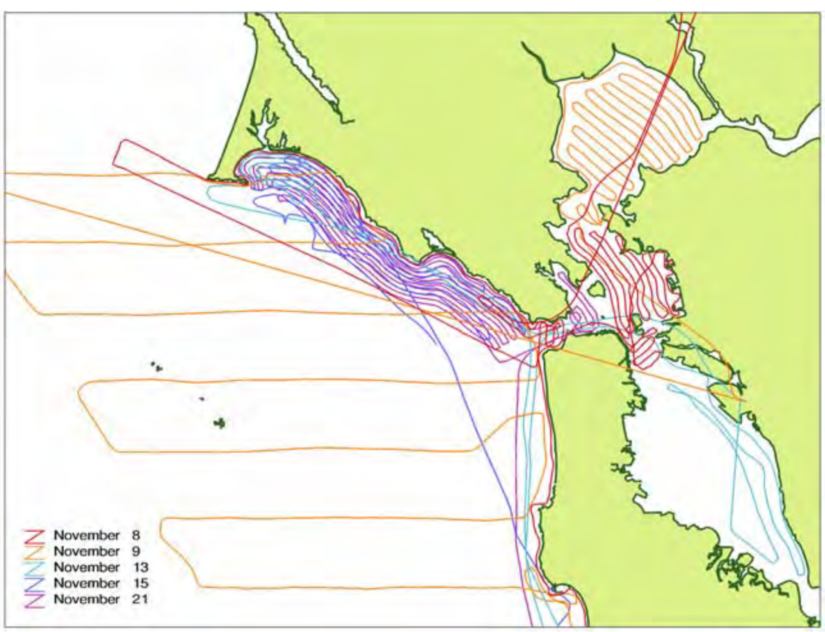

Figure 2. Aerial survey flight lines for five days in November 2007.

As is usual with seabirds and waterfowl, some of the surveyed area was densely populated and other areas were virtually empty. Waterfowl densities were relatively high throughout San Pablo Bay, especially along the northeast edge near the mouth of the Carquinez Straits. Densities were also high on the east side of the Bay south of the Dumbarton Bridge. In the east-central Bay, birds were concentrated within 1-2 miles of the shoreline in an arc extending from Richmond Inner Harbor to the base of the Bay Bridge. In the west-central Bay, moderate densities of birds were observed in Richardson Bay and on the north side of the Tiburon Peninsula (Figure 3).

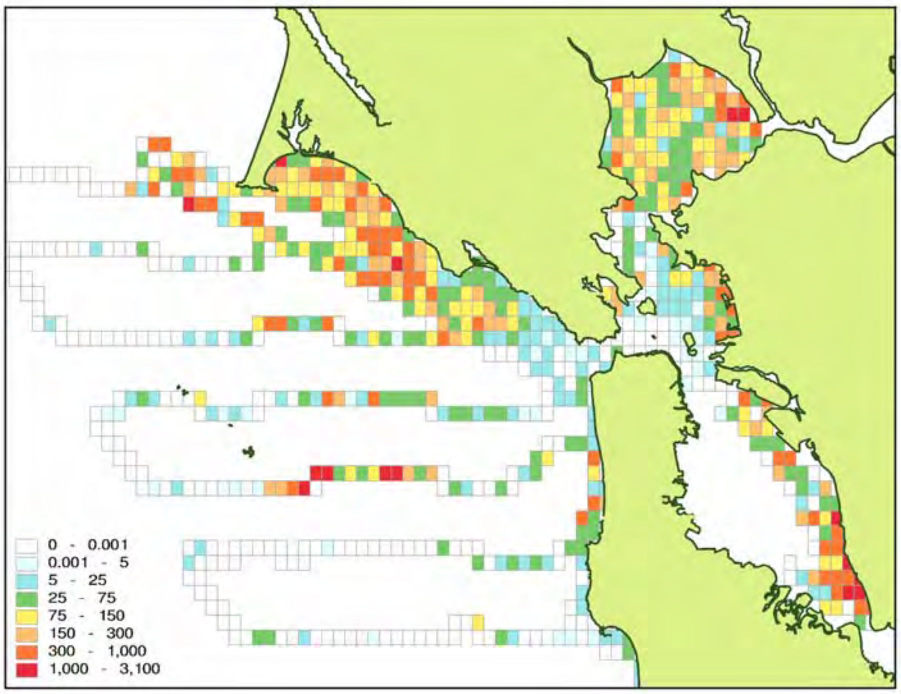

Figure 3. Density of the five most common taxa combined, based on all 5 days of aerial surveys. Birds include Common Murre, Western Grebe, cormorants, scoters and scaup. Observations and tracklines were binned into 1 minute latitude longitude blocks for display. Warmer colors (red and orange) indicate higher densities than cooler colors (blue and green). Density cut-points are based on geometric quantiles.

Along the outer coast, high bird densities were encountered throughout Drake's Bay, especially seaward of Bolinas. Further offshore, high density patches occurred southwest of Pt. Reyes and southeast of the Farallon Islands. The most common species encountered were the Western Grebe (12,928 birds across all five surveys), and the Common Murre (9,899 birds). Western Grebes tend to be found relatively near the shoreline along the outer coast, whereas Common Murres tend to occur further offshore. Sea ducks, notably Surf Scoters (5,778 birds) and scaup (5,688 birds) were common, especially inside the Bay. Cormorants (973) were ubiquitous both inside and outside of the Bay. Marbled Murrelets (86) were sighted in Drake's Bay and south toward the Marin headlands.

Bird Recoveries

A total of 1,547 birds, both alive and dead, were recovered within the Bay during the weeks following the spill. The peak in live bird collections occurred a few days after the spill, tapering off throughout the second half of November (Figure 4). The delayed pattern in the deposition of dead birds mirrors the pattern of live bird collections, a pattern typical of acute oil spills (Ford 2006). The lag in the deposition of dead birds probably occurs because oiled birds, although hypothermic and unable to forage, may take days to die. Many species do not come ashore, or are difficult to capture, until they are near death.

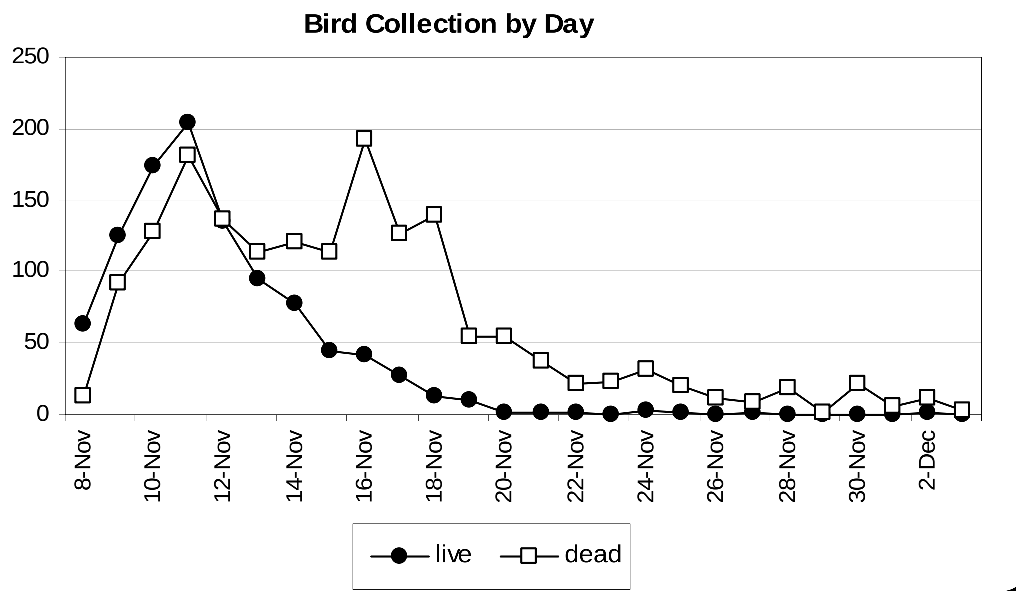

Figure 4. Number of live and dead birds collected by date during the *Cosco Busan* spill response.

The temporal pattern of deposition, combined with geographic location, is shown in Figure 5 for areas inside the Bay. The Fort Point area was affected shortly after the spill occurred, but deposition along the Bay side of the San Francisco Peninsula was low thereafter. The heaviest deposition inside the Bay was in the Richmond Inner Harbor area (roughly Pt. Potrero to Stege Marsh) during the 10-12 November period. High deposition continued in the East Bay from Richmond to Emeryville until 25-27 November. Deposition south of the Bay Bridge toward Alameda occurred later than impacts further north in the East Bay, and ended by 16-18 November. On the western side of the Bay, the Tiburon area was heavily affected during the 10-12 November period. Deposition in the area from the Golden Gate to San Quentin was episodically high until the response ended in December.

On the outer coast, a total of 1,295 birds were recovered during the response. The highest levels of deposition occurred immediately after the spill, west and north of the Golden Gate in the Tennessee Cove to Kirby Cove area. The spatial and temporal pattern of bird recoveries on the outer coast is shown in Figure 6. High deposition also occurred immediately after the spill in the Ocean Beach to Fort Funston area. The oil and birds appear to have drifted steadily north, reaching the outer portion of the Pt. Reyes peninsula and Tomales Bay by the 16-18 November period.

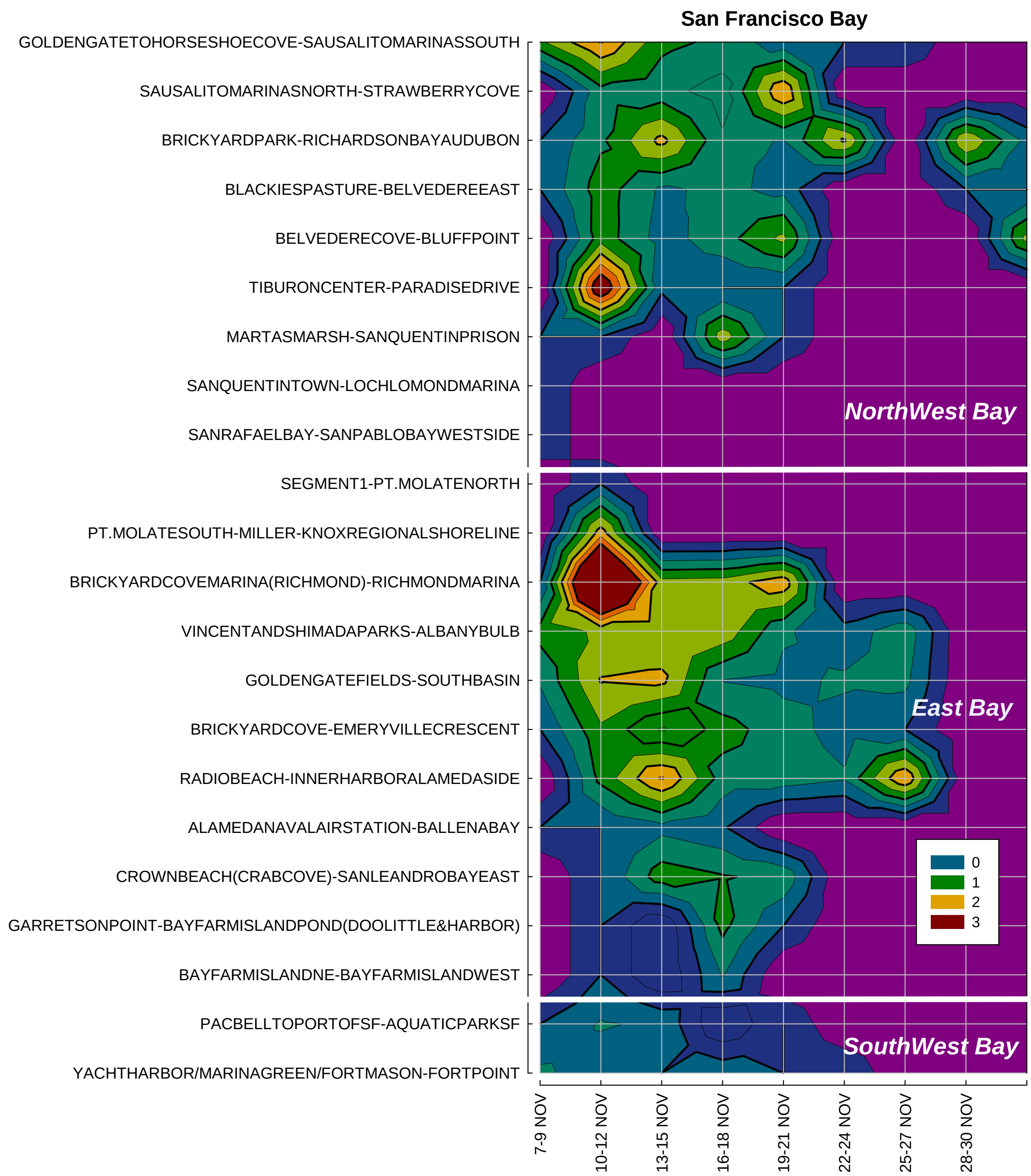

Figure 5. Number of birds recovered per km of search inside San Francisco Bay following the *M/V Cosco Busan* oil spill. The horizontal axis is date, the vertical axis is location. Segments are ordered in a clockwise fashion around the Bay, starting at the Golden Gate and ending at Fort Point. Contours were generated from a grid created by binning data for 5 consecutive shoreline segments over 3 day intervals. Grid cells containing less than 0.25 miles of search were ignored. The dark-violet background color indicates time/space regions with no search effort. Red and orange indicates high numbers of birds recovered per km searched.

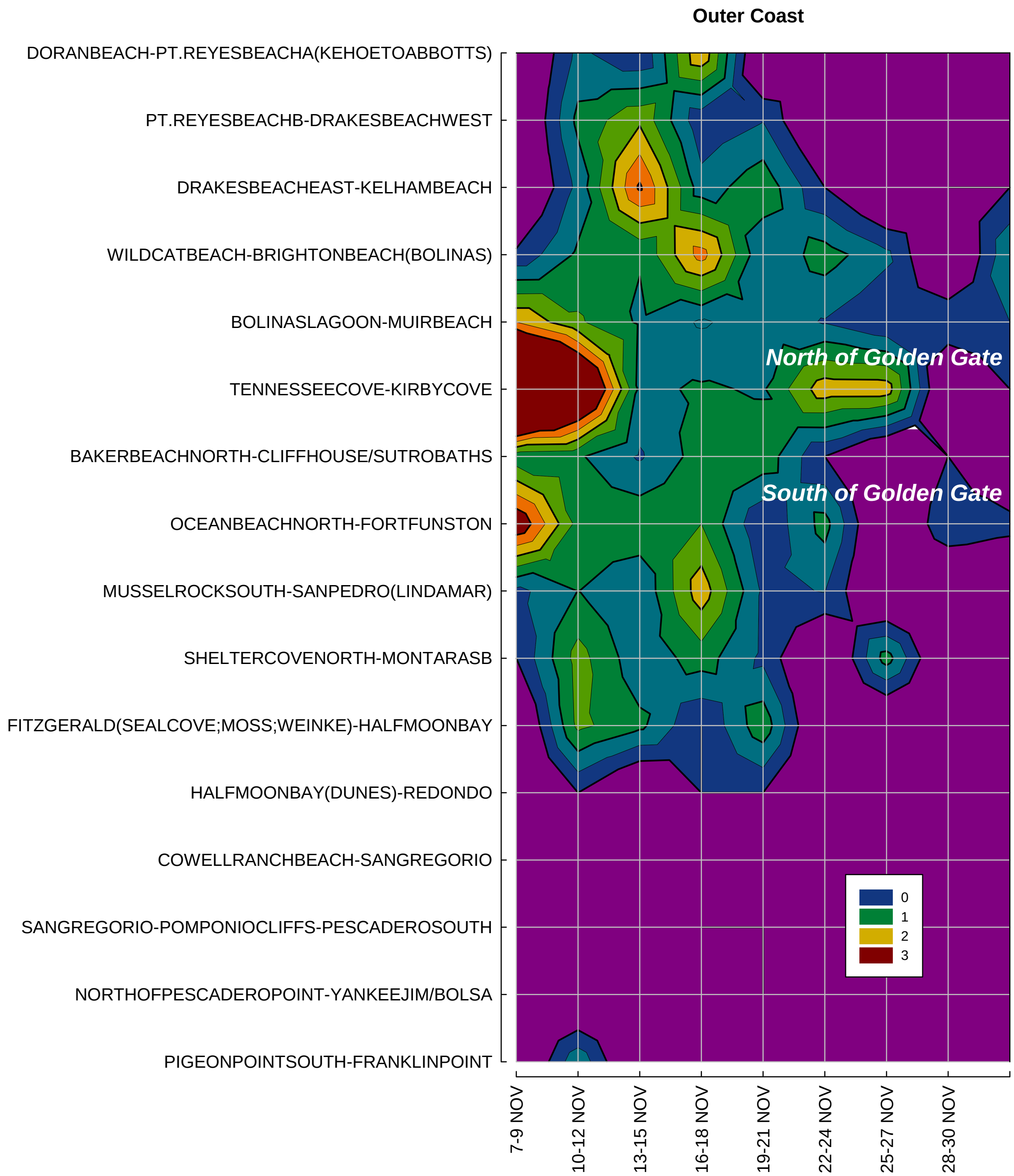

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Figure 6 Number of birds recovered per km of search on the outer coast following the *Cosco Busan* oil spill. The horizontal axis is date, the vertical axis is location. Segments are ordered in a north to south sequence, with the mouth of San Francisco Bay indicated by the dashed white line. Contours were generated from a grid created by combining data for 5 consecutive segments over 3 day intervals. Grid cells containing less than 0.25 miles of search effort were ignored. The dark-violet background color indicates time/space regions with no search effort. Red and orange indicates high numbers of birds recovered per km searched.

2.0 STUDIES TO DETERMINE BEACHED BIRD MODEL PARAMETERS

The Beached Bird Model (BBM) requires estimates of the rates of several processes in order to estimate the deposition rate of dead and dying birds. These processes are:

- Carcass persistence on shorelines
- Searcher efficiency when collecting dead and injured birds
- Carcass deposition under non-spill (background) circumstances

The values of these parameters can vary among sites or among times of year, and it is important that these parameter estimates be based on circumstances as similar as possible to the incident being analyzed. For the damage assessment for the *Cosco Busan*, the trustees and responsible party's representatives agreed to carry out four studies that could potentially improve the quality of the data used in the BBM analysis:

- Efficiency of searchers collecting birds along San Francisco Bay shorelines
- Persistence rates of all sizes of carcasses within San Francisco Bay
- Persistence rates of small carcasses on the outer coast north of the Golden Gate
- Background carcass deposition at selected beaches within San Francisco Bay

The design and results of these studies are presented in the following sections.

2.1 Searcher Efficiency on Central San Francisco Bay Shorelines

Rationale

It is surprisingly easy for searchers to miss beached birds. Debris or wrack filled beaches are visually difficult environments, and birds can be hidden in small depressions, blend in with other debris, or be too far away to recognize. The proportion of the birds which searchers actually find is termed 'searcher efficiency', and is an important parameter for the BBM.

During the *Cosco Busan* spill response, about half of the bird carcasses collected were recovered inside San Francisco Bay. We are not aware of any searcher efficiency studies that have been undertaken inside a bay, and there are no existing data directly applicable to the circumstances of the *Cosco Busan* spill. A searcher efficiency study was carried out as part of the assessment of the 1997 *Kure* oil spill (Ford et al. 2002), but that study addressed only beaches on the outer coast, which are very different from shorelines within San Francisco Bay. In order to generate BBM estimates of *Cosco Busan* impacts, we used searcher efficiency data based on the *Kure* response for the outer coast, and directly measured, through this study, searcher efficiency inside San Francisco Bay.

Study Design

The study was designed to approximate actual conditions during the response for the *Cosco Busan* to the maximum degree that was practical. Teams of searchers, many of whom had participated in the bird recovery effort during the *Cosco Busan* response, also participated in this experiment. During the spill response, searchers usually worked in teams of two. This study was carried out by fifteen teams (30 people total), including representatives of the responsible party, volunteer members of the public, government agency personnel, and contract biologists. Surveys were conducted over a span of three days. Each day, five teams surveyed four different beaches.

The study was conducted in early March 2009, when daylight and tidal conditions were similar to those during the spill event, November 2007, along portions of the Bay shore that had been affected by the *Cosco Busan* oil spill. Twelve beaches were surveyed, most of which had been surveyed during the spill and again during the carcass persistence study inside the Bay in December 2008 (Table 1, Figure 7). Beaches were chosen based on accessibility, shoreline type, and location within the Bay. In Table 2, classification of these segments in terms of their Environmental Sensitivity Indices (ESI) is compared to the relative frequency of ESI classifications within the entire response area (Petersen et al. 2002). The shoreline segments used in the searcher efficiency study comprised a representative subset of the shoreline habitats found within the area affected by the spill.

Table 1. Study sites and carcasses used in the Bay searcher efficiency study.

Shoreline Segment	Side of Bay	When Surveyed	Carcasses Initially Deployed	Carcasses used in Calculations
Bothin Marsh	West	Day 1	11	11
Brickyard Cove	East	Day 1	7	7
Shimada Friendship Park	East	Day 1	8	7
North Basin	East	Day 1	8	8
Brickyard Park	West	Day 2	6	4
Paradise Cay	West	Day 2	8	8
Stege Marsh	East	Day 2	11	10
Radio Beach	East	Day 2	10	8
Horseshoe Cove	West	Day 3	8	7
Blackie's Pasture	West	Day 3	12	12
Pt. Isabel	East	Day 3	9	9
South Basin	East	Day 3	9	9
TOTAL			**107**	**100**

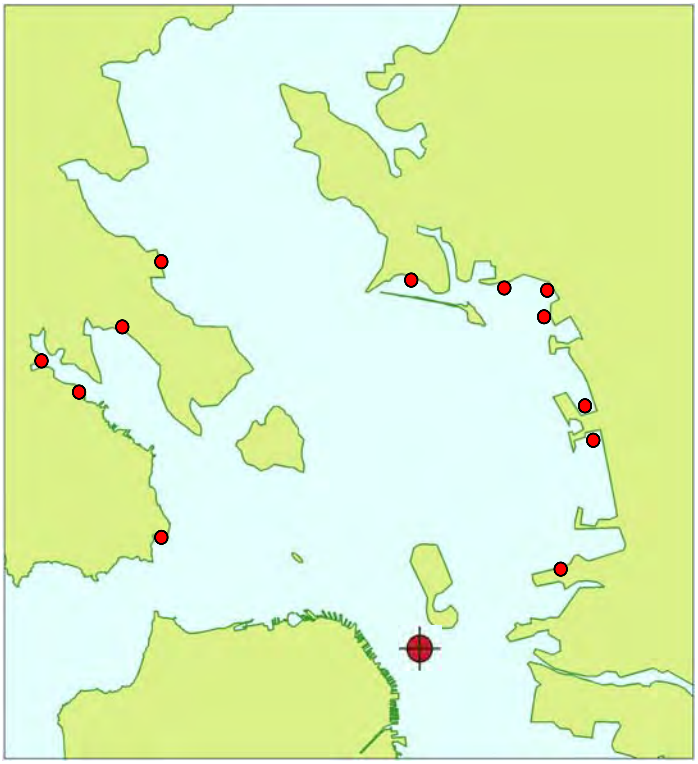

Figure 7. Approximate location of shoreline segments used for searcher efficiency study. Quartered circle is spill site.

Table 2. The percentages of Bay shorelines of various ESI types found within the area used in Beached Bird Model analyses compared to the percentages occurring in the segments used in the searcher efficiency study (SE) and the Bay carcass persistence study (Pers).

MODELED AREA	Overall	SE	Pers.
Exposed Rocky Shore	5.6%	-	3.1%
Exposed Wave-cut Platform	0.0%	-	-
Fine to Medium Sand Beach	1.8%	-	0.2%
Coarse Sand Beach	1.8%	-	0.2%
Gravel Beach	3.1%	-	-
Riprap	11.6%	10.6%	10.2%
Exposed Tidal Flat	1.8%	-	-
Sheltered Man-made Structure	2.0%	-	-
Sheltered Riprap	4.9%	10.5%	11.4%
Sheltered Tidal Flat	66.9%	78.2%	74.3%
Salt or Brackish Marsh	0.4%	0.6%	0.4%

Approximately fifty carcasses were used for the study, including waterfowl, grebes, and other species found commonly during the spill (Table 3). The range in body sizes of study birds was roughly comparable to that of birds recovered in the Bay. Using average species weights, 14 of the study birds were small and 83 were large, corresponding to 14% small and 83% large (Ruddy Ducks were excluded from this calculation since their average species weight straddles the 500g large/small cutoff). By comparison, 79% of the birds recovered in the Bay were large birds. Since small birds tend to be more difficult to find than large birds (Ford et. al 2002), a slight bias toward using larger birds in the study could have resulted in a slight overestimate of searcher efficiency.

Bird carcasses were placed on study beaches at randomized intervals based on a uniform random distribution ranging from 5 m to 105m (i.e. the mean distance between carcasses was 55m). A minimum distance of 5m ensured that carcasses could be uniquely identified using only GPS coordinates. Carcasses were placed randomly between the top of the beach and the high tide line, with the constraint that carcasses be placed high enough that they did not rewash during the day. The total number of birds placed on each beach varied between 6 and 12, depending on beach length and the randomized distance between carcasses. GPS locations were recorded for each bird, and specimens were tagged using inconspicuous black or translucent white zip ties, depending on which matched the birds' leg color more closely. Carcasses were deployed each day and picked up at the end of each day. All carcasses were in place by 9:30 am, about an hour after high tide.

Each day of the study, each survey team began with a different beach segment and proceeded to the other segments in a clockwise direction around the Bay, minimizing the chance of two teams being on the same beach simultaneously. Surveyors navigated to the respective study sites on their assigned day to conduct the surveys. Survey teams were directed to start searching any time after 10am and to finish as close to 3pm as possible. The maximum time allotted for a team of searchers to complete the four beaches was 3 hours, plus travel time.

Table 3. Seabird and waterfowl taxa used in the Bay searcher efficiency study. The Count column indicates the number of actual *deployments*, since some unscavenged carcasses were used on multiple days. Seven carcasses that were *not* recovered at the end of the day are *not* included in the table or used in the calculation of searcher efficiency. L = large; M = medium; S = small.

Taxa	Count
Waterfowl	
American Coot (L)	2
Bufflehead (S)	12
Mallard (L)	24
Ruddy Duck (M)	3
Scaup spp. (L)	3
Surf Scoter (L)	3
Seabirds	
Black-legged Kittiwake (S)	1
Brandt's Cormorant (L)	9
Clarks Grebe (L)	3
Common Murre (L)	16
Double-crested Cormorant (L)	1
Unid. Immature Gull (L)	2
Northern Fulmar (L)	4
Pacific Loon (L)	2
Rhinoceros Auklet (S)	1
Red-throated Loon (L)	2
Tufted Puffin (L)	1
Western Grebe (L)	8
Western Gull (L)	3
T0TAL	**100**

Once searchers arrived at a beach, they recorded the time and the location of the flag marker at the beginning of each transect. Searchers utilized the same methods for walking beaches that they used during the *Cosco Busan* response. When a carcass was located, it was left in place and not disturbed in any way. Searchers noted whether it had a black or white zip tie on the leg (identifying the bird as a survey bird), and recorded the GPS location and the condition of the bird. The location of the flag marker and the time at the ending point of the transect were recorded as each segment was completed. At the end of each day, data forms were collected from all survey teams and carcasses were retrieved and stored for possible use on subsequent days of the study.

Results
Carcasses that could not be located at the end of a given study day (a total of seven carcasses) probably had been removed by scavengers or members of the public. These carcasses were not used in calculations of searcher efficiency since we could not determine exactly when they disappeared.

Excluding these seven carcasses, a total of 100 carcass placements were made during the course of the study, with each carcass sought by five teams. Since there were 338 carcass 'finds' during the course of the study, the searcher efficiency rate for a two person team inside the Bay was estimated to be:

$$338 / 500 = 0.68$$

corresponding to a 68% chance of finding a carcass and a 32% chance of missing it.

Model Application
If finding a carcass is an independent random event, and if $\mathbf{p_1}$ is the probability that one searcher would miss a carcass, then $\mathbf{p_2}$ (the probability that two searchers would miss a carcass) is:

$$\mathbf{p_2} = \mathbf{p_1} * \mathbf{p_1} = 0.32$$

and therefore:

$$\mathbf{p_1} = \text{Sqrt}(0.32) = 0.57$$

Searcher efficiency for 1 searcher, $\mathbf{e_1}$, would therefore be:

$$\mathbf{e_1} = 1-0.57=0.43.$$

In general, if there were **n** searchers on a beach segment, then

$$\mathbf{p_n} = \mathbf{p_1} ** \mathbf{n}$$

and searcher efficiency for **n** searchers, $\mathbf{e_n}$, would be

$$(1) \quad \mathbf{e_n = 1 - p_n}$$

Although most searches were made by two person teams during the *Cosco Busan* spill response, some beaches were searched by only one observer or by more than two observers on a given day. In some cases the same beach was visited numerous times by different teams over a 24 hour period. For BBM runs, the probability that a carcass would be found on a particular day on a particular beach was estimated using Equation (1), where **n** was assumed to be the total number of searchers who visited that segment on that day.

2.2 Persistence of Seabird Carcasses on Central San Francisco Bay Shorelines

Rationale

There are few data available to characterize the persistence of bird carcasses in bays and estuaries. A study of this type was carried out as part of the damage assessment for the 1997 *Kure* oil spill in Humboldt Bay, but San Francisco Bay and Humboldt Bay are very different in terms of their shoreline characteristics. Much of Humboldt Bay is fringed by intact marshes which differ markedly from the shoreline habitats of central San Francisco Bay where shorelines tend to be narrow strips of marsh, grass, or rip-rap, and are often located near residential or industrial areas. The trustees and the responsible party therefore agreed to carry out a study of the persistence of seabird and waterfowl carcasses in December, 2008, on central San Francisco Bay shorelines.

Study Design and Methods

During the spill, most birds that beached within the Bay were recovered in the East Bay between the Bay Bridge in the south and Brooks Island in the north, or in the West Bay in the vicinity of Richardson Bay and the Tiburon Peninsula. We selected nine representative sites along the eastern and nine along the western shorelines of the Bay. (Table 4, Figure 8). Each of these sites was easily accessible by car, at least 500 m long, and had been visited by searchers during the course of the *Cosco Busan* spill response. Classification of these segments in terms of their Environmental Sensitivity Indices (ESI) is compared to the relative frequency of ESI classifications within the entire response area in Table 2. The shoreline segments used in the study were chosen so as to be a representative subset of the shoreline habitats found within the area affected by the spill.

Table 4. Shoreline sites used in persistence studies for San Francisco Bay

Western Shoreline Segments	Eastern Shoreline Segments
Horseshoe Cove	Shimada Friendship Park
Bothin Marsh	Stege Marsh
Strawberry Cove	Pt. Isabel South
Brickyard Park	Albany Bulb
Richardson Bay Audubon	North Basin
Blackie’s Pasture	Berkeley Marina
Keil Cove	Brickyard Cove
Romberg Tiburon Center	Emeryville South
Paradise Cay	Radio Tower Beach

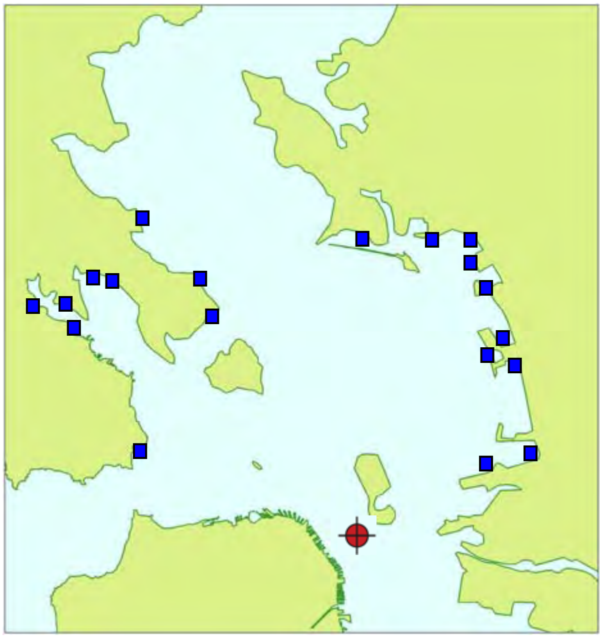

Figure 8. Approximate location of shoreline segments used for San Francisco Bay persistence study. Quartered circle is spill site.

A total of 90 carcasses from a range of species were used in the study (Table 5). For analysis, carcasses were categorized as either large or small using a weight cutoff of 500 g (Ford and Zafonte, in press).

Table 5. Species and sizes of bird carcasses used in San Francisco Bay persistence study.

Species	Large	Small	Total
American Coot	1	0	1
Black-crowned Night Heron	0	1	1
Brandt's Cormorant	13	0	13
Brown Pelican	2	0	2
Canada Goose	1	0	1
California Gull	4	0	4
Common Loon	2	0	2
Common Murre	18	18	36
Double-crested Cormorant	6	0	6
Eared Grebe	0	1	1
Heermann's Gull	0	1	1
Northern Fulmar	1	1	2
Snowy Egret	1	0	1
Surf Scoter	3	0	3
Western Grebe	4	1	5
Western Gull	10	1	11
TOTAL	**66**	**24**	**90**

Five carcasses were placed in randomized locations at each of the sites. Placement was based on a uniform random distribution of distances (0 m to 100 m) between carcasses, so that the average spacing was 50 m. Carcasses, each uniquely identified by a numbered poultry band placed on either a leg or wing, were placed randomly between the low and the high tide lines. An inconspicuous, one-inch square wooden block, marked with the carcass band identification number, was also placed beneath each carcass to help determine whether missing carcasses were rewashed or removed by scavengers.

Carcasses were checked on a daily basis for the first week. For each carcass that was found, we recorded the species, band identification number, whether the wooden block was present, which body parts were still present, whether the remains were articulated or fragmentary, and their latitude/longitude location. Carcasses still remaining after a week were checked periodically by volunteers, ideally on a twice weekly basis for up to three weeks after their placement.

Based on discussions with searchers who had worked in this area during the spill response, and a review of the photographs of birds collected, it was determined that fragmentary carcasses without organs or pectoral muscles would not have been recovered and classified as spill related mortality. This condition was therefore used as the criterion for a carcass being classified as 'present' or 'missing'.

Results

Persistence rates for small and large carcasses for all 18 sites in central San Francisco Bay are shown in Table 6 and in Figure 9. Large carcasses persisted longer than did smaller carcasses, as was found by Ford and Zafonte (in press) during similar studies conducted for the *Kure* and *New Carissa* oil spills. Both large and small carcasses disappeared more rapidly than during the *New Carissa* study, and more slowly than during the *Kure* study. Small carcasses disappeared more rapidly within the Bay than they did during the *Cosco Busan* persistence study on the outer coast (see below).

Table 6. Persistence of large and small carcasses, 18 San Francisco Bay study sites.

Day	Large Carcasses		Small Carcasses	
	Number Fragmented or Missing	Proportion Present	Number Fragmented or Missing	Proportion Present
0	0	1.000	0	1.000
1	13	0.8030	13	0.7083
2	3	0.7576	1	0.6667
3	6	0.6667	3	0.5417
4	6	0.5758	0	0.5417
5	1	0.5608	1	0.5000
6	1	0.5455	1	0.4583
7	1	0.5303	0	0.4583
8	3	0.4848	2	0.3750
9	2	0.4545	1	0.3333
10	0	0.4545	1	0.2917
11	3	0.4091	1	0.2500
12	0	0.4091	0	0.2500
13	0	0.4091	0	0.2500
14	0	0.4091	0	0.2500
15	6	0.3182	1	0.2083
16	1	0.3030	1	0.1667

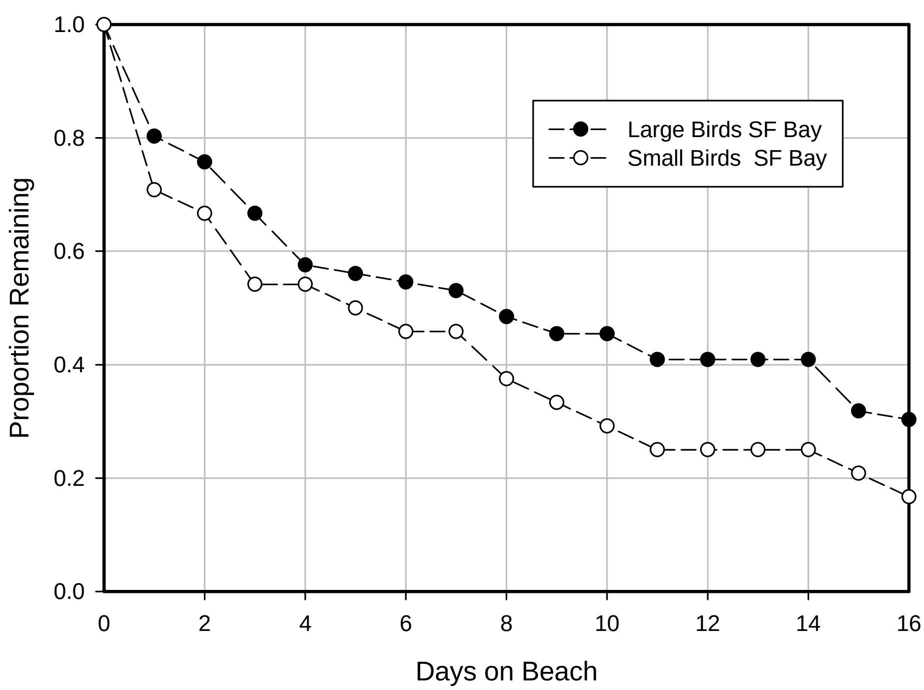

Figure 9. The proportion of carcasses that searchers during the spill response would have recovered as a function of the number of days since the carcasses were placed. Open circles indicate results for small carcasses (≤500 g), and solid circles indicate results for large carcasses (>500 g).   Data are for the interior of San Francisco Bay.

Model Application

[See analogous discussion on model application in Section 2.3 below.]

2.3 Persistence of Seabird Carcasses on Outer Coast Beaches

Rationale

The rate at which the carcasses of seabirds are removed by scavengers or tidal action varies widely, and the rate is often best measured in the actual area affected by a particular oil spill (Ford 2006). As part of the damage assessment for the *S.S. Jacob Luckenbach*, carcass persistence studies were carried out both in Drake's Bay and on the San Mateo Peninsula using murre size carcasses weighing about 1,000 g. Since other studies (Ford and Zafonte, in press) have shown that smaller carcasses may persist for significantly less time than larger carcasses, the persistence rate for murre size carcasses measured during the *Luckenbach* study are not necessarily applicable to smaller seabirds such as Marbled Murrelets.

During the response to the *Cosco Busan* spill, the UCSC aerial survey team recorded observations of 86 Marbled Murrelets in the northern Gulf of the Farallones (Figure 10) where impacts of *Cosco Busan* oil were recorded. Three murrelet carcasses were recovered in this area, one each at Muir Beach, Wildcat Beach, and northern Drake's Bay. Since Beached Bird Model estimates of the total deposition of Marbled Murrelets are dependent on the estimated persistence rate of small seabirds, we carried out a carcass persistence study for small birds in December, 2008 at study sites ranging from Drake's Bay to the Golden Gate (Figure 11).

Figure 10. Location of Marbled Murrelet observations during aerial surveys, 8-21 November 2007. Quartered circle in Bay is spill site.

Figure 11. Approximate location of shoreline segments used for outer coast persistence study. Quartered circle in Bay is spill site.

Methods

Forty-six juvenile Common Murre carcasses were placed at five sites from northern Drake's Bay to near the Golden Gate. Four groups of 10 carcasses were placed on Limantour Beach, RCA Beach, Agate Beach, and Stinson Beach. Because of its shorter length, only six carcasses were placed on Muir Beach.

The juvenile murre carcasses used in the study averaged 350 g in weight, and their size distribution overlaps the mean Marbled Murrelet size in California. These weights were well below the cutoff between 'small' and 'large' seabird carcasses (500 g) found by Ford and Zafonte. Carcasses were placed between the low and the high tide lines. Their positions along the beach were determined by a uniform random distribution of distances varying from 0 m to 200 m, so that the average inter-carcass spacing was about 100 m. Each carcass was uniquely identified by numbered bands placed on the upper humerus. An inconspicuous numbered wooden block was also placed beneath each carcass to help determine whether missing carcasses were rewashed or removed by scavengers.

Carcass condition was monitored daily for five days after placement, and again ten days later. For each carcass found, we recorded the identification tag number, which body parts were still present, whether the remains were articulated or fragmentary, and the latitude/longitude locations of the carcass fragments. If a carcass was missing, the beach was searched for at least 100 m beyond the last known position of that carcass.

Searchers who had worked in this area during the spill response stated that fragmentary carcasses without organs or pectoral muscles would not have been recovered and classified as spill related mortality. This condition was therefore used as the criterion for a carcass being classified as 'missing'.

Results and Discussion

Scavenging was rapid at all study sites, with 73.9% of all carcasses showing signs of scavenging within the first 24 hours after placement, and 91.3% showing signs of scavenging within 72 hours. Unlike the *Kure* scavenging study or the *Luckenbach* study, however, scavenged carcasses tended to be progressively degraded in the immediate vicinity of their original position rather than being removed completely between searches.

During the *Cosco Busan* persistence study, winds blew steadily from the northwest. Carcasses that re-floated during high tide, especially at RCA, Agate, and Stinson beaches, were thus pushed by the wind against the beach back, moving short distances along the beach before they were once more stranded in the wrack line. This wave action probably accelerated the process of decomposition and fragmentation, with many carcasses requiring only a few days to reach a state where they would have been ignored by searchers had they been found during the spill response (Figure 12).

Figure 12. Photographs of four carcasses that are typical of ‘fragmentary’ carcasses classified as ‘missing’ because they would not have been collected by spill responders. The carcasses in the figure had been on outer coast beaches for 2, 3, 4, and 5 days.

The proportion of the carcasses that remained by day is shown in Table 7 and in Figure 13 . Thirty-seven of 46 carcasses (80%) were missing by day 5, and 44 of 46 carcasses (96%) were missing by day 16.

Table 7. Persistence of small seabird carcasses on outer coast beaches.

Day	Number Missing Since Last Checked	Cumulative Number Missing	Persistence
0	0	0	1.000
1	9	9	0.8043
2	6	15	0.6739
3	5	20	0.5652
4	6	26	0.4348
5	11	37	0.1957
16	7	44	0.0435

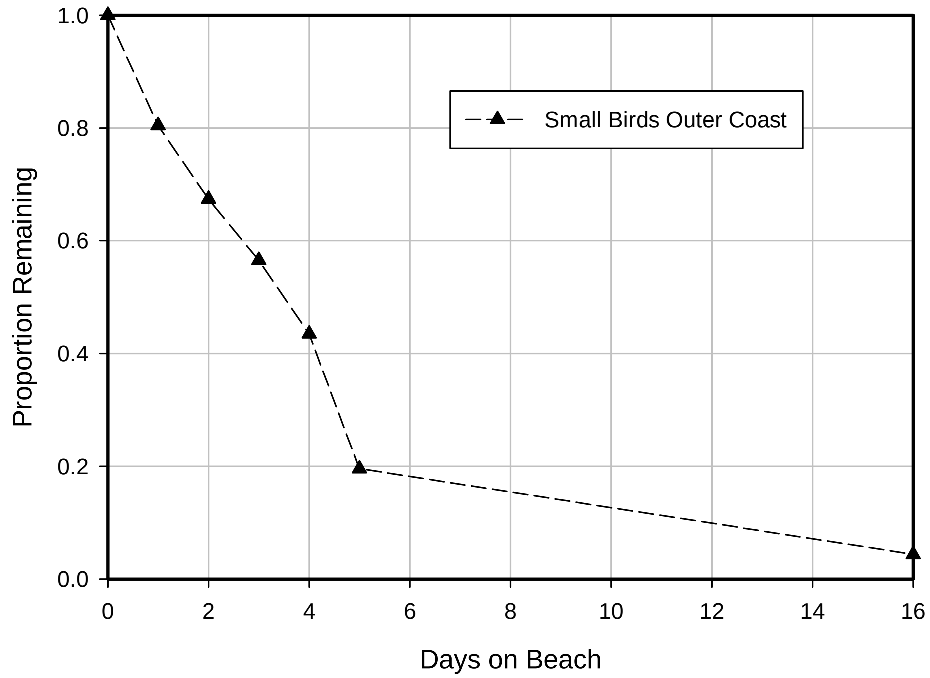

Figure 13. The proportion of carcasses that searchers during the spill response would have recovered as a function of the number of days since the carcasses were placed on beaches on the outer coast. Solid triangles indicate results for small carcasses (≤500 g).

Model Application

Persistence rates of large seabird carcasses were previously measured in the Drake's Bay area following the *Luckenbach* incident, but that study did not address the effect of rewash (a significant factor in this area) on small carcasses. The *Cosco Busan* persistence study was intended to provide this information for small bodied birds, while data from the *Luckenbach* study were to be used for large bodied birds.

In other studies at other sites (Ford and Zafonte, in press), large bird carcasses persisted *longer* than small bird carcasses. Small carcasses in the *Cosco Busan* study, however, persisted *longer* than did large carcasses in the *Luckenbach* study. This difference did not appear to result from differences in scavenger activity, since carcasses were scavenged more rapidly during the *Cosco Busan* study than during the *Luckenbach* study. It is likely that weather and hydrodynamic conditions prevailing at the time of the *Cosco Busan* study differed from conditions during the *Luckenbach* study. During the *Luckenbach* study, it was observed that rewashed carcasses very rarely stranded again. By comparison, daily cycles of rewash and stranding was common for carcasses during the *Cosco Busan* study.

Since we assume that large carcasses persist longer than small carcasses, we concluded that it would be illogical to utilize the persistence rate from the *Luckenbach* studies for large carcasses, and the persistence rate from the *Cosco Busan* study for small carcasses. We therefore used the persistence rate for small carcasses in the *Cosco Busan* study when estimating the mortality of large birds.

2.4 Background Deposition within San Francisco Bay

Rationale

Seabirds and waterfowl die and are beached regularly even in the absence of an oil spill. In order to determine the magnitude of the bird mortality that is directly caused by an oil spill, this 'background' or 'ambient' mortality must be subtracted from the mortality that was documented during the spill response. Background deposition rates, however, can vary by orders of magnitude in different times and places (Ford 2006). Although the BeachWatch program sponsored by the Gulf of the Farallones National Marine Sanctuary monitors carcass deposition along the part of the outer coast affected by the *Cosco Busan* oil spill, there are no programs that monitor deposition within San Francisco Bay itself. The trustees and the responsible party therefore agreed to examine the rate of background carcass deposition within San Francisco Bay.

Study Design

On December 1 and December 2, 2008, teams of 2-3 observers searched a total of 16 segments of shoreline (totaling 14.6 km in length) scattered throughout the part of San Francisco Bay affected by the oil spill (Table 8). This portion of the study was designed to estimate the number of carcasses that were already on the beach at the beginning of the spill response. Subsequently, six segments (totaling 3.9 km in length) were selected for additional more frequent searches on a 1 to 3 day basis (Table 9). Four of these sites corresponded directly to sites shown in Table 8, however, the surveys at Blackie's Pasture and Seabreeze Cove were subsections of larger survey areas. This subset was chosen based in part on how many birds were recovered on various segments during the first part of the study, giving preference to segments with more carcass recoveries.

Table 8. Carcass recoveries on first searches of 16 shoreline segments in early December 2008.

Date	Location	Distance (km)	Car-casses	Density (Birds/km)	Desiccated Parts (not Counted)
12/1/2008	South Basin (partial)	0.3	0	0.00	0
12/2/2008	South Basin, Berkeley	2.2	1	0.45	1
12/2/2008	Berkeley Marina SW	0.7	0	0.00	0
12/2/2008	Brickyard Cove	0.4	2	5.00	0
12/2/2008	Point Emory	0.5	0	0.00	0
12/2/2008	North Basin east	0.4	1	2.50	0
12/2/2008	Berkeley Marina NE	1	1	1.00	2
12/2/2008	Vincent/Shimada Parks	1.1	0	0.00	1
12/2/2008	Shimada/Stege Beach	0.3	2	6.67	4
12/2/2008	Horseshoe Cove	1.3	2	1.54	2
12/2/2008	Blackies Pasture	3	5	1.67	12
12/3/2008	North Basin SW	1.4	0	0.00	2
12/3/2008	Albany Beach	0.6	0	0.00	3
12/3/2008	Radio Tower Beach 1	0.1	1	10.00	0
12/3/2008	Radio Tower Beach 2	0.4	1	2.50	0
12/3/2008	Brickyard Cove	0.9	2	2.22	0
	TOTAL	**14.6**	**18**	**1.23**	

Table 9. Carcass recoveries on repeated searches of six shoreline segments in early December 2008.

Location	Starting Background 12/2/08	New Deposition					Total New Birds	Distanc e (km)
		12/3/ 2008	12/4/ 2008	12/5/ 2008	12/8/ 2008	12/18/ 2008		
Horseshoe Cove	2	0	1	3	1	0	5	1.3
Blackie's Pasture	0	1	0	0	1	2	4	1.2
Shimada Park	2	0	0	0	0	3	3	0.3
Seabreeze Cove	0	0	0	0	0	0	0	0.2
Brickyard Cove	2	0	0	0	1	1	2	0.4
Point Emery	0	0	0	0	0	0	0	0.5
TOTALS	**6**	**1**	**1**	**3**	**3**	**6**	**14**	**3.9**

Searchers included representatives of both the trustees and the responsible party. They recorded all bird remains that would have been recovered and classified as ‘carcasses’ during the spill response. Remains classified as “desiccated parts” were not considered carcasses, since these would not have been collected. All other carcasses, including fresh or decomposing scavenged carcasses, were included in the count.

Results
On beaches that had not been searched previously, a total of 18 carcasses were recovered over a distance of 14.6 km, corresponding to a deposition rate of 1.23 carcasses per km. On beaches that were searched multiple times, 14 carcasses were recovered along 3.9 km of shoreline during searches occurring between 3 and 18 December, 2008. This corresponds to 14 carcass recoveries along 3.9 km of shoreline over a 15-day period, or 3.59 carcasses per km.

Use in Model
If the rate of background carcass deposition measured in this study occurred throughout the 232 km of searched shoreline in the Bay, we would expect that about 232 km x 3.59 birds/km = 833 non-spill-related birds would be deposited over a 15-day period in San Francisco Bay under normal (i.e. non-spill) circumstances. Correcting for persistence, about twice as many, roughly 1,500 carcasses would have been deposited over this period. Since only 278 unoiled dead birds and 566 oiled dead birds were recovered in the Bay during the response, this estimate of background carcass deposition is obviously high. This bias may have been introduced by preferentially selecting high deposition beaches for the second part of this study.

We therefore did not use the background rate value of 3.59 birds/km per 15 days in the model runs. Instead, we assumed that all carcasses *with* visible oiling were killed by spill-related factors, and that all carcasses *without* visible oiling died of other causes. Since studies in three previous spills on the Pacific coast (described in Ford 2006) have shown that only about 50% of the birds dying of spill-related causes show signs of visible oiling, this approach probably *underestimates* the magnitude of spill related mortality. Historically, live birds, whether oiled or unoiled, are rarely recovered in San Francisco Bay. We therefore assume that all live birds collected within the Bay were injured by the spill. Virtually all of these live injured were visibly oiled.

3.0 BEACHED BIRD MODEL

OVERVIEW

The Beached Bird Model was used to estimate the number of birds deposited on the shoreline in the interval between consecutive searches on the same section of shoreline. The estimation procedure is based on the number of birds recovered, the probability of a beached bird persisting over a given time interval, and the likelihood that searchers will detect a beached bird. Derivation of the basic equation is from Ford et al. (1996) and Page et al. (1990) and has been used consistently in spill assessments since the *Apex Houston* damage assessment in 1986. Variations on Equation 8 (see below) have been used since it was demonstrated in 1998 following the *M/V Kure* spill that significant numbers of carcasses were missed by searchers. Applications of these equations include damage assessments for the *Apex Houston, Puerto Rican, Arco Anchorage, Nestucca, Exxon Valdez, Torch Irene, Cape Mohican, Kure, Stuyvesant, New Carissa, Tristan*, and the *Point Reyes Tarball Incidents* (Page et al. 1990, Dobbin et al. 1986, Ford & Bonnell 1998, Ford et al. 1991, 1996, 2001, 2002, Ford & Strom 2006, Carter & Golightly 2003, Trustee Council 2002, 2004). In addition to the ongoing analysis for the *Cosco Busan* oil spill, it is being used in current damage assessments for the *Selendang Ayu* and *Bouchard 120* oil spills.

SPATIAL ORGANIZATION

The BBM estimates carcass deposition along a section of shoreline that is repeatedly searched. It is important that each search is carried out within the bounds of the segment, and that searches of different segments do not overlap. Delineation of shoreline segments was based on practical considerations such as accessibility and length, and usually consisted of a section of beach (up to several kilometers in length) that could be searched in a few hours or less.

For purposes of analysis, shoreline segments (referred to as ‘minor’ segments) that were adjacent were grouped together into ‘major’ segments. Within each major segment, the daily deposition rate was estimated by averaging deposition estimates for all of the minor segments with usable effort for that day.

Environmental factors that affect estimates of bird deposition, such as scavenging or wave action, can differ between San Francisco Bay and the outer coast. Model results were therefore calculated separately for these regions.

Birds were collected from Salmon Creek (north of Bodega Bay) to Cayucos (south of Big Sur), and from the date of the spill to January 7, 2008. However, because the BBM can only be used when and where repeated searches occurred, the BBM only incorporates birds collected between Pt. Reyes and Half Moon Bay, and from the date of the spill thru December 2. Birds collected beyond these bounds, which account for about 9% of total birds collected, were not incorporated in the BBM. They were added to the total mortality estimate, but there is no multiplier associated with them. Average multipliers were applied to birds from incompletely specified or completely unknown locations (about 6% of birds).

BBM DESCRIPTION

Model Structure

For a segment that is searched on day *j* and again on day *k*, define the following variables:

j	Day of previous search
k	Day of current search
N_k	Number of birds recovered on search on day *k*
D_i	Deposition rate (birds per mile) on day *i*
D^*	Constant deposition rate between days *j* and *k*
$P_{m,n}$	Probability that a carcass will persist from day *m* to day *n*

Assuming that there were no birds remaining on the beach after the search on day *j*, that all the birds on the beach on day *k* were detected, and that the daily deposition rate was constant over the interval from *j* to *k*, then

(1) $$D^* = D_{j+1} = D_{j+2} = \ldots D_k$$

and

(2) $$N_k = P_{j+1,k} \cdot D^* + P_{j+2,k} \cdot D^* + \ldots P_{k,k} \cdot D^*$$

This can be rewritten as

(3) $$N_k = D^* \cdot (P_{j+1,k} + P_{j+2,k} + \ldots P_{k,k})$$

Solving for the deposition rate gives:

(4) $$D^* = N_k \ / \ (P_{j+1,k} + P_{j+2,k} + \ldots P_{k,k})$$

Not all the birds present on a beach segment will be found on a given search. To modify (3) to take into account less than perfect searcher efficiency, let F_k be:

F_k Probability that a bird will be found on a search on day *k*. If the segment is completely searched, then $1\text{-}F_k$ is the likelihood that the bird would be missed by searchers as they pass by it. If the segment is not searched completely, F_k is considered to be proportional to the fraction of the segment that was searched on day *k*.

Then

(5) $N_k = D^* \cdot F_k \cdot (P_{j+1,k} + P_{j+2,k} + \ldots \; P_{k,k})$

and (4) becomes:

(6) $D^* = N_k \; / \; (F_k \cdot (P_{j+1} + P_{j+2} + \ldots \; P_k))$

If the probability of locating a carcass is less than 1.0, then some birds deposited prior to the search interval will remain on the beach from one search to the next. We therefore calculate the number of birds deposited from day *1* to the end of the previous search interval (day *j*) that would remain on the beach and would be found on the search on day *k*. This is defined as O_k, the number of 'old' birds deposited prior to or on day *j*, and recovered on day *k*.

Let O_k be the number of old birds recovered on day *k* that were not deposited in the most recent interval, $j + 1$ to *k*. Then the number of old birds recovered on day *k* is the number of birds deposited on each day, times the probability that they persisted from the day of deposition to day *k*, times the probability that they were *not* found during the earlier search on day *j*, times the probability that they *were* found during the search on day *k*:

(7) $O_k = F_k \cdot (1 - F_j) \cdot (P_{1,k} \cdot D_1 + P_{2,k} \cdot D_2 + \ldots \; P_{j,k} \cdot D_j)$

In order to take into account birds persisting from one search interval to the next, the number of old birds recovered on a search must be subtracted from the total number of birds recovered on that search before estimating the deposition rate. This is accomplished by substituting $(N_k - O_k)$ for N_k in Equation 5 and solving for D^*:

(8) $D^* = (N_k - O_k) \; / \; (F_k \cdot (P_{j+1,k} + P_{j+2,k} + \ldots \; P_{k,k}))$

Deposition on Infrequently Searched Segments

Long intervals between searches can result in inaccurate estimates of D*. We therefore did not use the BBM to estimate carcass deposition for intervals greater than seven days in length. This means that for some beach segments, there are time periods during which deposition probably occurred, but the BBM did not estimate that rate. To fill in these missing data, we used deposition rate estimates from nearby segments to infer the deposition rate over gaps between searches that were longer than seven days.

We first estimated the deposition rate for each minor segment for all the days that fell between acceptable pairs of searches. For a given day and within a major segment, we calculated the length weighted average deposition rate by summing the estimated number of birds deposited on the searched beaches and dividing by the total length of the beach surveyed. This average deposition rate was then multiplied by the length of the entire major segment to generate an estimate of total deposition within a major segment on a given day. On days where there was no effort or when the search interval exceeded the maximum allowable, no usable estimates of deposition rate within a major segment could be made, and the total deposition rate was assumed to be zero.

The following example describes a major segment containing three minor segments, A, B, and C. The length of the segments are L_A, L_B, and L_C respectively, and their sum, the length of the entire major segment, is L*. Solid squares indicate days when a segment was searched, hollow squares indicate days when it was not. Lower case letters in the body of the matrix represent estimates of the beached bird deposition rate made between sequential searches. For example, the entry $b_{2,3}$ refers to the deposition rate calculated for segment B using Equation 8 and based on the searches on days 2 and 3. The rightmost column is the formula used for calculating the total deposition within the entire major segment on a given day. Note that on segment B, no estimates of deposition are made for the interval between the searches on days 4 through 11 because the 8 day gap is greater than the minimum search intervaI of 7 days.

Name		**A**	**B**	**C**	**Estimated number of**
Length		L_A	L_B	L_C	**birds deposited**
Day	0	▪	▪	▪	*No Estimate (assume 0)*
	1	▫ $a_{1,3}$	▪ $b_{1,1}$	▫	$L^*(L_A a_{1,3} + L_B b_{1,1})/(L_A+L_B)$
	2	▫ $a_{1,3}$	▫ $b_{2,3}$	▫	$L^*(L_A a_{1,3} + L_B b_{2,3})/(L_A+L_B)$
	3	▪ $a_{1,3}$	▪ $b_{2,3}$	▪ $c_{1,3}$	$L_A a_{1,3} + L_B b_{2,3} + L_C c_{1,3}$
	4	▪ $a_{4,4}$	▫	▫ $c_{4,7}$	$L^*(L_A a_{4,4} + L_C c_{4,7})/(L_A+L_C)$
	5	▫	▫	▫ $c_{4,7}$	$L^* c_{4,7}$
	6	▫	▫	▫ $c_{4,7}$	$L^* c_{4,7}$
	7	▫	▫	▪ $c_{4,7}$	$L^* c_{4,7}$
	8	▫	▫	▫ $c_{7,10}$	$L^* c_{7,10}$
	9	▫	▫	▫ $c_{7,10}$	$L^* c_{7,10}$
	10	▫	▫	▪ $c_{7,10}$	$L^* c_{7,10}$
	11	▫	▪	▫ $c_{11,12}$	$L^* c_{11,12}$
	12	▫	▪ $b_{12,12}$	▪ $c_{11,12}$	$L^*(L_B b_{12,12} + L_C c_{11,12})/(L_B+L_C)$

WITHIN-BAY MODEL SETUP

Beach Segmentation and Search Effort (within the Bay)
Within San Francisco Bay, most shoreline oiling occurred between the San Rafael Bridge in the north and the Oakland Bay Bridge in the south. In the East Bay, some oiling extended as far south as Crown Beach in Alameda. Search effort and bird collection data in San Francisco Bay was partitioned into 112 minor segments covering 223.20 km, from the Tiburon Peninsula to the Port of San Francisco on the western side of the Bay, from San Pablo Bay to Bay Farm Island on the eastern side of the Bay and including Angel, Treasure, and Alcatraz Islands. A total of 1,071.28 km of search were conducted in the course of 690 segment searches during the 26 days of the spill response.

The 112 minor segments were divided among 13 major segments described in Table 10 and illustrated in Figure 11. Beach lengths and search lengths were calculated by CDFG-OSPR from GPS coordinates. Search effort data (the 'search effort database') were compiled by CDFG-OSPR from search effort logs used by Wildlife Operations teams during the spill response, as well as additional data from Richardson Bay Audubon Society.

Table 10. Segments and search effort in San Francisco Bay.

Major Segment ID	Description	Number of Minor Segments	Total Segment Length (km)	Total Search Length (km)
GGN	Horseshoe Cove to Ft. Baker	2	2.08	40.24
SAU	Sausalito Headlands to Belvedere West	16	26.40	226.61
TIB	Belvedere Cliffs to Paradise Drive	12	15.20	69.98
SRF	Martas Marsh to San Pablo Bay (West)	15	28.64	13.06
PSP	Castro Crk East to San Rafael Bridge South	8	13.44	5.58
RIH	Keller Creek North to Albany Bulb	11	20.32	125.86
BRI	Brooks Island	1	7.68	69.12
BEM	Golden Gate Fields to Outer Harbor	12	27.84	273.33
ALO	Middle Harbor to Bay Farm Island West	23	43.04	108.78
GGS	PacBell to Port of SF to Fort Point	9	20.00	75.28
ANI	Angel Island	1	8.48	42.4
ALI	Alcatraz Island	1	1.28	2.56
TRI	Treasure Island	1	8.80	18.48
TOTAL		**112**	**223.2**	**1,071.28**

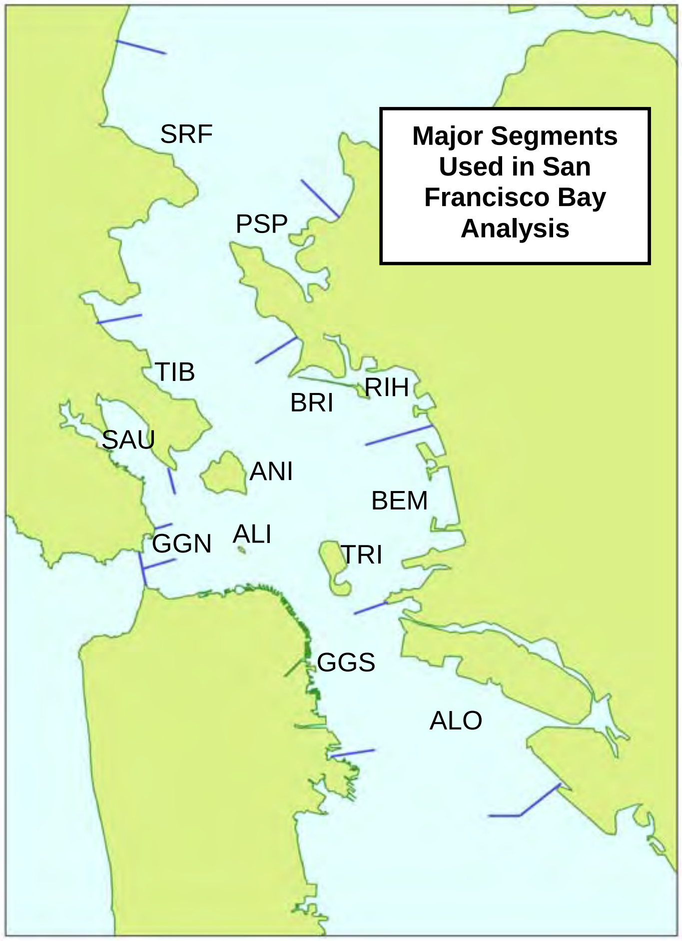

Figure 11. Locations of the 13 major segments in San Francisco Bay where the BBM was used to estimate carcass deposition rate.

Bird Recoveries (within the Bay)

Bird recovery data for San Francisco Bay were compiled into a single database which was integrated with the search effort database. Since search effort and bird recoveries were recorded separately, it was necessary to standardize place names in order to match recoveries with search effort. Bird recoveries and search effort were considered to be associated if they were collected from a segment on the same day that a search was documented. Birds that were recovered on days and segments without documented search effort were not included in BBM estimates of deposition, but were simply added to the total mortality estimate. For the BBM analysis within the Bay, only live injured birds or dead oiled birds were used. Dead unoiled birds were assumed to be part of background deposition.

A total of 409 large (>500 g) dead oiled birds and 69 (≤500 g) small dead oiled birds were collected on official searches or otherwise associated with particular dates and segments within the modeled area and time frame (Table 11). Additionally, 76 large birds and 12 small birds were not used in BBM calculations because they were not associated with documented search effort, were collected after the final date of the model analysis, 2 December, outside of the modeled area, after the last documented search, or from unknown locations within the spill response zone. Most dead oiled birds were collected on segments in the east–central Bay, between the Bay Bridge and Brooks Island area.

Table 11. Oiled bird carcasses collected in San Francisco Bay, from the intake database. Modeled birds were collected on documented searches, associated birds were collected within the modeled time period and modeled area but not on documented searches, unassociated birds could not be assigned to the model time period or area for various reasons.

Major Segment ID	Description	Modeled Birds		Non-Modeled (Associated) Birds		Total Oiled Dead
		Large Birds	Small Birds	Large Birds	Small Birds	
GGN	Horseshoe Cove - Ft. Baker	16	2	0	0	18
SAU	Sausalito Headlands - Belvedere W.	44	4	3	0	51
TIB	Belvedere Cliffs - Paradise Drive	16	1	7	0	24
SRF	Martas Marsh - San Pablo Bay W.	2	0	1	0	3
PSP	Castro Creek E. - San Rafael Bridge S.	1	0	0	0	1
RIH	Keller Creek North - Albany Bulb	68	17	15	4	104
BRI	Brooks Island	31	8	1	0	40
BEM	Golden Gate Fields - Outer Harbor	126	24	22	1	173
ALO	Middle Harbor - Bay Farm Is. W.	9	0	13	4	26
GGS	PacBell - Port of SF - Fort Point	8	2	5	0	15
ANI	Angel Island	15	0	2	1	18
TRI	Treasure Island	1	0	3	1	5
Subtotal – Modeled and Associated Birds		**337**	**58**	**72**	**11**	**478**
				Non-Modeled (Unassociated) Birds		
OUTSIDE MODELED AREA or MODELED TIME PERIOD				56	10	66
INCOMPLETELY SPECIFIED or UNKNOWN LOCATION				20	2	22
TOTAL OILED BIRD CARCASSES				**76**	**12**	**566**

A total of 703 live birds were recovered within the Bay, including 458 large birds and 170 small birds that were collected on official searches or otherwise associated with particular dates and segments within the modeled area and time frame. An additional 62 large birds and 13 small birds were not used in BBM calculations because they were not associated with documented search effort, were recovered after the final date of the model analysis, after the last documented search of a segment, outside the modeled area, or from unknown locations within the spill response zone (Table 12).

Table 12. Live birds collected in San Francisco Bay, from the intake database. Modeled birds were collected on documented searches, associated birds were collected with the modeled time period and modeled area but not on documented searches, unassociated birds could not be assigned to the model time period or area for various reasons.

Major Segment ID	**Description**	**Modeled Birds**		**Non-Modeled (Associated) Birds**		**Total Oiled Dead**
		Large Birds	**Small Birds**	**Large Birds**	**Small Birds**	
GGN	Horseshoe Cove - Ft. Baker	16	2	0	0	18
SAU	Sausalito Headlands - Belvedere W.	15	3	6	1	25
TIB	Belvedere Cliffs - Paradise Drive	12	0	3	1	16
SRF	Martas Marsh - San Pablo Bay W.	0	0	1	0	1
PSP	Castro Creek E. - San Rafael Bridge S.	0	0	0	0	0
RIH	Keller Creek North - Albany Bulb	89	35	30	14	168
BRI	Brooks Island	65	28	0	1	94
BEM	Golden Gate Fields - Outer Harbor	138	67	29	7	241
ALO	Middle Harbor - Bay Farm Is. W.	4	2	3	0	9
GGS	PacBell - Port of SF - Fort Point	23	7	9	1	40
ANI	Angel Island	7	1	3	0	11
TRI	Treasure Island	3	0	2	0	5
Subtotal – Modeled and Associated Birds		**372**	**145**	**86**	**25**	**628**
				Non-Modeled (Unassociated) Birds		
OUTSIDE MODELED AREA or MODELED TIME PERIOD				21	4	25
INCOMPLETELY SPECIFIED or UNKNOWN LOCATION				41	9	50
TOTAL BIRDS				**62**	**13**	**703**

Model Parameters (within the Bay)

Persistence:
Estimates of carcass persistence for both large and small birds were based on the 2008 persistence study in San Francisco Bay (Table 13).

Table 13. Carcass persistence by day based on San Francisco Bay persistence study.

Day	Large bird persistence	Small bird persistence
1	1.000	1.000
2	0.8030	0.7083
3	0.7576	0.6667
4	0.6667	0.5417
5	0.5758	0.5417
6	0.5608	0.5000
7	0.5455	0.4583
8	0.5303	0.4583
9	0.4848	0.3750
10	0.4545	0.3333
11	0.4545	0.2917
12	0.4091	0.2500
13	0.4091	0.2500
14	0.4091	0.2500
15	0.4091	0.2500
16	0.3182	0.2083
17	0.3030	0.1667

Searcher Efficiency:
Based on the San Francisco Bay searcher efficiency study, the efficiency of one searcher within the Bay was estimated to be 0.43, and for two searchers to be 0.68. Application of these values to a specific search interval was based on Equation (1) in that section.

Background deposition:
We assumed that all birds that were dead and oiled or alive but beached and incapacitated had been injured or killed by *Cosco Busan* oil. Recoveries of dead unoiled birds were assumed to comprise background deposition and were not used in model calculations.

Model Results (within the Bay)
Combining oiled bird carcasses and live birds, 867 large birds and 239 small birds recovered within San Francisco Bay were included in BBM model input. Based on the BBM analysis, we estimate that 1,460 large birds and 516 small birds were injured or killed by *Cosco Busan* oil and beached within the Bay. This corresponds to overall correction factors of 1.68 and 2.16 for large and small birds respectively. Compared with other oil spills, these are relatively low correction factors. The primary reason for this is

that the search effort was relatively thorough, with few unsearched areas on any given day. BBM results for San Francisco Bay are presented by major segment in Table 14.

Table 14. San Francisco Bay bird mortality for the *Cosco Busan* oil spill, as estimated by the Beached Bird Model. Both modeled and non-modeled but associated birds are included in model results. Modeled birds are extrapolated by the model while associated birds are added to the extrapolated total.

Major Segment ID	**Description**	**Large Birds**		**Small Birds**		**Total Estimated Mortality - Large and Small Birds Combined**
		Total Birds Collected in BBM Area	**Model Results**	**Total Birds Collected in BBM Area**	**Model Results**	
GGN	Horseshoe Cove – Ft. Baker	32	51	4	7	58
SAU	Sausalito Headlands - Belvedere W.	68	114	8	15	129
TIB	Belvedere Cliffs – Paradise Drive	38	66	2	3	59
SRF	Martas Marsh – San Pablo Bay W.	4	55	0	0	55
PSP	Castro Creek E. – San Rafael Bridge S.	1	3	0	0	3
RIH	Keller Creek North - Albany Bulb	202	355	70	235	590
BRI	Brooks Island	97	118	37	49	167
BEM	Golden Gate Fields – Outer Harbor	315	487	99	164	651
ALO	Middle Harbor – Bay Farm Is. W.	29	89	6	15	104
GGS	PacBell - Port of SF – Fort Point	45	79	10	25	104
ANI	Angel Island	27	31	2	2	33
TRI	Treasure Island	9	12	1	1	13
TOTALS		**867**	**1,460**	**239**	**516**	**1,976**
Correction Factors		1,460 / 867 = **1.68**		516 / 239 = **2.16**		

Birds not used in BBM calculations:

Within the Bay, 47 large and 8 small birds were recovered after documented search effort. An additional 7 large birds and 2 small birds were collected on documented searches but after the end of the modeled period (2 December). The BBM does not attempt to estimate a correction factor for these birds, but they are added to the total estimated mortality. Assuming these birds are a random subset of all birds recovered on any given segment, this approach does not bias model results.

A total of 23 large birds and 4 small birds were recovered within the Bay, but beyond the geographic limits of the spill response. It is nonetheless likely that some of these birds were killed by *Cosco Busan* oil, since birds are capable of moving considerable distances after being oiled (Campbell et al. 1978, CDFG 2004). Oiled birds or live injured birds that were recovered beyond the spill zone were considered to be part of the mortality estimate for the *Cosco Busan* spill, and 23 large birds and 4 small birds were therefore added to the estimated mortality in the Bay.

Sixty-one large birds and 11 small birds were recovered within the spill response zone during the period modeled with the BBM, but the locations where they were recovered were not recorded or were incompletely specified. In these cases, we applied the overall in-Bay correction factors for large and small birds, 1.68 and 2.16 respectively (see Table 14) , to correct the number of birds recovered to the number of birds deposited (Table 15).

Table 15. Birds collected in San Francisco Bay but not included in BBM calculations. Both live birds and oiled carcasses are included.

	Number of Birds Collected		Number Added to BBM Mortality Estimate		
Category	**Large Birds**	**Small 8Birds**	**Large Birds**	**Small Birds**	**Treatment**
Collected after last documented search	47	8	47	8	Added
Collected after end of modeled period	7	2	7	2	Added
Collected beyond defined spill zone	23	4	23	4	Added if live or oiled
Unknown or incompletely specified locations	61	11	102	24	Added after applying correction factors
TOTAL	**138**	**25**	**179**	**38**	

Total Estimated Mortality within the Bay
Total estimated bird mortality within the Bay includes both model results and birds not used in model calculations, as shown in Table 16.

Table 16. Total estimated San Francisco Bay bird mortality from the *Cosco Busan* oil spill, including results from the Beached Bird Model and birds not used in model calculations.

Category	Large Birds	Small Birds	TOTAL
Beached Bird Model results	1,460	516	1,976
Oiled or live birds collected beyond defined spill zone or time period	77	14	91
Unknown or incompletely specified locations	102	24	126
TOTAL	**1,639**	**554**	**2,193**

Comparison with Observations of Live Oiled Birds (within the Bay)
During the spill, spill responders, various organizations, and members of the public reported thousands of observations of live oiled birds. In particular, the Golden Gate Audubon Society organized systematic surveys and maintained a database of observations, denoting species, location, date, and time. These were at locations inside the Bay.

As a final check on the results of the BBM, the Trustees compared the model results with the surveys of the Golden Gate Audubon Society. The observations of live oiled birds by the surveyors likely missed many of the birds, but at the same time may have counted some birds multiple times, especially if the bird lived multiple days after oiling. To avoid double-counting of birds across multiple days, the Trustees only considered the highest one-day count for each species within each segment. This snapshot totaled 904 individual birds. Therefore, this was the minimum number of oiled individual birds within the Bay. Assuming the observers did not see every oiled bird, and that some birds seen on one day were different individuals from the birds enumerated during the day with the highest count, more than 904 birds were oiled.

The BBM estimated that 2,193 birds beached within the Bay, a little more than twice what the Audubon surveys counted. The Trustees consider this to be a reasonable ratio, implying that the surveys observed a little less than half of the oiled birds that existed. This suggests that the BBM performed reasonably well and correlates with the Audubon surveys.

OUTER COAST MODEL SETUP

Beach Segmentation and Search Effort (Outer Coast)

Shorelines on the outer coast, both to the north and to the south of the Golden Gate, were affected by oil from the *Cosco Busan*. Search effort and bird collection data from the outer coast were partitioned into 82 minor segments extending 176.16 km from Doran Beach in the north to Half Moon Bay in the south. A total of 51.36 km (29.2%) of this distance was classified as inaccessible and was never searched, although some of these segments did have limited access. A total of 1,128.65 km of search were conducted in the course of 573 segment searches during the 26 days of the spill response.

The 82 minor segments were aggregated into 9 major segments described in Table 17 and illustrated in Figure 12. While some searches and some bird recoveries were reported beyond this area, these were not used in model calculations.

Table 17. Segments, accessibility, and search lengths of outer coast beach segments.

Major Segment ID	Description	Number of Minor Seg-ments	Total Segment Length (km)			Total Search Length (km)
			Accessible	Inaccessible	TOTAL	
PTR	Doran Beach - Fish Docks	14	30.88	22.08	52.96	86.24
DBW	Drake's Beach West - Sculptured Beach	5	17.60	0	17.60	123.38
DBE	Kelham Beach - Wildcat Beach	3	7.52	0.96	8.48	26.06
BOS	Abalone Point - Stinson/Seadrift	5	16.64	0	16.64	356.03
LAB	Bolinas Lagoon	1	10.40	0	10.40	88.53
MAR	Steep Ravine - Kirby Cove	20	4.64	18.08	22.72	61.41
SFN	Baker Beach North - Thornton Beach	11	12.80	1.76	14.56	228.61
SFS	Fort Funston - Mavericks	20	19.20	8.48	27.68	117.01
PPT	Pillar Point Harbor - Half Moon Bay -Naples	3	5.12	0	5.12	41.38
		82	**124.8**	**51.36**	**176.16**	**1,128.65**

Beach lengths are presented in Carter and Page (1989) and search lengths were calculated by CDFG-OSPR from GPS coordinates. Search effort data were compiled by CDFG-OSPR from search effort logs used by Wildlife Operations teams during the spill response.

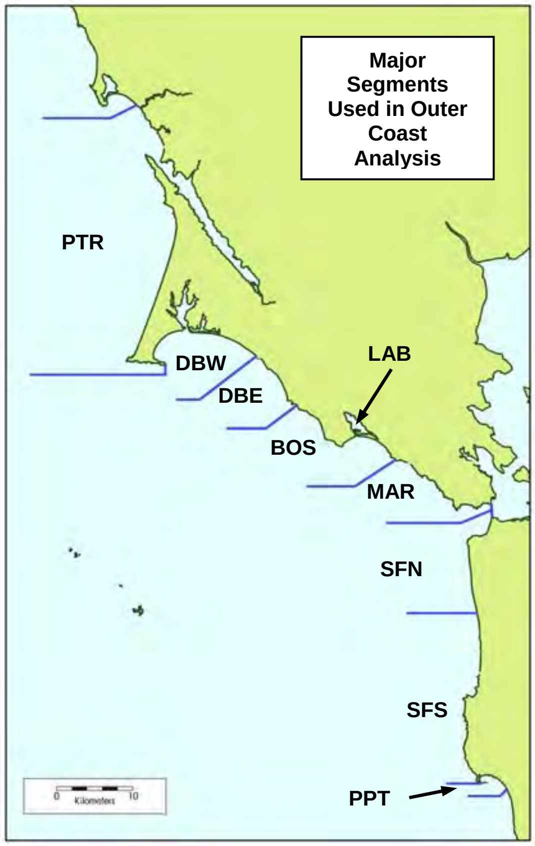

Figure 12. Locations of the 9 major segments on the outer coast where the BBM was used to estimate carcass deposition rate.

Bird Recoveries (Outer Coast)

Bird recovery data for the outer coast were compiled into a single database which was integrated with the search effort database. Since search effort and bird recoveries were recorded separately, it was necessary to standardize place names in order to match recoveries with search effort. Bird recoveries and search effort were considered to be associated if they were collected from a segment on the same day that a search was documented. Birds that were recovered on days and segments without documented search effort were not included in BBM estimates of deposition, but were simply added to the total mortality estimate.

A total of 816 large (>500 g) dead oiled birds and 47 (≤500 g) small dead oiled birds were collected on official searches or otherwise associated with particular dates and segments within the modeled area and time frame (Table 18). Additionally, 106 large birds and 3 small birds were not used in BBM calculations because they were not associated with documented search effort, were collected after the final date of the model analysis, 2 December, outside of the modeled area (e.g. in Monterey Bay), after the last documented search, or from unknown or incompletely specified locations within the spill response zone. Most bird carcasses recovered along the outer coast were found on coastal segments north of the Golden Gate.

Table 18. Bird carcasses collected from outer coast beaches, from the intake database. Modeled birds were collected on documented searches, associated birds were collected within the modeled time period and modeled area but not on documented searches, unassociated birds could not be assigned to the model time period or area for various reasons.

Major Segment ID	Description	Modeled Birds		Non-Modeled (Associated) Birds		Total Dead
		Large Birds	Small Birds	Large Birds	Small Birds	
PTR	Doran Beach - Fish Docks	38	3	1	2	44
DBW	Drake's Beach West - Sculptured Beach	92	5	33	3	133
DBE	Kelham Beach - Wildcat Beach	62	2	16	2	82
BOS	Abalone Point - Stinson/Seadrift	209	10	4	0	223
LAB	Bolinas Lagoon	25	1	0	0	26
MAR	Steep Ravine - Kirby Cove	86	4	22	0	112
SFN	Baker Beach North - Thornton Beach	159	7	11	1	178
SFS	Fort Funston - Mavericks	43	5	6	1	55
PPT	Pillar Point Harbor - Half Moon Bay - Naples	9	1	0	0	10
Subtotal - Modeled and Associated Birds		**723**	**38**	**93**	**9**	**863**
				Non-Modeled (Unassociated) Birds		
OUTSIDE MODELED AREA or MODELED TIME PERIOD				80	3	83
INCOMPLETELY SPECIFIED or UNKNOWN LOCATION				26	0	26
TOTAL BIRDS				**106**	**3**	**972**

A total of 323 live birds were recovered on outer coast beaches, including 237 large birds and 20 small birds that were collected on official searches or otherwise associated with particular dates and segments within the modeled area and time frame. An additional 60 large birds and 6 small birds were not used in BBM calculations because they were not associated with documented search effort, were recovered after the final date of the model analysis, after the last documented search of a segment, outside the modeled area, or from unknown locations within the spill response zone (Table 19).   Overall, 75.1% of the birds on the outer coast were dead when they were collected.

Table 19. Live birds collected from outer coast beaches, from the intake database. Modeled birds were collected on documented searches, associated birds were collected with the modeled time period and modeled area but not on documented searches, unassociated birds could not be assigned to the model time period or area for various reasons.

Major Segment ID	Description	Modeled Birds		Non-Modeled (Associated) Birds		Total Dead
		Large Birds	Small Birds	Large Birds	Small Birds	
PTR	Doran Beach - Fish Docks	2	0	4	0	6
DBW	Drake's Beach West - Sculptured Beach	14	0	5	0	19
DBE	Kelham Beach - Wildcat Beach	1	0	0	0	1
BOS	Abalone Point - Stinson/Seadrift	46	3	0	0	49
LAB	Bolinas Lagoon	4	0	0	0	4
MAR	Steep Ravine - Kirby Cove	31	1	8	1	41
SFN	Baker Beach North - Thornton Beach	46	11	10	1	68
SFS	Fort Funston - Mavericks	28	3	3	0	34
PPT	Pillar Point Harbor - Half Moon Bay - Naples	35	0	0	0	35
Subtotal - Modeled and Associated Birds		**207**	**18**	**30**	**2**	**257**
				Non-Modeled (Unassociated) Birds		
OUTSIDE MODELED AREA or MODELED TIME PERIOD				56	3	59
INCOMPLETELY SPECIFIED or UNKNOWN LOCATION				4	3	7
TOTAL BIRDS				**60**	**6**	**323**

Model Parameters (Outer Coast)

Persistence:
Estimates of carcass persistence were based on the 2008 outer coast persistence study (Table 20).

Table 20. Day by day carcass persistence based on outer coast persistence study.

Day	Carcass persistence
1	1.0000
2	0.8043
3	0.6739
4	0.5652
5	0.4348
6	0.1957

Searcher Efficiency:
Estimates of searcher efficiency on the outer coast were based on studies carried out for the *M/V Kure* oil spill (Ford et al. 2002). These data were also used in damage assessments for the *M/V Stuyvesant* spill (Stuyvesant Trustee Council 2007) and the *Luckenbach* spills (Ford et al. 2006). Searcher efficiency for *large* birds and a single observer on the outer coast was estimated to be 0.42. Searcher efficiency for *small* birds and a single observer was estimated to be 0.125. Application of these values to a specific search interval was based on Equation (1) in the section Field Studies: Searcher efficiency on central San Francisco Bay Shorelines:

$$\mathbf{e_n = 1 - p_1} ** \mathbf{n}$$

Where $\mathbf{p_1}$ is the probability that 1 searcher would miss a carcass, n is the number of searchers, and the searcher efficiency for **n** searchers is $\mathbf{e_n}$. If coverage of a segment during a search was less than 100%, searcher efficiency was considered to be reduced proportional to the amount of the segment that was searched.

Model Results (Outer Coast)
Combining bird carcasses and live birds, 1,053 large birds and 67 small birds recovered on outer coast beaches were included in BBM model input. Based on the BBM analysis, we estimate that 3,037 large birds and 288 small birds were injured or killed by *Cosco Busan* oil and beached on the outer coast. This corresponds to overall correction factors of 2.88 and 4.30 for large and small birds respectively. BBM results for the outer coast are presented by major segment in Table 21.

Table 21. Outer coast bird mortality for the *Cosco Busan* oil spill, as estimated by the Beached Bird Model. Both modeled and non-modeled but associated birds are included in model results. Modeled birds are extrapolated by the model while associated birds are added to the extrapolated total.

Major Segment ID	Description	Large Birds		Small Birds		Total Estimated Mortality - Large and Small Birds Combined
		Birds Collected in BBM Area	Model Results	Birds Collected in BBM Area	Model Results	
PTR	Doran Beach - Fish Docks	45	227	5	18	245
DBW	Drake's Beach West - Sculptured Beach	144	240	8	25	265
DBE	Kelham Beach - Wildcat Beach	79	242	4	18	260
BOS	Abalone Point - Stinson/Seadrift	259	337	13	50	387
LAB	Bolinas Lagoon	29	59	1	3	62
MAR	Steep Ravine - Kirby Cove	147	1,351	6	99	1,450
SFN	Baker Beach North - Thornton Beach	226	329	20	41	370
SFS	Fort Funston - Mavericks	80	194	9	30	224
PPT	Pillar Point Harbor - Half Moon Bay -Naples	44	58	1	4	62
TOTALS		***1,053***	***3,037***	***67***	***288***	***3,325***
Correction Factors		3,037 / 1,053 = **2.88**		288 / 67 = **4.30**		

Birds not used in BBM calculations:
On the outer coast, 32 large birds and 1 small bird were recovered after documented search effort. An additional 23 large birds were collected on documented searches but after the end of the modeled period (2 December). The BBM does not attempt to estimate a correction factor for these birds, but they are added to the total estimated mortality. Assuming these birds are a random subset of all birds recovered on any given segment, this approach does not bias model results.

A total of 81 large birds and 5 small birds were recovered beyond the geographic limits of the spill response area, Pt. Reyes to Pillar Point (Table 22). Many of these came from the Monterey Bay area. It is likely that some of the birds recovered beyond the spill response zone were killed by *Cosco Busan* oil, since birds are capable of moving considerable distances after being oiled (Campbell et al. 1978, CDFG 2004). Oiled bird carcasses or live injured birds that were recovered beyond the spill zone were considered to be part of the mortality estimate for the *Cosco Busan* spill; 69 large birds and 3 small birds were therefore added to the estimated mortality along the outer coast.

Thirty large birds and three small birds were recovered within the spill response zone during the period modeled with the BBM, but the locations where they were recovered were not recorded or were incompletely specified. In these cases, we applied the overall outer coast correction factors for large and small birds, 2.88 and 4.30 respectively (see Table 21), to correct the number of birds recovered to the number of birds deposited (Table 22).

Table 22. Birds collected from outer coast beaches but not included in BBM calculations. Both live birds and oiled carcasses are included.

	Number of Birds Collected		**Number Added to BBM Mortality Estimate**		
Category	**Large Birds**	**Small 8Birds**	**Large Birds**	**Small Birds**	**Treatment**
Collected after last documented search	32	1	32	1	Added
Collected after end of modeled period	23	0	23	0	Added
Collected beyond defined spill zone	81	5	69	3	Added if live or oiled
Unknown or incompletely specified locations	30	3	86	13	Added after applying correction factors
TOTAL	**166**	**9**	**210**	**17**	

Background deposition:
The proportion of birds recovered during the *Cosco Busan* response that represented background mortality was assumed to be the same as for the *Luckenbach* spill during the years 2001-2003 (Ford et al. 2006, Table 9) based on BeachWatch long-term monitoring data. During this period, it was estimated that 9,297 birds were beached, of which 985 birds were classified as background deposition (11%). We therefore assumed that 89% of the birds recovered on the outer coast during the *Cosco Busan* response were spill related, and that the remaining 11% represented background deposition.

Marbled Murrelets were treated separately from other species because of their special status. Because beachcast Marbled Murrelets are rarely found (less than 0.001 birds/km surveyed by BeachWatch (2006)), it was assumed that all three Marbled Murrelets recovered during the response represent spill-related deaths. All three were oiled and the oil was later matched to the *Cosco Busan*.

Total Estimated Mortality on Outer Coast Beaches
Total estimated bird mortality on outer coast beaches includes both model results and birds not used in model calculations, as shown in Table 23.

Table 23. Total estimated outer coast bird mortality from the *Cosco Busan* oil spill, including results from the Beached Bird Model and birds not used in model calculations.

Category	Large Birds	Small Birds	TOTAL
Beached Bird Model results	3,037	288	3,325
Oiled or live birds collected beyond defined spill zone or time period	124	4	128
Unknown or incompletely specified locations	86	13	99
Subtotal	**3,247**	**305**	**3,552**
Less Estimated Background Deposition (11%)	-357	-34	-391
TOTAL	**2,890**	**271**	**3,161**

ADDITIONAL BIRDS

In the intake database, 99 large birds and 7 small birds lacked sufficient location information to place them definitely in the Bay or on the outer coast. This often occurs with birds brought to Wildlife Operations by members of the public. Because many (51%) of these were live birds, the majority of them were likely collected inside the Bay. Therefore, we applied the in-Bay background and correction factors to these birds (Table 24).

Table 24. Additional birds without location data.

Category	Birds Collected	Oiled Carcasses or Live Birds	Correction Factor	Bird Mortality Estimate
Large Birds	99	82	1.68	138
Small Birds	7	4	2.16	9
Total	**106**	**86**	**-**	**147**

TOTAL ESTIMATED ACUTE SEABIRD AND WATERFOWL MORTALITY

To determine total estimated acute mortality, we combine mortality figures for the Bay, the outer coast, and additional birds without location information. From this figure, we subtract those rehabilitated and released birds that likely survived. It is estimated that this number is 25% of the scoters, or 64 large birds.

Mortality calculations included extrapolations from the few shorebirds recovered. Because shorebird mortality was estimated separately by the trustees using a different process, the shorebird component was subtracted from these mortality tables.

The total estimated acute mortality of 5,425 seabirds and waterfowl is summarized in Table 25.

Table 25. Total estimated acute seabird and waterfowl mortality from the *Cosco Busan* oil spill.

Location	**Large Birds**	**Small Birds**	**Total**
San Francisco Bay	1,639	554	2,193
Outer Coast	2,890	273	3,163
Unknown	138	9	147
Subtotal	**4,667**	**836**	**5,503**
Less Rehabilitated & Released	-64	-	-64
Less Shorebirds	-	-14	-14
TOTAL	**4,603**	**822**	**5,425**

Mortality Estimate by Species

In order to estimate mortality by species, overall correction factors for general species groups were calculated. These correction factors were applied to the individual species within each species group. Species groups and their respective correction factors are summarized in Table 26. Correction factors vary because the mix of small and large birds, and ocean and bay locations, varies among groups. Group correction factors were applied to species totals from the intake database in order to estimate mortality by species (Table 27).

Table 26. Species groups and correction factors.

Species Group	Species Included	Estimated Mortality	Group Correction Factor
Loons	Common Loon, Pacific Loon, Red-throated Loon, Loon sp.	92	1.7
Large Grebes	Western Grebe, Clark's Grebe, Western/Clark's Grebe	1,071	1.92
Large Diving Ducks	Greater Scaup, Scaup sp., White-winged Scoter, Surf Scoter, Scoter sp.	1,527	1.58
Salt Pond Divers	Horned Grebe, Eared Grebe, Eared/Horned Grebe, Pied-billed Grebe, Lesser Scaup, Bufflehead, Ruddy Duck	764	1.94
Brown Pelican	Brown Pelican	22	1.83
Cormorants	Double-crested Cormorant, Brandt's Cormorant, Pelagic Cormorant, Cormorant sp.	507	2.04
Gulls	Glaucous-winged Gull, Glaucous-winged x Western Gull, Western Gull, California Gull, Heermann's Gull, Mew Gull, Bonaparte's Gull, Gull sp., Parasitic Jaeger	236	1.96
Northern Fulmar	Northern Fulmar	134	2.35
Common Murre	Common Murre	633	2.18
Rhinoceros Auklet	Rhinoceros Auklet	104	3.37
Marbled Murrelet	Marbled Murrelet	13	4.33
Other Alcids	Pigeon Guillemot, Cassin's Auklet, Ancient Murrelet, Alcid sp.	33	3.0
Other Birds	Red-breasted Merganser, Long-tailed Duck, Duck sp., Canada Goose, Greater White-fronted Goose, Black-crowned Night Heron, Great Blue Heron, American Coot, Common Moorhen, Red-shouldered Hawk, Red-tailed Hawk, American Crow, Rock Pigeon, Eurasian Starling, Fox Sparrow, Unid. Bird sp.	289	1.81

Table 27. Estimated bird mortality by species. Note: Total estimated mortality does not match the sum of Table 26 due to rounding.

Species	Estimated Mortality	Species	Estimated Mortality
Greater White-fronted Goose	2	Great Blue Heron	4
Canada Goose	5	Black-crowned Night-Heron	4
Greater Scaup	260	Red-shouldered Hawk	2
Lesser Scaup	52	Red-tailed Hawk	4
scaup., sp.	55	Common Moorhen	2
Surf Scoter	1,147	American Coot	76
White-winged Scoter	43	Bonaparte's Gull	2
scoter, sp.	23	Heermann's Gull	8
Long-tailed Duck	2	Mew Gull	8
Bufflehead	16	Western Gull	110
Red-breasted Merganser	2	California Gull	31
Ruddy Duck	138	Glaucous-winged Gull	22
duck, sp.	16	Gl-w x Western Gull	4
Red-throated Loon	12	Glaucous Gull	2
Pacific Loon	17	gull, sp.	47
Common Loon	61	Parasitic Jaeger	2
loon, sp.	2	Common Murre	633
Pied-billed Grebe	2	Pigeon Guillemot	6
Horned Grebe	153	Marbled Murrelet	13
Eared Grebe	386	Ancient Murrelet	3
Horned/Eared Grebe	17	Cassin's Auklet	15
Western Grebe	769	Rhinoceros Auklet	104
Clark's Grebe	56	alcid, sp.	9
Western/Clark's Grebe	246	Rock Pigeon	5
Northern Fulmar	134	American Crow	5
Brown Pelican	22	Eurasian Starling	2
Brandt's Cormorant	262	Fox Sparrow	2
Double-crested Cormorant	135	Unidentified Birds	157
Pelagic Cormorant	16		
cormorant, sp.	94		
		TOTAL	**5,427**

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Appendix C: Shorebird Injury Assessment

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

For purposes of this injury assessment, we assessed the oiling rates and mortality caused by the oiling to two groups: Snowy Plovers and all other shorebirds (referred to as "General Shorebirds"). Shorebirds are defined as charadriiformes in the families Charadriidae, Haematopodidae, Recurvirostridae, and Scolopacidae (gulls are not included).

<u>OILING RATES</u>
We used a study of observed oiling rates of shorebirds during the spill period, combined with a total population estimate, to estimate total number of shorebirds oiled.

Oiling Rates for General Shorebirds
There were two studies of shorebird oiling rates: 1) GFNMS conducted surveys for shorebirds on Ocean Beach daily from 9 to 21 November 2007, noting number of oiled shorebirds (Table 1), and 2) PRBO Conservation Science conducted focused studies of shorebird oiling rates in the East Bay (Emeryville area) and Bolinas/Stinson Beach, from 29 November to 16 December 2007. GFMNS also conducted surveys elsewhere on the outer coast, but not daily. Only the GFNMS Ocean Beach data covered the first few weeks after the spill, when oiling was likely most severe. By late November and early December, when the PRBO studies were conducted, the observed oiling rate of shorebirds on Ocean Beach had fallen to zero (Table 1), but rates at Bolinas/Stinson Beach (5-18%) and the East Bay (4-8%) were still measurable. Thus, the initial oiling rates during the first two weeks may have been considerably higher inside the Bay and in the Bolinas/Stinson area, than at Ocean Beach. To be conservative, the Trustees will apply the maximum oiling rate at Ocean Beach (14.6%) to the other sites as well. For reasons described above, this may be an underestimate.

Table 1. Oiling rate of shorebirds at Ocean Beach (GFNMS data).

Week	Date Range	Number of Surveys	Total Birds Seen	Number Oiled	Oiling Rate
1	11/9-11/15	7	1,315	192	14.6%
2	11/16-11/23	7	1,850	150	8.1%
3	11/24-12/1	2	238	0	0
4	12/2-12/9	1	264	0	0
5	12/10-12-7	2	260	0	0

Surveys were conducted for overall shorebird abundance within San Francisco Bay and at Bolinas/Stinson Beach and Ocean Beach to Sharp Park by various groups (Table 2). For Bolinas/Stinson and Ocean Beach to Sharp Park, we used maximum counts from several surveys conducted during November 2007. Data within San Francisco Bay (between the Richmond-San Rafael Bridge and the Bay Bridge) came from a one-day census coordinated by California Audubon and PRBO Conservation Science. Using the oiling rate from the first week of Ocean Beach surveys (14.6%), we obtained a conservative estimate of 2,841 oiled shorebirds (Table 2).

Table 2. Estimate of total number of shorebirds oiled by the Cosco Busan spill.

Location	Survey	Survey Date	Total Shorebirds Counted	Oiling Rate	Oiled Birds
SF Bay	Audubon/PRBO	11/10	17,941	14.6%	2,619
Bolinas/Stinson	OSPR (Henkel)	11/10	934	14.6%	136
Ocean Beach to Sharp Park	GFNMS	11/11	582	14.6%	85
TOTAL			**19,456**	**14.6%**	**2,841**

Oiling Rates for Snowy Plovers

PRBO Conservation Science was contracted to conduct additional studies to assess oiling rates and effects of oiling on Western Snowy Plovers. Surveys were conducted at six sites: Half Moon Bay State Beach, Pacifica (Linda Mar), Ocean Beach, Crissy Field, Stinson Beach, and Limantour Beach. Between 6 and 26 surveys were conducted at each site between 21 November 2007 and 17 January 2008. Total number of Snowy Plovers at each site varied slightly over time. During each survey, all or some of the Snowy Plovers were assessed visually for signs of oiling.

We considered two methods of assessing total number of Snowy Plovers affected: an estimate based on oiling rate multiplied by mean flock size, and the maximum number of oiled birds observed at each site, corrected for potential movement between sites. We consider the second method to be more reliable.

For the estimate based on oiling rate we used overall oiling rate (total number of oiled birds seen divided by total number of birds inspected). To assess numbers of Snowy Plovers affected, we used mean flock size at each location multiplied by mean oiling rate (Table 3).

Table 3. Estimated number of Snowy Plovers Oiled during the Cosco Busan spill.

Location	Checked for Oil	Oiled	Mean Oiling Rate	Mean Flock	Estimated Oiled	Max. Observed Oiled	Corrected Max.	Date of Max.
Crissy Field	80	53	0.66	3.4	**2**	4	**4**	12/1 & 12/10
Half Moon Bay	218	12	0.06	41.2	**2**	5	**4**	12/17
Limantour	481	10	0.02	48.7	**1**	4	**4**	11/26
Pacifica	208	55	0.26	21.2	**6**	10	**9**	12/4
Ocean Beach	458	340	0.74	26.2	**19**	27	**24**	11/29
Stinson Beach	169	27	0.16	16.9	**3**	8	**7**	11/30
TOTAL					**33**		**52**	

Maximum numbers of oiled Snowy Plovers at each site were slightly higher than estimates of oiled birds based on mean values; maximum counts could be biased if birds moved between locations and the same birds were counted at multiple locations. Sightings of banded birds showed that of 45 individuals identified, 5 were seen at more than one location (11.1%; most overlap was between Ocean Beach and Crissy Field). To correct maximum values for potential double-counting of individuals that moved between sites, we decreased maximum values at each site by 11.1% for corrected maximum values (Table 3).

We consider the corrected maximum values to be the best estimate of total number of Snowy Plovers oiled. The estimates based on oiling rate include values through mid-January, by which time some oiled birds may have died or moved out of the area. Thus, we estimate that at least 52 Western Snowy Plovers were oiled as a result of the Cosco Busan oil spill in November 2007.

ESTIMATED MORTALITY

This section begins with the oiling rates described above and estimates how many of those birds may have died. We begin with the Snowy Plovers, which were intensively studied.

Mortality Estimate for Snowy Plovers

The same study that surveyed the Snowy Plovers also tracked 45 banded birds (14 of which were banded immediately after the spill for this purpose), so as to understand their fate after oiling. This included 23 oiled and 22 unoiled plovers. Only one of the birds was deemed sufficiently oiled as to require rehabilitation. This bird was captured and cleaned before being released. The others had limited oil on their plumage and were not cleaned. These birds were surveyed regularly thru the winter of 2007-2008, following the spill, and again in the following winter. As 52 plovers were estimated oiled, this study represented a significant percentage of the affected birds. [Note: numbers are based on Table 2 of the PRBO report.]

All of the banded oiled plovers were seen alive thru December 23, 6 ½ weeks after the spill. The following winter (2008-2009), the banded birds were expected to return. A follow-up survey focused on plovers in the San Francisco area. 6 of 14 unoiled plovers were found (43%), and 12 of 21 oiled plovers were found (57%). It thus appears there was not significant mortality among the Snowy Plovers as a result of the oil spill. This is likely due to the fact that all but one of the plovers was only very lightly oiled, and that Snowy Plovers forage high on the beach and do not need to get in the water to obtain food. The one moderately oiled Snowy Plover that had been cleaned and released was not observed the following winter. It is possible that this bird may have died. In other oil spills, repeated daily surveys of oiled plovers found that lightly oiled plovers tended to survive from day to day, while moderately oiled plovers disappeared. Due to their small size and cryptic coloration, dead Snowy Plovers are almost never found.

We have no observations of banded oiled plovers from the breeding grounds, although such observations would have been serendipitous, as they birds disburse widely. Thus, we are unable to assess impacts to reproduction. However, there have been anecdotal stories, from other oil spills, of plovers surviving oiling going on to nest the next summer.

Based on this information, the Trustees believe that only a small number, perhaps no more than five, Snowy Plovers may have died due to the spill.

Mortality Estimate for General Shorebirds

Unlike the Snowy Plover, none of the other species were banded and studied intensively. They were predominately Western Sandpipers, but also included significant numbers of Black-bellied Plovers, Dunlin, Willets, Sanderlings, and dowitchers. All of these species forage lower in the intertidal area than Snowy Plovers, often in the active intertidal swash zone. Thus, they are more susceptible to oiling and more vulnerable to hypothermia as a result of it.

2,841 shorebirds were estimated oiled. Only one shorebird (a Black Turnstone) was collected live, and only four were collected dead, likely due to their small size and cryptic coloration. In many oil spill cases, all oiled shorebirds are assumed to have died. However, given the results of the Snowy Plover banding study described above, and the fact that many of these other shorebirds were only lightly oiled, the Trustees estimate that approximately 50% (or 1,421) of these shorebirds died or were lost to the breeding population as a result of the spill.

The 2007 *Cosco Busan* oil spill: Field and laboratory assessment of toxic injury to Pacific herring embryos and larvae in the San Francisco estuary

Final Report
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Summary

On November 7, 2007 the container ship *Cosco Busan* allided with a tower supporting the San Francisco Bay Bridge spilling roughly 54,000 gallons of bunker fuel into the Bay. The spill contaminated the shoreline adjacent to North Central Bay areas expected to be major spawning grounds for Pacific herring in the following months, based on the preceding decade of surveys. Based on experience following the 1989 *Exxon Valdez* spill, it was anticipated that contamination of the intertidal and shallow subtidal zones with *Cosco Busan* bunker oil could result in toxic injury to early life history stages of Pacific herring. Because of the relative ease of collecting herring spawn samples and a strong scientific understanding of the impacts of oil to herring embryos, this species was also chosen for study as a surrogate for other ecologically important fish species that utilize the intertidal and shallow subtidal for spawning. The aims of this study during the 2007-2008 herring spawning season were to (1) assess and compare the biological responses of herring embryos and larvae that incubated adjacent to oiled shorelines with those incubated adjacent to reference non-oiled sites in the North Central Bay; and (2) characterize the exposure of herring embryos to polycyclic aromatic hydrocarbons (PAHs) potentially derived from *Cosco Busan* oil. Because the findings from the 2007-2008 season strongly suggested impacts to embryos incubated at oiled sites, follow-up field and lab studies were performed during the following two spawning seasons.

During the 2007-2008 spawning season, herring embryos developing in situ in San Francisco Bay were assessed for PAH exposure, sublethal cardiac toxicity, developmental abnormalities, and hatching success. Cages containing artificially fertilized embryos were moored together with passive water sampling devices for PAHs (polyethylene membrane devices; PEMDs) at six sites. Four of these sites were visibly oiled immediately after the spill, while two sites were not oiled but contiguous with the same heavily urbanized shoreline (reference sites). Caged embryos were in the subtidal zone, at a common depth at least 1 m below the surface throughout the tidal cycle. Naturally spawned embryos were collected from five mid to low intertidal sites, four of which were adjacent to the caged embryos. Embryos from all sites were transported to a laboratory for live imaging using digital photo- and videomicroscopy and for incubation to hatching. Chemical analysis of embryos collected in 2008 and 2010 included PAHs and a suite of persistent organic pollutants (POPs) routinely found in urban environments, including polychlorinated biphenyls (PCBs) and organochlorine pesticides. Additionally, ovaries and whole bodies of pre-spawning adult herring entering San Francisco Bay in 2008 were analyzed for PAHs and POPs to evaluate the potential for maternal transfer of contaminants.

Whereas embryos incubated in the turbid subtidal zone at oiled sites in 2008 showed heart rate defects and pericardial edema consistent with sublethal petroleum toxicity, the vast majority of embryos developing in the intertidal zone at oiled sites died just before the hatching stage, with major disruption of tissues. No toxicity was observed in natural spawn or caged embryos from unoiled reference sites. Very few larvae with normal morphology hatched from natural spawn samples collected at oiled sited in 2008. The composition of PAHs at oiled sites in embryos and PEMDs was consistent with oil exposure against a background of urban PAH sources, although tissue concentrations were too low to explain the dramatic lethality. Concentrations of other pollutants typically associated with urbanization were also too low to cause lethality. In a series of laboratory studies in 2009, Cosco Busan oil demonstrated a potent phototoxic effect, whereby tissues are disrupted through an interaction between as yet identified compounds and sunlight. This phototoxic activity remained potent after two months of weathering. Embryos developing in the subtidal zone at oiled sites were presumably protected from this effect by the highly turbid water above them, while more intense exposure to sunlight in the intertidal zone led to lethality. Natural spawn sampled two years later from oiled sites showed no elevated necrosis or mortality, indicating that phototoxic activity was eliminated by much more prolonged weathering.

Section 1: Background

1.1 Introduction. This report summarizes the design, implementation, and results of an assessment of potential injuries to Pacific herring (*Clupea pallasi*) undertaken by the NRDA fish injury workgroup, as part of the overall injury assessment for the *Cosco Busan* oil spill. The study design, implementation, analysis, and reporting was performed principally by the NOAA Northwest Fisheries Science Center and the University of California Davis Bodega Marine Laboratory, in cooperation with the natural resource trustee representatives and representatives for the responsible party.

Figure 1-1: Satellite overview of Central San Francisco Bay with response estimates of shoreline oiling

Considering the locations affected (Figure 1-1) and the nature of the released fuel oil, the Trustees consulted resource managers and reviewed existing information on the fisheries in San Francisco Bay and the coastal ocean environment nearby, and developed an initial list of fish species to consider for assessment. The entire impacted area is designated as an essential fish habitat (EFH), and San Francisco Bay (SFB) is a habitat area of particular concern (HAPC) under the Magnuson-Stevens Fishery Conservation and Management Act. In the first several days following the spill, fish species under consideration for potential assessment included Pacific herring, green sturgeon, several species of salmon, tidewater goby, northern anchovy, jack mackerel, pacific sardine, English sole, starry flounder, several species of rockfish, striped bass, California halibut, Pacific sanddab, lingcod, sand sole, leopard shark, spiny dogfish, big skate, pacific whiting (hake), soupfin shark, curlfin sole, bocaccio, and cabezon. The Trustees also considered investigating potential impacts to Dungeness crabs and other bottom dwelling macroinvertebrates, and to drift algae communities present along the coast outside of San Francisco Bay.

After considering all these species and communities and the characteristics of this spill the Trustees narrowed the focus of injury assessment to Pacific herring as a proxy for nearshore spawning fish species. (The Trustees also made preparations to assess potential injuries to grunion, a fish species that has been observed in recent years spawning on sandy beaches in San Francisco Bay from March through late spring. Although monitored, no grunion spawning was observed in San Francisco Bay during 2008.)

Among finfish, the potential for injury to Pacific herring (*Clupea pallasi*) is of particular concern. As forage fish, herring are a cornerstone of the pelagic food web. They therefore play an influential role in the ecology of the estuary. Herring and their spawned eggs also constitute the only remaining commercial fishery in San Francisco Bay, and the shoreline of the Central Bay serves as one of the largest spawning locations for herring in the state of California (detailed in Section 1.3). Visible oiling of herring spawning habitat, as indicated by the presence of spawn in recent years, ranged from non-detectable to heavy. The heaviest oil was observed between Keil Cove and Horseshoe Cove near the base of the Golden Gate Bridge. The season for herring spawning typically spans November to March, with peak spawning in December and January. Thus, in the winter and early spring of 2007/2008, herring were expected to spawn on eelgrass, seawalls, rip-rap, and other surfaces that were contaminated to varying degrees with *Cosco Busan* oil.

Due to both spawn timing and proximity to oiled substrates, early life stages of herring were likely to be disproportionately impacted by the *Cosco Busan* spill relative to most other finfish species in the Central Bay. In this respect, threats to herring paralleled those following the *Exxon Valdez* spill, which oiled herring spawning habitats in Prince William Sound, Alaska in 1989. Numerous studies following the latter spill have shown that herring embryos are highly sensitive to the toxicological effects of oil. This toxicity can

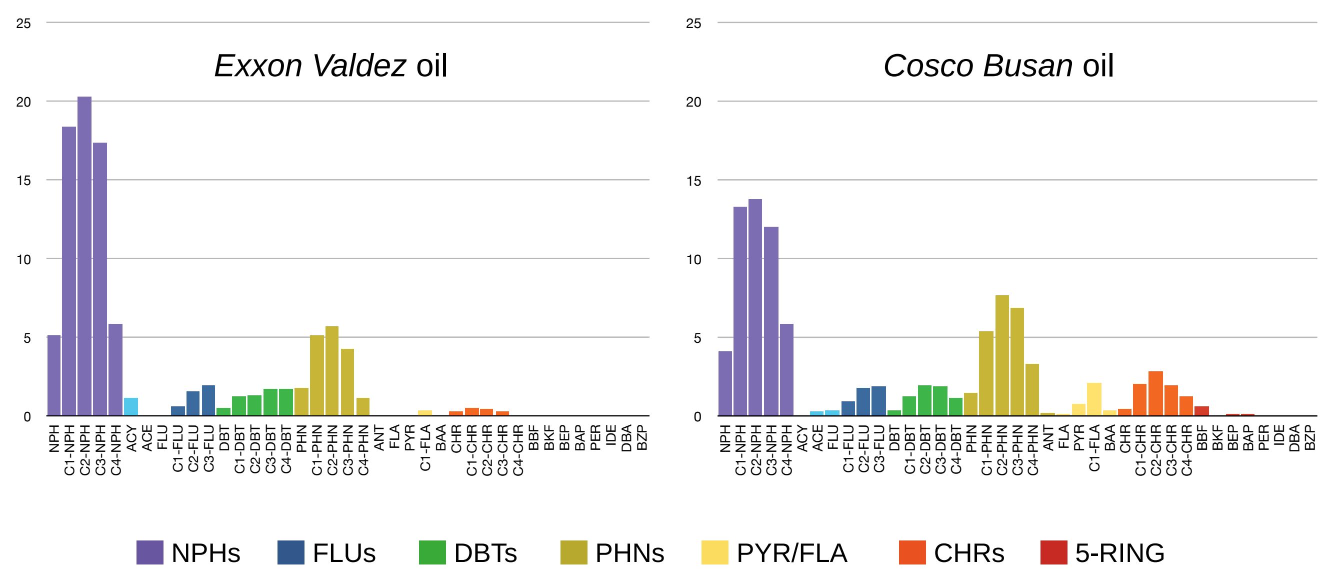


Figure 1-2: PAH composition of *Exxon Valdez* hold oil compared to *Cosco Busan* bunker oil. The x-axis is percentage of total PAHs. PAH subclasses are color-coded and degree of alkylation increases to the right (C1-, C2-, etc.). NPHs, naphthalenes; FLUs, fluorenes; DBTs, dibenzothiophenes; PHNs, phenanthrenes; PYR, pyrene; FLA, fluoranthene, CHR, chrysenes; 5-ring indicates benzo[a]pyrene, etc. EV data from NOAA Auke Bay Lab, CB data from NOAA NWFSC.

arise from (but does not require) direct contact with particulate oil (e.g., droplets) or exposure to dissolved-phase oil constituents in surrounding seawater (detailed in Section 1.6). This raises the possibility of developmental defects and embryo mortality in locations adjacent to but not necessarily in direct contact with an oiled shoreline after the *Cosco Busan* spill.

This injury assessment characterized the toxicological responses of herring embryos to *Cosco Busan* oil under both natural exposure conditions and in artificially spawned embryos that were outplanted and incubated at oiled sites, as well as at areas where no visible oiling of the shoreline had occurred. The objective was to provide a scientific basis for estimating the oil-induced loss of individual herring larvae from the 2008 year-class. In preliminary discussions with the Trustees (Nov. 14th, 2007), this was identified as the highest priority in terms of assessing injury to fish. However, because of the relative ease of collecting herring spawn samples and a strong scientific understanding of the impacts of oil to herring embryos, this species was also chosen for study as a surrogate for other ecologically important fish species that utilize nearshore areas for spawning. These include, for example, the California grunion. Spawning grunion have been observed in San Francisco Bay in recent years, albeit later than the herring run (typically beginning in March). Eggs remain on the beach in the sand for approximately two weeks and therefore may be at risk for residual oil exposure. Other forage fish that spawn in the Central Bay nearshore include northern anchovy, topsmelt, and jacksmelt.

The study did not directly address oil exposure and potential injury to other species of fish in the San Francisco Bay. These include, for example, salmonids, leopard shark, white sturgeon, striped bass, midshipmen, rockfish, staghorn and prickly sculpin, threespine stickleback, white croaker, shiner perch, bay goby, California halibut, English sole, and starry flounder. In addition, this assessment will not provide a basis for monitoring longer-term exposures to oil or recovery from injury over time for species other than herring. Certain species, such as white croaker, English sole, and starry flounder, have been monitored at various times since the 1980s as sentinels for hydrocarbon exposure in San Francisco Bay (e.g., as part of the National Benthic Surveillance Project) and may therefore be useful in terms of assessing any lingering impacts of *Cosco Busan* on fish in the estuary.

Table 1-1: Comparisons between crude, residual, and IFO cutting oils

	ANSCO[a]	*Exxon Valdez* oil[b]	No. 2 Diesel[a]	Residual fuel oil[a]	*Cosco Busan* oil
density (15°C)	0.87	NA	0.83	0.99	0.95[c]
percent aromatics	15	5	10	29	NA
TPAH (µg/g oil)	10600	13300	27000	29000	39000[d]

a, reference 3; b, NOAA Auke Bay Lab, unpublished; c, at 12.8°C, from OSPR; d, NOAA NWFSC this study; NA, data not available

1.2 Properties of *Cosco Busan* bunker oil. "Bunker fuel" is the generic term applied to the heavy oils burned in ship power plants. Bunker fuels consist mostly of a residual fuel oil, which is what remains after light fractions have been removed from a crude oil in the refining process. Neat residual fuel oils are highly viscous, and must be "cut" with a lighter fuel, typically diesel, in order to be pumped. The *Cosco Busan* carried IFO380, which is a residual oil cut with roughly 3% marine gasoil (equivalent to No. 2 diesel) to produce a viscosity of 380 centistokes. The specific gravity of residual oils varies from slightly less to greater than 1.0, and depending on water density and state of weathering, may float or sink. The diesel-cutting agent weathers more quickly, leaving behind the heavier residual oil. Because only a very small percentage of the oil is subject to evaporative weathering, IFO380 has the tendency to form tar balls that can become widely distributed.

Many chemical and elemental components of crude oil are much more highly concentrated in residual oils (Table 1-1) [1, 2, 86]. Residual oils and its mixed products such as IFO380 have a higher percentage of aromatic compounds, a higher total mass of PAHs, and importantly, fractions of uncharacterized polar compounds or "unresolved complex mixture" that can approach 30% of the mass [1]. In addition, residual oils are enriched with a higher content of metals such as nickel and vanadium [1]. Compared to Alaska North Slope crude oil (ANSCO) carried on the *Exxon Valdez*, *Cosco Busan* oil has three times the PAH mass (Table 1-1) and a higher percentage of the PAH classes that are toxic to fish early life history stages (Figure 1-2, detailed below in Section 1.6; note also that the chemical profile of "ANSCO" varies slightly depending on the exact oil field source). These compositional differences between bunker and crude oil are important in terms of predicting the potential toxicity of *Cosco Busan* oil. Relative to the size of the *Exxon Valdez* oil spill, the volume of the *Cosco Busan* spill was relatively small. However, strictly on the basis of normalized PAH toxicity, the *Cosco Busan* spill could be viewed as equivalent to approximately 150,000 gallons of *Exxon Valdez* oil. Moreover, although bunker fuels have not been studied nearly as intensively as ANSCO, the available studies generally indicate that residual oils are more toxic than predicted based on PAH content alone, consistent with their larger fraction of uncharacterized compounds (detailed in Section 1.6).

1.3 Pacific herring biology and the natural history of herring in San Francisco Bay. Estuaries provide essential habitats for Pacific herring reproduction, and are therefore an integral part of the herring life cycle. Reciprocally, herring are forage fish, and the adults, eggs, and larvae are important components of estuarine food webs. For this reason, herring are a keystone species. As such, they play a complex role in the dynamics and productivity of many predator populations, including other fish, birds, and marine mammals. They are also economically important to an international fishery that targets reproductive animals for the purposes of collecting ovaries (Kazunoku) and spawned eggs attached to kelp (Kazunoku Kombu).

General life history patterns for Pacific herring are alike throughout their range, which extends from Japan to the Arctic to California. Spawning, embryonic development, larval growth, and early juvenile life occur within estuaries, where lowered salinity and protected waters offer conditions conducive to success for early life stages [3]. San Francisco Bay supports the southern-most reproductive stock of Pacific herring in the Eastern Pacific Ocean. The San Francisco Bay stock is the youngest at first reproduction, and possesses the earliest and longest annual spawning seasons. Minimum age for reproduction is 2 years in the California stocks, 2-3 (in some years up to age 5) years in British Columbia fish and 4-5 years in Alaskan stocks [3-6]. The spawning season for the San Francisco Bay stock in most years extends from

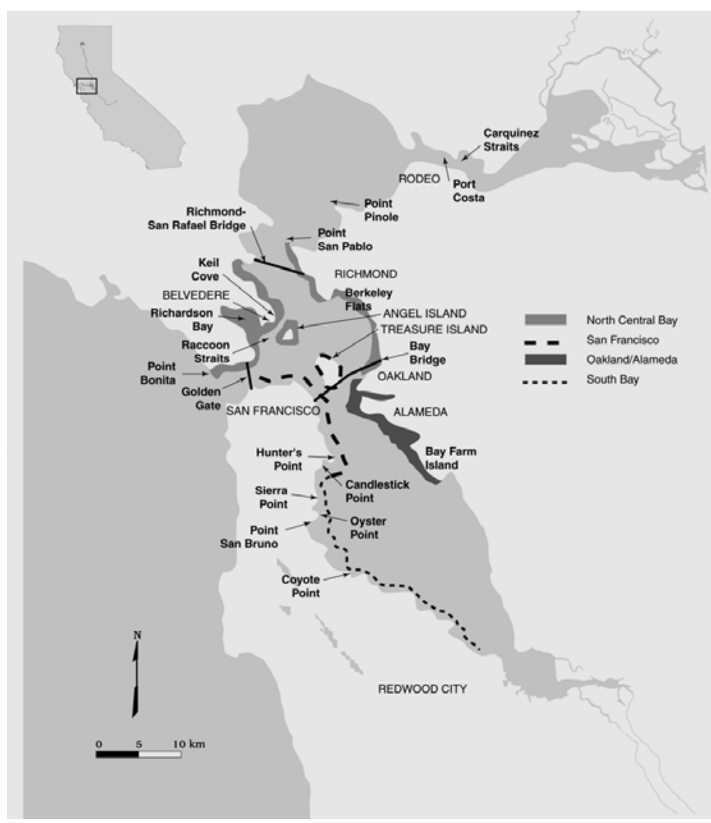


Figure 1-3: Historical Pacific herring spawning regions within San Francisco Bay. (From reference 11)

December through March with the peak of spawning occurring during January and February, although it has begun as early as October [5, 7-9].

San Francisco Bay is a large, complex body of water that consists of at least three sub-bays. These sub-bays, although physically connected, have different biological communities and fish assemblages. They include the North Bay, Central Bay, and South Bay. Use of the larger bay by herring as spawning and nursery sites varies within and between years. In terms of historical spawning patterns, the San Francisco shoreline can be divided into four regions [10]; the North Central Bay, San Francisco, Oakland/Alameda, and the South Bay (Figure 1-3). The North Central Bay encompasses the Marin County shoreline from Point Bonita through Richardson Bay to Point San Quentin. From 1974-2000 the North Central Bay was used for spawning in every year but one, and was the predominant spawn region in 13 out of the 26 years (Figure 1-4; [10].

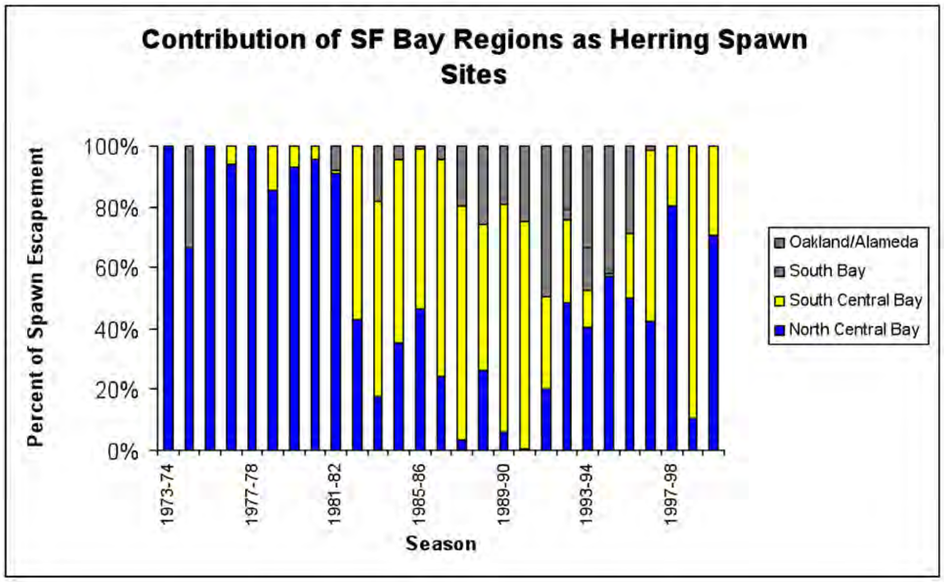


Figure 1-4: Percent of Pacific herring spawning adult biomass (i.e., escapement) by region for each season in San Francisco Bay, 1973–2000. Average percent biomass for each region was 54.9% North Central bay, 34.2% South Central Bay, 9.8% Oakland–Alameda, and 1.1% South Bay. (From reference 11; San Francisco spawn data is listed as South Central Bay).

During spawning, females deposit the adhesive eggs onto substrates such as marine vegetation, gravel, and rocks while males continue to release sperm in close proximity [11]. In San Francisco Bay, there have been declines in the percent cover of the eelgrass *Zostera*, a preferred substrate for spawning, and marine algal species (e.g. *Gracilaria* sp. and *Laminaria* sp.). Non-biological substrates, both natural and man-made (rocks, sand, pilings, boats) have been increasingly used as substrates for spawn [5, 10]. Herring avoid mud or silt-laden habitats. In 1979 divers sampled 15 sites in Richardson Bay and found *Zostera* and *Gracilaria* to be the only two significant marine vegetative species, with *Zostera* occupying only patches of subtidal habitat [5]. Density of vegetative coverage was variable throughout Richardson Bay, ranging from 0.003 kg of vegetation per square meter (northeast of Strawberry Point) to 0.164 kg/ m^2 (off Belvedere, near the mouth of Richardson Bay).

Surveys of herring spawn locations were conducted from 1973-74 through 1979-80 in San Francisco Bay, focusing on the North Central Bay [5]. In addition to intertidal and shoreline spawning from just inside the Golden Gate Bridge to Paradise Cove, major subtidal spawning areas were discovered in Richardson Bay and in the flats off Richmond and Oakland. Spawning during this period was also documented to occur off of Coyote Point in the South Bay, but was not surveyed for size [5]. During the period of these studies, estimates of spawning biomass for the Bay per season varied from 3,682 tons (1977-78) to 46,439 tons (1979-80). Similar wide fluctuations have been reported for Pacific herring spawning biomass in other regions (e.g. Alaska, British Columbia, and Washington). Spawning of a school of herring may take place over several hours or days depending on the size of the school. Typically several separate schools enter San Francisco Bay to spawn every two to three weeks over the course of a season. These spawning “waves” are typically separated temporally, but may overlap geographically. It is also not uncommon for one or two of these waves of spawners to contribute the majority of the spawn for the season [5, 9].

Herring eggs are monospermic in that normal fertilization requires that only one sperm fuse with and enter an egg. Embryonic development in *C. pallasi* is typical for teleosts [12-15]. Temperature and salinity correlate with changes in embryonic development times [15, 16], and the timing and landmark stages of Pacific herring embryonic development have been detailed for the San Francisco Bay stock [12]. These stages (periods) are generally: cleavage, blastula, gastrula, segmentation, pharyngula, and hatching periods. Early cleavages are confined to the animal pole of the egg with the first cleavage occurring about 3 hrs post-fertilization. Subsequent cleavages continue through the next 12 hrs and result in the formation of a cap of blastomeres (cells) termed the blastodisc, that migrate at a cell sheet (epiboly) to encase the vegetal regions of the embryo, producing the gastrula stage at about 20-21 hrs post-fertilization. By this stage the embryo has a definite bilateral symmetry with anterior/posterior, dorsal/ventral, and right/left axes evident. The next landmark stage, segmentation, becomes apparent with the development of somites by 42-48 hrs, and the pharyngula period is reached by day 5 of development. Hatching of swimming larvae in San Francisco Bay begins at 10.5 days at 10.5 ^{o}C [7]. In the laboratory, larval hatching occurs over a protracted period of 2-3 days, 8-10 days post-fertilization at 12^{o}C [12]. At hatching, herring larvae are transparent, retain a yolk-sac, and measure approximately 6-9 mm in length [13, 16].

1.4 Natural and anthropogenic causes of morbidity and mortality during herring egg stages. Herring spawning sites in San Francisco Bay are susceptible to several natural threats. Other threats originate from various human activities (past and present) in this heavily urbanized and industrialized estuary. Mortality during embryonic development in relatively pristine areas varies with location and year; it can range from 56-99% in British Columbia. In a two-year study conducted in Barkley Sound and the Strait of Georgia (1988-90), spawn sites were sampled to determine total biomass remaining as embryonic development proceeded. Predation is the primary cause of mortality, with average daily loss at 6-8% producing an overall loss of 50-70% by hatching [17]. Two additional potential natural causes of mortality involve embryos being dislodged from substrata and presumptive hypoxia when eggs are deposited in multiple layers of greater than eight eggs thick at spawning [3]. Both field observations and lab studies have shown that herring embryos can be significantly delayed or suffer high rates of mortality in the deeper layers at very high densities [18-22]. There is only one report of egg layers approaching or exceeding eight eggs in field-collected samples from San Francisco Bay [23].

The morphological effects of hypoxia on herring embryos have not been described in detail. However, some predictions can be made based on studies in other fish species. The embryos of a range of teleosts are generally resistant to lethal hypoxia at early developmental stages, and become more sensitive closer to hatching. In fish with relatively small eggs such as herring, this may be due to the very large surface-to-volume ratio [21]. In several species, hypoxia was shown to be a mild teratogen. At moderate levels of hypoxia, the most common effect is developmental delay with no overall changes in gross morphology. In zebrafish, an increase in body axis defects was observed with severe hypoxia (0.8 mg/L O_2), but only at much later stages of development (after hatching), and then in only about 20% of the animals [24]. Subtle somite defects have been observed in the embryos of several pelagic marine species, leading to vertebral abnormalities in juveniles and adults [25-27]. Hypoxia is not associated with cardiac arrhythmia and has not been found to induce edema in any species. Zebrafish embryos respond to hypoxia with an accelerated heart rate [24].

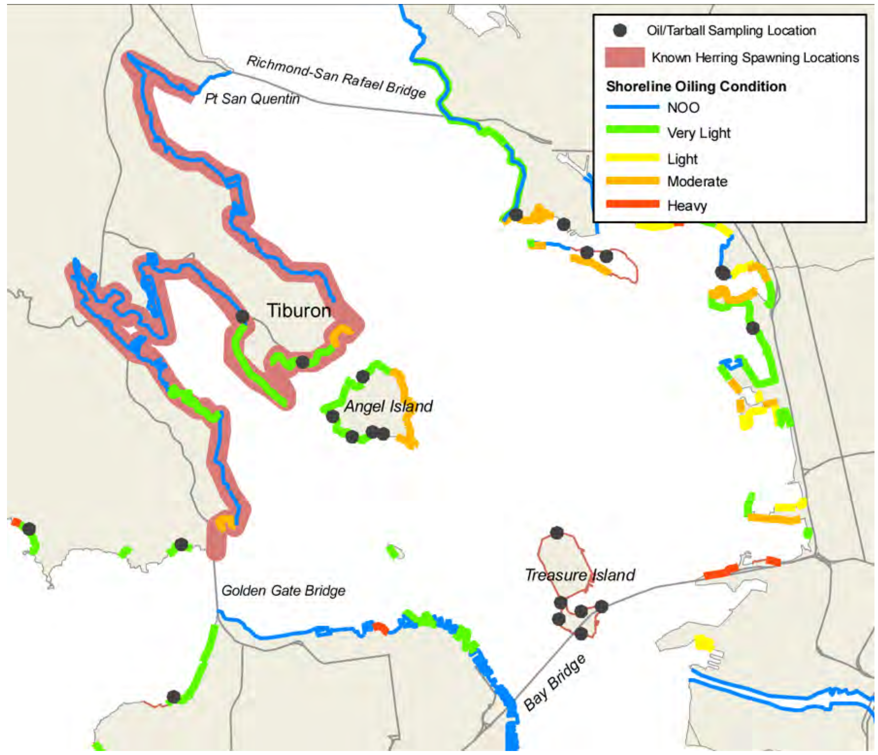


Figure 1-5: Relationship of shoreline oiling to recent herring spawning grounds in the Central Bay.

Temperature and salinity also influence herring development. Higher temperatures decrease embryonic development times, but result in larvae that are smaller than those developing at lower temperatures [16]. Eggs deposited in the intertidal are vulnerable to exposure and temperature shock. In Oregon the estimate for mortality in intertidal zones was dependent on weather, with higher mortality rates in warm, dry weather and lower mortality in cool, moist weather [28]. Hatching success declines with increasing water depth. Only 10-12% of embryos developing at 18 meters hatched compared to those that develop near the surface [19]. Herring embryos from stocks in the White Sea (Russia) arrested at early cleavage in salinity at or below 1 ppt [29]. At a slightly higher salinity (3 ppt), abnormal development occurs. This salinity is the lowest at which herring embryos have been reported to hatch. Hatching of White Sea herring occurred over a wider range (5-34 ppt) than that reported for Pacific herring from San Francisco Bay [12]. Consistencies between California herring and White Sea herring include higher numbers of malformed embryos and even larvae at both high and low salinity, incidences of partial hatching at low salinity, and delayed hatching at high salinity [12, 29].

Suspended sediments pose another potential threat. Theoretically, coating of eggs with fine suspended sediments could result in hypoxia. These effects might be expected to mimic those of hypoxia induced experimentally using water with low dissolved oxygen. Also, sediment-induced hypoxia might be similar to the effects of heavy spawn density. However, several studies using either Pacific or Atlantic herring embryos failed to find any significant effects of suspended sediments on embryos [30-33]. The potential threats associated with sedimentation have been a recurring issue for San Francisco Bay herring spawning grounds. This is due to the periodic need for dredging associated with the widespread maintenance of channels and harbors. However, a recent assessment found there to be little risk for impacts of suspended sediments on herring spawn in San Francisco Bay [34].

Inputs of effluent or overflows from sewage treatment plants are common in urbanized waterways such as San Francisco Bay. During the period of January-February 2008, there was a leakage of 2.7 million gallons of partially treated sewage into Richardson Bay (January 31) and a 1500 gallon spill of raw sewage from the San Quentin prison (February 14). Although the primary effects of sewage effluent are related to endocrine disruption by xenoestrogens, impacts of sewage on early development in fish has not been studied in detail. A single study tested the effects of sewage sludge on Atlantic herring development [35]. Concentrations of suspended sludge ≥ 0.1% caused premature hatching but no mortality in embryos. There were otherwise no significant effects at concentrations ≤ 0.2%. Given that concentrated sewage in the form of sludge is likely to be more toxic than partially treated effluent, it is highly unlikely that sewage spills to San Francisco Bay would produce acute morphological defects in herring embryos.

1.5 Timeline and pattern of the spill in relation to herring spawning. The spill occurred in early November, two months before the average peak of herring spawning. Based on the last 10 years of surveys by California Department of Fish and Game, the most likely sites for spawning in 2007-2008 were in the North-Central portion of San Francisco Bay from Golden Gate to Point San Quentin. Major sections of this shoreline that had visible oil included areas near the Golden Gate, the Sausalito waterfront, and the southern part of the Tiburon peninsula (Figure 1-5). In the 2007-2008 season, spawning occurred much later than typical. Schools of herring began to enter the Bay intermittently in January 2008, but sampling showed low percentages of fish with ripe gametes. Small spawning events occurred intermittently through February, and major spawning occurred on the San Francisco waterfront for the first time since this area was oiled by the *Cape Mohican* spill in 1996. Ripe fish caught near Richardson Bay provided gametes for the outplant portion of this study (see Section 1.7) starting the second week of February. Spawning along the North-Central shoreline, including oiled sites, occurred fairly widely but at relatively low densities starting February 17, a full 14 weeks after the spill.

1.6 Impacts of petroleum hydrocarbons on herring and other fish embryos. The body of scientific research that followed the 1989 *Exxon Valdez* oil spill in Prince William Sound was a major advance in terms of understanding the toxicological impacts of crude oil on early life history stages of fish. Our current understanding of how petroleum hydrocarbon exposures impact the normal development of fish embryos and larvae has been largely determined by research and monitoring in the years since *Exxon Valdez*. Much of this work was published after 1996 and was hence unavailable to inform the response to and damage assessment for the last major oil spill in San Francisco Bay (*Cape Mohican*). The *Exxon Valdez* spill contaminated spawning grounds for Pacific herring and pink salmon. In subsequent years, a large number of field and laboratory studies revealed that the embryos of both species are highly sensitive to polycyclic aromatic hydrocarbons (PAHs) in petroleum products. In both herring and pink salmon, PAHs from weathered oil caused a common syndrome of developmental defects [36-39]. Lower frequencies of essentially identical defects were previously described in earlier studies focusing on higher concentrations of fresh oil [40-43]. Gross malformations included pericardial and yolk sac edema, small jaws, and spinal curvature, accompanied by heart rate reduction (bradycardia) and cardiac arrhythmia. These effects of petroleum-derived PAH mixtures were subsequently documented in a variety of other teleost species [44-46] as well as in herring embryos exposed to PAH-rich creosote [47]. Overall, these toxicological effects occur at relatively low (ppb) total aqueous PAH concentrations, and do not require direct contact with oil droplets or

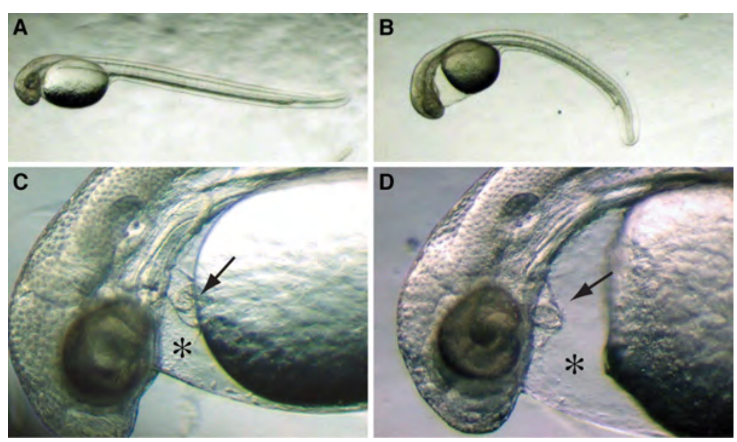


Figure 1-6: Cardiogenic edema in Pacific herring embryos exposed to ANSCO. (A, B) Gross morphology of embryos at 7 days post-fertilization exposed to clean (A) or oiled (B) gravel effluent. (C, D) Higher magnifications showing the heart (arrows) and pericardial space (asterisks) in embryos exposed to clean (C) or oiled (D) gravel effluent. From reference 60.

particulate oil [48].

Unrefined crude oils generally contain PAH fractions that consist of roughly 50-60% naphthalenes, 40-50% tricyclic compounds (fluorenes, dibenzothiophenes, and phenanthrenes), and 1-3% chrysenes [2]. Higher molecular weight PAHs such as benzo(a)pyrene usually constitute < 1% of the total PAHs in crude oils. During the weathering of oiled substrates (e.g. beach gravel) by water, PAHs (and other constituents) move into water from the substrate over time. This timed release is in essence the definition of weathering, described by first-order loss-rate kinetics [49], and results in a ‘water-washed’ pattern of dissolved PAHs. Lower molecular weight compounds with fewer alkyl substitutions are dissolved most readily, and dissolution rates are proportional to hydrophobicity. Effluent from substrates with relatively fresh oil is initially dominated by the relative proportions of naphthalenes. Over time, the concentrations of tricyclic PAHs and alkylated isomers become proportionately greater. As the pattern of dissolved PAHs shifts to these tricyclic compounds, both mortality and defects such as pericardial edema occur at much lower total PAH concentrations [38, 39]. Thus, oil toxicity to fish embryos is predominantly associated with fluorenes, dibenzothiophenes, and phenanthrenes.

Considerable progress has been made over the past five years in terms of elucidating the different toxicological pathways by which crude oil and these individual PAH compounds disrupt fish development. Several lines of evidence from studies using zebrafish and other experimental models have identified the developing heart as a primary target for PAHs enriched in crude oil. These studies demonstrated that the now-familiar morphological defects associated with oil exposure are (1) attributable to the tricyclic PAH fraction, (2) secondary to direct impacts on cardiac function, and (3) independent of the aryl hydrocarbon receptor/cytochrome P4501A (AHR/CYP1A) pathway traditionally associated with toxicity of high molecular weight PAHs [46, 50-53]. Importantly, these studies have made key distinctions between the effects of crude oil and its most abundant low molecular weight PAHs, and the effects of other aromatic compounds that are widely distributed in San Francisco Bay. These include the higher molecular weight pyrogenic PAHs such as pyrene, benz[*a*]anthracene, and benzo[*a*]pyrene, the co-planar PCBs, and dioxins. Most of these compounds disrupt teleost heart development in a manner similar to dioxins through activation of the AHR. However, cardiac rhythm disturbances are not the primary response associated with exposure to potent AHR ligands such as 2,3,7,8-tetrachlorodibenzo-p-dioxin, co-planar PCBs, or benz[*a*]anthracene, and all of these compounds produce cardiac malformations at later developmental stages than the tricyclic PAHs [52, 54-56].

In zebrafish embryos, exposure to non-alkylated tricyclic PAHs through the pharyngula stage (36-48 hours post-fertilization, hpf) produces a dose-dependent reduction of heart rate (bradycardia), followed by more complex arrhythmias consistent with atrioventricular conduction block [50, 51]. Somewhat more complex effects, including reduced contractility, were observed in zebrafish embryos exposed to weathering oil that produced total tricyclic alkyl-PAH aqueous concentrations in the range of 20-30 ppb [50]. Comparison to the phenotypes of known zebrafish cardiac mutants suggests several potential myocardial targets for oil toxicity, including cardiac potassium channels [57-59], sarcoplasmic or plasma membrane calcium channels [60] or gap junctions [61]. These findings recently were extended to Pacific herring embryos (Figure 1-6), thereby confirming that early cardiac dysfunction (i.e. arrhythmia) is the primary and earliest toxicological response to unrefined crude oil exposure in herring, occurring at the same developmental stage as in zebrafish [62]. Therefore, the best available science indicated that an assessment of *in vivo* cardiac defects and their sequelae (e.g. edema) would likely be the most sensitive indicator of toxicity in herring embryos exposed to *Cosco Busan* oil.

Despite these recent advances in our understanding of PAH and the toxicity of unrefined crude oil, there are still significant data gaps concerning the toxicity of heavier residual oil products that comprise "bunker" fuels. The heavier distillates of crude oil have not been studied nearly as intensively as crude oils, particularly Alaskan crude oils. However, studies on a variety of invertebrates and fish generally have shown that crude oil distillates typically have comparably higher toxicity than unrefined petroleum [63-65]. Moreover, the toxicity of heavier refined products often cannot be attributed to just the PAH fraction. This is because the observed toxicity of refined oil is higher than predicted by the aqueous concentrations of PAHs [66-68]. Some studies suggest that exposure of fish embryos to heavy residual oils may not produce the canonical syndrome associated with Alaska North Slope crude oil. A field study following a spill of bunker fuel in a freshwater lake found no association of edema with oil exposure in lake whitefish (*Coregonus clupeaformis*), but increased incidence of body axis defects was highly correlated with incubation near oiled sites [69]. Similarly, a laboratory study using spotted halibut (*Verasper variegates*) embryos described novel defects in spinal neural development caused by heavy oil exposure, apparently with the absence of edema [70]. Finally, very small spills of bunker fuel have been associated with high rates of mortalities in other marine vertebrates [71].

The effects of PAHs and petroleum products described above are all based on studies of oil effects in the absence of other stressors. An additional pathway of toxicity identified for individual PAHs and whole oils involves interactions with ultraviolet (UV) wavelengths of sunlight. Specifically, a large body of literature demonstrates that certain PAHs are capable of producing cellular phototoxicity through the UV-mediated activation of bioaccumulated compounds and subsequent generation of reactive oxygen species and membrane damage [87,88]. This has been raised as a mechanism that is putatively important in the environment, due to the potential susceptibility of unpigmented organisms to UV exposure from solar radiation in shallow waters [89]. Most of the studies on PAH phototoxicity in aquatic systems have focused on planktonic invertebrates e.g. [90-92], while a few have focused on phototoxicity of individual PAHs and ANSCO preparations in fish early life history stages [93-96]. A recent study compared the phototoxicity of bunker oils to ANSCO in zebrafish embryos and found that bunker oils had much greater phototoxic potential, and that the phototoxicity was largely from compounds other than the typically measured PAHs [97].

In summary, the literature on the toxicity of different types of petroleum products (i.e. crude and bunker oils) indicates that there is likely to be considerable overlap with the types of toxicity observed with ANSCO, but also that there may be novel effects associated with the more chemically complex bunker oils.

1.7 General goals and approach for the assessment of injuries in the field. The overall aims of this assessment were to monitor the *in situ* exposure of herring embryos to *Cosco Busan* oil at sites with varying histories of visible oiling, and to assess the toxicological response of herring embryos over the same range of oil exposures in the field. A simple approach to estimating herring spawn exposure to *Cosco Busan* oil would be to compare the distribution of visible oil (or tar balls) along the shoreline of San Francisco Bay with specific spawning locations for the 2007/2008 season as determined from California Department of Fish and Game field surveys. However, the presence or absence of visible oil in the days immediately after the spill may be a poor indicator of the spatial distribution of dissolved-phase PAHs or other oil compounds months later during the herring spawning season. Instead, a tiered approach was developed. The aim of the first tier (Tier 1) was to determine the extent of bunker oil exposure by analyzing PAH profiles in 1) the tissues and eggs of pre-spawning adult females, 2) eggs spawned naturally at locations within and external to the visible *Cosco Busan* oil spill zone, 3) eggs fertilized and outplanted at locations within and external to the visible spill zone, and 4) passive sampling devices deployed in tandem with the outplanted herring embryos. A related Tier 1 aim was to assess the early development, viability, and larval performance of naturally spawned and outplanted herring embryos for evidence of early life stage toxicity that might be attributable to exposure to residual *Cosco Busan* bunker oil. The goal of Tier 2 was to determine whether *Cosco Busan* oil could be detected in intertidal and subtidal sediments adjacent to locations where natural spawn and outplanted eggs incubated, respectively. Collections for the Tier 3 analysis were intended to qualitatively assess and quantify the induction of CYP1A (a biomarker for PAH exposure; *51*, *53*) in both naturally spawned and outplanted embryos. This report only describes the results of the Tier 1 studies. An adequate assessment was obtained with the completion of Tier 1 studies, and part from analysis of sediments, Tiers 2 and 3 were not implemented.

To determine whether there were biological impacts to herring spawn from *Cosco Busan* oil, the basic approach was to look for the morphological and functional defects associated with (crude) oil exposure (described in Section 1.6) in embryos collected from spawning locations with different degrees of *Cosco Busan* oiling (based on maps Shoreline Cleanup and Assessment Teams; SCAT). The same observations were made for embryos collected from non-oiled urban reference sites. Since it was unknown in advance where herring would actually spawn, laboratory-fertilized embryos were outplanted in moored cages at sites selected by recent history of spawning and degree of oiling. Four sites were chosen in the Central Bay/ Marin area that had different degrees of oiling based on SCAT surveys, but also different degrees of cleanup activity, and two non-oiled reference sites were chosen further northeast on the same shoreline. There was generally delayed and reduced spawning in the Central Bay in early 2008, and only three of the oiled sites and one reference site were assessed for impacts to naturally spawned embryos. Natural spawn and caged artificial spawn also differed in their incubation by depth and distance from shore: all natural spawning occurred in the intertidal zone, while caged embryos were incubated in the shallow subtidal zone.

To characterize oil exposure to herring embryos, PAH levels were analyzed in composite samples from natural spawn and caged artificial spawn. PAHs were also analyzed in the bodies and ovaries of adult animals to determine whether there could be maternal contribution to any exposure In addition, polyethylene membrane devices (PEMDs) were deployed to passively sample PAHs over the normal duration of herring egg incubation at the cage deployment sites. PEMDs bind dissolved-phase PAHs, eliminate the potential for PAH metabolism associated with fish tissues, and, unlike eggs, are less susceptible to fouling by sediments and artifactual measurements of sediment-bound PAHs. Sediment samples were also collected for potential Tier 2 PAH analysis from the same transects in the intertidal zone where natural spawn was sampled, as well as the subtidal locations for caged embryos. Samples of embryos were also retained in order to qualitatively and quantitatively assess induction of CYP1A if necessary (Tier 3).

Because significant biological effects were observed in herring embryos incubated at oiled sites in February 2008, follow-up sampling was performed in 2009 and 2010. The goal of these studies was to collect natural spawn from the same locations sampled in 2008. In 2009, there was no overlap of natural spawn in intertidal zones sampled in 2008, but spawning occurred in the intertidal zone in a new reference site on the Tiburon Peninsula, Paradise Cove Park. In 2010, intertidal spawning occurred at the exact same GPS coordinates sampled in 2008 at Sausalito, Peninsula Point, and Keil Cove, and at the 2009 reference site, Paradise Cove. A summary of all the sites and the types of samples analyzed are provided in Table 1-2.

Table 1-2: Physical shoreline characteristics of sample sites and types of samples collected each year.

Site	SCAT rating	Cleanup	Adjacent land use/maritime use	Subtidal sampling		Intertidal sampling
				Incubated Caged Embryos[2]	PEMDs	Natural spawn sampled[1]
Keil Cove (KC)	oiled; heavy	extensive wiping, removal of rock	residential, undeveloped forest	2008	yes	2008, 2010
Horseshoe Cove (HC)	oiled; moderate-light	extensive wiping of rip-rap	marina, major highway	2008	yes	ND
Sausalito (SA)	oiled; very light-light	some wiping	marina, commercial, residential	2008	yes	2008, 2010
Peninsula Point (PP)	oiled; light	some wiping	residential	2008	yes	2008, 2010
San Rafael Bay (SRB)	no oil	NA	commercial parking lot, major highway	2008	yes	2008
Paradise Cove (PC)	no oil	NA	residential, public green space	not sampled	no	2009, 2010
Point San Quentin (PSQ)	no oil	NA	commercial/industrial parking lots, major highway	2008	yes	not sampled

[1]All caged and naturally spawned embryos were assessed for sublethal exposure to PAHs and POPs, except the 2009 samples.
NA = not applicable, ND = no spawn detected

1.8 Laboratory studies supporting interpretation of field injury assessment. Contemporary research on oil toxicity, largely in response to the Exxon Valdez spill, has focused on crude oil, and in particular petrogenic polycyclic aromatic hydrocarbons (PAHs). The hallmark of "canonical" crude oil toxicity in fish embryos is cardiogenic edema, attributable to the tricyclic PAH fraction of unrefined petroleum such as Alaska North Slope crude oil (ANSCO). It was anticipated that if any lingering oil toxicity followed the Cosco Busan spill, it would be observed as a small increase in the detection of pericardial edema in herring embryos incubated near oiled shoreline. The 2007-2008 Fish Injury studies were designed to detect such differences. While there were statistically significant increases in measures of sublethal pericardial edema in caged embryos incubated in the subtidal zone of oiled shorelines, embryos that incubated in the intertidal zones of oiled shoreline apparently succumbed to a dramatically different type of lethal toxicity. The complete absence of this lethality at the non-oiled site, plus the inability to associate lethality with other chemical or abiotic stressors, strongly suggests a link to exposure to Cosco Busan oil. While canonical petrogenic PAH toxicity is sublethal, previous laboratory studies with ANSCO and herring larvae showed that oil can produce acutely lethal toxicity when combined with exposure to ambient sunlight or UV wavelength light. At the same time, modern residual fuel oils such as that carried on board the Cosco Busan have distinct chemical differences from unrefined crude oil that could result in different types of toxicity. On this basis, the novel lethal effect observed in 2007-2008 natural spawn samples and the differences in effects observed in subtidal vs. intertidal incubation leads to these specific aims: **(1) Does the inherent toxicity of Cosco Busan bunker oil differ significantly from unrefined Alaska North Slope crude oil? (2) Did sunlight exposure of beached Cosco Busan bunker oil produce**

novel toxic compounds through photo-oxidation? (3) Was the observed necrosis in natural spawn samples due to phototoxicity of PAHs or other bunker oil constituents?

To test these specific aims, a laboratory study was designed by investigators at NOAA's Northwest Fisheries Science Center and the UC-Davis Bodega Marine Laboratory, and implemented at the Bodega Marine Laboratory December 2008 through March 2009. Oiled gravel columns were used to generate water contaminated with dissolved-phase oil constituents in a way that mimics intertidal conditions following an oil spill. The basic principle was to expose herring embryos to oil during weathering by initiating weathering of the columns in January with continuously flowing seawater, and incubating herring embryos in the column effluents at different points between January and whenever the availability of gametes ceased (potentially April). A replicate design tested effluents from columns containing clean gravel, gravel from a non-oiled urbanized beach in San Francisco Bay, gravel coated with three concentrations of ANSCO as a positive control, and gravel coated with three concentrations of Cosco Busan oil. Both the columns and the incubation reservoirs for embryos were exposed outdoors to either full sunlight or sunlight with reduced UV wavelengths with the use of covers constructed from UV transmitting (UVT) or UV blocking (UVB) plastic.

Due to the constraints of obtaining sufficient masses of herring gametes and the time to analyze the embryos from a single experiment, only Aim 3 was rigorously tested. The study as it was executed could not rule in or out a contribution of photo-oxidation to toxicity. The toxicity of the two oils was not directly compared in the laboratory without the additional stressor(s) of outdoor exposure. Embryos were incubated in the column effluents at four points between late January and late March 2009. After incubation to 8 days post-fertilization (just before hatch), embryos were examined for signs of necrosis. In order to verify the oiled gravel dose response relationships, PAHs were measured in water samples at the start and end of embryo incubation, and in embryos tissues at the end of incubation. However, PAH concentrations were not intended to be used as the sole determinant in the interpretation of toxic effects, as there may be other unmeasured compounds contributing to toxicity of a given oil.

An additional lab study addressed whether incubation at higher than optimal salinity could account for some of the abnormalities observed in embryos from oiled sites in 2008. This study is described in Section 4.7.

Section 2: Methods and Implementation

2.1 Field studies. The major aim of field studies was to opportunistically sample herring embryos naturally deposited at a variety of oiled and reference shorelines. In the event that herring did not spawn along oiled shoreline, but moved to other locations in greater San Francisco Bay, herring embryos fertilized in vitro were incubated in cages placed on replicate moorings in the shallow subtidal zones of four oiled and two reference shorelines. Sites selected in January 2008 for mooring caged embryos included four oiled (Horseshoe Cove, Sausalito waterfront, Peninsula Point, Keil Cove) and two reference sites (Point San Quentin, San Rafael Bay). In 2008 three oiled sites and one reference site had natural spawn depositions that could be sampled. Methods described here were established for those sites, and were also applied to follow-up sampling taken in 2009 and 2010. An additional reference site was available in 2009 and 2010, Paradise Cove on the Tiburon Peninsula.

2.1.1 Selection of natural spawn sampling sites and collection of natural spawn. Selection of natural spawn sampling sites was opportunistic. The 2007-2008 spawning season was atypical, with ripe fish appearing in large numbers relatively late in the season. Significant spawning events did not occur along the Central Bay waterfront until late February. Spawning occurred at only four of the six study sites chosen for deployment of caged embryos (see below). Over the period from 2/26/08 through 2/29/08 natural spawn samples were collected at San Rafael Bay (MRU01), Sausalito (MRQ10/P01), Peninsula Point (MRQ01), and Keil Cove (MRR20). No natural spawning occurred over the course of the study at the Horseshoe Cove site (MRP04), and although natural spawning was observed at the Point San Quentin site (MRT04), the spawning density there was very light. It also occurred concurrently with a sewage spill from the San Quentin prison near this site which prohibited access to the water, and at the same time as a much more dense natural spawning event at the nearby reference site, San Rafael Bay. It was not possible to process natural spawn samples from two sites in the same day, and it was decided not to hold field-collected natural spawn samples in the lab after arrival from the field prior to the beginning of laboratory processing. Accordingly, natural spawn samples were not collected from Point San Quentin. At subtransects within the Sausalito (N5) and Keil Cove (N6) sites, it was necessary to combine two adjacent subtransect collections (20-m total distance at each) together to be able to collect enough sample quantity to provide the required laboratory subsamples (see Table 2-1).

Table 2-1: Summary of Natural Spawn Sampling Sites

Site	N1	N2	N3	N4	N5	N6	N7	N8
San Rafael Bay (MRU01)	37^{0}56.690N x 122^{0} 28.841W	37^{0}56.693 x 122^{0} 28.849	37^{0}56.696 x 122^{0} 28.854	37^{0}56.698 x 122^{0} 28.859	37^{0}56.702 x 122^{0} 28.864	37^{0}56.707 x 122^{0} 28.873	37^{0}56.711 x 122^{0} 28.877	37^{0}56.717 x 122^{0} 28.887
Date/Time begun	2/26/08 10:30 AM	2/26/08 10:40 AM	2/26/08 10:48 AM	2/26/08 10:57 AM	2/26/08 11:04 AM	2/26/08 11:12 AM	2/26/08 11:24 AM	2/26/08 11:40 AM
Sausalito (N1-5, MRQ10 N6-8, P01)	37^{0}51.688 x 122^{0} 29.174	37^{0}51.691 x 122^{0} 29.181	37^{0}51.693 x 122^{0} 29.185	37^{0}51.696 x 122^{0} 29.191	37^{0}51.697 x 122^{0} 29.199 & 37^{0}51.698 x 122^{0} 29.205	37^{0}51.482 x 122^{0} 28.719	37^{0}51.487 x 122^{0} 28.718	37^{0}51.493 x 122^{0} 28.716
Date/Time begun	2/27/08 10:11 AM	2/27/08 10:23 AM	2/27/08 10:36 AM	2/27/08 10:49 AM	2/27/08 11:05 AM	2/27/08 12:04 PM	2/27/08 12:18 PM	2/27/08 12:33 PM

Keil Cove (MRR20)	37^{0}52.826 x 122^0 26.413	37^{0}52.824 x 122^0 26.407	37^{0}52.821 x 122^0 26.402	37^{0}52.816 x 122^0 26.391	37^{0}52.814 x 122^0 26.387	37^{0}52.811 x 122^0 26.382 & 37^{0}52.809 x 122^0 26.376	37^{0}52.806 x 122^0 26.371	37^{0}52.803 x 122^0 26.365
Date/Time begun	2/28/08 11:53 AM	2/28/08 11:58 am	2/28/08 12:05 PM	2/28/08 12:11 PM	2/28/08 12:17 PM	2/28/08 12:24 PM	2/28/08 12:36 PM	2/28/08 12:36 PM
Peninsula Pt. (MRQ01)	37^{0}52.056 x 122^0 27.994	37^{0}52.052 x 122^0 27.989	37^{0}52.048 x 122^0 27.988	37^{0}52.042 x 122^0 27.983	37^{0}52.039 x 122^0 27.978	37^{0}52.036 x 122^0 27.975	37^{0}52.032 x 122^0 27.969	37^{0}52.030 x 122^0 27.963
Date/Time begun	2/29/08 12:15 PM	2/29/08 12:29 PM	2/29/08 12:36 PM	2/29/08 12:47 PM	2/29/08 12:54 PM	2/29/08 1:02 PM	2/29/08 1:11 PM	2/29/08 1:17 PM

Figure 2-1: Collection of natural spawn

Generally, the spawning occurred on substrates in the intertidal and shallow subtidal zones. Abundant spawn was not found at depths adjacent to moorings for cages (see below). Collection of naturally spawned herring eggs was conducted in the intertidal zone, at positions shoreward of all of the subtidal cage/mooring deployment sites where natural spawning events also occurred. At all sites, samples were collected seven days after the natural spawning event had originally been detected by rake or shore-based surveys, or based on field examination of the embryo developmental stage at each site by visual inspection after fixation in Stockard's solution. At each location, attempts were made to collect marine vegetation with spawned herring eggs attached from the middle to lower intertidal zone. These efforts were successful in most situations. At some sites, marine vegetation was largely absent in the lower intertidal, and the herring had primarily spawned in the upper intertidal zone. In these situations samples were collected as low in the intertidal zone as possible, and in no cases were samples collected above the waterline.

The protocol for collection of natural spawn was performed uniformly at all sampling sites. At each site, samples were collected along a 100-m transect at positions shoreward of the cage deployment positions (A1 through A5) and parallel to the shore within the intertidal zone. Each 100-m transect was divided into ten distinct 10-m subtransects from which vegetation samples with attached spawn were pooled into eight distinct samples (N1-N8); two subtransects within the 100-m transect were randomly skipped at each site. GPS coordinates were recorded at the midpoint of each subtransect. Samples were collected from the shoreline by personnel with chest waders and/or by snorkeling. Algal holdfasts were cut with a knife and the entire sample placed in heavy duty ziplock bags containing ambient seawater. When a sufficient sample size for processing the required laboratory subsamples had been collected at each subtransect, the ziplock bag was filled with

Figure 2-2: Construction of moorings

ambient water at the same subtransect, sealed, and placed in a large cooler lined with freshly frozen blue ice. Individual samples from the same site (e.g. N1-N8 from San Rafael Bay) were separated from one another by frozen blue ice blocks, to maintain an ambient, or lower than ambient, water temperature during transport back to the laboratory at the Bodega Bay for sample processing and imaging. In all cases, processing of the natural spawn samples in the lab was begun within six hours after the last natural spawn subtransect site was collected in the field.

Samples taken in 2009 and 2010 followed identical procedures (Table 2-2). However, in 2009 intertidal spawning occurred at only a single site, Paradise Cove. In this case spawning was higher in the intertidal zone and on substrate dissimilar to previous samples (about half the samples were collected from rocks). Although this deviated from the Standard Operating Procedures manual (SOP, Section 7.4) established in 2008, samples were processed accordingly. In 2010 intertidal spawning occurred at the same three oiled sites in 2008 and at the Paradise Cove reference site, at the same intertidal depth as the original samples. However, only three of the eight transects at Sausalito had observable spawn deposition.

Table 2-12: Summary of 2009 and 2010 Natural Spawn Sampling Sites

Site	N1	N2	N3	N4	N5	N6	N7	N8
Paradise Cove (MRS003b)	37^{0}53.644 x 122^{0} 27.448	37^{0}53.643 x 122^{0} 27.441	37^{0}53.642 x 122^{0} 27.436	37^{0}53.641 x 122^{0} 27.428	37^{0}53.646 x 122^{0} 27.423	37^{0}53.638 x 122^{0} 27.415	37^{0}53.636 x 122^{0} 27.380	37^{0}53.641 x 122^{0} 27.386
Date/Time begun	1/27/09 2:17 PM	1/27/09 2:38 PM	1/27/09 3:16 PM	1/27/09 3:32 PM	1/27/09 3:50 PM	1/27/09 4:08 PM	1/27/09 4:18 PM	1/27/09 4:36 PM
Paradise Cove (MRS003b)	37^{0}53.641 x 122^{0} 27.403	37^{0}53.641 x 122^{0} 27.397	37^{0}53.639 x 122^{0} 27.395	37^{0}53.638 x 122^{0} 27.368	37^{0}53.633 x 122^{0} 27.358	37^{0}53.638 x 122^{0} 27.359	37^{0}53.634 x 122^{0} 27.353	37^{0}53.633 x 122^{0} 27.346
Date/Time begun	2/06/10 11:42 AM	2/06/10 11:48 AM	2/06/10 11:59 AM	2/06/10 12:18 PM	2/06/10 12:23 PM	2/06/10 12:42 PM	2/06/10 12:50 PM	2/06/10 12:57 PM
Sausalito (N1-5, MRQ10 N6-8, P01)	37^{0}51.688 x 122^{0} 29.174	37^{0}51.691 x 122^{0} 29.181	37^{0}51.693 x 122^{0} 29.185	37^{0}51.696 x 122^{0} 29.191	37^{0}51.697 x 122^{0} 29.199 & 37^{0}51.698 x 122^{0} 29.205	37^{0}51.482 x 122^{0} 28.724	37^{0}51.487 x 122^{0} 28.718	37^{0}51.493 x 122^{0} 28.718
Date/Time begun	no spawn	no spawn	no spawn	no spawn	no spawn	2/04/10 11:45 AM	2/04/10 11:54 AM	2/04/10 12:04 PM
Keil Cove (MRR20)	37^{0}52.826 x 122^{0} 26.411	37^{0}52.824 x 122^{0} 26.405	37^{0}52.821 x 122^{0} 26.392	37^{0}52.816 x 122^{0} 26.391	37^{0}52.815 x 122^{0} 26.387	37^{0}52.811 x 122^{0} 26.380	37^{0}52.806 x 122^{0} 26.369	37^{0}52.803 x 122^{0} 26.362
Date/Time begun	2/05/10 12:51 PM	2/05/10 12:55 PM	2/05/10 1:00 PM	2/05/10 1:04 PM	2/05/10 1:11 PM	2/05/10 1:16 PM	2/05/10 1:19 PM	2/05/10 1:23 PM
Peninsula Pt. (MRQ01)	37^{0}52.056 x 122^{0} 27.994	37^{0}52.051 x 122^{0} 27.988	37^{0}52.046 x 122^{0} 27.987	37^{0}52.042 x 122^{0} 27.980	37^{0}52.039 x 122^{0} 27.976	37^{0}52.036 x 122^{0} 27.973	37^{0}52.032 x 122^{0} 27.969	37^{0}52.030 x 122^{0} 27.965
Date/Time begun	2/04/10 9:58 AM	2/04/10 10:07 AM	2/04/10 10:13 AM	2/04/10 10:22 AM	2/04/10 10:25 AM	2/04/10 10:32 AM	2/04/10 10:37 AM	2/04/10 10:40 AM

2.1.2 Mooring design and deployment. The design of moorings for caged embryo outplants and PEMDs was the same as that described in the SOP manual, to address the potential for cages or PEMDs to contact bottom sediments at low tides. Briefly, the anchor-buoy units consisted of a large primary and small secondary float attached to either end of a braided polypropylene line that was passed through a stainless steel O-ring attached to the middle of a pair of concrete blocks weighing 60-lb. Cages and passive samplers were attached with two heavy duty Zipties through the braided line just beneath the small secondary float, which line was in turn attached by heavy duty Zipties to the same and opposite line leading to the primary float, which maintained the cages vertical at a preset depth (~1 foot from the bottom, the depth of the cinder blocks plus a few inches of line between the cinder block and the attached cage) no matter the level of the tide (Figure 2-2). Anchor-buoy units were installed 1-2 days prior to embryo cage deployment to allow any disturbed bottom sediments to clear.

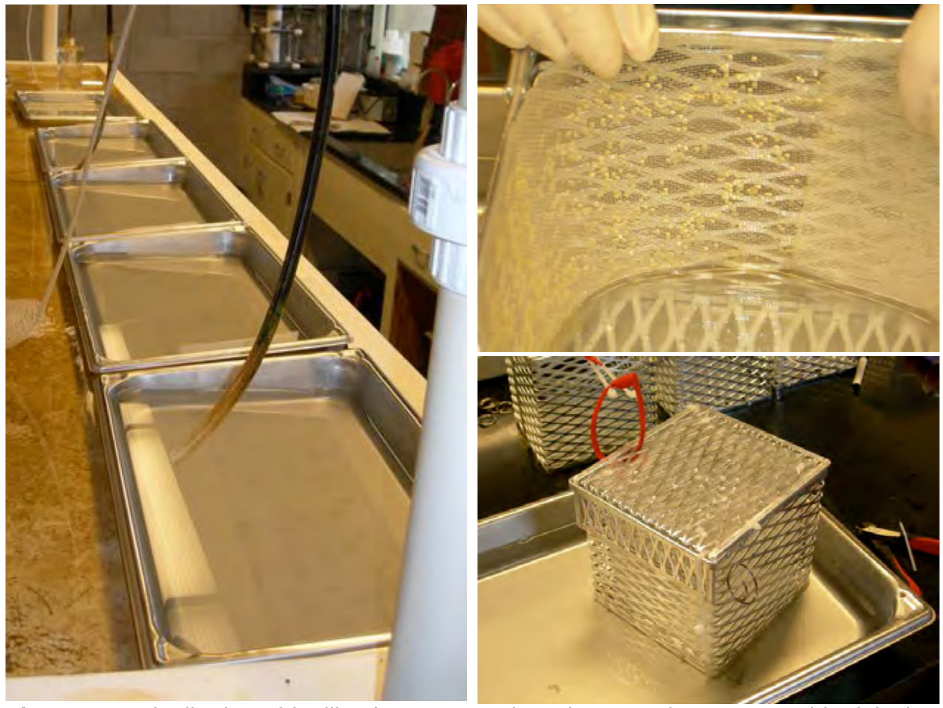


Figure 2-3: Distribution of fertilized eggs onto nitex sheets and cage assembly. (A) Five replicate sheets with monolayers of eggs incubating in milt. (B) Insertion of nitex sheet with fertilized eggs into cage. (C) Fully assembled cage with numbered security tag.

2.1.3 Collection of adults for analyses of background PAHs and persistent organic pollutants (POPs) in whole body and ovary samples. These steps were carried out as described in the SOP manual.

2.1.4 Preparation of caged embryos, cage deployment and retrieval. These steps were carried out as described in the SOP manual. Cage assembly and the process of deployment are shown in Figures 2-3 and 2-4, respectively.

2.1.5 PEMD deployment and retrieval. PEMDs were deployed and retrieved as detailed in the SOP manual, and following procedures developed at the NOAA Alaska Fisheries Science Center, Auke Bay Lab (Juneau, AK). Additional details and field observations are described here. Three PEMDs were deployed at each cage deployment site, as follows: one PEMD was attached to the mooring line just above the cage at each Mooring #1 (A1), Mooring #3 (A3), and Mooring #5 (A5), as part of the cage deployment process. At each deployment, previously prepared PEMDs (double-wrapped in aluminum foil and placed in a sealed ziplock bag) were opened while under water by personnel wearing fresh nitrile gloves, removing the outer bag and both layers of aluminum foil. While still underwater, the PEMD was then attached to the mooring line leading to the secondary, smaller mooring buoy (which served as flotation for the PEMD and cage) by two heavy-duty plastic zip-ties, at a position 6" to 1' above the cage. The primary mooring line bearing the larger orange primary marker buoy was then pulled taut by shipboard personnel, so that the attached cage became adjacent to and just above the stainless steel ring in the center of the double-cinder block anchor resting on the bottom. A snorkeler then attached the two lengths of the mooring line with two heavy duty zip ties, thereby ensuring the cage and PEMD were maintained above the center of the mooring anchor and out of contact with the sediment. At the time of deployment and without boat engines running, a PEMD "air blank" was deployed by unwrapping (while wearing fresh nitrile gloves) the

PEMD and exposing it to ambient air for a 60 seconds, and then re-wrapping it in a double layer of aluminum foil. It was then labeled, double-bagged it in ziplock bags, placed it on ice in a cooler reserved only for PEMDs. Following transport to the BML, PEMDs were stored in a locked freezer. PEMD air blanks at deployment were routinely conducted at the mooring #3 (A3) at the cage deployment sites.

Figure 2-4: Deployment of cages: Cages were transported to the field in large ziplock bags with half-strength seawater on ice, lowered into the water in a closed bag, removed from the bag underwater and handed to a free diver to be clipped onto the mooring. Retrieval was a reverse of this process.

At retrieval, the PEMDs were collected in a reverse process of the deployment procedure. After the snorkeler had severed the zip ties connecting the two sides of the mooring line, the secondary buoy was brought to the surface and handed to shipboard personnel at the waterline. At that point the cage containing herring embryos was collected, double-bagged underwater in a heavy-duty ziplock bag filled with ambient water and placed on ice in a cooler. Next, while keeping the PEMD underwater, shipboard personnel hanging over the side of the boat double-wrapped the PEMD in aluminum foil, placed the wrapped PEMD in an appropriately labeled ziplock bag, then drained the excess water from the foil-wrapped PEMD and placed the PEMD and inner ziplock bag into another larger, labeled ziplock bag. The PEMD was then placed on ice in a cooler reserved only for PEMDs, transported back to the BML and placed in a locked freezer. Following the same methods described above for the PEMD deployment process, at retrieval of cages and submerged PEMDs, a PEMD “air blank” sample was also collected at the #3 mooring (A3) at each of the cage sites.

2.1.6 Laboratory processing of embryos and imaging. These steps were carried out as described in the SOP manual.

2.1.7 Laboratory assays of hatching and larval swimming behavior.

2.1.7.1 Hatching rates. Upon arrival of natural spawn samples in the laboratory, several strands of vegetation with attached embryos were placed into 11- x 21-mm rectangular glass dishes containing 600-700 ml half-strength, 0.45 µm-filtered seawater (½ FSW) and incubated in a 12˚C incubator. The initial methodology for quantifying hatching success was to incubate embryos on natural substrate. However, following overnight incubation of the first spawn samples (San Rafael Bay), it was subsequently determined that visualization of embryos on the substrate presented several logistical problems, including opacity of vegetation obscuring the developing embryos and contamination of the incubation media with vegetation-associated organisms. Therefore, up to 100 embryos were carefully removed from the vegetation into 6-well culture plates (20-30 embryos/well) and incubated at 12˚C with daily water changes. 48 hrs post retrieval, embryos, larvae, and empty chorions (egg shells) were enumerated as follows: eyed non-hatched embryos, dead or unfertilized embryos, number of empty chorions, and normal and abnormal larvae. Due to adherence of sediments or other suspended particles to caged embryos, it was difficult to determine incidence of non-fertilized versus embryos with arrested development, thus these embryos were counted as dead/unfertilized. Partially hatched larvae (embryos/larvae that had partially exited the chorion but were non-viable, see Figure 3-6) were counted as non-hatched embryos. Larvae were defined as normal if they had straight body axes, lack of pericardial or yolk sac edema, regularly beating hearts, and ability to swim and respond to stimuli (touch). Normal larvae (up to 50) were transferred to dishes containing ½ FSW for larval survival (see below). Abnormal larvae exhibiting scoliosis, yolk and/or pericardial edema, or opacity were removed, and any live abnormal larvae were euthanized in an overdose of MS-222. Subsequent daily counts enumerated only eyed non-hatched embryos, partially hatched embryos, abnormal larvae that were removed and euthanized, and normal larvae transferred to glass culture dishes for larval survival or behavior studies.

For caged embryos, upon arrival at the lab, a section of mesh containing up to 200 embryos (assessed macroscopically) was removed from the larger mesh and placed into 250 ml glass culture dishes containing 200 ml ½ FSW and incubated in a 12 °C incubator. Most of the sites showed evidence of hatching (empty chorions) prior to retrieval, so initial numbers of embryos for monitoring purposes were reduced. Daily water changes of ½ FSW were performed for the duration of incubation and counts were performed daily for 2-6 days, based on the variability in days to hatching observed between sites.

Normal hatching was defined as the number of normal larvae per total number of hatched and unhatched embryos combined.

2.1.7.2 Larval Survival. Normal larvae from caged embryos (N = 6 sites with 4-5 cages/site) or natural spawns (N = 8 transects/site for San Rafael Bay, and 4 transects/site for Keil Cove) were incubated in ½ FSW with 50% daily water changes. Hatching success for naturally spawned herring embryos was significantly reduced at Peninsula Point (no normal larvae), Sausalito (only 1 normal larva), and Keil Cove (only 4 transects with normal larvae, and no normal larvae from the other 4 transects). Thus, monitoring for larval survival was only performed for San Rafael Bay (transects N1-N8) and Keil Cove (transects N1-N4 only). Larvae were observed daily, and abnormal or dead larvae were removed and/or euthanized in MS-222. Types of abnormalities (body axis defects, edema, opacity) were recorded. Typically larvae that appeared moribund were incubated for an additional day. Observations were carried out for 4-6 days. In cases where few larvae were available (Keil Cove), larvae were assessed for survival, and then utilized for larval behavioral assessments. All surviving larvae were euthanized in MS-222 and larval lengths recorded. Percent survival was defined as the number of normal larvae surviving for 4-6 days per number of initial larvae.

2.1.7.3 Statistical Analysis. All data were arcsin transformed and analyzed by one-way analysis of variance (ANOVA), followed by Tukey's HSD Test for all pairwise multiple comparisons, or Kruskal-Wallis one Way Analysis of Variance on Ranks (larval survival for caged embryos). Results were considered to be significant at $p < 0.05$.

2.1.7.4 Swimming Behavior. *Test Chamber*: The test system consisted of a rectangular chamber, recirculating temperature control water supply, illumination, black and white CCD camera and a video recorder. A black plastic flow chamber was used for the swimming behavior tests. The overall chamber measured 284 mm long, 22 mm wide and 14 mm deep. Since video recordings were made for each test a smaller recording chamber was established (58 mm long) in the center of the main chamber. The bottom of this chamber had a clear plastic insert so that it could be illuminated from below. A fine-meshed grid was used at each end of the smaller chamber to separate it from the larger system. Flat black plastic covers were placed over the top of the mesh dividers to prevent light being "piped" up the mesh and interfering with digitizing the image. The input and outlet tubes (5 mm ID) were placed at each end of the larger chamber. Tubing from each chamber end was passed through a Cole-Parmer 1-100 rpm peristaltic pump connected to a Masterflex speed controller. The pump output side was connected to 7 foot coiled stainless steel tubing placed in a Neslab RTE 221 water bath and then attached to the input side of the chamber. Temperature was controlled at 12˚C$\pm$ 1˚C within the imaging chamber. Temperature measurements were made in the test chamber with a stainless steel digital thermometer (traceable to NTSF standards). There was some slight temperature increase depending upon the length of the test caused by heat from the lighting system.

Lighting System. Because the herring larvae are nearly transparent is was necessary to produce dark field images that could be detected by the CCD camera and later digitized for further analyses. An adjustable intensity fiber-light (Dolan-Jenner) was used with a fiber optic ring light (140-mm diameter, Edmunds Scientific). This lighting unit was placed 70 mm under the test chamber (clear bottom section) and covered with an IR glass filter with a 720 Hz transmission band. The use of the IR illumination was done to reduce any behavioral changes in the larvae when exposed to light from below (not a natural situation) A flat black ring (115 mm diameter) with a 63 mm hole was centered 10 mm directly below the test chamber. A Sanyo B&W CCD camera with a Fuijinon TV 1:14/25 lens was located 240 mm above the bottom of the clear test chamber. The system components, camera, black disc and ring light were carefully centered to produce near dark field. The CCD images were monitored (Ikegami Monitor) and also recorded on a Sony VHS recorder.

The characteristics of the velocity profile in the chamber are important in the consideration of swimming speed. It is difficult to maintain laminar flow at higher velocities in the chamber design used for the experiments. However, the use of fine-meshed grids produced a rectilinear front of fairly uniform turbulence. Based on dye releases in the test chamber it would appear that sufficient turbulence persists to eliminate most advantageous wall effect developing at the downstream end of the chamber.

Larvae. Larvae from cages and natural spawn samples were transferred to the Motion Analysis laboratory for swimming behavior analyses. Each set of larvae, from a single sample area (i.e., cages) was transferred and the behavioral test completed before the next set was exchanged. Samples moved to the Motion Analysis laboratory were placed in an ECHO-term chilling incubator and keep at 12˚C until tested. The number of larvae used for each test set was limited to five or fewer. Four factors determined the maximum number used in each test and the number of tests that could be conducted for each sample. The first was that all larvae had to exhibit healthy behavior. Second, five larvae were the maximum that could be observed in the test and still trace the fatigue time for each larva. Third was the length of time to conduct each test and still keep up with incoming samples and lastly, in some samples there were very limited larvae available for testing. Larval behavioral testing was conducted for most samples 5-7 days after the samples were removed from the field. If larvae had significant differing body lengths, the critical velocity achieved by each larvae is adjusted to the equivalent maximum velocity of the larvae of the mean body length by means of the formula: $U_{crit} = \sqrt{}$ mean U_{crit}^2/L for the purpose of standardization. In reviewing the measured body lengths for each sample (conducted for the survival analysis) and applying the standardization formula the correction factor for a length difference of 0.2 mm would be >0.01 mm/sec. Based on this analysis, it was determined if the SD was less than 0.5 around the mean, the lengths would not be adjusted for this first analysis of swimming speed. The larvae for each behavioral test were preserved and can be measured in the future, if necessary.

Incremental Velocity Test Protocol. There are two experimental procedures to quantify swimming performance of fish, the fixed velocity (or fatigue) test and the incremental velocity test [72, 73]. Tests on juvenile fish have used widely variable test periods (minutes to hours) and flow velocities. More recent studies of larval swimming speeds for coral reef fishes used much shorter velocity increase steps (e.g. 2 minutes) [74]. During the incremental velocity tests, herring larvae were forced to swim in an increasing current field. The current velocity, and thus the swimming speed, were not increased gradually, but rather in steps, each speed being maintained for a certain period of time until exhaustion occurs (fatigue or threshold speed).

The fatigue speed or critical speed (U_{crit}) for increased velocity tests is calculated as:

$$U_{crit} = Vp + \left(\frac{t_f}{t_i} \times Vi \right)$$

Vi = velocity increment (cm/sec)
Vp = penultimate velocity as which the larvae swam before fatigue
t_f = elapsed time from the velocity increase to fatigue
t_i = time between the velocity increments

A peristaltic pump was used to provide a recirculating water flow, which could be increased in five steps. The step velocities are as follows:

Step 2 = 0.29 cm/sec
Step 4 = 0.57 cm/sec
Step 6 = 1.14 cm/sec
Step 8 = 1.67 cm/sec
Step 10 = 1.93 cm/sec

Because of the limitations of the pump controller the differences between the steps were not evenly spaced. Step 2-4 increased by 0.28 cm/sec, step 4-6 increased by 0.57 cm/sec, step 6-8 increased by 0.53 cm/sec and step 8-10 increased by 0.26 cm/sec. While it would have been more uniform to have even velocity increases, these differences were taken into consideration by the formula used to calculate U_{crit}.

Based upon recent larval swimming reports [74, 75] and preliminary tests run on herring in our laboratory, three-minute time intervals were selected and used between velocity increments (Vi) for this project. This time interval worked well for the first series of samples when many larvae became fatigued before reaching the last velocity increment. In later samples it was found that some larvae could continue swimming, without fatigue, for over 15 minutes at the highest velocity level. Over half (53%) of the 124 individual larvae tested did not demonstrate fatigue at the highest velocity after 3 minutes of exposure. Wide ranges for U_{crit} values are frequently observed [72, 76, 77]. These prolonged times to fatigue values at the highest exposure velocity presented potential problems with analysis. If 3 minutes was scored for those fish that swam beyond the time limit, the U_{crit} might be under estimated. Extending the time to fatigue period during the last velocity step to cover those larvae that were able to swim beyond the original 3-minute time period would make the velocity increments uneven. Thus, it would not be possible to determine if larvae would fatigue at a lower velocity during a longer exposure period rather than moving to the next higher increment. Based upon these facts it was decided to conduct two types of analyses. First, 3-minute increments were used for each velocity change for a total of 12 minutes, and U_{crit} was calculated. To investigate the longer fatigue times the data were adjusted using the last increment for the 12-minute period where most of the larvae reached fatigue. Thus, all increments except the last level (1.93 cm/s) were treated as 3-minute increments.

Only larvae that could actively swim and had no visible morphological abnormalities were used for testing. Larvae were required to swim for the acclimation period, for three minutes at step 2 before the test was started, and after the completion of the tests (recovery analysis). The larvae were acclimated to the test chamber for 20 minutes before the test was started at step 2 (0.29 cm/sec), run for three minutes, then moved to step 4 and continued to be exposed to increasing flow velocities until fatigue occurred or the time for the penultimate increment had elapsed. If a larva could not extend one body length off the downstream barrier for 1 minute it was considered fatigued.

Light was supplied through the bottom of the test chamber as IR (790 Hz) so that the larvae were not affected by light coming from a direction not encountered in nature. Room lights were dimmed during the test period. Recirculating water was checked in the video chamber for temperature increase after each velocity increment change. Water was pumped from the system after each full test (five velocity increments) and exchanged with 12 °C oxygenated water before the next test series was started.

2.1.8 Selection of sediment collection sites and sediment collection.

2.1.8.1 Subtidal sediment collection at cage deployment sites and moorings. Subtidal sediments were collected at cage deployment sites as detailed in the SOP. Briefly, sediments were collected from the BML vessel *Cape Horn* or *Klamath* with a small Ponar grab deployed from the boat. At each mooring (five per site), three replicate grabs were taken adjacent to the mooring anchor. The top 2 cm of the grab contents of each of the three grabs at each mooring were then combined into an isopropyl alcohol-rinsed stainless steel bowl and thoroughly mixed with a isopropyl alcohol-rinsed stainless steel spoon. The contents of these three replicate grabs were then placed into two separate pre-labeled, rinsed ICHEM glass jars (one for analysis of PAHs, and another for sediment grain size). Therefore, at each cage deployment site, five sediment samples were collected for PAH analysis (representing a composite of three grabs at each mooring) and sediment grain size analysis. All samples were placed on ice in the field and transported on ice to the BML. The jars for PAH analysis and sediment grain size analysis, respectively, were transferred to the locked freezer and refrigerator at the BML.

2.1.8.2 Intertidal sediment collection at natural spawn sites. Intertidal sediments were collected at the natural spawn sites as detailed in the SOP manual, with the exception that "cookie cutter" devices were not used to collect sediments. Instead, an isopropyl alcohol-rinsed large stainless steel spoon was used to hand-collect all intertidal sediments by wading. Sampling positions were chosen to coincide with locations where marine vegetation (or substrate) with attached herring eggs at the natural spawn sites. At each natural spawn site, we conducted five separate ~10-m transects perpendicular to the shoreline, moving from high water to low water within the intertidal zone, which were conducted at the 10-m, 30-m, 50-m, 70-m, and 90-m marks of the original 100-m transect laid out for collection of natural spawn samples (parallel to the shoreline). The individual transects perpendicular to the shoreline were intended to encompass the range of suitable herring spawning habitat, from the high intertidal to low intertidal. Depending on the shoreline grade, the length of each transect covered from approximately 5-m to 10-m. In all cases, sediments were collected within the intertidal area where natural spawn samples had been collected. The only exception to this transect pattern was at the Sausalito site, where the five transects were conducted at every 10-m mark along the original transect where the natural spawn samples were collected at the Sausalito Bay site (corresponding to natural spawn samples N1 through N5). This change was necessary because the appropriate sediments were not available within the Spinnaker Cover portion of the Sausalito site. As with the subtidal locations, samples from each transect were combined into a stainless steel bowl, mixed thoroughly and divided into two separate 4 oz. ICHEM jars (one for analysis of PAHs, and another for sediment grain size). All samples were placed on ice in the field and transported on ice to the BML. Samples for PAH analysis and sediment grain size analysis, respectively, were transferred to a locked freezer or refrigerator for storage at the BML.

2.1.9 Analytical chemistry. Analyses of the whole body and ovary samples of adult female herring for PAHs, POPs and lipid content, as well as PAH and lipid analyses of natural spawn and cage-deployed eggs, were conducted as described in the SOP manual. For the PAH analyses of the PEMDs, the following modification was done. An additional cleanup step using size-exclusion high-performance liquid chromatography was conducted for each PEMD extract to remove any additional compounds that were found to interfere with PAH determinations (as determined from PEMD test samples).

2.1.10 Data analysis and statistics. For the biological responses, statistical treatments are described independently for each section or figure. For analytical chemistry, concentrations of sum LAHs, sum HAHs and sum PAHs, as well as the various sum values of POPs (i.e., sum PCBs, sum DDTs) were $\log_{10}$-transformed and the percent lipid values were arcsine transformed to increase the homogeneity of variances. One-way analysis of variance (ANOVA) and the Tukey-Kramer HSD Test were used to determine if mean concentrations of PAHs, POPs, percent lipid or dry weight values varied among collection sites. The Tukey-Kramer HSD Test is one of a number of post-hoc methods recommended to use to test differences between pairs of means among groups that contain unequal sample sizes. The correlations between percent lipid and contaminant concentrations, as well as dry weight and contaminant levels, between paired whole body and ovary samples were assessed by simple correlation analyses. One-way ANOVA and simple t-Test were used to compare mean concentrations of contaminants, percent lipid and dry weight values between whole body and ovary samples of adult female herring. If the sum contaminant value was reported as less than the lower limit of quantification (< LOQ) in a sample, a value of zero was substituted for this value prior to calculating the mean and standard error values and conducting statistical analyses. All statistical analyses were completed using JMP Statistical Software (SAS Institute, Inc., Cary, NC). The level of significance used for all statistical tests was $\alpha \leq 0.05$.

2.2 Laboratory studies. These methods are described in detail in the Laboratory SOP manual (Section 7.5)

2.2.1 Laboratory oiled gravel column exposure and phototoxicity study

2.2.1.1 Exposure system. Exposures were conducted outdoors on a south-facing concrete pad. Six water tables to holed eight columns each were constructed in a terraced array to prevent tables from shading each other. Ambient full-strength seawater was mixed with fresh water to 22 ppt ("treatment water") in a 3800-l holding tank. Fine clay silt present in the laboratory's well-water supply was removed with a 5-micron bag filter. Treatment water was delivered from the holding tank via a manifold to a peristaltic pump (Masterflex L/S variable speed drive with 8-channel cartridge, Cole-Parmer, Vernon Hills, IL) beneath each table, which distributed water to each of eight columns at a rate of 0.8 to 1 l/hr. Water was pumped into the bottom of each column via a tube (a section of 5-ml borosilicate glass pipet) and up-welled over the lip of the beaker and was collected in custom made 20 X 41 X 8 cm aquaria serving as embryo exposure reservoirsFigure. A standpipe in each aquarium held the steady-state volume at 4-l.

Three replicates of each oil dose and control gravel weathered either under a cover of UV-transmitting plastic or UV-blocking plastic (to allow exposure to visible sunlight wavelengths). Covers were designed to block typical southerly or northerly rainfall, but were open on either end to allow air circulation and prevent heat trapping. Columns were randomly distributed by dose and oil type across all the tables, and half of each table (e.g. four columns) was randomized for a UV-blocking or UV-transmitting cover. Water flow to the columns was initiated 14 January 2009. Embryo incubations were initiated on 23 January, 13 February, 26 February, and 18 March.

2.2.1.2 Preparation of oiled gravel columns. Oiled gravel was prepared by tumbling in a portable cement mixer using a modification of previously published methods [1]. Locally obtained river gravel obtained from a landscaping supplier was washed on 1-cm plastic sieves, and spread into monolayers on cardboard sheet to dry. Final drying was achieved with a heat gun. Aliquots (~20 ml) of each oil were held in brown glass bottles briefly at 65˚C in a water bath to maintain fluidity. A 5-ml glass pipet was calibrated to deliver desired masses of oil by adding oil drop-wise to a pre-weighed 25-ml beaker on an analytical balance. The number of drops required to deliver 1 gram of oil was calibrated in triplicate and was 52 drops for ANSCO and 47 drops for CBBO. For the lowest doses (0.1 g/kg and 0.3 g/kg) oil was scattered drop-wise over gravel in the mixer drum. 11 kg batches of gravel were oiled using a separate mixer for each oil. For ANSCO at 0.1 g/kg, 54 drops (1.1 g) were added before tumbling. For CB bunker at 0.1 g/kg, drops were added in three groups (16, 16, and 17; 1.1 g total) with brief tumbling between. For the CB bunker 0.3 g/kg dose, 147 drops were added in five groups with tumbling between each. For the 10 g/kg doses, heated oil was weighed into a pre-weighed beaker, then poured onto tumbling gravel. The beaker was re-weighed after pouring to ensure delivery of 11 g total. Each batch of gravel was tumbled for 10 minutes after all oil was added. Gravel was spread out on aluminum foil-covered cardboard to dry up to 12 hours before packing into columns. Each dose of gravel was divided equally among 6 replicate columns (1-liter glass beakers, 1.8 kg gravel each). Columns were covered with aluminum foil and stored indoors at room temperature until used.

Three of four experiments included two negative controls; clean gravel of the same batch used to generate oiled gravel, and gravel collected from a San Francisco Bay beach outside of the spill zone ("urban" gravel). Gravel of similar grain size was selected from the beach at China Camp State Park on the north side of Point San Pablo. The urban gravel was processed in the same way as the commercially obtained gravel.

2.2.1.3 Water quality monitoring. During incubation daily water quality measurements collected manually included temperature, salinity and dissolved oxygen. In addition, the aquarium for one control column (e.g. clean or urban gravel) on each table contained a continuous temperature probe that recorded every 10 min. Each water table also contained a continuous temperature recorder to monitor the water bath. Ammonia levels were measured colorimetrically for each aquarium prior to addition of embryos and at the end of incubation.

2.2.1.4 Embryology. Capture of ripe adults, preparation of gametes, and fertilizations were carried out as described in the SOP (Appendix). Test fertilizations were conducted with eggs from individual females, and those with high fertilization success (≥ 90%) were pooled for large-scale fertilizations. Mean (± SEM) female weights for each experiment were 103.6 ± 4.6 g (n = 5), 59.7 ± 3.8 g (n = 26), 61.2 ± 2.8 g (n = 33), and 62.7 ± 4.8 (n = 13). Milt was pooled from five males for each experiment. Eggs were kept from clumping prior to fertilization with polyvinyl alcohol (see SOP), and were distributed onto two substrates for exposure. For morphological observations, eggs were deposited onto frosted microscope slides targeting ~100 eggs per slide. For analytical chemistry samples, 2-3 grams of eggs were deposited onto 10 X 20 cm sheets of nylon mesh. Embryos were distributed to exposure aquaria within two hours of fertilization.

Embryos and larvae were observed with oblique coherent contrast illumination using Nikon SMZ800 stereomicroscopes fitted with diascopic bases, and digital images captured using Fire-i 400 industrial cameras (Unibrain, Inc., San Ramon, CA) and BTV Pro 5.4.1 (www.bensoftware.com) on Apple PowerBook G4 computers. Pre-hatch embryos were imaged without anesthesia either through the chorion or after manual dechorionation with fine forceps, while larvae were anesthetized with MS-222. In the first (13 January) experiment, embryos were subsampled, dechorionated and examined in detail daily beginning at 5 dpf. During this experiment, cytolytic phototoxicity was observed by 8 dpf. Because this phenotype was readily visible through the chorion, and affected embryos did not remain intact with dechorionation, in subsequent experiments phototoxicity was quantified by counting cytolysed embryos through the chorions. In the 26 January experiment, counts on one slide from each column included total eggs attached, unfertilized eggs, embryos that died during or before gastrulation, necrotic (cytolyzed) eyed embryos, and viable eyed embryos. Percentage of embryos showing necrotic phototoxicity was then normalized to total eyed embryos by subtracting unfertilized eggs and early lethal embryos from total eggs. In the 18 March experiment, counts for each slide included total eggs, unfertilized eggs, viable eyed embryos, and dead embryos irrespective of stage. Embryos that died during early development were quantified in the laboratory controls and averaged 13%. This value was indistinguishable from the rate of early mortality in the earlier experiments, where it was found that early mortality rates were independent of any treatment. The value for necrotic late embryos was obtained by subtracting the average early mortality (13%) from total mortality normalized to fertilized embryos.

2.2.1.5 Assessment of larval hatching and abnormalities. On the day of embryological observations (8 dpf), one replicate slide from each column was placed into 250 ml glass culture dishes containing 200 ml 16 ppt seawater and incubated in a 12˚C incubator. Hatched larvae were collected daily up to 8 days after retrieval from column effluent (i.e. 15 dpf), anesthetized with MS-222 and examined microscopically using an Olympus SZH stereo zoom microscope. Selected images were collected using a Pixel Link camera and PixelLinkCapture software. Treatments were evaluated for the following: unhatched eyed embryos, unfertilized embryos (1st day only), non-viable embryos (dead plus unfertilized), partial hatched embryos, hatched larvae live, hatched larvae normal, hatched larvae abnormal. For the 1/23/09 and 2/13/09 column experiments unfertilized embryos were not counted separately from dead embryos. Abnormal morphology included the following: scoliosis, edema, opaque yolk, opaque head, opaque tail, kinked tail, bent heads, jaw abnormalities. Other types of abnormalities were not observed on a consistent basis: For the 1/23/09 experiment, hatching commenced on 2/1/09 for one bowl and on 2/2/09 for 7 bowls, facilitating observation of abnormal motor activity in hatchlings prior to anesthesia in MS-222. Subsequent days resulted in a large amount of hatching in most bowls, increasing the time necessary to score morphology. As a result, larvae were transferred to bowls for anesthesia in MS-222 prior to observation of motor activity and abnormal motor activity was observed only in extremely abnormal larvae (i.e. severely deformed larvae continue to twitch despite the presence of MS-222). For the 1/23/09 experiment, hatchlings were observed and photographed for abnormal cardiac function (bradycardia, arrhythmia) or morphology during the first few days of hatching at high magnification on a dissecting microscope. Due to the amount of time required for these observations, counts on all bowls were not performed on a daily basis. In subsequent experiments, daily counts were performed and hatchlings were primarily observed at low magnification, thus cardiac abnormalities were not always quantified.

Percent normal hatch was calculated as normal hatch as a percentage of total embryos/larvae (the sum of eyed unhatched, non-viable, partial hatched, hatched larvae dead, and hatched larvae live).

2.2.2 Salinity study.

2.2.2.1 Preparation of incubation media:

½ strength seawater was prepared by diluting Bodega Bay 0.45 µM filtered seawater (FSW) 1:1 with distilled water

22 ppt seawater was prepared by diluting 647 ml of 34 ppt Bodega Bay FSW with distilled water QS to 1000 ml

30 ppt seawater was prepared by diluting 882 ml of 34 ppt Bodega Bay FSW with distilled water QS to 1000 ml.

Salinity was checked with a refractometer

2.2.2.2 Fertilization and incubation:

Trial fertilization:

Herring eggs from each female were distributed individually into 1 compartment of 4 quadrant petri plates in ½ strength FSW.

A drop from a diluted suspension of sperm was added to each quadrant and the plates placed into a 12^0C incubator for 15 minutes

Percent fertilization for each female was assessed by observing for elevation of the chorion

2.2.2.3 Salinity treatments

Treatment	Fertilization salinity	Incubation Salinity (7 days)	Incubation Salinity (through hatching)
16-16	16 ppt	16 ppt	16 ppt
16-22	16 ppt	22 ppt	16 ppt
16-30	16 ppt	30 ppt	16 ppt
22-22	22 ppt	22 ppt	16 ppt
30-30	30 ppt	30 ppt	16 ppt

Using a spatula, eggs from females with 90% or greater fertilization rate in the trial fertilization were suspended in approximately 250 ml of ½ Calcium Magnesium free artificial seawater (CaMgFSW) containing 0.25% polyvinyl alcohol (PVA). This prevents the normally adhesive eggs from adhering to the nalgene beaker or to each other.

A sperm suspension was prepared by macerating the testis from 2-3 males in approximately 100 ml ½ FSW 7"x3" loaf pans containing 4 microscope slides each were filled with approximately 200 ml of ½ FSW, 22 ppt FSW or 30 ppt SW and 5 ml of the sperm suspension added to the pans. The pan were gently swirled to ensure dispersal of the sperm suspension.

50-100 eggs from the beaker of ½ CaMgFSW were dropped onto each slide and the pans gently swirled to maximize contact of the eggs with sperm.

Eggs were incubated for 30 min at 120C in the water table or in the incubator, then rinsed with fresh FSW of the same salinity to remove sperm.

Slides were transferred to 100 x 50 mm finger bowls (2 slides/bowl) containing the appropriate salinity solutions (16, 22, or 30 ppt) and incubated in a 120C incubator with daily water changes of the appropriate salinity.

On the 7th day of incubation, 4 slides from each treatment (2 from each bowl) were shipped to Northwest Fisheries Science Center, NOAA in Seattle, WA.

From the 8th day of incubation through final hatching, all treatments were incubated in 16 ppt FSW.

2.2.2.4 Scoring of embryos

Duplicate slides were received at NWFSC from BML on 3/13/09 (8 dpf), along with BML 16 ppt seawater for processing. All slides were examined upon receipt and showed similar numbers of viable eyed embryos. Due to time constraints, the most relevant treatments were selected for dechorionation, i.e. optimal laboratory salinity regimen (fertilized at 16 ppt, incubated at 16 ppt) and high salinity regimen (fertilized at 30 ppt, incubated at 30 ppt). For dechorionation, slides were transferred to 16 ppt seawater and held at 12˚C on a cooling stage. At least 20 embryos were dechorionated at 16 ppt from a single slide for each treatment, and held at 16 ppt for imaging.

At commencement of hatching at BML, culture were counted as follows:

Unhatched eyed embryos
Unfertilized embryos (1st day only)
Non-viable embryos (dead plus unfertilized)
Partial hatched embryos
Hatched larvae live
Hatched larvae normal
Hatched larvae abnormal

Abnormal larvae were evaluated for scoliosis, edema, opaque yolks, heads, or tail, kinked tails, bent heads, jaw abnormalities.

Percent normal hatch was calculated as normal hatch as a percentage of total embryos/larvae (the sum of eyed unhatched, non-viable, partial hatched, hatched larvae dead, and hatched larvae live).

Section 3: Results of Field Assessment

3.1 Overview of study sites. Sites were selected based on likelihood of proximity to oiled substrates as determined by SCAT surveys and other observations of oiling. The sites (Table 3-1) differed in the degree of oiling and cleanup, so the actual amount of residual oiling at each location at the time of the assessment is unknown. Accessibility, safety, and stability of moorings were also considered. Reference sites were chosen to most closely match the habitat, temperature, and salinity conditions at sites within the (visible) spill zone. Satellite images showing locations of natural spawn subtransects and caged embryo/ PEMD placement are shown in Figure 3-1. Green pins show caged embryo moorings, with black diamonds indicating moorings with PEMDs. Blue pins indicate natural spawn sample locations. Natural spawn of sufficient density was only available at four of the six sites where caged embryos were deployed. These were Sausalito, Peninsula Point, Keil Cove, and San Rafael Bay. All natural spawn occurred in the intertidal zone, while caged embryos were all incubated in the shallow subtidal (-3 to -6 ft mean low water).

Table 3-1: Characteristics of study sites

site	NRDA designation	SCAT rating	cleanup	land use and other features related to PAH inputs
Horseshoe Cove (HC)	MRP04	moderate-light	extensive wiping of rip-rap	marina, adjacent to US101
Sausalito (SA)	MRQ10/P01	very light-light	some wiping	marina, commercial, residential
Peninsula Point (PP)	MRQ01	light	some wiping	residential
Keil Cove (KC)	MRR20	heavy-light	extensive wiping, removal of rock	residential, undeveloped
Point San Quentin (PSQ)	MRT04	no oil	NA	residential, industrial, adjacent to I580
San Rafael Bay (SRB)	MRU01	no oil	NA	commercial, adjacent to I580

Figure 3-1A: Horseshoe Cove

Figure 3-1B: Sausalito

Figure 3-1C: Peninsula Point

Figure 3-1D: Keil Cove

Figure 3-1E: Point San Quentin

Figure 3-1F: San Rafael Bay

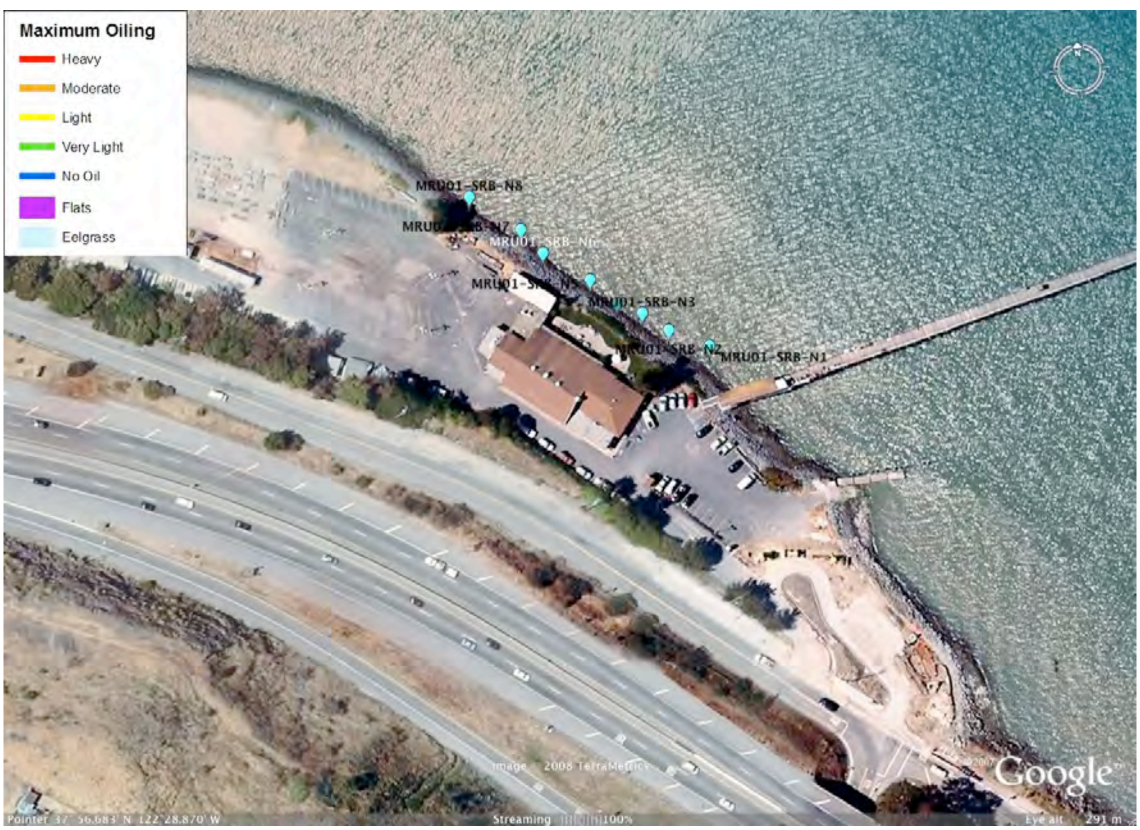


Figure 3-1G: Close-up of San Rafael Bay natural spawn grabs

3.2 High rates of body axis defects, neural tissue necrosis, and cardiac arrhythmia in 2008 natural spawn samples from oiled sites. General descriptions of natural spawn grab samples are provided in Table 3-2. The predominant substrates were brown and red bladed algae such as *Fucus*, *Cryptopleura*, and *Chondrocanthus*, filamentous red algae (e.g. *Gracilaria*, *Microcladia*, or *Odonthalia*), and some green algae (*Ulva*). The highest density spawn was at San Rafael Bay adjacent to the Marin Rod and Gun Club, where the samples were collected almost exclusively on *Fucus*. *Fucus* also predominated at Sausalito, but samples were much more variably mixed at Peninsula Point and Keil Cove, the former predominated by filamentous red forms. Typical samples are shown in Figure 3-2. The spawn at San Rafael Bay was medium density, approaching 4 layers of embryos (Figure 3-2E). Spawning at the three oiled sites was less dense, ranging from very light "salt-and-pepper" density (Figure 3-2C) to light density with contiguous patches of a single layer (Figure 3-2D).

Table 3-2: Characteristics of natural spawn samples

site	dates of deposition/date sampled	spawn density	predominant substrate
SA	20-22 Feb/27 Feb	light	*Fucus*
PP	20-22 Feb/29 Feb	very light-light	mixed, *Gracilaria, Fucus*, *Cryptopleura*, *Chondrocanthus*, *Ulva*
KC	20-22 Feb/28 Feb	very light-light	mixed, *Fucus*, *Cryptopleura*, *Chondrocanthus*, *Gracilaria, Ulva*
SRB	17-19 Feb/26 Feb	medium	*Fucus*

Because of the requirement to document cardiac function with digital video, only embryos with obvious heart beats were selected for imaging. This was a challenge in most natural spawn samples from the three oiled sites. Viable embryos were scored for gross abnormalities including body axis defects, tissue opacity (indicative of necrosis), and pericardial or yolk sac edema. Cardiac abnormalities were scored in video clips as arrhythmia based on the presence of atrioventricular conduction block, silent ventricle, severe bradycardia, minimal overall contractility, or complete absence of heart beat. Representative images of dechorionated embryos from natural spawn grabs by site are shown in Figure 3-3, and scores for abnormalities summarized in Table 3-3. The most striking features of embryos obtained from Sausalito, Peninsula Point, and Keil Cove were high rates of body axis defects (Figure 3-3) and tissue opacity (Figure 3-4). These abnormalities were consistently observed at all three oiled sites, but were entirely absent in samples from San Rafael Bay (Figure 3-4A). At Sausalito, body axis defects were observed in 7/8 grab samples, and occurrence ranged from 25-82% (mean 60%, $p < 0.05$). At Peninsula Point, body axis defects were observed in 8/8 grabs, and occurrence

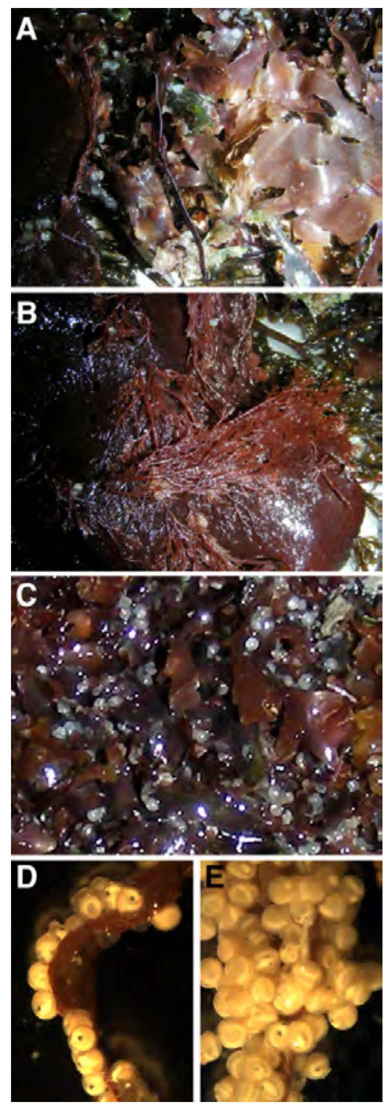


Figure 3-2: Representative 2008 natural spawn samples. (A) and (B) Mixed algae typical of Peninsula Point and Keil Cove. (C) Close-up of fresh natural spawn sample from Peninsula Point with "salt-and-pepper" density. (D) Light single-layer spawn sample from Keil Cove fixed in Stockard's. (E) Medium density spawn from San Rafael Bay (Stockard's fixed), up to four embryos deep at points.

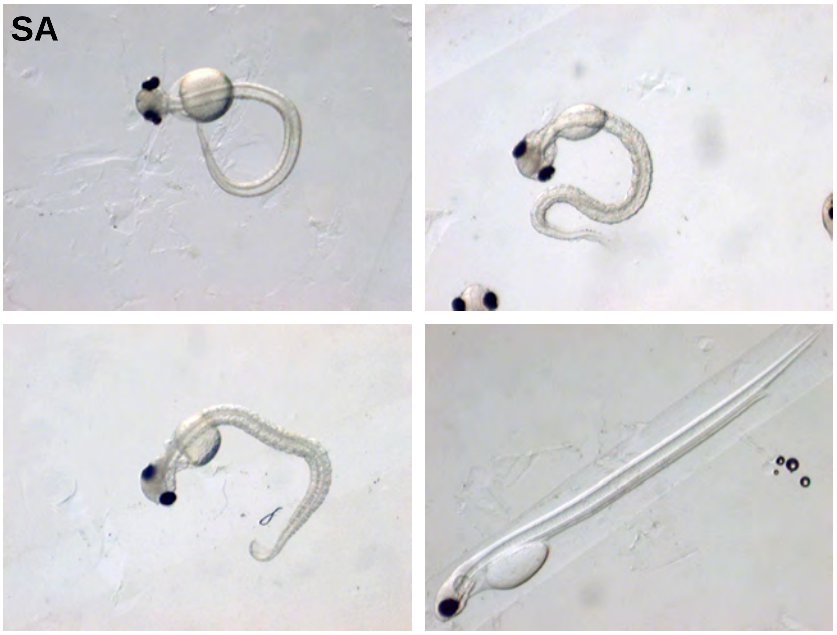


Figure 3-3: Body axis defects in 2008 natural spawn samples from oiled sites compared to typical normal morphology from San Rafael Bay samples

ranged from 85-100% (mean 98%, $p < 0.05$). At Keil Cove, body axis defects were observed in 8/8 grabs, and occurrence ranged from 60-100% (mean 90%, $p < 0.05$). The body axis defects did not appear to be a malformation *per se*, but rather a failure to straighten after dechorionation (movie files available) due to loss of neuromuscular capacity.

Notably, the primary tissue opacity observed was in the developing central nervous system, starting anteriorly in the brain (Figure 3-4). CNS opacity appeared to progress from a pair of bilateral structures in the diencephalon and ventral midbrain in milder cases (Figure 3-4D - F), to the entire brain and anterior spinal neural tube in the most severe cases (Figure 3-4B, C). These defects appeared identical in embryos from Sausalito, Peninsula Point, and Keil Cove (Figure 3-4D - F). At Sausalito, tissue opacity was observed in 7/8 grabs, with the same grab (#7) showing an absence of both body axis defects and tissue opacity. Opacity could not be quantified in two grabs due to inconsistent lighting in the images. However, in the five remaining grabs, the occurrence ranged from 55-71% (mean 60 %, $p < 0.05$). At Peninsula Point, tissue opacity was observed in 8/8 grabs, and occurrence ranged from 85-100% (mean 96%, $p < 0.05$). At Keil Cove, tissue opacity was observed in 8/8 grabs, and occurrence ranged from 55-100% (mean 86%, $p < 0.05$).

Due to the failure of most embryos to straighten after dechorionation, images of the appropriate lateral view often could not be obtained for samples from Sausalito, Peninsula Point, and Keil Cove. This precluded the planned quantitative measure of pericardial edema in individuals (as detailed in the SOP). Instead a binary score was obtained for the presence of absence of edema. Edema was defined as increased ratio of pericardial space to apparent heart volume in addition to flattening of the yolk profile from its typical radial curvature (Figure 3-5), or the presence of fluid between the yolk and lateral portion of the yolk sac. At Sausalito, edema was observed in 8/8 grabs, and occurrence ranged

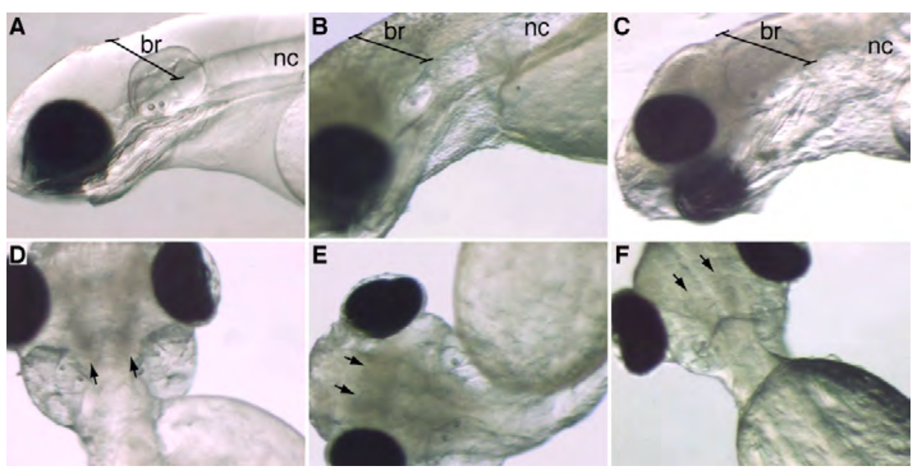


Figure 3-4: CNS opacity in natural spawn samples from oiled sites. (A-C) lateral views of the head. (A) Typical translucent embryo from San Rafael Bay. The line indicates the span of brain tissue (*br*), which lies above anterior portion of the notochord (*nc*). (B) Embryo from Peninsula Point. (C) Embryo from Keil Cove. (D-F) Dorsal or ventral views, arrows indicate bilateral structures in the base of the diencephalon/midbrain. Embryos are from (D) Keil Cove, (E) Peninsula Point, and (F) Sausalito.

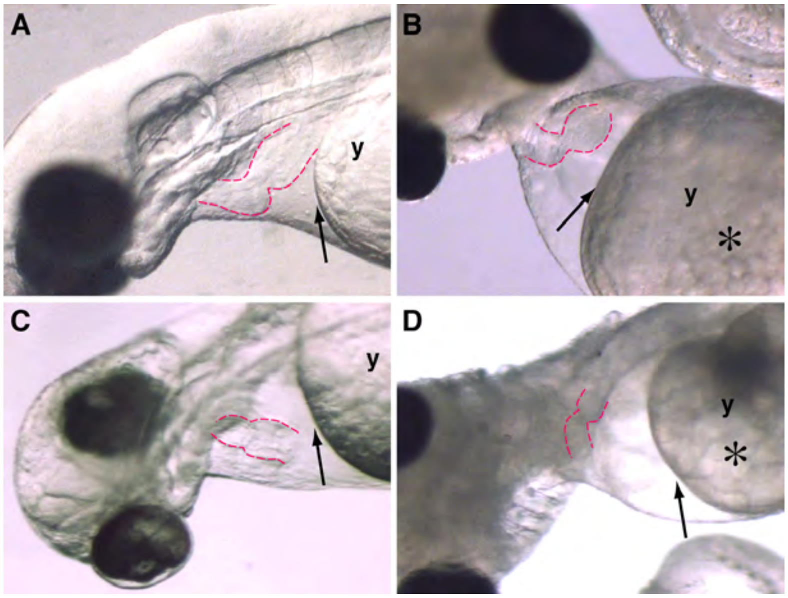


Figure 3-5: Pericardial edema in 2008 natural spawn samples from oiled sites. (A) San Rafael Bay, (B) Sausalito, (C) Peninsula Point, (D) Keil Cove. Red dashed lines indicate the outline of the heart. In the embryos from SRB (A), the heart takes up most of the pericardial space, and the anterior end of the yolk (*y*) is smoothly arced (arrow). The yolks in embryos from oiled sites (B-D) are flattened anteriorly (arrows), and in many cases yolk platelets had an abnormal appearance (asterisks).

from 5-76% (mean 33%, $p < 0.05$). At Peninsula Point, edema was observed in 6/8 grabs, and occurrence ranged from 5-26% (mean 11%, $p > 0.05$). At Keil Cove, edema was observed in 8/8 grabs, and occurrence ranged from 5-20% (mean 11%, $p > 0.05$). At San Rafael Bay, a single edematous embryo was observed in each of two grabs for a mean of 1%.

Finally, cardiac function was assessed in video clips for each individual. Abnormal heart rhythms were observed in 8/8 grabs from Sausalito, with occurrence ranging from 15-76% (mean 48%, $p < 0.05$). At Peninsula Point, arrhythmia was observed in 8/8 grabs, with occurrence ranging from 50-100% (mean 91%, $p < 0.05$). At Keil Cove, arrhythmia was observed in 8/8 grabs, with occurrence ranging from 45-95% (mean 70%, $p < 0.05$). No

Table 3-3: Overall scores for abnormalities in 2008 natural spawn samples

site	measure / subtransect	N1	N2	N3	N4	N5	N6	N7	N8	mean %
SA	total	22	21	20	19	20	20	20	20	
	body axis defect	18	16	13	16	14	16	0	5	***60 ± 11***
	tissue opacity	14	15	9	nd	nd	11	0	2	***41 ± 10***
	edema	12	13	3	5	10	5	6	1	***33 ± 7***
	arrhythmia	15	16	10	9	4	11	10	3	***48 ± 7***
PP	total	20	20	20	20	20	19	20	20	
	body axis defect	19	17	20	20	20	19	20	20	***98 ± 2***
	tissue opacity	19	17	19	20	20	18	20	20	***96 ± 2***
	edema	1	4	3	4	0	5	1	0	11 ± 4
	arrhythmia	19	12	10	10	19	18	17	20	***91 ± 11***
KC	total	20	20	19	20	20	19	20	22	
	body axis defect	12	19	18	15	20	19	19	22	***90 ± 5***
	tissue opacity	11	19	16	11	20	19	19	22	***86 ± 7***
	edema	4	3	2	3	1	3	1	0	11 ± 2
	arrhythmia	9	10	17	12	15	18	13	16	***70 ± 6***
SRB	total	20	21	20	20	20	20	20	20	
	body axis defect	0	0	0	0	0	0	0	0	0
	tissue opacity	0	0	0	0	0	0	0	0	0
	edema	1	0	0	1	0	0	0	0	1 ± 0.6
	arrhythmia	0	0	0	0	0	0	0	0	0

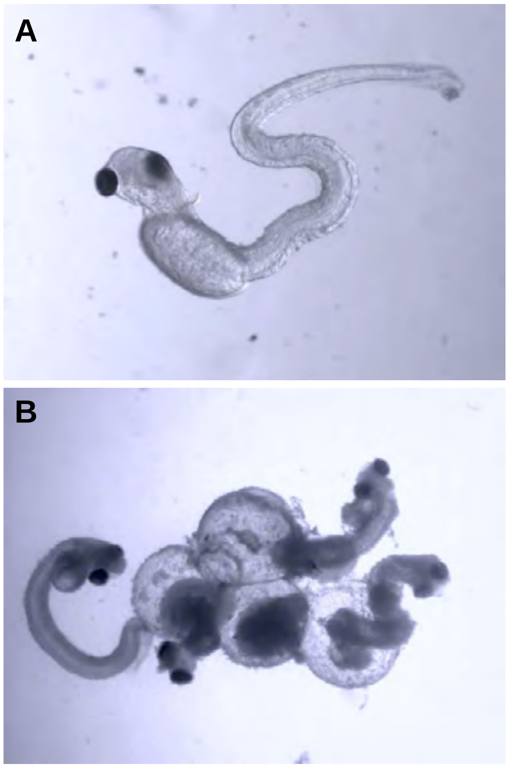


Figure 3-6: (A) Hatched abnormal larva with typical body axis defects; (B) Partially hatched dead larvae

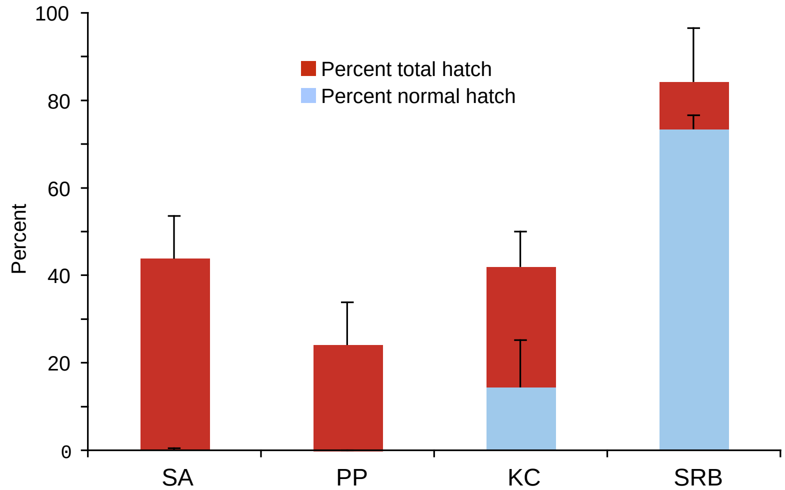


Figure 3-7: Laboratory hatching in samples of natural spawn in 2008. Red bars, percent total larvae hatched; blue bars, percent hatched larvae with normal morphology.

abnormalities in cardiac function were observed in samples from San Rafael Bay. Because only viable embryos with obvious heartbeats were imaged, these data probably underestimate the true frequency of abnormalities. The total values presented in Table 3-3 do not reflect a quantification of mortality.

3.3 Reduced hatching success and high rates of abnormal morphology in larvae from 2008 natural spawn at oiled sites. Data for hatching rates and occurrence of abnormal morphology (Figure 3-6A) in hatched larvae are summarized in Table 3-4 and Figure 3-7. For samples from San Rafael Bay, 84 ± 11 % of the embryos incubated in the laboratory hatched, and 74 ± 3% showed normal morphology (range 48 – 94%). For samples from Sausalito, 44 ± 10% of embryos incubated successfully hatched, with only 0.1 ± 0.1% showing normal morphology. For samples from

Table 3-4: Numbers of natural spawn embryos assayed for hatching and percentage hatched with normal morphology

site	subtransect	N1	N2	N3	N4	N5	N6	N7	N8	mean (± SE)
SA	embryo N	83	81	81	77	91	85	84	88	83
	percent normal hatch	0	0	0	0	1	0	0	0	0.1 ± 0.1
PP	embryo N	70	69	72	61	79	53	70	55	66
	percent normal hatch	0	0	0	0	0	0	0	0	0
KC	embryo N	52	47	39	72	53	55	49	58	53
	percent normal hatch	67	6	23	19	0	0	0	0	15 ± 11
SRB	embryo N	93	71	49	81	58	53	50	63	64
	percent normal hatch	72	90	94	88	64	70	48	63	74 ± 3

Peninsula Point, 24 ± 10% of embryos hatched, with none showing normal morphology. Finally, for samples from Keil Cove, 42 ± 8% of embryos hatched, and 14 ±11 % had normal morphology (range 0 – 67%). Only four subtransects from Keil Cove produced larvae with normal morphology. Keil Cove grab N1 was the only sample with relatively high rates of normal larvae, and this same grab had the lowest number of body axis defects detected in dechorionated embryos (Table 3-3). Significantly higher numbers partially hatched embryos (Figure 3-6B) were observed at Sausalito and Peninsula Point. The total hatch as San Rafael Bay was significantly different from all three oiled sites ($p < 0.001$). The percentage of normal larvae hatching from San Rafael Bay samples was also significantly different from all three oiled sites ($p < 0.05$ for Sausalito and Peninsula Point, $p = 0.052$ for Keil Cove).

3.4 Reduced survival of larvae from 2008 natural spawn at oiled sites. The only oiled site with surviving larvae was Keil Cove. An average of 77 ± 4% (67-85%) from 4 grabs survived an average of 5.25 days post-hatching. In contrast, a significantly greater average of 88 ± 3% (75-100%) that hatched from 8 San Rafael Bay grabs survived an average of 5.9 days post-hatching (Figure 3-8).

3.5 Behavior in larvae from 2008 natural spawn. Critical swimming speeds were determined for larvae hatched from natural spawn. However, there were only larvae available to develop U_{crit} values for two sites, Keil Cove and San Rafael Bay. There were no statistically significant differences between the mean U_{crit} for larvae from the two sites (Figure 3-9).

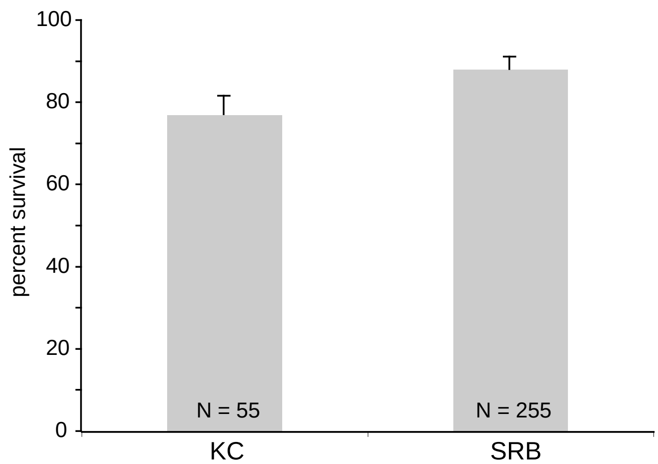


Figure 3-8: Percent survival of hatched larvae from naturally spawned embryos. Dead or abnormal larvae (abnormalities included body axis defects, edema, or opacity) were removed each day. Percent survival was determined at the end of the 5 day incubation period. (KC is significantly different from SRB; $p<0.05$; ANOVA with Tukey-Kramer HSD test for all pairwise multiple comparisons).

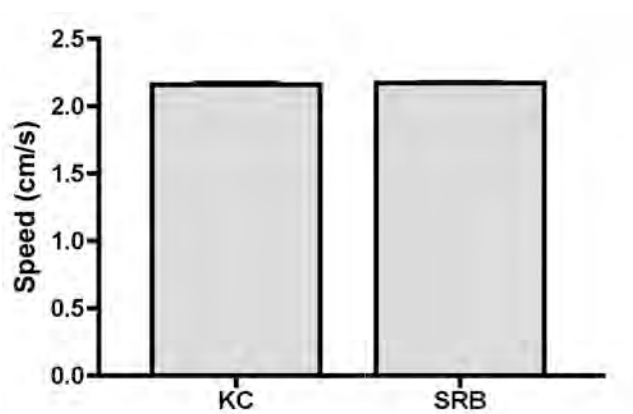


Figure 3-9: Critical swimming speed (U_{crit}) in larvae hatched from natural spawn samples. Keil Cove provided the only surviving oiled-site larvae that satisfied the requirements for swimming performance (see Section 2.7.4). There is no statistical difference between the two sites for Ucrit based on a Mann-Whitney Rank Sum Test ($p= 0.469$).

3.6 Recovery of normal natural spawn at intertidal zones of oiled sites in 2010. Herring did not spawn at any of the same sites in 2009, but they did spawn at another unoiled reference location (Paradise Cove; PC; sampled in January). The natural spawn from PC was higher in the intertidal zone than the naturally spawned sites samples in 2008, distributed on rocks as well as macroalgae. A relatively high proportion of embryos from this site failed to gastrulate (28 ± 7%), nevertheless, viable embryos from PC produced a normal hatch rate of 77 ± 4% (Figure 3-10).

In 2010, herring once again spawned at several locations where natural spawn was collected in 2008. The overlap was exact at two oiled sites (PP, KC) and partial at a third oiled site (SA). (The SA site was subsquently divided into an inner marina SA1 subsite and outer SA2 subsite, Figure 3-1b). Moreover, herring spawned again at the PC reference site, at an intertidal depth equivalent to the samples collected in 2008. Spawn densities were higher than in 2008, with all sites showing medium-high densities (3-6 layers of embryos). Larvae at all three oiled sites had normal cardiac and spontaneous motor activity. Furthermore, hatching rates were similar among the oiled and reference sites (Figure 3-10), and these were similar to the relatively high hatching rates for non-oiled reference sites sampled in previous years (SRB in 2008 and PC in 2009). However, there was a small but significant increase in pericardial edema in larvae from oiled KC site (3.5± 0.7%) relative to the other sites (SA, 1.6 ± 0.3%; PP, 1.0 ± 0.3%; PC, 1.2 ± 0.3%; ANOVA $p < 0.003$, Tukey-Kramer HSD).

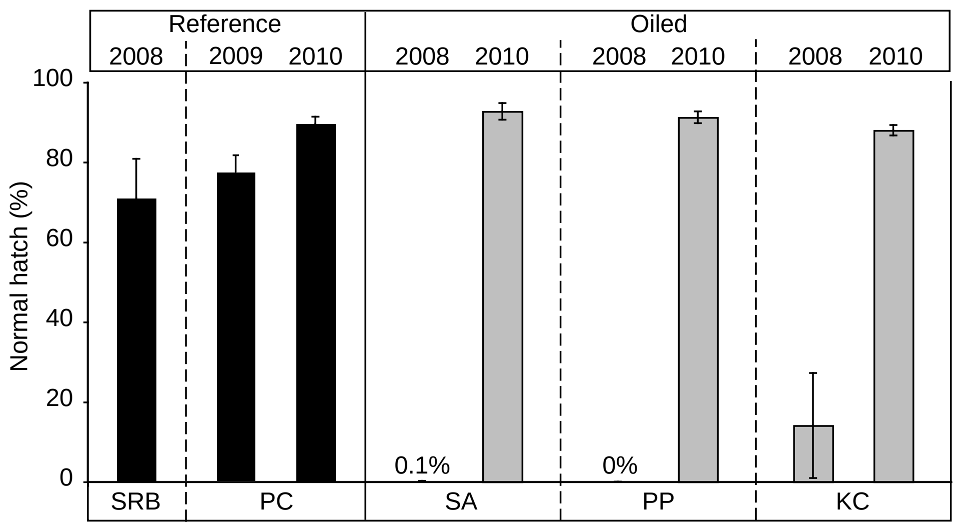


Figure 3-10: Hatching rates of larvae from natural spawn samples across all three years of field sampling. Values represent mean ± s.e.m. normal hatch rates, calculated as percent morphologically normal larvae hatched from total eggs in 8 transect subsamples per site. Grand totals of eggs assessed for each site were 535 (SRB 2008), 820 (PC 2009), 683 (PC 2010), 968, (SA 2008), 385 (SA 2010), 549 (PP 2008), 919 (PP 2010), 469 (KC 2008), 726 (KC 2010).

3.7 Reduced heart rate (bradycardia) in caged embryos incubated adjacent to oiled sites in 2008. Heart rates were quantified in 20-sec digital video clips. Pronounced bradycardia was observed at all four oiled sites, with significant variability among cages at a given site (Figure 3-11). At three of the oiled sites, all five cages showed a significant bradycardia in the range of 90 beats/min (HC, 90 ± 1; SA, 92 ± 1; PP 92 ± 1). Only one of five cages at the KC oiled site showed significant bradycardia (cage 1, 95 ± 1 beats/min), and the overall mean (114 ± 2 beats/min) was thus similar to reference sites. There was no significant variation among heart rates within the five cages from each of the two reference sites (Figure 3-11a), and both sites had an overall mean heart rate of 116 ± 1 beats/min (Figure 3-11b). Mean temperatures were indistinguishable among sites (Table 3-5), indicating that differences in heart rate were not due to incubation temperatures.

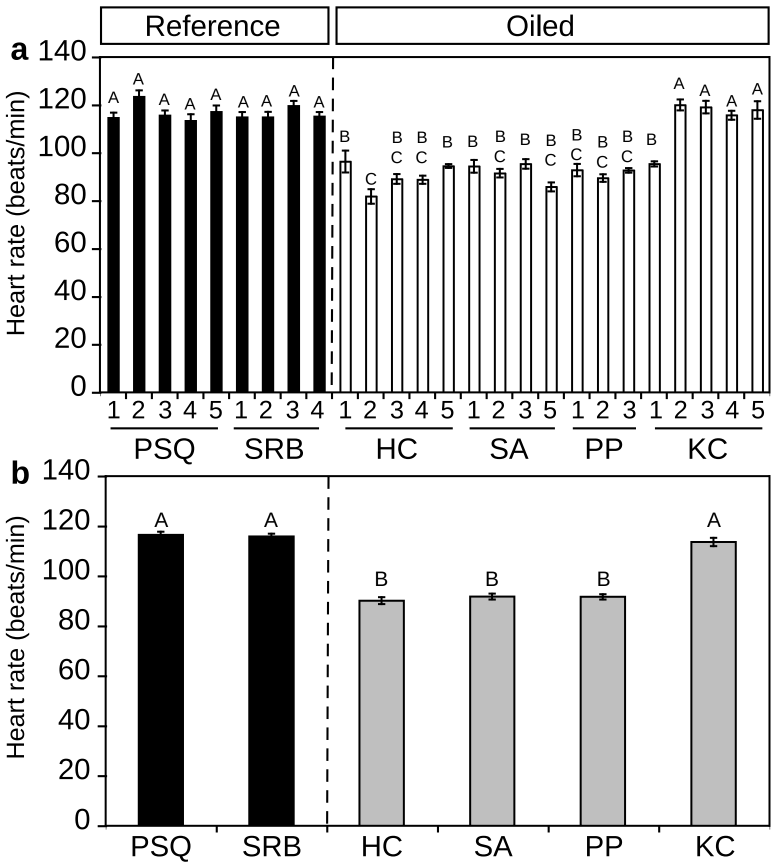


Figure 3-11: Reduced heart rate in embryos incubated in subtidal cages at oiled sites in 2008. (a) Mean heart rate (N = 30) by cage. Reference (non-oiled) and oiled sites indicated by black and grey, respectively. (b) Mean heart rate by site. Mean heart rates from individual cages were pooled for a site mean. Error bars in (b) and (c) are s.e.m. Nested ANOVA (cages nested under site, nested under oiled state) indicated effects of cage ($P < 0.001$), site ($P < 0.001$), and oiled state ($P < 0.001$). In (a) letters A-C indicate statistically similar cages identified by post-hoc means comparison with Tukey-Kramer HSD (α = 0.05). In (b) oiled sites HC, SA, and PP were statistically different than oiled site KC and reference sites PSQ and SRB (Tukey-Kramer HSD, α = 0.05). Overall, oiled sites were statistically different than non-oiled sites (T test, α = 0.05).

Table 3-5: Temperature and salinity measurements collected at cage moorings

site[1]	mean[2] temperature	maximum temperature	mean salinity	maximum salinity
PSQ	11.2 ± 0.3	12.1	20.2 ± 2.9	26.1
HC	10.9 ± 0.6	11.8	27.6 ± 1.4	30.1
SA	11.0 ± 0.4	12.2	24.8 ± 0.8	27.6
PP	11.0 ±0.6	13.6	26.7 ± 1.8	30.5
KC	10.9 ± 0.4	12.4	26.4 ± 1.6	29.9

[1]Data absent from site SRB due to logger failure
[2]means ± s.e.m.

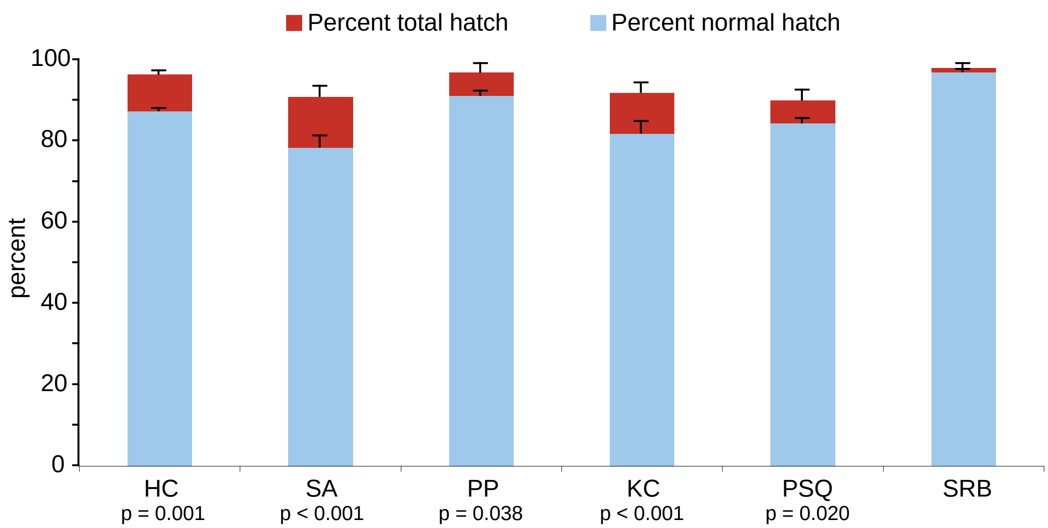


Figure 3-12: Mean hatching success of embryos incubated in deployed cages, Feb 2008. Total hatched larvae as percent of embryos are indicated by red bars, percent of total with normal morphology indicated by blue bars. Total number of embryos indicated at the bar base. P-value in comparison to SRB indicated below other site names.

3.8 Hatching success and pericardial edema in larvae from 2008 caged embryos. Average total hatching for caged embryos incubated in the laboratory ranged from 79 ±2 % at Sausalito to 97 ± 1% at San Rafael Bay (Figure 3-12), differences that were not statistically significant. In contrast, of embryos that did hatch, significantly fewer numbers with normal morphology were observed at all four oiled sites, but also at Point San Quentin. However, when abnormal morphology was specifically categorized, larvae with pericardial edema were detected only from cages incubated at oiled sites (Figure 3-13). Cardiogenic edema, produced by more severe impairment of cardiac rhythm in developing fish embryos, was observed in a small but significant percentage of larvae hatched from each oiled site, ranging from 0.9 to 2.5% (Figure 3-12). No edema was observed among 652 larvae hatched in cages at reference sites (PSQ, n = 308; SRB, n = 344).

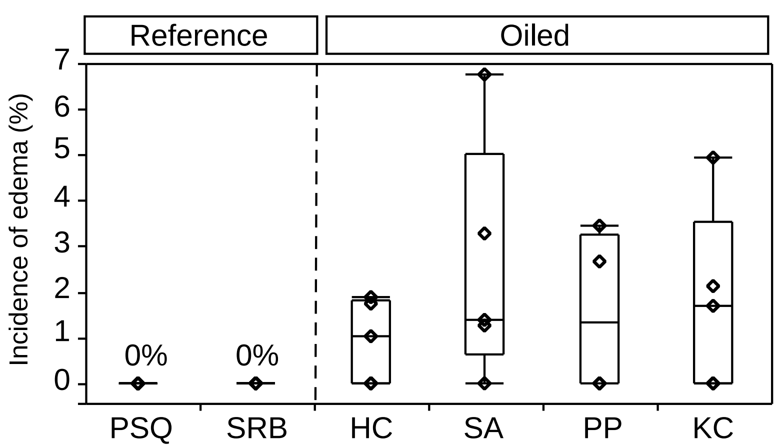


Figure 3-13: Incidence of pericardial edema in larvae hatched in the laboratory after incubation to 7 days post-fertilization in subtidal cages. Box plots encompass individual values for each cage, error bars show 95% confidence interval and upper and lower box limits show 75th and 25th percentiles, respectively. Edema tended to be observed more frequently at oiled sites (Wilcoxon rank sums test p = 0.06).

3.9 Larval survival from caged embryos in 2008. Average survival in laboratory incubations for larvae from caged embryos ranged from 78% at Point San Quentin to 92% at San Rafael Bay. No statistical differences in survival were observed between any of the sites ($p > 0.119$) (Figure 3-14).

3.10 Lower critical swimming speed in larvae hatched from cages incubated at oiled sites in 2008. Results of the critical swimming speed analysis were combined for each set of cages at each station. For the

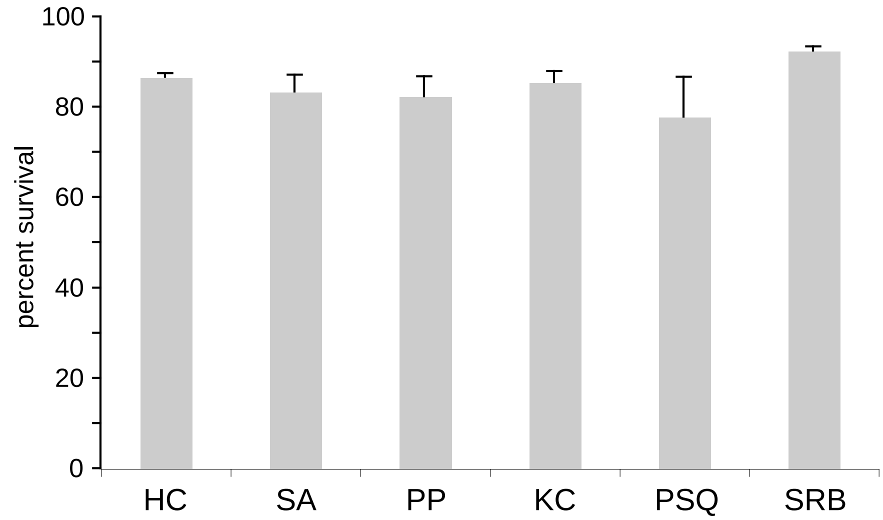


Figure 3-14: Percent survival of hatched larvae from 2008 caged embryos. Dead or abnormal larvae (abnormalities included body axis defects, edema, or opacity) were removed each day. Percent survival was determined at the end of the 5 day incubation period. (KC is significantly different from SRB; $p<0.05$; ANOVA with Tukey-Kramer HSD test for all pairwise multiple comparisons).

first analysis, the 3-minute increment steps were used for a total of 12 minutes and the U_{crit} calculated. Based on this analysis, station PP and KC are statistically different from the other locations (Figure 3-15). A Kruskal-Wallis one-way ANOVA of Variance on Ranks was applied to determine differences between stations ($P= <0.001$). A second analysis was conducted by adjusting the last increment to a 12-minute exposure rather than the 3-minute used in the first analysis. This was done to compensate for the fact that over half of the larvae tested did not reach fatigue within 3 minutes at the highest speed (1.93 cm/s). There were no statistically significant differences between the two different approaches to determining the U_{crit} values. To determine within-site variability, the six stations were analyzed individually by comparing the results for each cage within the station (Figure 3-16). Sample sizes were small so that statistical analyses were limited. One-way ANOVAs were conducted on the U_{crit} values for all stations except SRB where a Kruskal-Wallis ANOVA on Ranks was applied. These results indicate no statistical differences between cages at the HC site while three of the cages were statistically significant at the SA site. All other sites had one cage at each station that was statistically significant with site PP having two cages that were significantly different.

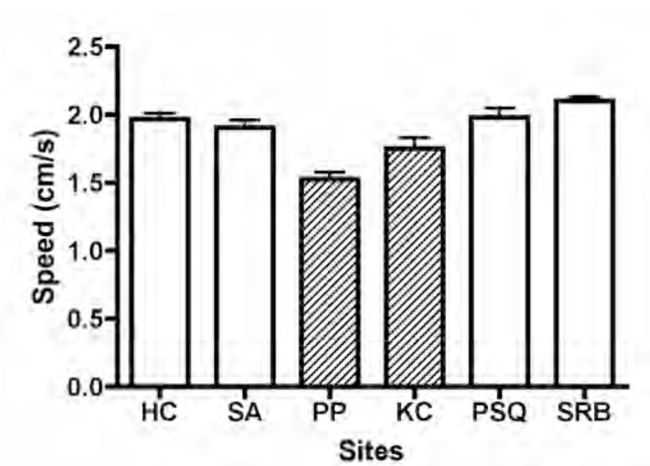


Figure 3-15: Mean critical swimming speed in larvae from 2008 caged embryos by site. Sites PP and KC are statistically different from the remaining locations. The individual cage results were combined for each station. A Kruskal-Wallis One Way ANOVA of Variance on Ranks was applied to determine differences between stations ($P = <0.001$).

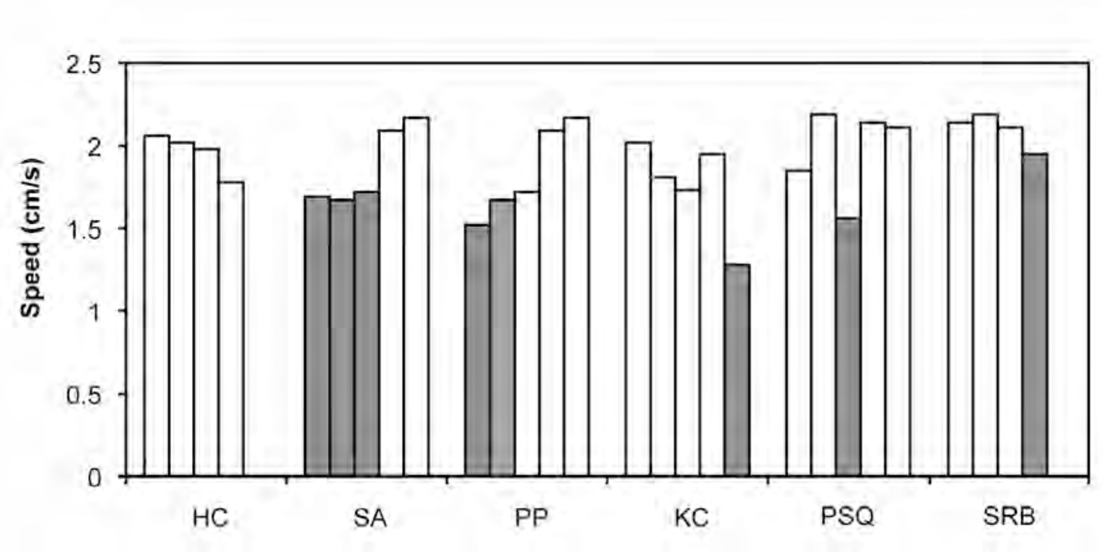


Figure 3-16: Mean critical swimming speed in larvae for each cage. Dark bars indicate a statistically significant difference between cages within the station. A one way analysis of variance was conducted on all the stations groups except for station SRB where a Kruskal-Wallis ANOVA on Ranks was used.

3.11 Background levels of PAHs and POPs in reproductively mature Pacific herring from San Francisco Bay in 2008. Very low levels of PAHs were detected in herring entering San Francisco Bay during the 2007-2008 spawning season. In samples of fish captured at Richardson Bay and South of the Bay Bridge in February 2008 (Table 3-6), concentrations of sum PAHs ranged from 23 – 52 ng/g in whole bodies and

Table 3-6: PAHs and POPs in maternal tissues of herring in San Francisco Bay and Puget Sound

Tissue	Region	Site	Year	Percent lipid					
Whole body	SF	Richardson Bay (n=6)	2008	3.4 ± 0.24	44 ± 1.7	3.2 ± 0.3	47 ± 11	33 ± 4.0	12 ± 0.61
	PS	Port Orchard (n=56)	1999-2004*	6.4	NA	NA	NA	19	160
	PS	Quartermaster Harbor (n=10)	1999-2004*	8.1	NA	NA	NA	19	120
	PS	Cherry Point (n=20)	1999-2004*	3.3	NA	NA	NA	11	41
Ovary	SF	Richardson Bay (n=6)	2008	0.40 ± 0.10	11 ± 0.7	0.5 ± 0.1	12 ± 0.6	2.8 ± 0.32	1.6 ± 0.40
	PS	Port Orchard (n=2)	2001†	3.1 ± 0.14	23 ± 0.0	2.2 ± 0.1	25 ± 0.1	5.5 ± 0.57	51 ± 7.1
	PS	Quartermaster Harbor (n=1)	2001†	2.9 ± 0.0	24	1.1	25.1	4 ± 0.29	44 ± 0.0
	PS	Cherry Point (n=2)	2001†	2.8 ± 0.1	23 ± 0.7	1.6 ± 0.7	24 ± 0.0	12 ± 0.07	70 ± 18

*Data from West et al., 2008, Sci. Total Environ. 394:369-378. Standard error values not reported.
NA - not analyzed for PAHs
†Data from O'Neill and West, WDFW PSAMP

8.6 – 13 ng/g. Low molecular weight PAHs (LAHs) comprised more than 90% of the sum PAHs measured in both whole body and ovary samples, and naphthalenes represented roughly 90% of the sum LAHs (Table). For the Richardson Bay fish, mean sum PAH levels (based on wet weight) in the whole bodies and ovaries were significantly different ($p < 0.0001$), with whole body concentrations being 3-6 times higher as those measured in ovaries. Similarly, significant differences ($p < 0.0001$) in mean sum LAHs and HAHs values were also found between these tissues. Percent lipid values were significantly correlated with the ovary sum LAHs ($r^2 = 0.9177$; $p = 0.0017$) and sum PAHs ($r^2 = 0.7931$; $p = 0.0109$) concentrations whereas the percent dry weight values of the ovaries were not significantly correlated with these sum LAH, HAH or PAH values at the $p < 0.05$ level. For herring whole body samples, lipid concentrations were not significantly correlated with sum LAHs ($p = 0.1258$), HAHs ($p = 0.2279$) or sum PAHs ($p = 0.1275$). Dry weight percentage values were also not correlated with herring body sum LAH ($p = 0.3415$), HAH ($p = 0.6218$) or PAH ($p = 0.3912$) levels.

Persistent organic pollutants (POPs) were also measured in whole body and ovary samples of the San Francisco Bay herring, with DDTs and PCBs being the most abundant classes of POPs (Table 3-6). Other classes of POPs (e.g., chlordanes, polybrominated diphenyl ethers, hexachlorocyclohexanes) were also detected in the herring whole body samples but were less than the limit of quantification (< LOQ) in the ovaries. Sum DDTs and PCBs (based on wet weight), as well as percent lipid values, were significantly different ($p < 0.0001$) between the tissues of the Richardson Bay fish, with whole body levels being 4–18 times higher than the ovary values. Percent lipid values were not strongly correlated with wet weight concentrations of sum DDTs and sum PCBs measured in whole body ($p = 0.1551$ and $p = 0.9190$, respectively) or ovary ($p = 0.1815$ and $p = 0.1461$, respectively) samples. Similarly, no significant relationships were found between percent dry weight values and sum PCBs or sum DDTs in herring whole bodies ($p = 0.3796$ and $p = 0.7229$, respectively) or ovaries ($p = 0.1146$ and $p = 0.6872$, respectively).

The contaminant levels determined in the California herring tissues were compared to those measured in the same tissues of herring captured from various sites in Puget Sound, WA. In general, the mean PAH levels measured in ovaries of the California herring were lower than those determined in ovaries of Puget

Sound herring captured in 2001 (O'Neill and West pers. commun.) (Table 3-6). In the whole body samples, mean sum DDT concentrations were higher in the California herring whereas the mean sum PCBs were higher in the Puget Sound fish. It should be noted that PAH concentrations have yet to be determined in whole body samples of herring captured in Puget Sound, WA so these comparisons could not be made.

3.12 PAHs detected in embryos from natural spawn samples (2008-2010) and deployed cages (2008). The mean PAH concentrations measured in embryos compared to background levels in ovaries from adult females are shown in Figure 3-17. The mean sum PAH levels from natural spawn samples ranged from 13 ng/g to 53 ng/g, wet weight. The highest levels were detected in embryos from Sausalito (53 ± 34 ng/g), followed by Keil Cove (40 ± 20 ng/g), with similar levels detected in embryos from Peninsula Point (14 ± 6 ng/g) and San Rafael Bay (13 ± 2 ng/g). Mean sum LAHs contributed 57 – 77% to sum PAHs in embryos from Keil Cove, Peninsula Point and San Rafael but comprised only 47% of mean sum PAHs in embryos collected from Sausalito. In cage-deployed embryos levels of sum PAHs in these samples ranged from 9 ng/g to 70 ng/g. The highest levels were detected in embryos incubated at Horseshoe Cove (70 ± 12 ng/g), followed by Sausalito (41 ± 7 ng/g), Keil Cove (16 ± 3 ng/g), Point San Quentin (16 ± 2 ng/g), Peninsula Point (11 ± 1 ng/g), with the lowest levels at San Rafael Bay (9 ± 3 ng/g). Embryos incubated at both Horseshoe Cove and Sausalito had approximately equal percentages of LAHs and HAHs (~ 50% each) contributing to the sum PAH values whereas at the other four sites, the deployed embryos contained primarily LAHs

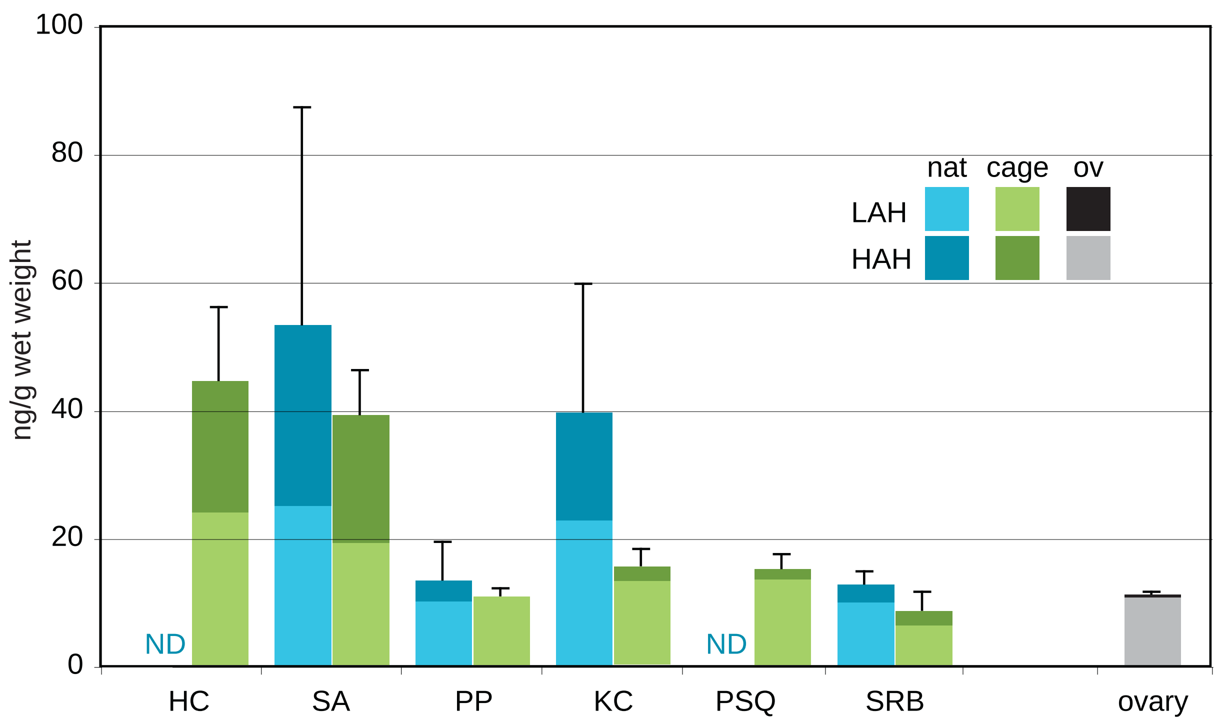


Figure 3-17: Mean sums of PAHs in embryos from natural spawn samples, caged embryos, and prespawn ovaries from SF Bay adults in 2008. Blue bars are natural spawn embryos, green bars are caged embryos; lighter shades represent sum of low molecular weight PAHs, darker shades sum of high molecular weight PAHs. ND, not determined.

(comprising > 70% of sum PAHs). Background ovary mean sum PAH level was 11 ± 0.3 ng/g and predominantly LAH naphthalenes.

We found no differences (p = 0.1468) in percent lipid values of embryos collected among the four natural spawn sites in 2008. However, significant differences (p < 0.0001) in egg percent lipid values were found among the deployment stations, with embryos from San Rafael and Sausalito containing lower lipid content than those measured in embryos deployed at Point San Quentin (Table 3-7). Embryos from Horseshoe Cove, Peninsula Point and Keil Cove also had higher percent lipid values than those determined in embryos deployed at San Rafael Bay. In embryos from natural spawn samples, there was a weak correlation between percent lipid and sum LAHs (r^2 = 0.1227; p = 0.0279) whereas no significant relationships were found for lipid values and sum HAHs (p = 0.6704) or sum PAHs (p = 0.2451). Similarly for caged embryos, there was significant but weak relationship (r^2 = 0.1223; p = 0.0414) between percent lipid and sum LAHs whereas no significant correlations were found between lipids and sum HAHs (p = 0.6362) or sum PAHs (p = 0.3972).

Differences were apparent in the mean sum alkyl-phenanthrenes detected in embryos (Figure 3-18).

Table 3-7: Lipid content of cage-deployed embryos

Collection site	Date deployed	Date retrieved	Percent lipid
HC (n = 4)	Feb 10, 2008	Feb 17, 2008	0.39 ± 0.08*a,b*
SA (n = 5)	Feb 12, 2008	Feb 19, 2008	0.29 ± 0.04*b,c*
PP (n = 4)	Feb 18, 2008	Feb 25, 2008	0.48 ± 0.07*a,b*
KC (n = 5)	Feb 13, 2008	Feb 20, 2008	0.36 ± 0.05*a,b*
PSQ (n = 5)	Feb 18, 2008	Feb 25, 2008	0.65 ± 0.1*a*
SRB (n = 4)	Feb 15, 2008	Feb 22, 2008	0.13 ± 0.06*c*

Unlike italic letters after values in Percent lipid column indicate significant differences using Tukey-Kramer honestly significant difference (HSD) test (p < 0.0001).

These are the most abundant of the toxicologically relevant tricyclic PAHs in *Cosco Busan* bunker oil (Figure 1-2). The natural spawn samples with the highest total alkyl-phenanthrenes were Sausalito (3.4 ± 2.5 ng/g) and Keil Cove (2.3 ± 0.9 ng/g), while Peninsula Point (1.2 ± 1 ng/g) was higher than San Rafael Bay (0.6 ± 0.3). Thus, while Peninsula Point and San Rafael Bay have similar total PAH levels (14 ± 6 ng/g vs. 13 ± 2 ng/g, respectively), the levels of alkyl-phenanthrenes were 2-fold higher at Peninsula Point. A similar

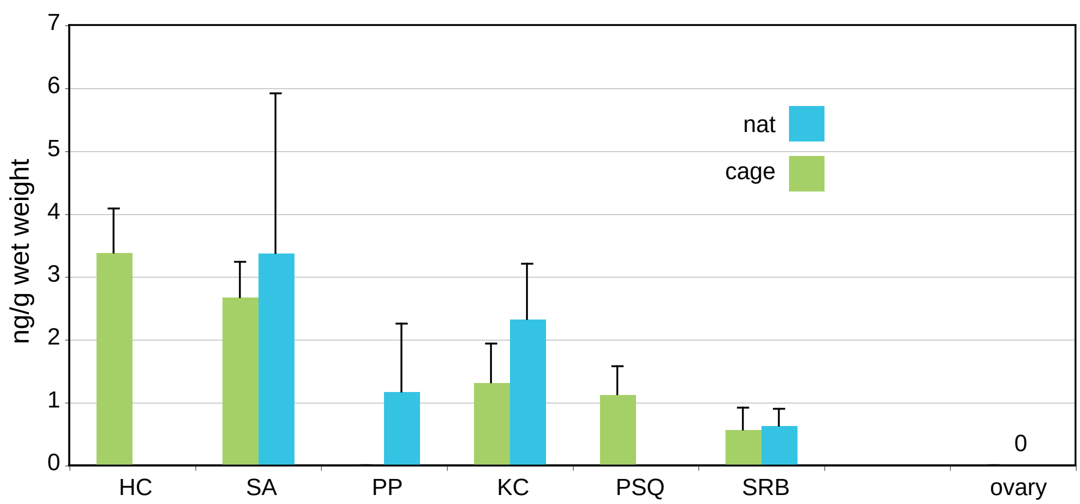


Figure 3-18: Sum alkyl-phenanthrenes (C1- through C4-PHN) in embryos from natural spawn samples, cages, and prespawn ovaries in 2008. Values are mean and standard error. Alkyl-phenanthrenes were below detection limits in ovaries.

ranking was observed for caged embryos, where the highest alkyl-phenanthrene levels were observed at Horseshoe Cove (3.4 ± 0.7 ng/g), followed by Sausalito (2.7 ± 0.6 ng/g), Keil Cove (1.3 ±0.6 ng/g) and San Rafael Bay (1.1 ± 0.4 ng/g). Caged embryos incubated at Peninsula Point had alkyl-phenanthrene levels that were below detection limits. In both cases, Keil Cove stands out as having high alkyl-phenanthrene levels with an absence of obvious PAH inputs from land-based or other maritime sources.

When comparing caged and naturally spawned embryos across all three years of sampling, analyses of individual classes of PAHs representing petrogenic or pyrogenic sources also revealed significant differences among sites (Table 3-8), despite generally low mean ∑PAH concentrations that were in many cases statistically indistinguishable from maternal background levels using standard parametric tests. Sulfur-containing dibenzothiophenes are petrogenic PAHs and often used for characterizing sources of oil in the environment [78-81]. Although Cosco Busan bunker oil is low in sulfur compared to other fuels, with a C2-dibenzothiophene/C2-phenanthrene (D2/P2) ratio of 0.26, the alkyl-dibenzothiophenes are nevertheless one of this bunker oil's most abundant PAH classes. Total alkyl-dibenzothiophenes tended to be higher in natural spawn embryos from each oiled site and in caged embryos from three of four oiled sites than from non-oiled sites in 2008 (Wilcoxon rank sums test $P = 0.08$). Co-detection of C2- and C3-dibenzothiophene was also higher in both caged and naturally spawned embryos from oiled sites in 2008. In 2010, alkyl-dibenzothiophenes in natural spawn were not detected at oiled site PP but remained significantly elevated at oiled site KC (ANOVA $P = 0.03$, Tukey-Kramer HSD $\alpha = 0.05$). The pyrogenic PAH fluoranthene did not show the same relationship. Slightly lower fluoranthene levels at reference sites were not statistically significant ($P = 0.28$, Wilcoxon rank sums test), and there was only a weak correlation between mean fluoranthene and total alkyl-dibenzothiophene concentrations ($r^2 = 0.6$).

Table 3-8: Summary of selected PAH concentrations (ng/g wet weight) measured in naturally spawned and caged embryos collected in 2008 and 2010

Matrix/yr (*N*)	Site[1]	Mean ∑PAHs[2]	Mean FLA	Mean alkyl-DBTs	Frequency C2/C3-DBT (%)[3]
Spawn/08 (8)	SRB	21 ± 2	1.1 ± 0.2	0.05 ± 0.03	0
Spawn/08 (5)	SA1[4]	81 ± 40	2.9 ± 0.7	0.49 ± 0.29	20
Spawn/08 (3)	SA2	18 ± 3	0.6 ± 0.1	0	0
Spawn/08 (8)	PP	19 ± 5	0.8 ± 0.1	0.12 ± 0.08	25
Spawn/08 (8)	KC	45 ± 18	3.8 ± 2.2	0.28 ± 0.09	75
Spawn/10 (8)	PC	28 ± 3	0.5 ± 0.1	0.05 ± 0.05	13
Spawn/10 (3)	SA2	27 ± 1	1.4 ± 0.1	0	0
Spawn/10 (8)	PP	23 ± 1	0.6 ± 0.1	0	0
Spawn/10 (8)	KC	34 ± 9	1.8 ± 1.0	0.48 ± 0.16	100
Cage/08 (5)	PSQ	23 ± 2	1.0 ± 0.2	0.09 ± 0.06	0
Cage/08 (4)	SRB	17 ± 3	0.8 ± 0.3	0	0
Cage/08 (4)	HC	52 ± 10	3.7 ± 0.9	0.48 ± 0.23	50
Cage/08 (5)	SA	48 ± 6	2.7 ± 0.5	0.51 ± 0.13	80
Cage/08 (4)	PP	21 ± 1	0.8 ± 0.1	0	0
Cage/08 (5)	KC	24 ± 3	0.7 ± 0.1	0.21 ± 0.10	40

[1]Reference sites = PC, PSQ, SRB; Oiled sites = HC, SA, PP, KC
[2]Mean and s.e.m. values from given *N*
[3]frequency of samples with both C2- and C3-DBT detected
[4]
FLA = fluoranthene
DBTs = dibenzothiophenes

3.13 Distinct patterns of PAH inputs evident from analysis of PEMD passive samplers. A comparison of PAH patterns in PEMDs deployed along side the caged embryos indicated distinct PAH chemical fingerprints among the six subtidal sites, reflecting their surrounding upland development (Figure 3-19). Moreover, as expected for an urbanized estuary, all sites had mixed inputs of petrogenic and pyrogenic PAHs. Non-metric multidimensional scaling (nMDS) and an analysis of similarity (ANOSIM) revealed that PAHs patterns were highly significantly different among sites (Figure 3-19; $P = 0.001$, $R = 0.69$). A pair wise

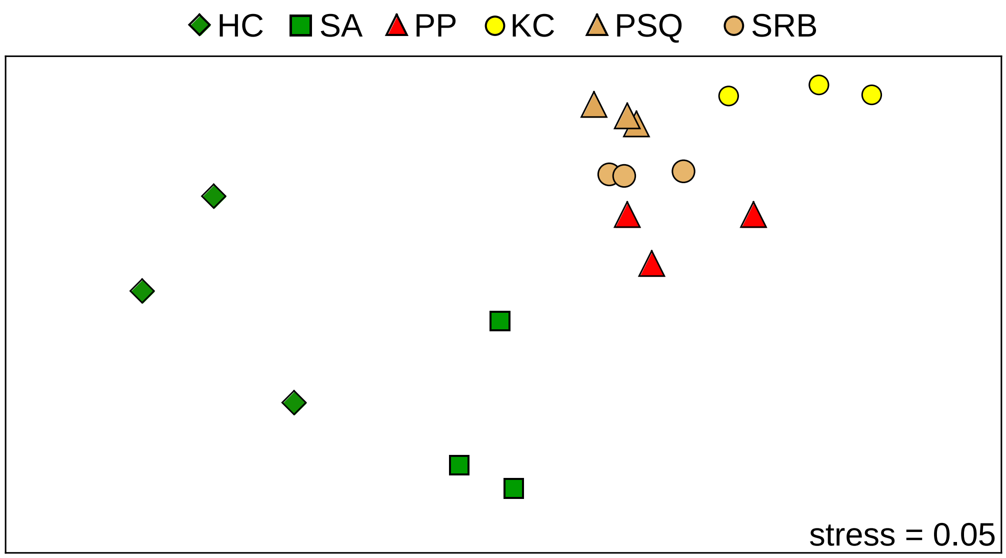


Figure 3-19. Comparison of PAH patterns in PEMDs deployed at six sites indicates distinct PAH sources. Non-metric multidimensional scaling (nMDS) was used to represent a large number of PAH compounds in low dimensional (2D) space. nMDS analysis was carried out using Primer 6.0 as described in the Methods. Axes surround a unitless space within which samples are placed according to the degree of similarity in the relative abundance of five influential PAH compounds (pre-selected from 34 compounds using the Primer BEST routine). Similarity in PAH patterns determines the distance between points in the space; samples with similar patterns are placed close together and dissimilar patterns farther apart. The observed patterns are statistically different from a random configuration of points (Stress = 0.05). PSQ, SRB are reference sites; HC, SA, PP, and KC are oiled sites.

ANOSIM test showed that sites HC and SA, both of which have marinas and were oiled, were similar (R=0.33) and different from all other sites (R range from 0.85 to 1.0). Similarly, reference sites PSQ and SRB, which are on opposite sides of a major highway (Richmond Bridge; Figure 31E, F), were indistinguishable from each other (R=0.26) and were isolated from all other sites (R range from 0.85 to 1.0). Oiled sites PP and KC, which are residential or minimally developed, were isolated from each other and all other sites (R range from 0.85 to 1.0). Diagnostic PAH ratios also showed differences among sites (Table 3-9). The ratio of sum alkyl-phenanthrenes to phenanthrene (MP/P) is widely used to distinguish pyrogenic from petrogenic sources [82], with the latter having MP/P ratios > 2. Conversely, the ratio of fluoranthene + pyrene to sum C2- through C4-phenanthrene (Fl + Py/C24P) increases with increasing pyrogenic composition [81]. The MP/P ratio was > 2 for only the most heavily oiled site, KC (MP/P = 2.6), while the FL+PY/C24P ratios clustered into four groups that matched the nMDS analysis. This analysis is consistent with heterogeneous background PAH inputs among the six sites that are associated with the adjacent upland development and land use, as well as an elevation of petrogenic signal above the background level at the heavily oiled site KC.

Table 3-9: Diagnostic PAH ratios for PEMD samples.

Site (description)	MP/P (diagnosis)	FL+PY/C24P (diagnosis)
KC (heavily oiled/residential	2.6 petrogenic	2.1 (least pyrogenic)
PP (lightly oiled/residential)	1.5 petrogenic/pyrogenic	2.7 (less pyrogenic)
PSQ (non-oiled/ developed)	1.9 petrogenic/pyrogenic	2.9 (intermediate pyrogenic)
SRB (non-oiled/ developed)	1.9 petrogenic/pyrogenic	3.0 (intermediate pyrogenic)
HC (oiled/ marina)	1.1 petrogenic/pyrogenic	4.2 (high pyrogenic)
SA (oiled marina)	1.0 petrogenic/pyrogenic	4.7 (high pyrogenic)

MP/P is the ratio of the sum of alkyl-phenanthrenes to parent non-alkylated phenanthrene; Fl + Py/C24P is the ratio of fluoranthene + pyrene to sum C2- through C4-phenanthrenes.

Section 4: Results of Laboratory Studies

4.1 Phototoxicity Trial 1, January 22-30 2009. This trial was considered a “dry run” in which there would not be a full work-up of samples for chemical analysis. The primary purpose was to check that the oiled gravel doses were correctly targeted, and that the positive controls were producing the expected sublethal toxicity. Embryos on randomly selected replicate slides were examined daily from 5 dpf through 8 dpf. Representative images were collected from most but not all dose and light combinations.

Results at 8 dpf are shown in Figure 4-1. In general, the positive and negative controls produced expected results. Normal development was observed in clean and urban gravel effluents. Embryos exposed to ANS under UVB plastic showed dose-dependent pericardial edema (not shown), as did embryos exposed to ANS under UVT plastic (arrows, Figure 4-1, second column, top). In addition, at the highest dose of ANS under UVT plastic, there was a reduction in the size of the embryos, and a slight dorsal curvature. This novel effect of oil + UV exposure was also observedFigure in the CB 0.3 g/kg UVT treatment (fourth column, middle). Dose-dependent pericardial edema was also observed in embryos exposed to CB oil under UVB plastic (arrows, Figure 4-1, third column). While embryos exposed to CB oil under UVT plastic appeared viable at 6 dpf (Figure 4-2), by 8 dpf embryos exposed to 1 g/kg CB oil and UV were completely necrotic (Figure 4-1, third column), making them impossible to dechorionate.

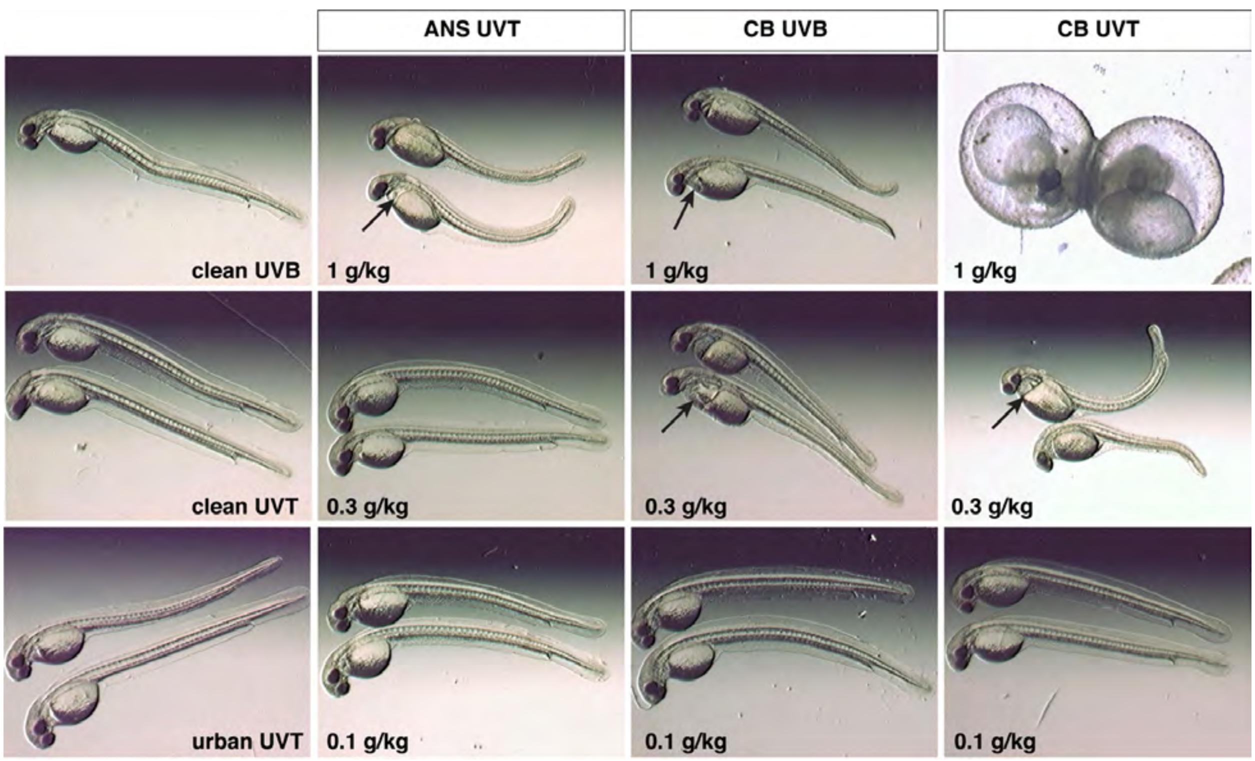


Figure 4-1: Morphology of 8 dpf embryos, Trial 1. Arrows indicate pericardial edema

During this trial, continuous temperature loggers were placed in one control effluent aquarium on each table. Temperature in the exposure aquaria fluctuated around the desired 12°C incubation temperature

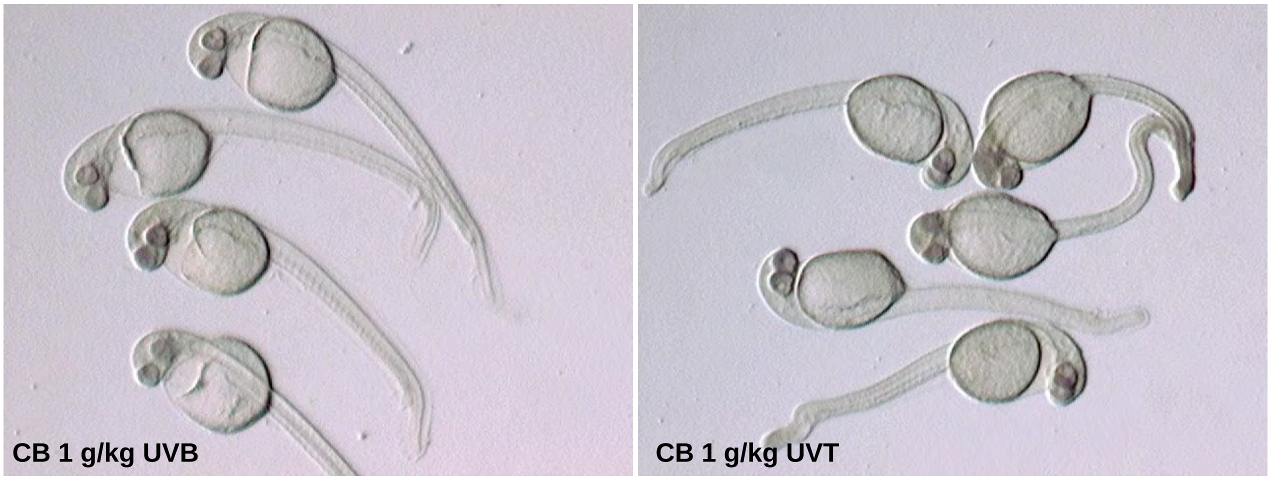


Figure 4-2: Morphology of high dose CB-exposed embryos at 6 dpf, Trial 1

on a diurnal basis, peaking around 18 °C between 12:00 and 14:00 (Figure 4-3). However, all tables showed very similar temperature profiles. Spot checking temperatures randomly in other column effluents showed that the logger data were broadly representative of all columns in a table. Data was not collected from Table 4 due to failure of the logger.

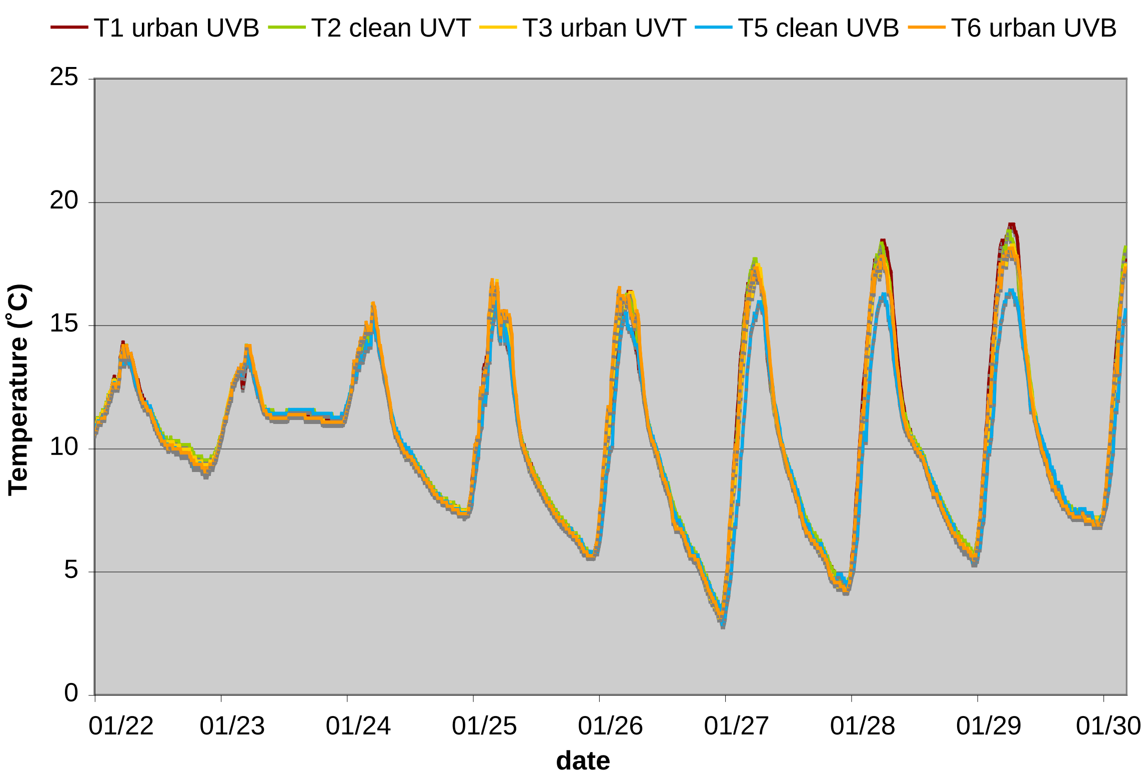


Figure 4-3: Trial 1 temperature logger data from control column effluents, recorded every 10 min.

4.2 Phototoxicity Trial 2, February 13-22 2009. During this trial, it was noted at 5 dpf that there were high rates of abnormal early embryos in lab incubator controls. These embryos had gastrulation defects. Because of this, it was decided to abort this trial due to the time it would take to distinguish oil-associated lethality from background. However, a small-scale analysis was completed. So that the columns could be prepared for a new batch of embryos, one or two replicates of each treatment were removed from the column effluents at 7 dpf and placed in 20-gal aquaria with 22 ppt seawater, immersed in a 4-ft tank for temp control, and incubated an additional 2 days under the appropriate UVT or UVB plastic. Thus oil exposure stopped at 7 dpf, while sunlight exposure continued to 9 dpf when embryos were analyzed.

Results are shown in Figure 4-4. Embryos were scored as viable eyed embryos. Similar to what was observed in Trial 1, high rates of cytolyzed eyed embryos were observed in the CB 1 g/kg UVT treatment. Only a few embryos from the CB 1 g/kg UVT treatment were sufficiently intact to dechorionate (Figure 4-5).

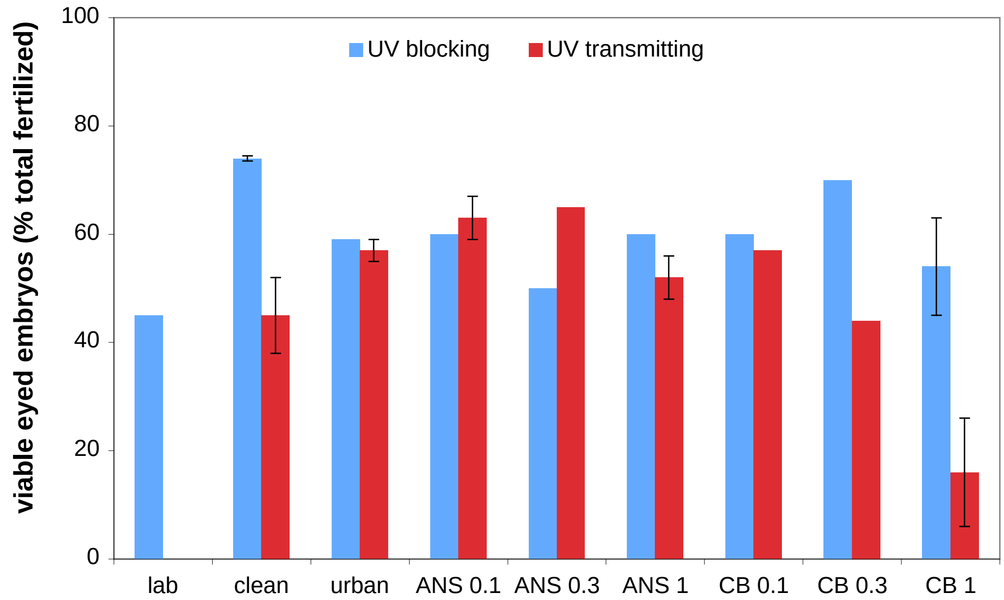


Figure 4-4: Viable eyed embryos, Trial 2. Error bars present for samples with n = 2.

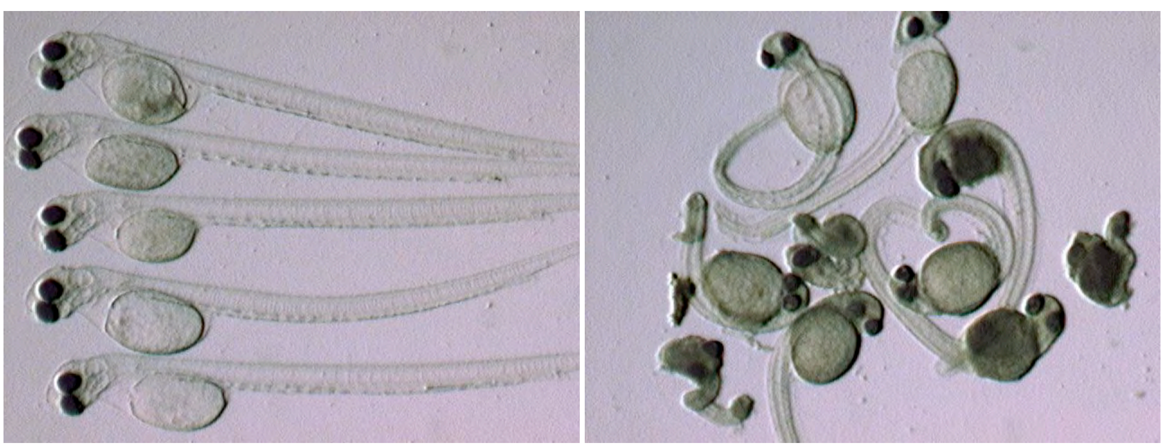


Figure 4-5: Morphology of non-cytolyzed CB 1 UVT embryos compared to CB 1 UVB

Some changes were made for this trial to improve the temperature control. A chiller was added to cool the water leaving the head tank providing source water for the columns. The water baths were switched from freshwater to seawater to dampen the night time chilling effect. Incubation temperatures still fluctuated several degrees around the desired 12°C, with higher temperature peaks (20°C) coming with warmer sunny days. Consistent with Trial 1, all tables showed similar temperature trends (Figure 4-6). The last two days of incubation for this trial were carried out in 20-gal aquaria submerged in 4-foot tanks held at 12°C. It was noted during this run that diatom growth was becoming visible in the incubator tanks and tubing feeding the columns. Tanks were scrubbed prior to placement of embryo slides.

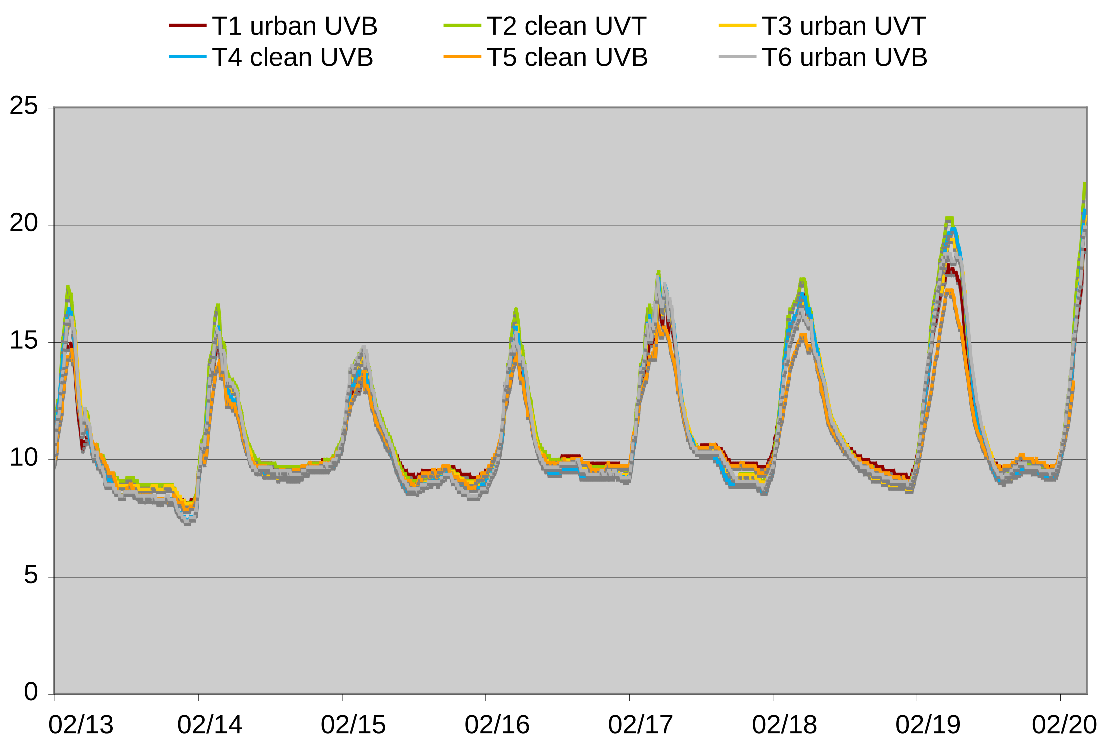


Figure 4-6: Trial 2 temperature logger data from control column effluents, recorded every 10 min.

4.3 Phototoxicity Trial 3, February 26 - March 7 2009. Laboratory controls were satisfactory for this trial (about 10% background embryos with abnormal early development), and a full experiment was completed with samples taken for water and tissue PAH analysis. Embryos were incubated to 9 dpf and analyzed. Due to higher daytime temperatures then the previous trials, development was accelerated, and some hatching had occurred by 9 dpf. Therefore, embryos were scored as unfertilized eggs, dead during segmentation or earlier (no eye pigment), viable with eye pigment, necrotic with eye pigment, or hatched (empty chorion). During this trial, heavy growth of singular and filamentous diatoms had occurred between days 6 and 9 of incubation, coating the outer chorions. Embryos on slides were gently scraped with forceps to allow visual scoring through the chorion.

This was the first trial for which there was a complete set of samples taken for PAH analysis in both water and tissue. Two duplicate sets of column effluent samples (200-ml) were collected and analyzed for PAHs. One was analyzed by the NOAA NWFSC without filtering. The second set was analyzed by the Alpha Analytical Woods Hole Division (Mansfield, MA), after filtration ostensibly to remove particulate oil or oil droplets. The Alpha Analytical data are reported here. Aqueous PAH levels correlated well with oil doses loaded on gravel (Figure 4-7). PAH levels were trace, with the highest CB oil dose producing total PAHs (TPAH) less than 1 ppb (µg/l). The lowest oil doses (0.1 g/kg) produced aqueous TPAH that were nominally higher than but difficult to distinguish from background levels of about 100 ppb.

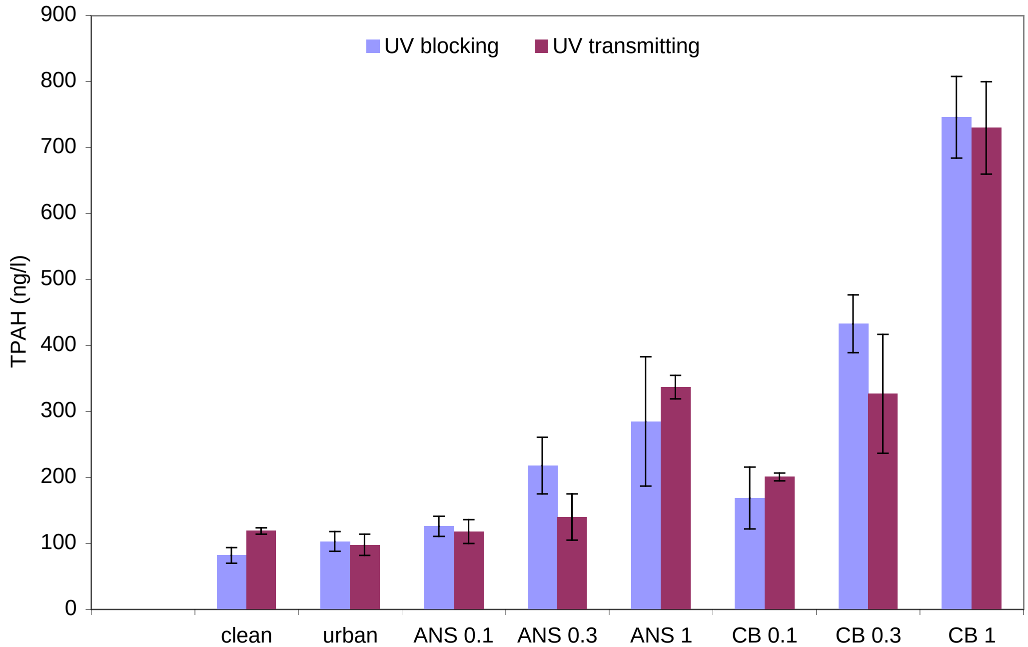


Figure 4-7: Total aqueous PAHs in column effluents (38 analytes). Values are mean ± SE for three replicate columns from samples taken at the start of incubation.

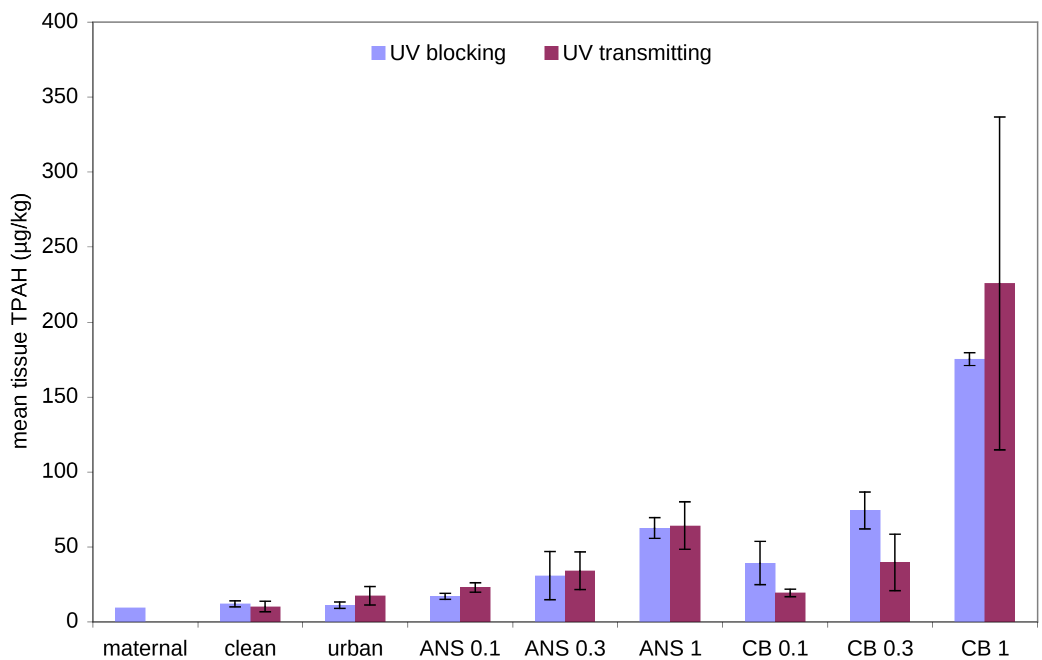


Figure 4-8: Total PAHs in embryos (38 analytes). Values are wet weight mean ± SE for three replicates.

TPAH measured in embryo tissues correlated with aqueous TPAH and oil loading dose (Figure 4-8). The highest TPAH values were found in embryos exposed to the highest (1 g/kg) dose of CB oil, where both UVB and UVT treatments accumulated about 200 ppb TPAH. For reference, the doses of ANSCO producing sublethal effects on heart rate in herring resulted in TPAH at 480 ppb at the lowest tested dose

(0.4 g/kg) at an earlier phase of weathering (Incardona et al., 2009 *Environ Sci Technol* 43:201). The lower doses of both CB oil and ANS produced TPAH below 75 ppb.

Embryos were examined beginning at 5 dpf. As was observed in the first two trials, embryos progressed through development to the eye pigmentation stage, with high numbers of deteriorating, cytolyzed embryos in the CB 1 g/kg UVT treatment appearing close to hatching. Results for necrotic eyed embryos are shown in Figure 9. For the CB 1.0 g/kg dose under UV transmitting plastic, a mean of 91% was found to be cytolyzed by the late eyed stage, consistent with the effect observed in Trial 1. The middle dose of CB oil (0.3 g/kg) under UV transmitting conditions produced a statistically significant increase in necrotic lethality at 16% compared to 3% under UV blocking conditions. The high dose of ANSCO also produced a statistically significant increase in necrotic lethality at 16% compared to 6% under UV blocking conditions. The percentage of necrotic embryos did not correlate with tissue PAH levels (Figure 4-8 vs.

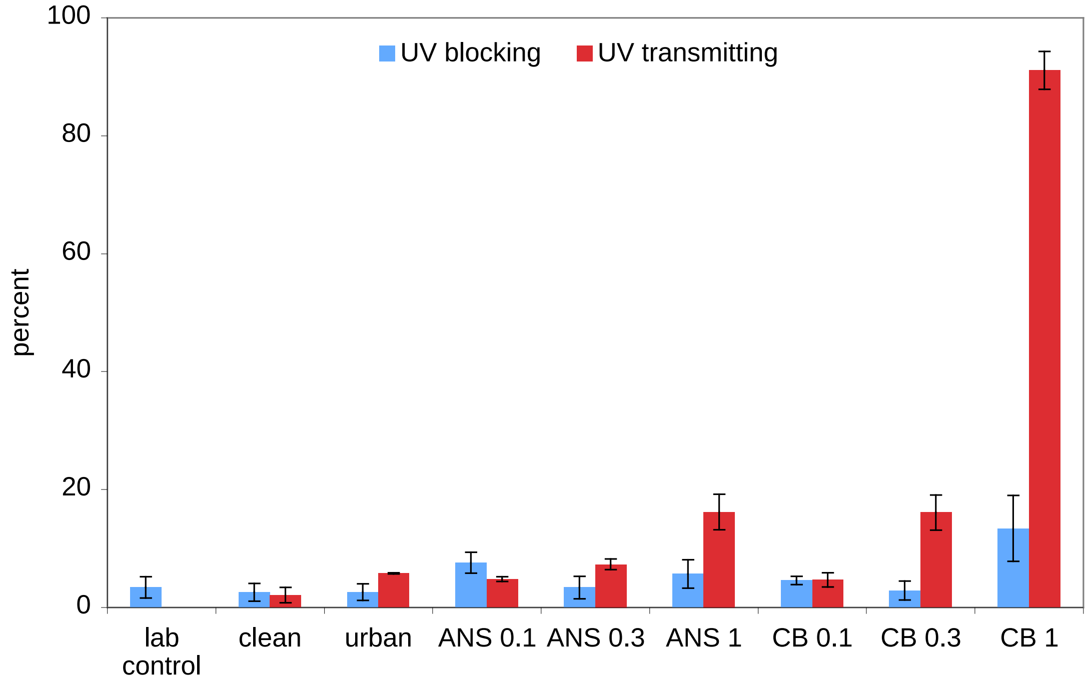


Figure 4-9: Necrotic eyed embryos, Trial 3. Mean and SE for n = 3, except CB 0.3 g/kg UVT treatment, n = 2. Denominator for percentage is total eyed eggs per slide (necrotic eyed + viable eyed + hatched)

Figure 4-9): While the CB 0.3 g/kg UVT treatment and the ANS 0.3 g/kg UVT treatment had indistinguishable PAH levels (40 ± 19 ng/g vs. 34 ± 13 ng/g, respectively), only the CB 0.3 g/kg UVT treatment produced a significantly higher percentage of necrotic embryos (16 ± 3% vs. 4.8 ± 0.4%).

With increasing daytime temperatures and day length, incubation temperatures continued to have diurnal variation and diatom growth became much heavier than the previous trial. Temperature peaked on two days at 22.5 - 24°C (Figure 4-10). All tables showed similar temperature trends. Algae growing in the columns and incubation aquaria was examined microscopically and found to consist of green filamentous (stacking) and brown singular diatoms, with some flagellated forms. Chorions were coated with clustered singular diatoms. The presence of algae resulted in a diurnal pattern of high dissolved oxygen levels coupled with elevated pH, coincident with peak daytime photosynthesis. Daily dissolved oxygen levels, measured at mid-day, are shown for clean gravel effluents and CB 1 g/kg doses in Figure 4-11. Daily pH values, measured at mid-day, are shown for clean gravel effluents and CB 1 g/kg doses in Figure 4-12.

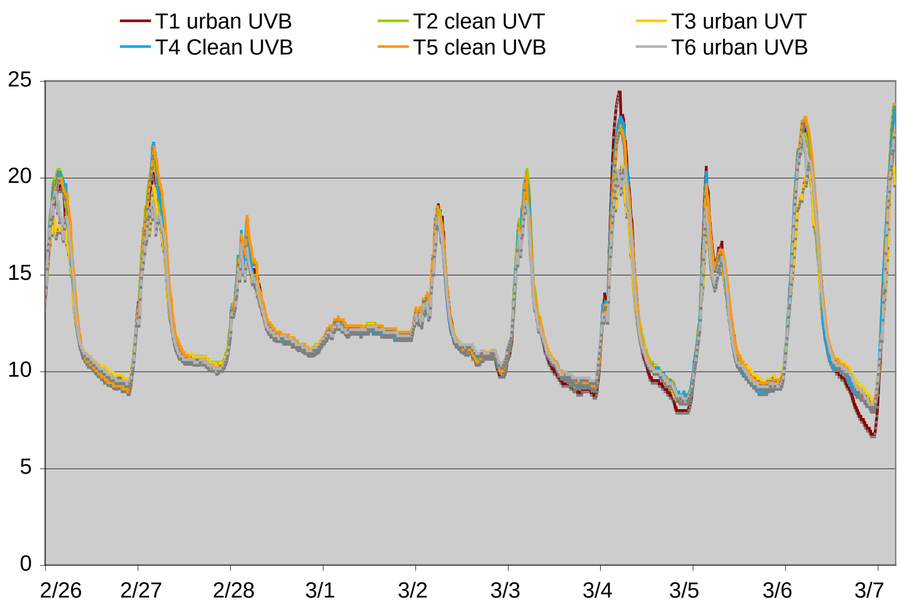


Figure 4-10: Trial 3 temperature logger data from control column effluents, recorded every 10 min.

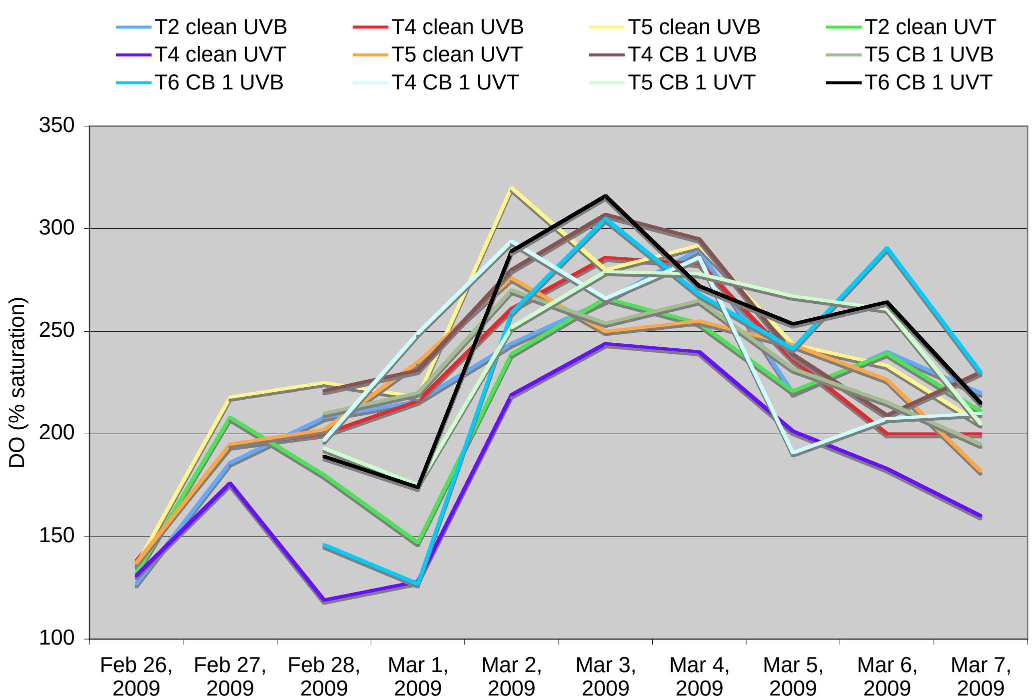


Figure 4-11: Trial 3 daily dissolved oxygen levels, clean gravel vs. CB 1 g/kg, UVB and UVT

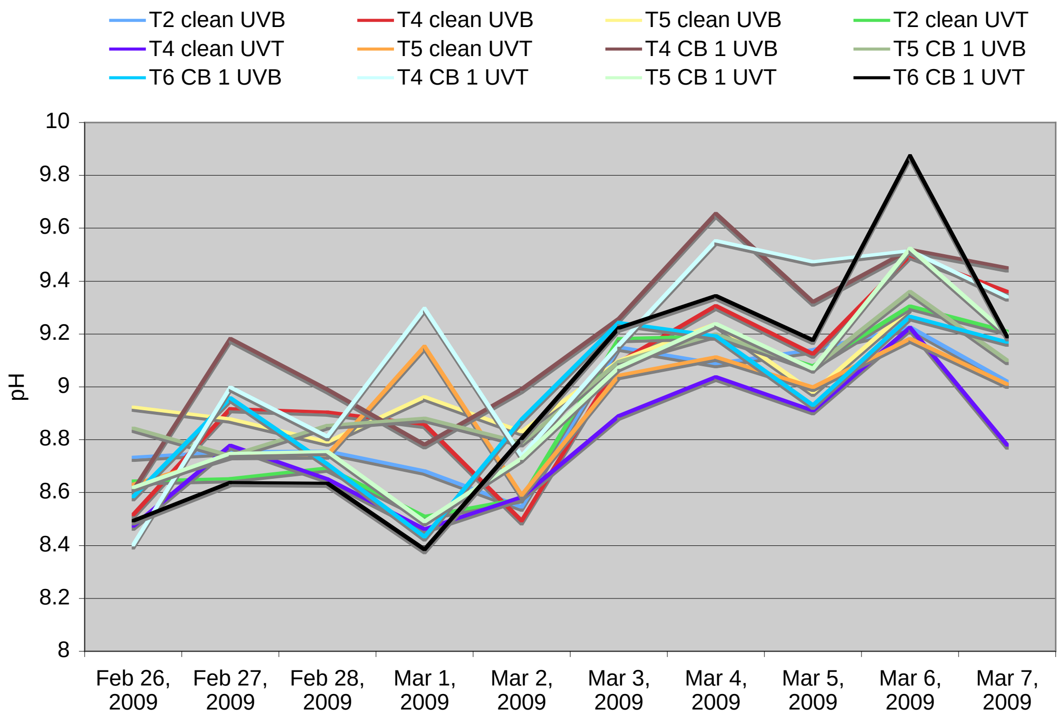


Figure 4-12: Trial 3 daily pH, clean gravel vs. CB 1 g/kg, UVB and UVT

Algal growth was assessed and described in a semi-quantitative manner for each column/incubation aquarium pair and noted. These data are shown in Table 4-1. Throughout this trial ammonia was undetected or at background levels.

Table 4-1: Characterization of algal growth in columns and incubator aquaria, Trial 3

Table	dose	plastic	column	aquarium	color
Table 1	ANS 0.1	UVB	slight	heavy	green
Table 3	ANS 0.1	UVB	heavy	slight/med	brown
Table 5	ANS 0.1	UVB	slight	medium	green
Table 1	ANS 0.1	UVT	slight	slight/med	green
Table 3	ANS 0.1	UVT	medium	heavy	green
Table 5	ANS 0.1	UVT	slight	slight	green
Table 1	ANS 0.3	UVB	slight	slight/med	green
Table 2	ANS 0.3	UVB	slight	heavy	green
Table 6	ANS 0.3	UVB	heavy	heavy	mixed
Table 1	ANS 0.3	UVT	slight	medium	green
Table 2	ANS 0.3	UVT	slight	slight	green
Table 6	ANS 0.3	UVT	slight	heavy	green
Table 3	ANS 1	UVB	slight	heavy	brown
Table 4	ANS 1	UVB	slight	slight	green
Table 5	ANS 1	UVB	slight	slight	green
Table 3	ANS 1	UVT	slight	slight	green
Table 4	ANS 1	UVT	slight	slight	green
Table 5	ANS 1	UVT	slight	slight	green
Table 2	CB 0.1	UVB	heavy	heavy	green
Table 4	CB 0.1	UVB	heavy	heavy	green
Table 6	CB 0.1	UVB	heavy	heavy	mixed
Table 2	CB 0.1	UVT	heavy	heavy	green
Table 4	CB 0.1	UVT	slight	slight/med	green
Table 6	CB 0.1	UVT	heavy	heavy	mixed
Table 1	CB 0.3	UVB	slight	medium	green
Table 2	CB 0.3	UVB	heavy	heavy	green
Table 3	CB 0.3	UVB	heavy	heavy	green
Table 1	CB 0.3	UVT	slight	slight/med	green
Table 2	CB 0.3	UVT	heavy	heavy	green
Table 3	CB 0.3	UVT	slight	slight	brown
Table 4	CB 1	UVB	slight	medium	green
Table 5	CB 1	UVB	slight	slight/med	green
Table 6	CB 1	UVB	slight	medium	green
Table 4	CB 1	UVT	slight	medium	green
Table 5	CB 1	UVT	heavy	medium	brown
Table 6	CB 1	UVT	medium	heavy	mixed
Table 2	clean	UVB	heavy	heavy	green
Table 4	clean	UVB	heavy	medium	green
Table 5	clean	UVB	heavy	heavy	green
Table 2	clean	UVT	slight	heavy	green
Table 4	clean	UVT	slight	slight	green
Table 5	clean	UVT	slight	medium	green
Table 1	Urban	UVB	slight	slight/med	green
Table 3	Urban	UVB	slight/med	medium	green
Table 6	Urban	UVB	heavy	heavy	mixed
Table 1	Urban	UVT	slight	medium	brown
Table 3	Urban	UVT	medium	slight	green
Table 6	Urban	UVT	medium	slight/med	green

4.4 Phototoxicity Trial 4, March 18-26, 2009. Due to the coating of eggs by diatoms and higher temperatures during Trial 3, some modifications were made for a fourth trial. Between the trials, all components were cleaned of algae. The gravel was rinsed with cold freshwater, and the lines, aquaria, and water baths were bleached and treated with thiosulfate. Flow of 25 ppt seawater was initiated 48 hr prior to embryo incubation. A major goal was to increase the water flow rate weathering the columns to help stabilize the temperatures. The size of the head tank limited the total volume at a higher rate, so some treatments had to be eliminated. The ANS columns and urban gravel negative control were eliminated, cutting the number of columns from 48 to 24. Flow rate was increased from 12 ml/min to 30 ml/min. In addition, to reduce the exponential growth of algae typically observed in the last few days of incubation, a 90% shade cloth was used to cover each bank of columns starting on day 5 of incubation. The shade cloth was removed for the last 24 hours of exposure.

The aqueous TPAH levels in this trial were similar to Trial 3, with the highest gravel loading producing TPAH in the 0.7-0.9 ppb range (Figure 4-13). Tissue TPAH levels were also similar to Trial 3, with the CB 1 g/kg treatments producing roughly 150-200 ppb by 8 dpf (Figure 4-14).

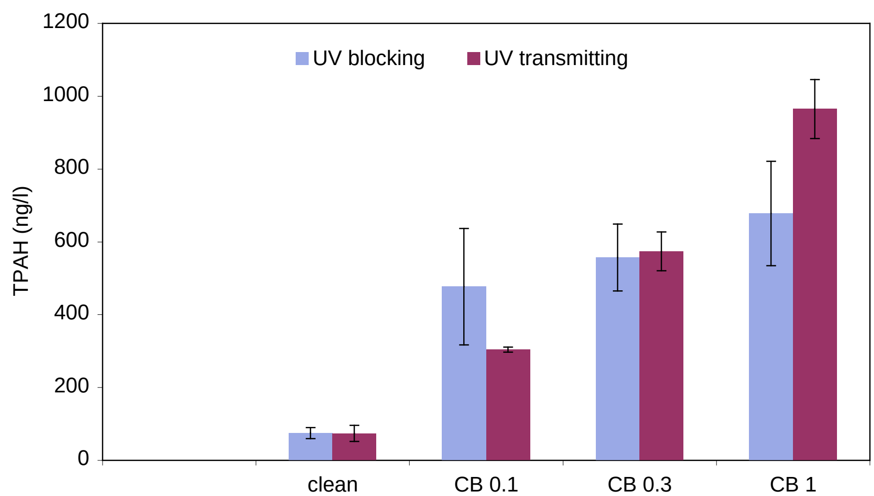


Figure 4-13: Total aqueous PAHs in column effluents (38 analytes). Values are mean ± SE for three replicate columns from samples taken at the start of incubation.

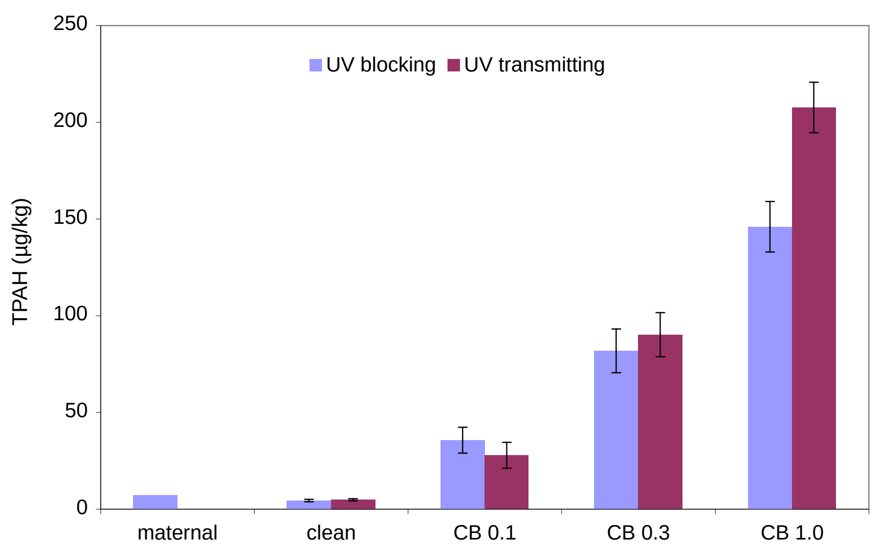


Figure 4-14: Total PAHs in embryos (38 analytes). Values are wet weight mean ± SE for three replicates.

As in previous trials, embryos were examined daily from 5 dpf and were found to progress into the eye pigmentation stage. By 8 dpf, large numbers of deteriorating eyed embryos were observed in the CB 1 g/kg UVT treatment. Accumulation of diatoms on the chorions was still heavy enough to require removal by

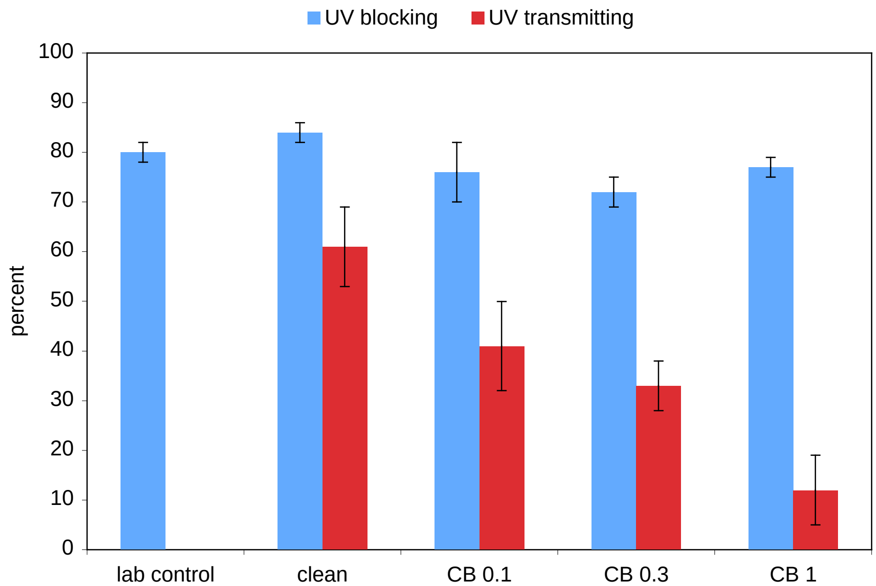


Figure 4-15: Viable eyed embryos, Trial 4. Mean and SE for n = 3. Denominator for percentage is total fertilized eggs per slide.

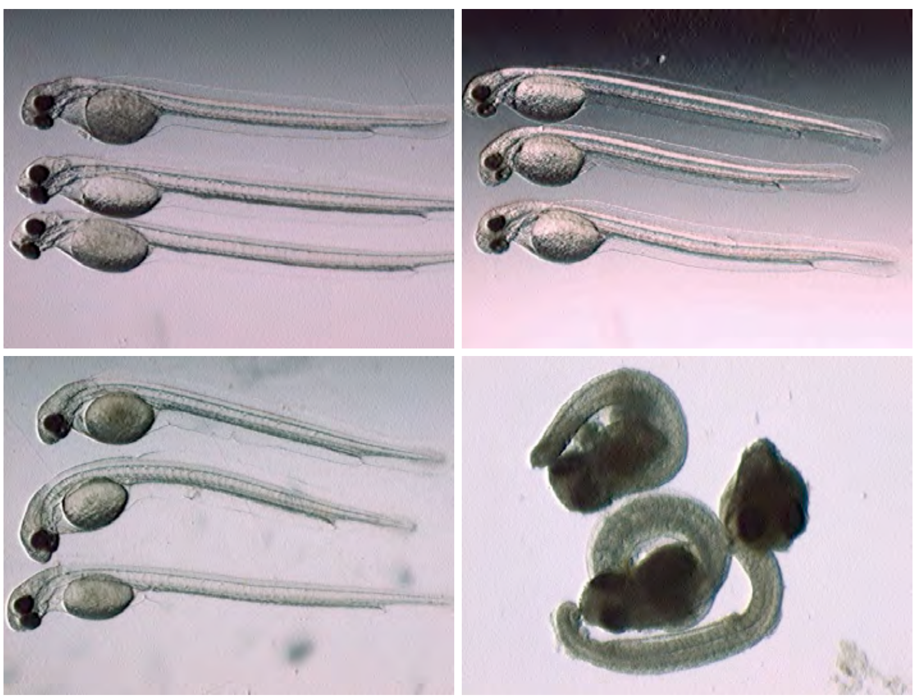


Figure 16: Lethal effects of CB 1 UVT treatment, Trial 4. Examples of viable dechorionated embryos shown for clean UVB and UVT treatments, and CB 1 g/kg UVB treatment, necrotic embryos from CB 1 g/kg UVT treatment.

careful scraping with forceps. To streamline the scoring process, in this trial the counts included total eggs on each slide, unfertilized eggs, and viable (i.e. non-necrotic) eyed embryos. There was not a count for embryos that died at early stages for each treatment, but random checks showed a background rate of about 10% in laboratory controls and column specimens. The data for viable eyed embryos are shown in Figure 4-15. Examples of viable and necrotic embryos are shown in Figure 4-16.

The increased flow rate did lead to better temperature control, but there were still diurnal fluctuations

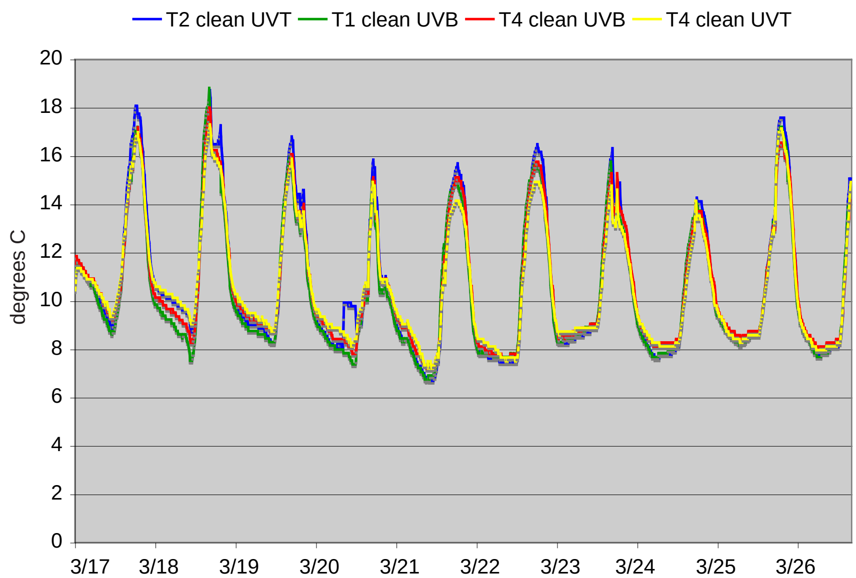


Figure 4-17: Trial 4 temperature logger data from control column effluents, recorded every 10 min.

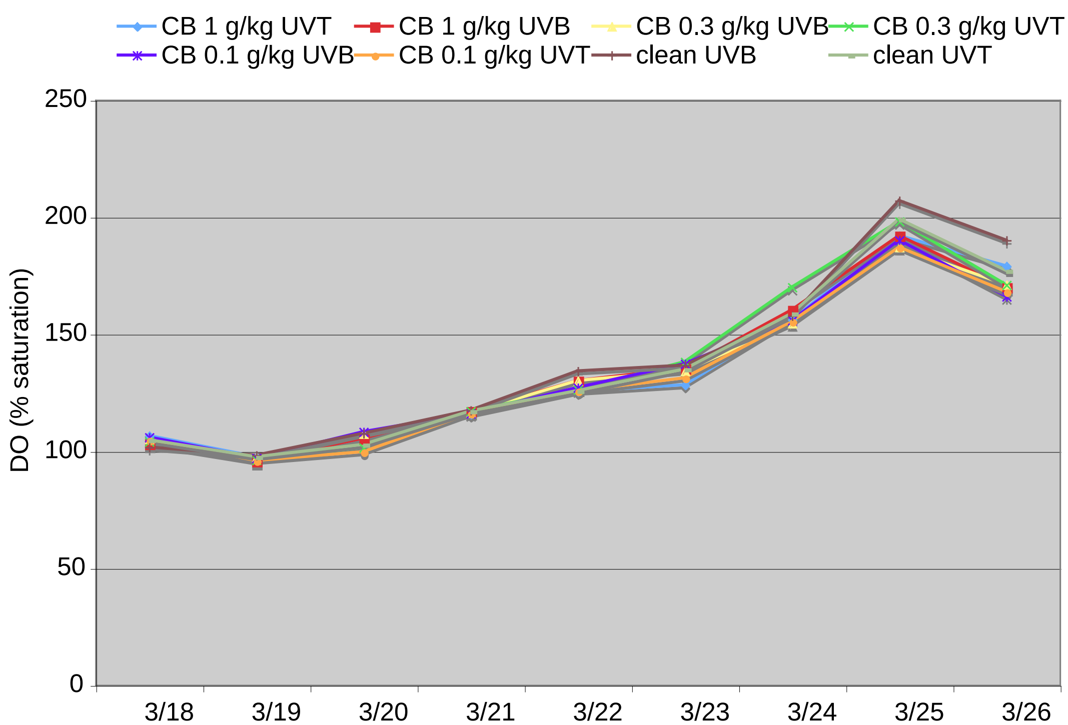


Figure 4-18: Trial 4 daily dissolved oxygen levels in one replicate of each treatment

with peaks around 18˚C at 12:00-14:00 on three days (Figure 4-17). Although growth of diatoms was reduced in this trial relative to Trial 3, there was still a gradual increase of algal growth throughout the incubation period, which resulted in a gradual increase in dissolved oxygen levels (Figure 4-18) and pH

(Figure 4-19). However, there was little variation among treatments with respect to temperature, dissolved oxygen, and pH. Throughout this trial ammonia was undetected or at background levels.

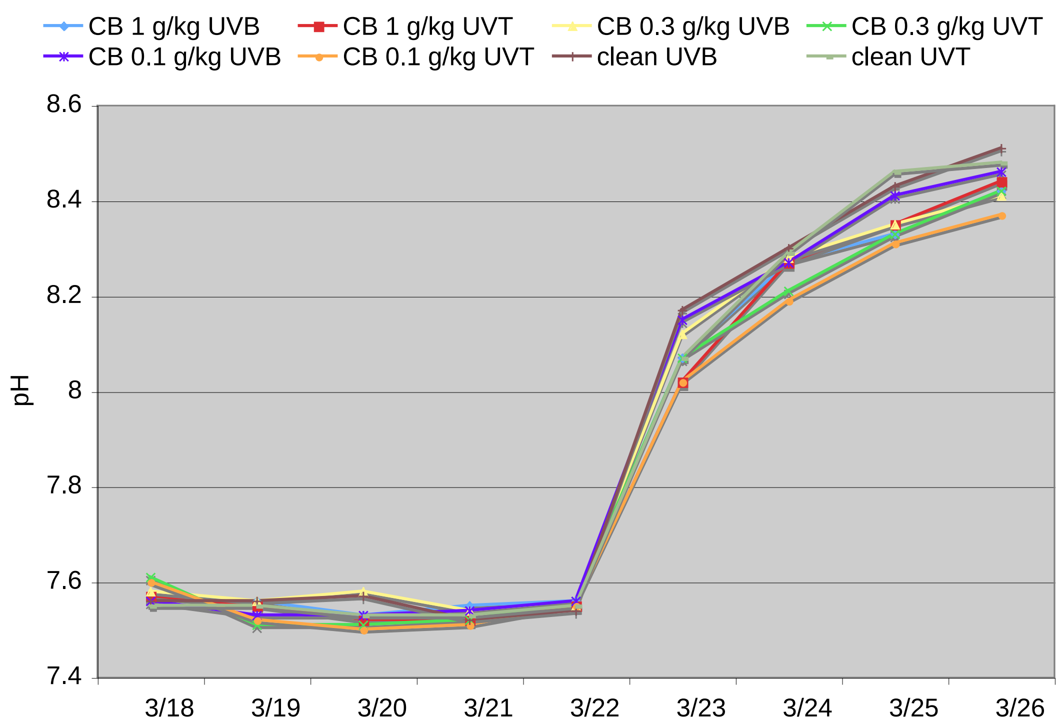
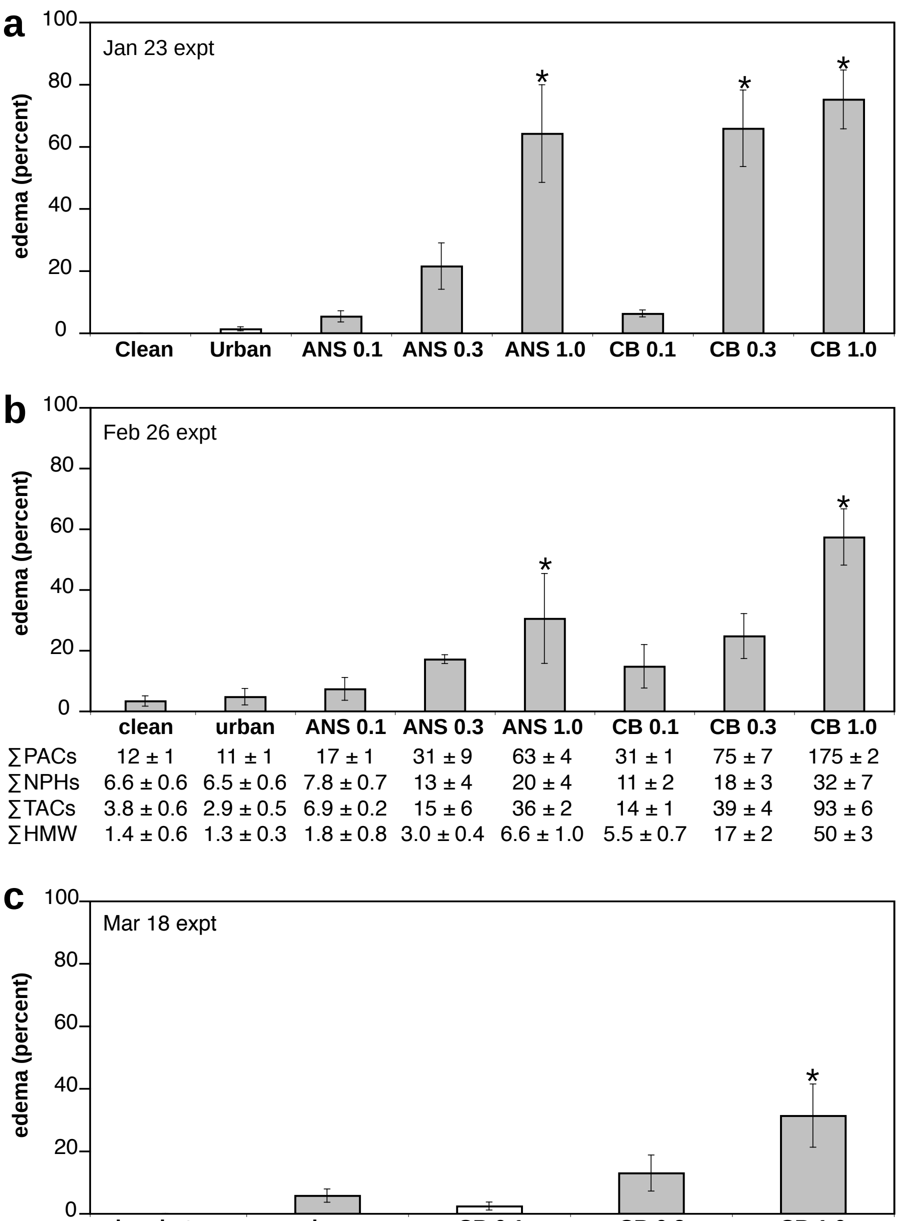


Figure 4-19: Trial 4 daily pH in one replicate of each treatment

4.5 Cosco Busan bunker oil produced canonical petrogenic cardiotoxicity under UV-reducing conditions. In the first two experiments we compared exposure to equivalent oil mass loadings of ANSCO and CBBO. ANSCO served as a positive control to reproduce canonical crude oil toxicity, as a context for identifying possible novel effects from refined CBBO exposure. As expected from prior studies, dose-dependent pericardial edema was observed in hatched larvae following exposure to oiled gravel effluent under UV-reducing conditions (Figure 4-20). Incidence of edema generally correlated with declining water and tissue PAH concentrations. In the first experiment starting January 23, the incidence of larval edema was 64 ± 17% after exposure to ANSCO 1.0 g/kg gravel effluent, and 66 ± 12% and 75 ± 9% in larvae exposed to CBBO 0.3 g/kg and 1.0 g/kg gravel effluent, respectively (Figure 4-20a). Over the next month of weathering, aqueous PAH concentrations would be predicted to decline exponentially. Consistent with this, herring embryos from the exposure beginning Feb 26 showed a decline in edema to 30 ± 15% for exposure to ANSCO 1.0 g/kg, with an embryonic tissue ∑PAH concentration of 63 ± 4 ng/g (Figure 4-20b). Exposure to the equivalent mass dose of CBBO resulted in a higher incidence of edema (57 ± 9%) with a tissue ∑PAH concentration of 175 ± 2 ng/g. The CBBO 0.3 g/kg dose produced toxicity similar to the ANSCO 1.0 g/kg dose (25 ± 7% edema and ∑PAH 75 ± 7 ng/g). For CBBO exposures, the incidence of edema correlated closely ($P < 0.0001$, $R2 = 0.86$) with total tissue tricyclic aromatic compounds (∑TAC). Although remixing of the gravel and higher flow rates in the 18 March experiment resulted in higher ∑PAH, largely due to an increase in naphthalenes, tissue ∑TAC and concentrations of higher molecular weight compounds (∑HMW) at the highest CBBO dose were 82% (76 ± 8 ng/g) and 60% (30 ± 2 ng/g) lower, respectively, and the incidence of edema was significantly lower at 31 ± 10% (Figure 4-20c; t test, α =

0.05). These results indicate that under UV-blocking conditions, exposure to CBBO results in canonical petrogenic PAH toxicity represented by cardiogenic edema. The incidence of edema was higher for CBBO relative to an equivalent mass dose of ANSCO, consistent with the higher PAH fraction of the residual oil.



	clean	urban	ANS 0.1	ANS 0.3	ANS 1.0	CB 0.1	CB 0.3	CB 1.0
∑PACs	12 ± 1	11 ± 1	17 ± 1	31 ± 9	63 ± 4	31 ± 1	75 ± 7	175 ± 2
∑NPHs	6.6 ± 0.6	6.5 ± 0.6	7.8 ± 0.7	13 ± 4	20 ± 4	11 ± 2	18 ± 3	32 ± 7
∑TACs	3.8 ± 0.6	2.9 ± 0.5	6.9 ± 0.2	15 ± 6	36 ± 2	14 ± 1	39 ± 4	93 ± 6
∑HMW	1.4 ± 0.6	1.3 ± 0.3	1.8 ± 0.8	3.0 ± 0.4	6.6 ± 1.0	5.5 ± 0.7	17 ± 2	50 ± 3

	incubator	clean	CB 0.1	CB 0.3	CB 1.0
∑PACs	12 ± 1	4.5 ± 0.6	34 ± 6	75 ± 9	135 ± 12
∑NPHs	6.6 ± 0.6	2.9 ± 0.3	10 ± 1	18 ± 2	30 ± 2
∑TACs	3.8 ± 0.6	0.7 ± 0.1	19 ± 3	43 ± 6	76 ± 8
∑HMW	1.4 ± 0.6	0.7 ± 0.1	4.6 ± 1.1	14 ± 2	30 ± 2

Figure 4-20: Dose-dependent pericardial edema after oil exposure under UV-reducing plastic. Edema was quantified in live hatched larvae. Values represent the mean percent ± SEM from three replicates for each control or oil dose for the experiments starting 23 January (a), 26 February (b) and 18 March (c). Nominal oil loadings (0.1, 0.3, and 1.0 g/kg) are indicated for each oil (ANSCO, ANS; CBBO, CB). Tissue PAHs (ng/g wet weight) are shown for the 26 February and 18 March experiments as sum total (∑) PAHs, sum parent and alkylated naphthalenes (NPHs), sum parent and alkylated tricyclic compounds (TACs; fluorenes, dibenzothiophenes, phenanthrenes), and sum high molecular weight compounds (HMW; fluoranthene, pyrene, C1-fluoranthene/pyrenes, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[j]fluoranthene/benzo[k]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, perylene, indeno[1,2,3-cd]pyrene, dibenz[a,h]anthracene/dibenz[a,c]anthracene, and benzo[ghi]perylene).

4.6 Trials 1-4, Assessment of hatching and larval morphology in the Laboratory Exposure and Phototoxicity Study. These data do not directly address the Specific Aims of the Laboratory Exposure and Phototoxicity Study as described in the Introduction. The primary focus of this study was to determine whether Cosco Busan bunker oil could produce lethal embryonic necrosis. Data on larval hatching rates and morphology are provided as supplemental information in Appendix 2 of this report.

4.7 Laboratory Salinity Study. This study tested alternative hypotheses whether (1) high salinity could produce embryonic lethality such as that observed at intertidal zones of oiled sites in the 2007-08 spawning season, and (2) whether embryos fertilized and incubated at high salinity would show pericardial edema when dechorionated at low salinity (i.e. 16 ppt), as a potential explanation for signs of edema in subtidal caged embryos at oiled sites in 2007-08.

Fertilizations were carried out at the Bodega Marine Lab on March 5, 2009 according to the study plan. Duplicate slides were received at NWFSC from BML on 3/13/09 (8 dpf), along with BML 16 ppt seawater for processing. All slides were examined upon receipt and showed similar numbers of viable eyed embryos. Due to time constraints, the most relevant treatments were selected for dechorionation, i.e. optimal laboratory salinity regimen (fertilized at 16 ppt, incubated at 16 ppt) and high salinity regimen (fertilized at 30 ppt, incubated at 30 ppt). For dechorionation, slides were transferred to 16 ppt seawater and held at 12 ˚C on a cooling stage. At least 20 embryos were dechorionated at 16 ppt from a single slide for each treatment, and held at 16 ppt for imaging.

At BML after 7 days of incubation, the remaining slides were transferred to 16 ppt salinity and incubated at 12^0C with daily water changes of 16 ppt seawater. At commencement of hatching, the remaining embryos and larvae were evaluated as described previously.

Embryo Results:

A. Fertilized at 16 ppt, incubated at 16 ppt, dechorionated and imaged at 16 ppt
23/23 embryos between Hill and Johnston (1997) stages *o* and *p*. Edema present in 0/23 embryos. Body axis defects present in 0/23 embryos. Pericardial sPAHe larger than embryos from high salinity regimen (see below), but this is due to more advanced head rotation. Representative samples shown in Figure 4-21, top.

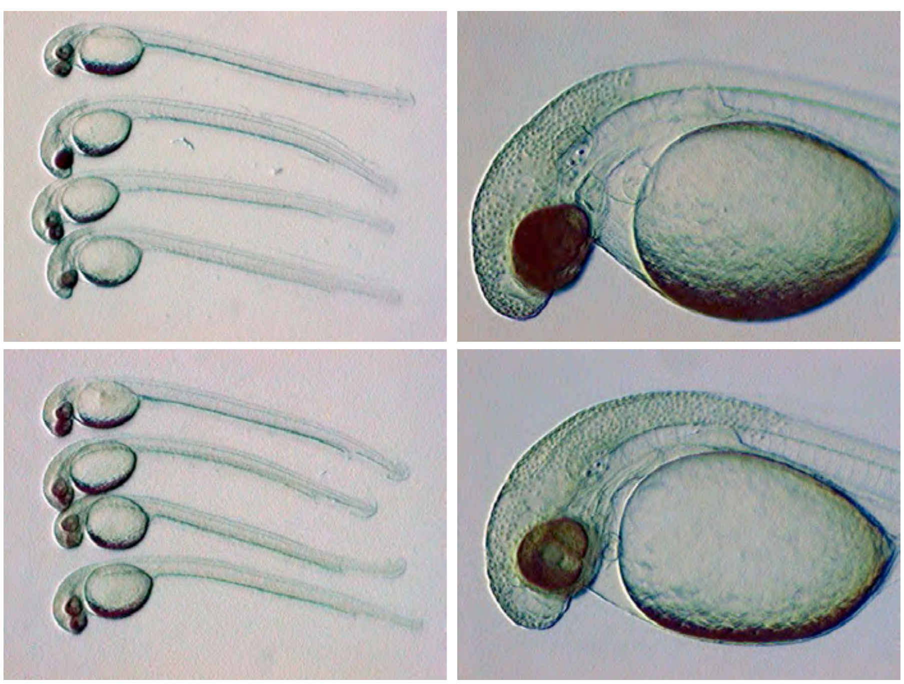


Figure 4-21: Morphology of embryos exposed to optimal salinity (16 ppt, top) or high salinity (32 ppt, bottom).

B. Fertilized at 30 ppt, incubated at 30 ppt, dechorionated and imaged at 16 ppt.
26/26 embryos between stages *o* and *p*, but slightly delayed relative to optimal regimen. This was evident in the degree of head rotation, eye pigmentation, and length of tail bud. Edema present in 0/26 embryos. Body axis defects present in 0/26 embryos. Representative samples shown in Figure 4-21Figure, bottom.

Hatching Results:
Cumulative daily hatch rates were collected for all tested salinity regimens: Fertilized at 16 ppt and incubated at 16 ppt (16-16), fertilized at 16 ppt and incubated at 22 ppt (16-22), fertilized at 22 ppt and incubated at 22 ppt (22-22), fertilized at 16 ppt and incubated at 30 ppt (16-30), and fertilized at 30 ppt and incubated at 30 ppt (30-30). Data (Figure 4-22) are reported as percent normal hatch, that is the number of hatched larvae with normal morphology divided by the total number of embryos/larvae (unhatched embryos, dead hatched and live hatched). Total and normal hatching rates were observed to have the following trend: total hatching rates for embryos fertilized and incubated in 16 ppt > embryos fertilized in 16 ppt and incubated in 22 ppt > embryos fertilized in 22 ppt and incubated in 22 ppt > embryos fertilized in 30 ppt and incubated in 30 ppt > embryos fertilized in 16 ppt and incubated in 30 ppt (Figure 4-22). The same trend was obserbed for normal hatching, except that the hatching rate for embryos fertilized in 16 ppt and incubated in 30 ppt was greater than that for embryos fertilized in 30 ppt and incubated in 30 ppt.

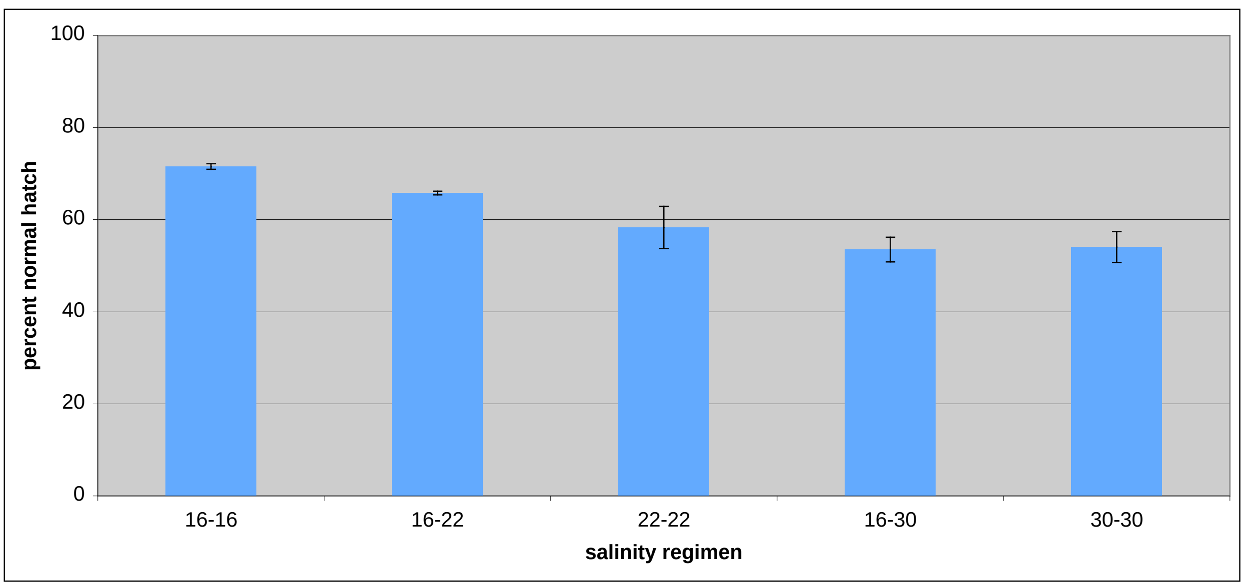


Figure 4-22: Normal hatch rates after fertilization and incubation under various salinity regimens. Data are mean ± SE for two replicates.

Morphological abnormalities were observed in all treatments (Figure 4-23). The incidence of edema was highest for embryos fertilized and incubated in 16 ppt seawater (3.08 +/- 2.57), and lowest for embryos fertilized and incubated in 22 ppt (0.97 +/- 0.31). In general, the incidence of other morphological abnormalities observed (opaque yolk sac, bent heads, scoliosis, and jaw abnormalities) was similar for all treatments except for embryos fertilized and incubated in 30 ppt. Yolk opacity, bent heads, and scoliosis were higher in this treatment. Jaw abnormalities were highest in the embryos fertilized in 16 ppt and incubated at 22 ppt, and were lowest in the 16-30 and 30-30 treatment groups.

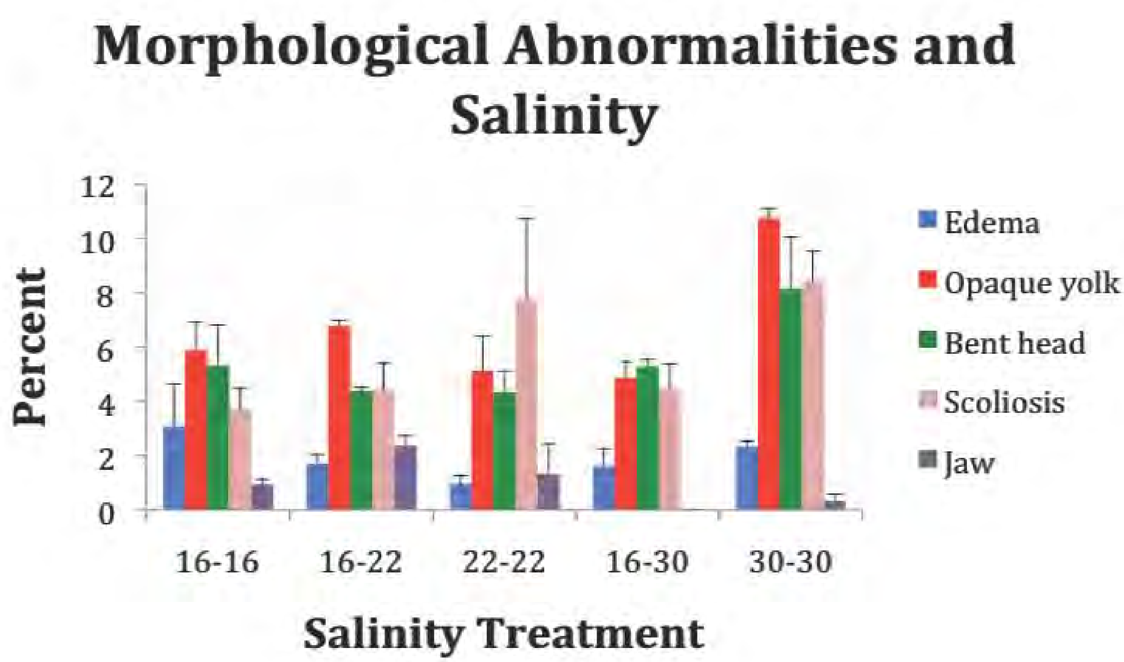


Figure 4-23: Morphological abnormalities in herring larvae fertilized at 16, 22, or 30 ppt and incubated at 16, 22 or 30 ppt. (Means +/- SE)

Section 5: Discussion

5.1 Field studies. Unlike *Exxon Valdez*, the *Cosco Busan* oil spill occurred within a highly urbanized estuary with multiple inputs of petroleum hydrocarbons. This posed the difficult challenge of assessing the ecological impacts of the spill against a backdrop of pollution in San Francisco Bay. Based on years of oil toxicity research in the years since *Exxon Valdez*, we anticipated lingering oil toxicity, if any, would be evident as a small increase in the detection of sublethal cardiac effects (arrhythmia, edema) in herring embryos incubated near oiled shorelines. While significant increases in bradycardia and pericardial edema were observed in caged embryos from oiled sites relative to unoiled locations, natural spawn from oiled intertidal zones revealed an unexpectedly severe (i.e., lethal) form of developmental toxicity.

The high rate of natural spawn mortality at oiled sites in 2008 does not appear attributable to natural causes or anthropogenic causes unrelated to the spill. The spawning layers were not dense enough (< 4 layers at all sites) to cause the density-dependent hypoxia that occurs when eggs are deposited in layers of greater than eight eggs thick [18-22]. Euryhaline Pacific herring embryos develop normally at salinities of 8-28‰ [12,16], and even suboptimal salinities would not be expected to cause acute mortality late in development. Natural spawn did not show evidence of accelerated development, as would be expected following exposures to high, potentially lethal temperatures [16, 83]. Coating of herring eggs with fine sediments does not produce the late developmental mortality we observed here [30-34, 84]. Two sewage spills occurred during the 2008 spawning season; on 13 January in Richardson Bay, near oiled sites SA and PP, and 14 February 2008 offshore of San Quentin Prison, near reference site PSQ. However, the available evidence indicates that sewage (i.e., concentrated sludge) is not acutely lethal to herring embryos [35]. Finally, background PCB and DDT levels in ovaries and embryos from San Francisco Bay are not expected to cause the observed mortalities, as the levels were much lower than that associated with reduced hatching success in Baltic herring [85].

Our chemical analyses of PAHs in embryos and PEMDs support the conclusion that embryos from oiled sites were exposed to oil, particularly at Keil Cove (KC), even though a PAH "fingerprint" of *Cosco Busan* oil was not discernable against the background of urban PAH inputs. On the other hand, the PEMD data indicate unique patterns of PAH inputs across sites, consistent with the diversity of proximal land use patterns and vessel activities. However, embryonic phenotype did not follow this pattern of site-specific chemical variation. In contrast, the effects observed in natural spawn from each of the three oiled sites (SA, PP, KC) were indistinguishable, and pericardial edema was observed only in larvae that were incubated subtidally at oiled sites. The only common feature linking these sites was a shoreline presence of visible oil in the weeks following the spill. The absence of these effects at reference sites and the marked recovery at oiled sites by 2010 indicate that background urban inputs of contaminants (e.g. via stormwater) are not likely causal. The most parsimonious explanation is that the 2008 herring embryo mortality in San Francisco Bay was caused by exposure to *Cosco Busan* oil.

PAHs in the tissues of embryos collected from oiled intertidal sites in 2008 were below levels that would be expected to cause acute lethality based on laboratory studies [38,62]. This, together with the dramatic difference in survival between intertidal spawn and embryos in nearby subtidal cages, implicates natural sunlight as a contributing factor in the observed embryolarval toxicity. Sequential exposures to crude oil and sunlight in the laboratory are acutely lethal in herring larvae [93]. This presumably occurs via activation of PAHs or other oil components by ultraviolet radiation ("phototoxicity"), thereby generating reactive oxygen species that cause membrane damage [87]. Recent work using zebrafish has further shown that bunker oils have a much higher phototoxic potential than crude oil and cause an acutely lethal cellular necrosis when embryos are exposed sequentially to oil and sunlight [97]. Lastly, the

2009 laboratory studies to investigate the potential role of sunlight in the observed 2008 natural spawn mortality showed that *Cosco Busan* bunker oil contains a phototoxic activity that (1) produces late embryonic mortality in herring embryos characterized by a loss of tissue integrity similar to that observed in the 2008 field-collected samples, (2) is resistant to weathering, and (3) is unexplained by tissue PAH concentrations, thus suggesting a causal role for one or more unmeasured compounds. Because modern bunker fuels contain the concentrated residuum of the crude oil refining process, they have much higher relative levels of many compounds, including the uncharacterized polar compounds that make up an "unresolved complex mixture" [86]. The most parsimonious explanation for our collective findings is that an uncharacterized and slowly weathering component of *Cosco Busan* bunker oil accumulated in natural spawn and then interacted with sunlight during low tides to produce lethal phototoxicity. Embryos in nearby cages, submerged beneath ~ 1 m or more of highly turbid San Francisco Bay water, exhibited canonical oil toxicity (i.e. bradycardia and pericardial edema) with no indication of a sunlight interaction.

Research following the Exxon Valdez oil spill established a new paradigm for oil toxicity to fish at early life stages, with a central role for PAHs. Our ecological assessments of the *Cosco Busan* spill have extended this and reinforced 1) the importance of oil composition (i.e., crude vs. bunker), 2) the significance of combinatorial stressors (i.e., oil and sunlight), 3) the current limitations of tissue PAH chemistry as a predictor of embryo toxicity, 4) the need to toxicologically characterize the non-PAH components of refined fuels, and 5) the exceptional vulnerability of fish early life stages to spilled oil.

5.2 Laboratory studies. Based on the results of the oiled gravel column phototoxicity studies, we conclude that below a certain dose of UV radiation, *Cosco Busan* bunker oil produces canonical and sublethal petrogenic PAH cardiotoxicity. These effects were significant at aqueous total PAH concentrations of 0.5 ppb, from very lightly oiled gravel (0.3 g/kg) – i.e., unlikely to be characterized as visibly oiled in a post-spill shoreline survey. Thus, in the absence of sunlight, *Cosco Busan* bunker oil toxicity resembles previous observations of crude oil toxicity that is largely attributable to the tricyclic PAHs such as the phenanthrenes. Consistent with this, ANSCO exposure produced a lower incidence of pericardial edema than a *Cosco Busan* bunker oil exposure that, while mass equivalent, contained a 2.3-fold higher tricyclic PAH content. This supports an interpretation of findings of petrogenic cardiotoxic bradycardia and edema in caged embryos incubated in the turbid subtidal zones at oiled sites. In sharp contrast, in the presence of natural sunlight, *Cosco Busan* bunker oil produced a novel form of lethal toxicity that is not predictable based on the known toxicity of an equivalent mass loading of unrefined crude oil.

Exposures to UV in natural sunlight were both necessary and sufficient to activate a phototoxic potential in CB *Cosco Busan* bunker oil BO and cause abrupt late-embryonic mortality in early life stage herring. This toxic etiology is very similar to that recently reported for zebrafish embryos exposed to bunker oils [97], and it persisted relatively unabated after two months of column weathering. These findings, together with the strikingly similar condition of naturally-spawned herring embryos sampled four months following the *Cosco Busan* spill, support the conclusion that embryos from oiled intertidal locations in San Francisco Bay succumbed to *Cosco Busan* bunker oil-induced phototoxicity.

5.3 Alternative hypotheses. Several other hypotheses have been discussed above, i.e. hypoxia, suboptimal salinity, sewage spills, suspended sediment. The only other alternative hypothesis remaining is that poor or immature maternal condition resulted in low quality eggs that, coupled with suboptimal salinity, resulted in high mortality at oiled sites in 2008. Several lines of evidence discredit this hypothesis. First, the natural spawn deposition that occurred in 2008 was a continuous "wave" that started at reference site SRB and propagated west continuously over the next several days. It is highly unlikely that there was a distinct subpopulation of females in poor condition that spawned only at the oiled sites and not at the reference site. More importantly, there is not a plausible biological mechanism that links poor maternal condition (or suboptimal salinity) to the type of acute, necrotic mortality observed at oiled sites. These embryos apparently developed normally up to the hatching stage, then succumbed to an acute insult. While not studied directly in herring, poor maternal condition in fish generally leads to smaller eggs that produce smaller but morphologically normal larvae. This is well established in reef fish that deposit demersal eggs, similar to herring, and in ovoviviparous rockfish [98-101]. In other situations, poor egg quality has been shown to result in very early embryonic defects, e.g. abnormal cleavage or gastrulation [102,103]. This would result in pre-hatch embryos with true developmental defects (e.g. abnormal patterning of tissues), rather than sudden acute mortality of normal formed embryos.

The combination of air, sunlight and elevated temperature has also been suggested as a possible etiology for embryo lethality observed in 2008 natural spawn from the intertidal zone. However, several lines of evidence are also inconsistent with this hypothesis. The tidal and weather conditions during the 2008 spawning events and field sampling do not support the likelihood of high temperature shock to intertidal spawn. The low tides during the incubation period (Feb 20-26, 2008) were in the morning and late afternoon, and lowest tide was +1 ft, indicating that the eggs would not have been exposed to peak daytime air temperatures. Low tides during collection (Feb 27-29, 2008), were late morning to mid-day, but all samples were collected from below the water surface, and none were exposed to air. In San Francisco the highest recorded daytime air temperature during the incubation period was 19°C and average temperatures were in the range of 12-13°C. These conditions were actually matched closely during some of the oiled gravel column studies, which demonstrated that temperature elevation alone could not reproduce late embryonic lethality. In contrast, the 2009 laboratory studies demonstrated a clear mechanism by which *Cosco Busan* bunker oil produces acute, late stage mortality through phototoxicity.

Section 6: Summary and Conclusions

• Incubation of caged herring embryos in the subtidal zone at oiled sites 3 months following the spill resulted in signs of canonical petrogenic PAH sublethal toxicity, characterized by reduced heart rate and pericardial edema.
• Natural spawn deposited in the intertidal zones of oiled sites 3 months after the spill showed near complete mortality, characterized by acute necrosis of late-stage embryos (near hatching).
• Signs of sublethal oil cardiotoxicity and acute late-stage mortality were absent at reference sites 3 months following the spill and at urban reference sites 15 month and 27 months following the spill.
• Acute late-stage necrotic mortality was absent in natural spawn at re-sampled oiled site intertidal zones 27 months following the spill.
• Forensic analytical chemistry focusing on PAHs showed very low levels (near detection limits) in both caged embryos (17-52 ppb) and natural spawn (18-81 ppb) from all sites.
• Low levels coupled with high variability weakened standard comparative statistics for PAH data, but other methods support the presence of a petrogenic signal in embryos and PEMDS above background at oiled sites.
• Increased petrogenic input at the most heavily oiled site, Keil Cove, was also supported by PEMD data.
• Consistent with the persistent elevation of pericardial edema at Keil Cove, a petrogenic signal remained elevated in embryos from this heavily oiled site 27 months after the spill.
• Under conditions of reduced UV exposure, Cosco Busan bunker oil produced canonical oil cardiotoxicity with a lowest effective tissue concentration in the range of 30-75 ppb.
• Under conditions of normal UV exposure (i.e. unblocked), Cosco Busan bunker oil is both necessary and sufficient to cause an acute phototoxic response characterized by loss of tissue integrity (necrosis) in late stage herring embryos.
• Cosco Busan bunker oil remained highly phototoxic even after 2 months of weathering in oiled gravel columns.

These findings support the following conclusions: First, biological indicators such as herring embryos appear to be more sensitive for detecting oil-related adverse affects than current methods in analytical chemistry used for quantification of PAHs. Thus, an increased incidence of pericardial edema was detected in embryos incubated in the subtidal zone at oiled sites, despite lack of a clear chemical measure of exposure. The laboratory studies indicate that oil-induced pericardial edema occurs near and below the detection limits for tissue PAHs. Despite the inability to "fingerprint" Cosco Busan oil in embryos or PEMDs at all oiled sites, the highly consistent lethal phenotype observed in natural spawn indicates a common exposure at all oiled sites. The PEMD data indicate that each site has unique urban/maritime inputs of PAHs, therefore, an urban source cannot be the common exposure. Similarly, differences in salinity or temperature, potential exposure to sewage effluent, and other factors were not consistent among all the oiled sites. The one common factor to these sites was the presence of Cosco Busan oil detected by SCAT surveys. Therefore, the most parsimonious explanation for the collective findings is that an uncharacterized (i.e. non-PAH) and slowly weathering component of Cosco Busan bunker oil accumulated in natural spawn and then interacted with sunlight during low tides to produce lethal phototoxicity. Embryos in nearby cages, shielded by highly turbid San Francisco Bay water, exhibited canonical oil toxicity (i.e. bradycardia and pericardial edema) with no indication of a sunlight interaction. Recovery at oiled sites evident in 2010 natural spawn sampling are consistent with eventual loss of Cosco Busan oil toxicity with prolonged weathering, and indicate that other continuous urban background stressors were not the cause of sublethal or lethal toxicity in 2008.

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Section 7: Attachments

7.1 Summary of samples collected and data files

2008
Caged embryo outplant samples representing 6 sites, Horseshoe Cove (HC), Sausalito (SA), Peninsula Point (PP), Keil Cove (KC), San Rafael Bay (SRB), and Point San Quentin (PSQ).

A. Image and video datasets for 30 embryos each from 5 cages at HC, SA, KC, and PSQ. For PP and SRB, 4 datasets were collected due to loss of eggs from one cage (PP) and loss of a cage at retrieval (SRB). (28 datasets total, 150 embryos per site)
B. Fixed embryos from all imaged specimens for all sites (for CYP1A immunofluorescence).
C. Frozen pools of 100 embryos from each of the 28 cages (for RNA isolation).
D. Frozen 3 g samples of embryos for PAH quantification from 27 cages. A single cage from HC did not have sufficient embryos for chemical analysis (but enough for images analysis and RNA sample).
E. Continuous temperature and salinity recordings for 5 sites; logger at SRB failed to collect data.

Natural spawn samples representing 4 sites, SA, PP, KC, and SRB. From each site 8 grab samples were collected along a transect.

F. Image and video datasets for 20 embryos each for 8 grabs from all 4 sites (32 datasets total, 160 embryos per site.
G. Fixed embryos from all imaged specimens for all sites (for CYP1A immunofluorescence).
H. Frozen pools of 100 embryos from each of the 32 grabs (for RNA isolation).
I. Frozen 3 g samples of embryos for PAH quantification from 32 grabs.

Passive samplers (PEMDs) deployed at the embryo outplant sites. 5 PEMDs for each of the 6 sites: 3 PEMDs deployed for the duration of egg incubation anchored with 3 of the 5 cages; 1 PEMD air blank exposed at deployment, 1 PEMD air blank exposed at retrieval.

Sediment samples for analytical chemistry. 5 samples each of subtidal sediments taken from the 6 outplant sites. 5 samples each of intertidal samples taken from 3 sites, KC, SA, and SRB.

Samples of adult male and female herring caught in SF Bay for analytical chemistry (addressing potential maternal transfer of PAHs/POPs to eggs). 94 fish resulting in 11 composite samples for analysis of PAH metabolites in bile, 7 composite samples for PAH/POP analysis of ovaries and carcasses.

2009
Raw data files:

Laboratory studies:
Trial 1 (Preliminary)

Sample Code Key: N/A
Egg Source Information: CBOS09 fem wts.xls**,** fertilization_tests.pdf (in folder “Data files and lab notes”)
Experimental Conditions: column temp log Jan-Mar09.xls, ColumnWQJan14toFeb23.pdf (in folder “Data files and lab notes”)
Embryo Images: in folders “Data files and lab notes”>”Trial 1”> “5 dpf”, “6 dpf”, and “8 dpf”

Trial 2 (Aborted)

Sample Code Key: N/A
Egg Source Information: CBOS09 fem wts.xls**,** fertilization_tests.pdf (in folder “Data files and lab notes”)
Experimental Conditions: column temp log Jan-Mar09.xls, ColumnWQJan14toFeb23.pdf (in folder “Data files and lab notes”)
Embryo Images and scoring: in folders “Data files and lab notes”>”Trial 2”; “Data files and lab notes”> Embryo Scores Final.xls (Trial 2 tab)

Trial 3

Sample Code Key: “Data files and lab notes”>”Trial 3”>Trial 3 key to egg chemistry.doc
Egg Source Information: CBOS09 fem wts.xls**,** fertilization_tests.pdf (in folder “Data files and lab notes”)
Experimental Conditions: column temp log Jan-Mar09.xls, WaterQuality022609.xls (in folder “Data files and lab notes”)
Embryo Images and Scoring Results: in folders “Data files and lab notes”>”Trial 3”; “Data files and lab notes”> Embryo Scores Final.xls (Trial 3 tab)
Water Sample PAH Analysis: in folders “Data files and lab notes”>”Trial 3”>Trial 3 water PAH.xls
Eggs Sample PAH Analysis: in folders “Data files and lab notes”>”Trial 3”>Trial 3 tissue PAH.xls

Trial 4

Sample Code Key: “Data files and lab notes”>”Trial 4”>Trial 4 key to egg chemistry.doc
Egg Source Information: CBOS09 fem wts.xls**,** fertilization_tests.pdf (in folder “Data files and lab notes”)
Experimental Conditions: column temp log 031809.xls, WaterQuality031809.xls (in folder “Data files and lab notes”)
Embryo Images and Scoring Results: in folders “Data files and lab notes”>”Trial 4”; “Data files and lab notes”> Embryo Scores Final.xls (Trial 4 tab)
Water Sample PAH Analysis: in folders “Data files and lab notes”>”Trial 4”>Trial 4 water PAH.xls
Eggs Sample PAH Analysis: in folders “Data files and lab notes”>”Trial 4”>Trial 4 tissue PAH.xls

Laboratory salinity study:

Egg Source Information: CBOS09 fem wts.xls**,** fertilization_tests.pdf (in folder “Data files and lab notes”)
Experimental Conditions: in folder “Work plans and SOPs”>CBOS Salinity Experiments.doc
Embryo Images and Scoring Results: in folders “2008-09 Salinity study”>”16-16-16 ppt” and “30-30-16 ppt”, data files CBOS Salinity Study embryo results.doc and CBOS salinity hatch data 09.xls

Natural spawn sampling:

Single site sampled, Paradise Cove
A. Image and video datasets for 50 embryos each for 8 sub-transects.
B. Fixed embryos from all imaged specimens for all sites (for CYP1A immunofluorescence).

C. Frozen 3 g samples of embryos for PAH quantification from each sub-transect.
Data files:
•CBOS external drive: Hatch data:2009:MRS-003b-FEM2 natural spawn 09.xlsx
•New MRS-003b-FEM2 natural spawn 09_v2.xls
•CBOS external drive:CBOS:CBOS images:Paradise natural spawn 1-29-09

2010
Natural spawn samples:

A. Image and video datasets for 3 random subsamples from each of 8 sub-transects of natural spawn on algae substrate. Sausalito site had spawn at only 3 of the 8 original coordinates (27 datasets total, Keil Cove, Peninsula Point, Paradise Cove, 8 each).
B. Frozen 3 g samples of embryos for PAH quantification from 27 samples.
C. Larval hatch data for 27 sub-samples of each natural spawn collection

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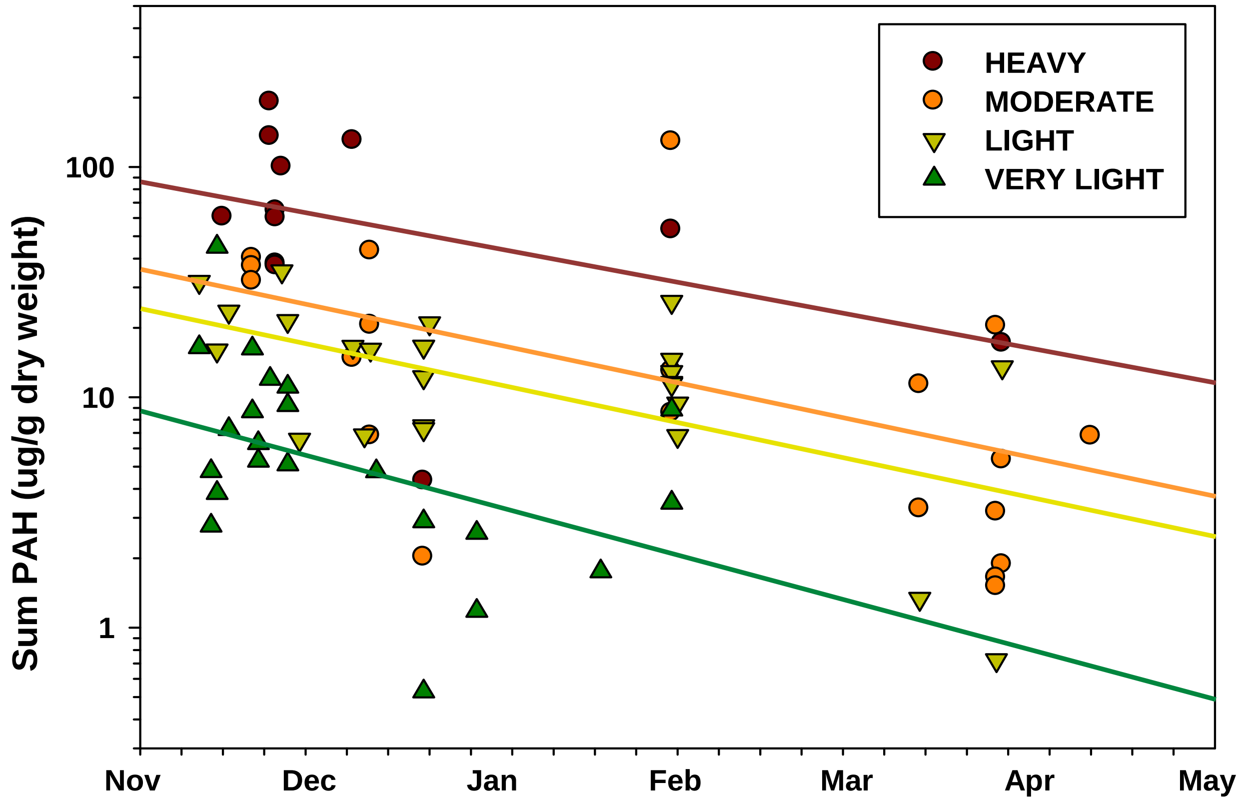
Figure 1. Total PAH (ug/g dry weight) concentrations from bivalve samples collected up to 6 months post-spill. Samples are identified by oiling designation assigned during spill response.



DEGREE	AVG. (1^{ST} MONTH)	MIN. (1^{ST} MONTH)	MAX. (1^{ST} 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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Koch Marcellinas Creek

Base year = 2010, Restoration Implementation = 2015

Table 1. Summary of injury HEA results.

Habitat Types	Wooded Habitats			Ground Cover		Aquatic
	Lost DSAYs	Relative Value	Dense Wood Equivalent Lost DSAYs	Terrestrial Lost DSAY's	Wet Lost DSAY's	Lost DSAY's
Sparse Woody Vegetation	13.08	0.30	3.92	5.30		
Medium Woody Vegetation	67.90	0.80	54.32	27.49		
Dense Woody Vegetation	491.49	1.00	491.49	198.90		
Scrub Woody Vegetation	47.68	0.60	28.61	17.15		
Grassland Vegetation				24.97		
Wet Grassland Vegetation					4.30	
Marcellinas Creek						2.11
TOTAL			578.34	273.81	4.30	2.11

Table 2. Summary of habitat construction requirement calculations.

Habitat Segment	Wooded	Ground Cover		Aquatic
		Terrestrial	Wet	
Total lost DSAY's	578.34	273.81	4.30	2.11
DSAY Credit/acre constructed	17.48	27.86	21.96	11.37
Acres to be Constructed[1]	33.09	9.83	0.20	0.19
Habitat Segment Relative Value (%)	0.80	0.20	0.30	
Complete Wooded Habitat Equivalent[2]	26.48	1.97	0.06	
Total Wooded Habitat Construction	28.50			0.19

[1] Determined by dividing total lost DSAY's by DSAY credit per acre of constructed habitat

[2] Determined by multiplying acres to be constructed by the habitat segment relative value

Table 3. Summary of habitat preservation requirements

Habitat Segment	Wooded	Ground Cover		Aquatic
		Terrestrial	Wet	
Total lost DSAY's	578.34	273.81	4.30	2.11
Habitat Segment Relative Value (%)	0.80	0.20	0.30	
Wooded habitat equivalent	462.67	54.76	1.29	
Total wooded habitat equivalent DSAY's	518.73			
		Hamilton Property 2012 implementatoin		
Preservation options	Generic	Conserved	Non-Conserved	
DSAY Credit/acre preserved	2.06	2.30	3.01	
Preservation acreage required	251.91	70.60	118.42	
Total Acreage Required	251.91	189.02		

Table 4. Evaluationof Goiliad Tract preservation and restoration requirements

Goliad Tract evaluation				
Woodland equvalent DSAY lost	Goliad Tract Woodland Preservation DSAY	Remainder Woodland Requirement DSAY	Goliad tract Construction Value (DSAY) per acre	Construction Required (acres)
518.73	55.65	463.07	15.6	29.6

Calculation of Total Discounted Acre-Years of Resources Services Gained

Scenario : Goliad Property Preservation - woodlands
Area Constructed (acres) : 19.0
Base Year : 2010

	% services	Time (mo)
Initial level of injury	0	1998
End of First Restoration Phase	0	2015
End of Second Restoration Phase	15	2045
End of Third Restoration Phase	15	2203
End of Fourth Restoration Phase	15	2203
End of Fifth Restoration Phase	0	2203
End of restoration period	0	2203

TOTAL LOST DSAY 55.65

Year	Percent of Resource Services Provided (Beginning of Period)	Percent of Resource Services Provided (End of Period)	Percent of Resource Services Provided (Average of Period)	Acre-years of Resource Services Provided	Discount Factor	Discounted Acre-years of Resource Services Provided
1998	0.00	0.00	0.00	0.00	1.43	0.00
1999	0.00	0.00	0.00	0.00	1.38	0.00
2000	0.00	0.00	0.00	0.00	1.34	0.00
2001	0.00	0.00	0.00	0.00	1.30	0.00
2002	0.00	0.00	0.00	0.00	1.27	0.00
2003	0.00	0.00	0.00	0.00	1.23	0.00
2004	0.00	0.00	0.00	0.00	1.19	0.00
2005	0.00	0.00	0.00	0.00	1.16	0.00
2006	0.00	0.00	0.00	0.00	1.13	0.00
2007	0.00	0.00	0.00	0.00	1.09	0.00
2008	0.00	0.00	0.00	0.00	1.06	0.00
2009	0.00	0.00	0.00	0.00	1.03	0.00
2010	0.00	0.00	0.00	0.00	1.00	0.00
2011	0.00	0.00	0.00	0.00	0.97	0.00
2012	0.00	0.00	0.00	0.00	0.94	0.00
2013	0.00	0.00	0.00	0.00	0.92	0.00
2014	0.00	0.00	0.00	0.00	0.89	0.00
2015	0.00	0.50	0.25	0.05	0.86	0.04
2016	0.50	1.00	0.75	0.14	0.84	0.12
2017	1.00	1.50	1.25	0.24	0.81	0.19
2018	1.50	2.00	1.75	0.33	0.79	0.26
2019	2.00	2.50	2.25	0.43	0.77	0.33
2020	2.50	3.00	2.75	0.52	0.74	0.39
2021	3.00	3.50	3.25	0.62	0.72	0.45
2022	3.50	4.00	3.75	0.71	0.70	0.50
2023	4.00	4.50	4.25	0.81	0.68	0.55
2024	4.50	5.00	4.75	0.90	0.66	0.60
2025	5.00	5.50	5.25	1.00	0.64	0.64
2026	5.50	6.00	5.75	1.09	0.62	0.68
2027	6.00	6.50	6.25	1.19	0.61	0.72
2028	6.50	7.00	6.75	1.28	0.59	0.75
2029	7.00	7.50	7.25	1.38	0.57	0.79
2030	7.50	8.00	7.75	1.47	0.55	0.82
2031	8.00	8.50	8.25	1.57	0.54	0.84
2032	8.50	9.00	8.75	1.66	0.52	0.87
2033	9.00	9.50	9.25	1.76	0.51	0.89
2034	9.50	10.00	9.75	1.85	0.49	0.91
2035	10.00	10.50	10.25	1.95	0.48	0.93
2036	10.50	11.00	10.75	2.04	0.46	0.95
2037	11.00	11.50	11.25	2.14	0.45	0.96
2038	11.50	12.00	11.75	2.23	0.44	0.98
2039	12.00	12.50	12.25	2.33	0.42	0.99
2040	12.50	13.00	12.75	2.42	0.41	1.00
2041	13.00	13.50	13.25	2.52	0.40	1.01
2042	13.50	14.00	13.75	2.61	0.39	1.01
2043	14.00	14.50	14.25	2.71	0.38	1.02
2044	14.50	15.00	14.75	2.80	0.37	1.03
2045	15.00	15.00	15.00	2.85	0.36	1.01
2046	15.00	15.00	15.00	2.85	0.35	0.98
2047	15.00	15.00	15.00	2.85	0.33	0.95
2048	15.00	15.00	15.00	2.85	0.33	0.93
2049	15.00	15.00	15.00	2.85	0.32	0.90
2050	15.00	15.00	15.00	2.85	0.31	0.87
2051	15.00	15.00	15.00	2.85	0.30	0.85
2052	15.00	15.00	15.00	2.85	0.29	0.82
2053	15.00	15.00	15.00	2.85	0.28	0.80
2054	15.00	15.00	15.00	2.85	0.27	0.78
2055	15.00	15.00	15.00	2.85	0.26	0.75
2056	15.00	15.00	15.00	2.85	0.26	0.73
2057	15.00	15.00	15.00	2.85	0.25	0.71
2058	15.00	15.00	15.00	2.85	0.24	0.69
2059	15.00	15.00	15.00	2.85	0.23	0.67
2060	15.00	15.00	15.00	2.85	0.23	0.65
2061	15.00	15.00	15.00	2.85	0.22	0.63
2062	15.00	15.00	15.00	2.85	0.22	0.61
2063	15.00	15.00	15.00	2.85	0.21	0.59
2064	15.00	15.00	15.00	2.85	0.20	0.58
2065	15.00	15.00	15.00	2.85	0.20	0.56
2066	15.00	15.00	15.00	2.85	0.19	0.54
2067	15.00	15.00	15.00	2.85	0.19	0.53
2068	15.00	15.00	15.00	2.85	0.18	0.51
2069	15.00	15.00	15.00	2.85	0.17	0.50
2070	15.00	15.00	15.00	2.85	0.17	0.48
2071	15.00	15.00	15.00	2.85	0.16	0.47
2072	15.00	15.00	15.00	2.85	0.16	0.46
2073	15.00	15.00	15.00	2.85	0.16	0.44
2074	15.00	15.00	15.00	2.85	0.15	0.43
2075	15.00	15.00	15.00	2.85	0.15	0.42
2076	15.00	15.00	15.00	2.85	0.14	0.41
2077	15.00	15.00	15.00	2.85	0.14	0.39

2078	15.00	15.00	15.00	2.85	0.13	0.38
2079	15.00	15.00	15.00	2.85	0.13	0.37
2080	15.00	15.00	15.00	2.85	0.13	0.36
2081	15.00	15.00	15.00	2.85	0.12	0.35
2082	15.00	15.00	15.00	2.85	0.12	0.34
2083	15.00	15.00	15.00	2.85	0.12	0.33
2084	15.00	15.00	15.00	2.85	0.11	0.32
2085	15.00	15.00	15.00	2.85	0.11	0.31
2086	15.00	15.00	15.00	2.85	0.11	0.30
2087	15.00	15.00	15.00	2.85	0.10	0.29
2088	15.00	15.00	15.00	2.85	0.10	0.28
2089	15.00	15.00	15.00	2.85	0.10	0.28
2090	15.00	15.00	15.00	2.85	0.09	0.27
2091	15.00	15.00	15.00	2.85	0.09	0.26
2092	15.00	15.00	15.00	2.85	0.09	0.25
2093	15.00	15.00	15.00	2.85	0.09	0.25
2094	15.00	15.00	15.00	2.85	0.08	0.24
2095	15.00	15.00	15.00	2.85	0.08	0.23
2096	15.00	15.00	15.00	2.85	0.08	0.22
2097	15.00	15.00	15.00	2.85	0.08	0.22
2098	15.00	15.00	15.00	2.85	0.07	0.21
2099	15.00	15.00	15.00	2.85	0.07	0.21
2100	15.00	15.00	15.00	2.85	0.07	0.20
2101	15.00	15.00	15.00	2.85	0.07	0.19
2102	15.00	15.00	15.00	2.85	0.07	0.19
2103	15.00	15.00	15.00	2.85	0.06	0.18
2104	15.00	15.00	15.00	2.85	0.06	0.18
2105	15.00	15.00	15.00	2.85	0.06	0.17
2106	15.00	15.00	15.00	2.85	0.06	0.17
2107	15.00	15.00	15.00	2.85	0.06	0.16
2108	15.00	15.00	15.00	2.85	0.06	0.16
2109	15.00	15.00	15.00	2.85	0.05	0.15
2110	15.00	15.00	15.00	2.85	0.05	0.15
2111	15.00	15.00	15.00	2.85	0.05	0.14
2112	15.00	15.00	15.00	2.85	0.05	0.14
2113	15.00	15.00	15.00	2.85	0.05	0.14
2114	15.00	15.00	15.00	2.85	0.05	0.13
2115	15.00	15.00	15.00	2.85	0.04	0.13
2116	15.00	15.00	15.00	2.85	0.04	0.12
2117	15.00	15.00	15.00	2.85	0.04	0.12
2118	15.00	15.00	15.00	2.85	0.04	0.12
2119	15.00	15.00	15.00	2.85	0.04	0.11
2120	15.00	15.00	15.00	2.85	0.04	0.11
2121	15.00	15.00	15.00	2.85	0.04	0.11
2122	15.00	15.00	15.00	2.85	0.04	0.10
2123	15.00	15.00	15.00	2.85	0.04	0.10
2124	15.00	15.00	15.00	2.85	0.03	0.10
2125	15.00	15.00	15.00	2.85	0.03	0.10
2126	15.00	15.00	15.00	2.85	0.03	0.09
2127	15.00	15.00	15.00	2.85	0.03	0.09
2128	15.00	15.00	15.00	2.85	0.03	0.09
2129	15.00	15.00	15.00	2.85	0.03	0.08
2130	15.00	15.00	15.00	2.85	0.03	0.08
2131	15.00	15.00	15.00	2.85	0.03	0.08
2132	15.00	15.00	15.00	2.85	0.03	0.08
2133	15.00	15.00	15.00	2.85	0.03	0.08
2134	15.00	15.00	15.00	2.85	0.03	0.07
2135	15.00	15.00	15.00	2.85	0.02	0.07
2136	15.00	15.00	15.00	2.85	0.02	0.07
2137	15.00	15.00	15.00	2.85	0.02	0.07
2138	15.00	15.00	15.00	2.85	0.02	0.06
2139	15.00	15.00	15.00	2.85	0.02	0.06
2140	15.00	15.00	15.00	2.85	0.02	0.06
2141	15.00	15.00	15.00	2.85	0.02	0.06
2142	15.00	15.00	15.00	2.85	0.02	0.06
2143	15.00	15.00	15.00	2.85	0.02	0.06
2144	15.00	15.00	15.00	2.85	0.02	0.05
2145	15.00	15.00	15.00	2.85	0.02	0.05
2146	15.00	15.00	15.00	2.85	0.02	0.05
2147	15.00	15.00	15.00	2.85	0.02	0.05
2148	15.00	15.00	15.00	2.85	0.02	0.05
2149	15.00	15.00	15.00	2.85	0.02	0.05
2150	15.00	15.00	15.00	2.85	0.02	0.05
2151	15.00	15.00	15.00	2.85	0.02	0.04
2152	15.00	15.00	15.00	2.85	0.02	0.04
2153	15.00	15.00	15.00	2.85	0.01	0.04
2154	15.00	15.00	15.00	2.85	0.01	0.04
2155	15.00	15.00	15.00	2.85	0.01	0.04
2156	15.00	15.00	15.00	2.85	0.01	0.04
2157	15.00	15.00	15.00	2.85	0.01	0.04
2158	15.00	15.00	15.00	2.85	0.01	0.04
2159	15.00	15.00	15.00	2.85	0.01	0.03
2160	15.00	15.00	15.00	2.85	0.01	0.03
2161	15.00	15.00	15.00	2.85	0.01	0.03
2162	15.00	15.00	15.00	2.85	0.01	0.03
2163	15.00	15.00	15.00	2.85	0.01	0.03
2164	15.00	15.00	15.00	2.85	0.01	0.03
2165	15.00	15.00	15.00	2.85	0.01	0.03
2166	15.00	15.00	15.00	2.85	0.01	0.03
2167	15.00	15.00	15.00	2.85	0.01	0.03
2168	15.00	15.00	15.00	2.85	0.01	0.03

2169	15.00	15.00	15.00	2.85	0.01	0.03
2170	15.00	15.00	15.00	2.85	0.01	0.03
2171	15.00	15.00	15.00	2.85	0.01	0.02
2172	15.00	15.00	15.00	2.85	0.01	0.02
2173	15.00	15.00	15.00	2.85	0.01	0.02
2174	15.00	15.00	15.00	2.85	0.01	0.02
2175	15.00	15.00	15.00	2.85	0.01	0.02
2176	15.00	15.00	15.00	2.85	0.01	0.02
2177	15.00	15.00	15.00	2.85	0.01	0.02
2178	15.00	15.00	15.00	2.85	0.01	0.02
2179	15.00	15.00	15.00	2.85	0.01	0.02
2180	15.00	15.00	15.00	2.85	0.01	0.02
2181	15.00	15.00	15.00	2.85	0.01	0.02
2182	15.00	15.00	15.00	2.85	0.01	0.02
2183	15.00	15.00	15.00	2.85	0.01	0.02
2184	15.00	15.00	15.00	2.85	0.01	0.02
2185	15.00	15.00	15.00	2.85	0.01	0.02
2186	15.00	15.00	15.00	2.85	0.01	0.02
2187	15.00	15.00	15.00	2.85	0.01	0.02
2188	15.00	15.00	15.00	2.85	0.01	0.01
2189	15.00	15.00	15.00	2.85	0.01	0.01
2190	15.00	15.00	15.00	2.85	0.00	0.01
2191	15.00	15.00	15.00	2.85	0.00	0.01
2192	15.00	15.00	15.00	2.85	0.00	0.01
2193	15.00	15.00	15.00	2.85	0.00	0.01
2194	15.00	15.00	15.00	2.85	0.00	0.01
2195	15.00	15.00	15.00	2.85	0.00	0.01
2196	15.00	15.00	15.00	2.85	0.00	0.01
2197	15.00	15.00	15.00	2.85	0.00	0.01
2198	15.00	15.00	15.00	2.85	0.00	0.01
2199	15.00	15.00	15.00	2.85	0.00	0.01
2200	15.00	15.00	15.00	2.85	0.00	0.01
2201	15.00	15.00	15.00	2.85	0.00	0.01
2202	15.00	15.00	15.00	2.85	0.00	0.01
2203	15.00	0.00	7.50	1.43	0.00	0.00
2204	0.00	0.00	0.00	0.00	0.00	0.00
2205	0.00	0.00	0.00	0.00	0.00	0.00
2206	0.00	0.00	0.00	0.00	0.00	0.00
2207	0.00	0.00	0.00	0.00	0.00	0.00
2208	0.00	0.00	0.00	0.00	0.00	0.00
2209	0.00	0.00	0.00	0.00	0.00	0.00
2210	0.00	0.00	0.00	0.00	0.00	0.00
2211	0.00	0.00	0.00	0.00	0.00	0.00
2212	0.00	0.00	0.00	0.00	0.00	0.00
2213	0.00	0.00	0.00	0.00	0.00	0.00
2214	0.00	0.00	0.00	0.00	0.00	0.00
2215	0.00	0.00	0.00	0.00	0.00	0.00
2216	0.00	0.00	0.00	0.00	0.00	0.00
2217	0.00	0.00	0.00	0.00	0.00	0.00
2218	0.00	0.00	0.00	0.00	0.00	0.00
2219	0.00	0.00	0.00	0.00	0.00	0.00
2220	0.00	0.00	0.00	0.00	0.00	0.00
2221	0.00	0.00	0.00	0.00	0.00	0.00
2222	0.00	0.00	0.00	0.00	0.00	0.00
2223	0.00	0.00	0.00	0.00	0.00	0.00
2224	0.00	0.00	0.00	0.00	0.00	0.00
2225	0.00	0.00	0.00	0.00	0.00	0.00
2226	0.00	0.00	0.00	0.00	0.00	0.00
2227	0.00	0.00	0.00	0.00	0.00	0.00
2228	0.00	0.00	0.00	0.00	0.00	0.00
2229	0.00	0.00	0.00	0.00	0.00	0.00
2230	0.00	0.00	0.00	0.00	0.00	0.00
2231	0.00	0.00	0.00	0.00	0.00	0.00
2232	0.00	0.00	0.00	0.00	0.00	0.00
2233	0.00	0.00	0.00	0.00	0.00	0.00
2234	0.00	0.00	0.00	0.00	0.00	0.00
2235	0.00	0.00	0.00	0.00	0.00	0.00
2236	0.00	0.00	0.00	0.00	0.00	0.00
2237	0.00	0.00	0.00	0.00	0.00	0.00
2238	0.00	0.00	0.00	0.00	0.00	0.00
2239	0.00	0.00	0.00	0.00	0.00	0.00
2240	0.00	0.00	0.00	0.00	0.00	0.00
2241	0.00	0.00	0.00	0.00	0.00	0.00
2242	0.00	0.00	0.00	0.00	0.00	0.00
2243	0.00	0.00	0.00	0.00	0.00	0.00
2244	0.00	0.00	0.00	0.00	0.00	0.00
2245	0.00	0.00	0.00	0.00	0.00	0.00
2246	0.00	0.00	0.00	0.00	0.00	0.00
2247	0.00	0.00	0.00	0.00	0.00	0.00
2248	0.00	0.00	0.00	0.00	0.00	0.00
2249	0.00	0.00	0.00	0.00	0.00	0.00
2250	0.00	0.00	0.00	0.00	0.00	0.00
2251	0.00	0.00	0.00	0.00	0.00	0.00
2252	0.00	0.00	0.00	0.00	0.00	0.00
2253	0.00	0.00	0.00	0.00	0.00	0.00
2254	0.00	0.00	0.00	0.00	0.00	0.00
					TOTAL	55.65

Calculation of Total Discounted Acre-Years of Resources Services Gained

Scenario : Goliad Woody restoration
Area Constructed (acres) : 1.0
Base Year : 2010

	% services	Time (mo)
Initial level of injury	0	1998
End of First Restoration Phase	0	2015
End of Second Restoration Phase	80	2045
End of Third Restoration Phase	80	2065
End of Fourth Restoration Phase	80	2215
End of Fifth Restoration Phase	0	2215
End of restoration period	0	2215

TOTAL LOST DSAY 15.65

Year	Percent of Resource Services Provided (Beginning of Period)	Percent of Resource Services Provided (End of Period)	Percent of Resource Services Provided (Average of Period)	Acre-years of Resource Services Provided	Discount Factor	Discounted Acre-years of Resource Services Provided
1998	0.00	0.00	0.00	0.00	1.43	0.00
1999	0.00	0.00	0.00	0.00	1.38	0.00
2000	0.00	0.00	0.00	0.00	1.34	0.00
2001	0.00	0.00	0.00	0.00	1.30	0.00
2002	0.00	0.00	0.00	0.00	1.27	0.00
2003	0.00	0.00	0.00	0.00	1.23	0.00
2004	0.00	0.00	0.00	0.00	1.19	0.00
2005	0.00	0.00	0.00	0.00	1.16	0.00
2006	0.00	0.00	0.00	0.00	1.13	0.00
2007	0.00	0.00	0.00	0.00	1.09	0.00
2008	0.00	0.00	0.00	0.00	1.06	0.00
2009	0.00	0.00	0.00	0.00	1.03	0.00
2010	0.00	0.00	0.00	0.00	1.00	0.00
2011	0.00	0.00	0.00	0.00	0.97	0.00
2012	0.00	0.00	0.00	0.00	0.94	0.00
2013	0.00	0.00	0.00	0.00	0.92	0.00
2014	0.00	0.00	0.00	0.00	0.89	0.00
2015	0.00	2.67	1.33	0.01	0.86	0.01
2016	2.67	5.33	4.00	0.04	0.84	0.03
2017	5.33	8.00	6.67	0.07	0.81	0.05
2018	8.00	10.67	9.33	0.09	0.79	0.07
2019	10.67	13.33	12.00	0.12	0.77	0.09
2020	13.33	16.00	14.67	0.15	0.74	0.11
2021	16.00	18.67	17.33	0.17	0.72	0.13
2022	18.67	21.33	20.00	0.20	0.70	0.14
2023	21.33	24.00	22.67	0.23	0.68	0.15
2024	24.00	26.67	25.33	0.25	0.66	0.17
2025	26.67	29.33	28.00	0.28	0.64	0.18
2026	29.33	32.00	30.67	0.31	0.62	0.19
2027	32.00	34.67	33.33	0.33	0.61	0.20
2028	34.67	37.33	36.00	0.36	0.59	0.21
2029	37.33	40.00	38.67	0.39	0.57	0.22
2030	40.00	42.67	41.33	0.41	0.55	0.23
2031	42.67	45.33	44.00	0.44	0.54	0.24
2032	45.33	48.00	46.67	0.47	0.52	0.24
2033	48.00	50.67	49.33	0.49	0.51	0.25
2034	50.67	53.33	52.00	0.52	0.49	0.26
2035	53.33	56.00	54.67	0.55	0.48	0.26
2036	56.00	58.67	57.33	0.57	0.46	0.27
2037	58.67	61.33	60.00	0.60	0.45	0.27
2038	61.33	64.00	62.67	0.63	0.44	0.27
2039	64.00	66.67	65.33	0.65	0.42	0.28
2040	66.67	69.33	68.00	0.68	0.41	0.28
2041	69.33	72.00	70.67	0.71	0.40	0.28
2042	72.00	74.67	73.33	0.73	0.39	0.28
2043	74.67	77.33	76.00	0.76	0.38	0.29
2044	77.33	80.00	78.67	0.79	0.37	0.29
2045	80.00	80.00	80.00	0.80	0.36	0.28
2046	80.00	80.00	80.00	0.80	0.35	0.28
2047	80.00	80.00	80.00	0.80	0.33	0.27
2048	80.00	80.00	80.00	0.80	0.33	0.26
2049	80.00	80.00	80.00	0.80	0.32	0.25
2050	80.00	80.00	80.00	0.80	0.31	0.25
2051	80.00	80.00	80.00	0.80	0.30	0.24
2052	80.00	80.00	80.00	0.80	0.29	0.23
2053	80.00	80.00	80.00	0.80	0.28	0.22
2054	80.00	80.00	80.00	0.80	0.27	0.22
2055	80.00	80.00	80.00	0.80	0.26	0.21
2056	80.00	80.00	80.00	0.80	0.26	0.21
2057	80.00	80.00	80.00	0.80	0.25	0.20
2058	80.00	80.00	80.00	0.80	0.24	0.19
2059	80.00	80.00	80.00	0.80	0.23	0.19
2060	80.00	80.00	80.00	0.80	0.23	0.18
2061	80.00	80.00	80.00	0.80	0.22	0.18
2062	80.00	80.00	80.00	0.80	0.22	0.17
2063	80.00	80.00	80.00	0.80	0.21	0.17
2064	80.00	80.00	80.00	0.80	0.20	0.16
2065	80.00	80.00	80.00	0.80	0.20	0.16
2066	80.00	80.00	80.00	0.80	0.19	0.15
2067	80.00	80.00	80.00	0.80	0.19	0.15
2068	80.00	80.00	80.00	0.80	0.18	0.14
2069	80.00	80.00	80.00	0.80	0.17	0.14
2070	80.00	80.00	80.00	0.80	0.17	0.14
2071	80.00	80.00	80.00	0.80	0.16	0.13
2072	80.00	80.00	80.00	0.80	0.16	0.13
2073	80.00	80.00	80.00	0.80	0.16	0.12
2074	80.00	80.00	80.00	0.80	0.15	0.12
2075	80.00	80.00	80.00	0.80	0.15	0.12
2076	80.00	80.00	80.00	0.80	0.14	0.11
2077	80.00	80.00	80.00	0.80	0.14	0.11

2078	80.00	80.00	80.00	0.80	0.13	0.11
2079	80.00	80.00	80.00	0.80	0.13	0.10
2080	80.00	80.00	80.00	0.80	0.13	0.10
2081	80.00	80.00	80.00	0.80	0.12	0.10
2082	80.00	80.00	80.00	0.80	0.12	0.10
2083	80.00	80.00	80.00	0.80	0.12	0.09
2084	80.00	80.00	80.00	0.80	0.11	0.09
2085	80.00	80.00	80.00	0.80	0.11	0.09
2086	80.00	80.00	80.00	0.80	0.11	0.08
2087	80.00	80.00	80.00	0.80	0.10	0.08
2088	80.00	80.00	80.00	0.80	0.10	0.08
2089	80.00	80.00	80.00	0.80	0.10	0.08
2090	80.00	80.00	80.00	0.80	0.09	0.08
2091	80.00	80.00	80.00	0.80	0.09	0.07
2092	80.00	80.00	80.00	0.80	0.09	0.07
2093	80.00	80.00	80.00	0.80	0.09	0.07
2094	80.00	80.00	80.00	0.80	0.08	0.07
2095	80.00	80.00	80.00	0.80	0.08	0.06
2096	80.00	80.00	80.00	0.80	0.08	0.06
2097	80.00	80.00	80.00	0.80	0.08	0.06
2098	80.00	80.00	80.00	0.80	0.07	0.06
2099	80.00	80.00	80.00	0.80	0.07	0.06
2100	80.00	80.00	80.00	0.80	0.07	0.06
2101	80.00	80.00	80.00	0.80	0.07	0.05
2102	80.00	80.00	80.00	0.80	0.07	0.05
2103	80.00	80.00	80.00	0.80	0.06	0.05
2104	80.00	80.00	80.00	0.80	0.06	0.05
2105	80.00	80.00	80.00	0.80	0.06	0.05
2106	80.00	80.00	80.00	0.80	0.06	0.05
2107	80.00	80.00	80.00	0.80	0.06	0.05
2108	80.00	80.00	80.00	0.80	0.06	0.04
2109	80.00	80.00	80.00	0.80	0.05	0.04
2110	80.00	80.00	80.00	0.80	0.05	0.04
2111	80.00	80.00	80.00	0.80	0.05	0.04
2112	80.00	80.00	80.00	0.80	0.05	0.04
2113	80.00	80.00	80.00	0.80	0.05	0.04
2114	80.00	80.00	80.00	0.80	0.05	0.04
2115	80.00	80.00	80.00	0.80	0.04	0.04
2116	80.00	80.00	80.00	0.80	0.04	0.03
2117	80.00	80.00	80.00	0.80	0.04	0.03
2118	80.00	80.00	80.00	0.80	0.04	0.03
2119	80.00	80.00	80.00	0.80	0.04	0.03
2120	80.00	80.00	80.00	0.80	0.04	0.03
2121	80.00	80.00	80.00	0.80	0.04	0.03
2122	80.00	80.00	80.00	0.80	0.04	0.03
2123	80.00	80.00	80.00	0.80	0.04	0.03
2124	80.00	80.00	80.00	0.80	0.03	0.03
2125	80.00	80.00	80.00	0.80	0.03	0.03
2126	80.00	80.00	80.00	0.80	0.03	0.03
2127	80.00	80.00	80.00	0.80	0.03	0.03
2128	80.00	80.00	80.00	0.80	0.03	0.02
2129	80.00	80.00	80.00	0.80	0.03	0.02
2130	80.00	80.00	80.00	0.80	0.03	0.02
2131	80.00	80.00	80.00	0.80	0.03	0.02
2132	80.00	80.00	80.00	0.80	0.03	0.02
2133	80.00	80.00	80.00	0.80	0.03	0.02
2134	80.00	80.00	80.00	0.80	0.03	0.02
2135	80.00	80.00	80.00	0.80	0.02	0.02
2136	80.00	80.00	80.00	0.80	0.02	0.02
2137	80.00	80.00	80.00	0.80	0.02	0.02
2138	80.00	80.00	80.00	0.80	0.02	0.02
2139	80.00	80.00	80.00	0.80	0.02	0.02
2140	80.00	80.00	80.00	0.80	0.02	0.02
2141	80.00	80.00	80.00	0.80	0.02	0.02
2142	80.00	80.00	80.00	0.80	0.02	0.02
2143	80.00	80.00	80.00	0.80	0.02	0.02
2144	80.00	80.00	80.00	0.80	0.02	0.02
2145	80.00	80.00	80.00	0.80	0.02	0.01
2146	80.00	80.00	80.00	0.80	0.02	0.01
2147	80.00	80.00	80.00	0.80	0.02	0.01
2148	80.00	80.00	80.00	0.80	0.02	0.01
2149	80.00	80.00	80.00	0.80	0.02	0.01
2150	80.00	80.00	80.00	0.80	0.02	0.01
2151	80.00	80.00	80.00	0.80	0.02	0.01
2152	80.00	80.00	80.00	0.80	0.02	0.01
2153	80.00	80.00	80.00	0.80	0.01	0.01
2154	80.00	80.00	80.00	0.80	0.01	0.01
2155	80.00	80.00	80.00	0.80	0.01	0.01
2156	80.00	80.00	80.00	0.80	0.01	0.01
2157	80.00	80.00	80.00	0.80	0.01	0.01
2158	80.00	80.00	80.00	0.80	0.01	0.01
2159	80.00	80.00	80.00	0.80	0.01	0.01
2160	80.00	80.00	80.00	0.80	0.01	0.01
2161	80.00	80.00	80.00	0.80	0.01	0.01
2162	80.00	80.00	80.00	0.80	0.01	0.01
2163	80.00	80.00	80.00	0.80	0.01	0.01
2164	80.00	80.00	80.00	0.80	0.01	0.01
2165	80.00	80.00	80.00	0.80	0.01	0.01
2166	80.00	80.00	80.00	0.80	0.01	0.01
2167	80.00	80.00	80.00	0.80	0.01	0.01
2168	80.00	80.00	80.00	0.80	0.01	0.01

2169	80.00	80.00	80.00	0.80	0.01	0.01
2170	80.00	80.00	80.00	0.80	0.01	0.01
2171	80.00	80.00	80.00	0.80	0.01	0.01
2172	80.00	80.00	80.00	0.80	0.01	0.01
2173	80.00	80.00	80.00	0.80	0.01	0.01
2174	80.00	80.00	80.00	0.80	0.01	0.01
2175	80.00	80.00	80.00	0.80	0.01	0.01
2176	80.00	80.00	80.00	0.80	0.01	0.01
2177	80.00	80.00	80.00	0.80	0.01	0.01
2178	80.00	80.00	80.00	0.80	0.01	0.01
2179	80.00	80.00	80.00	0.80	0.01	0.01
2180	80.00	80.00	80.00	0.80	0.01	0.01
2181	80.00	80.00	80.00	0.80	0.01	0.01
2182	80.00	80.00	80.00	0.80	0.01	0.00
2183	80.00	80.00	80.00	0.80	0.01	0.00
2184	80.00	80.00	80.00	0.80	0.01	0.00
2185	80.00	80.00	80.00	0.80	0.01	0.00
2186	80.00	80.00	80.00	0.80	0.01	0.00
2187	80.00	80.00	80.00	0.80	0.01	0.00
2188	80.00	80.00	80.00	0.80	0.01	0.00
2189	80.00	80.00	80.00	0.80	0.01	0.00
2190	80.00	80.00	80.00	0.80	0.00	0.00
2191	80.00	80.00	80.00	0.80	0.00	0.00
2192	80.00	80.00	80.00	0.80	0.00	0.00
2193	80.00	80.00	80.00	0.80	0.00	0.00
2194	80.00	80.00	80.00	0.80	0.00	0.00
2195	80.00	80.00	80.00	0.80	0.00	0.00
2196	80.00	80.00	80.00	0.80	0.00	0.00
2197	80.00	80.00	80.00	0.80	0.00	0.00
2198	80.00	80.00	80.00	0.80	0.00	0.00
2199	80.00	80.00	80.00	0.80	0.00	0.00
2200	80.00	80.00	80.00	0.80	0.00	0.00
2201	80.00	80.00	80.00	0.80	0.00	0.00
2202	80.00	80.00	80.00	0.80	0.00	0.00
2203	80.00	80.00	80.00	0.80	0.00	0.00
2204	80.00	80.00	80.00	0.80	0.00	0.00
2205	80.00	80.00	80.00	0.80	0.00	0.00
2206	80.00	80.00	80.00	0.80	0.00	0.00
2207	80.00	80.00	80.00	0.80	0.00	0.00
2208	80.00	80.00	80.00	0.80	0.00	0.00
2209	80.00	80.00	80.00	0.80	0.00	0.00
2210	80.00	80.00	80.00	0.80	0.00	0.00
2211	80.00	80.00	80.00	0.80	0.00	0.00
2212	80.00	80.00	80.00	0.80	0.00	0.00
2213	80.00	80.00	80.00	0.80	0.00	0.00
2214	80.00	80.00	80.00	0.80	0.00	0.00
2215	80.00	0.00	40.00	0.40	0.00	0.00
2216	0.00	0.00	0.00	0.00	0.00	0.00
2217	0.00	0.00	0.00	0.00	0.00	0.00
2218	0.00	0.00	0.00	0.00	0.00	0.00
2219	0.00	0.00	0.00	0.00	0.00	0.00
2220	0.00	0.00	0.00	0.00	0.00	0.00
2221	0.00	0.00	0.00	0.00	0.00	0.00
2222	0.00	0.00	0.00	0.00	0.00	0.00
2223	0.00	0.00	0.00	0.00	0.00	0.00
2224	0.00	0.00	0.00	0.00	0.00	0.00
2225	0.00	0.00	0.00	0.00	0.00	0.00
2226	0.00	0.00	0.00	0.00	0.00	0.00
2227	0.00	0.00	0.00	0.00	0.00	0.00
2228	0.00	0.00	0.00	0.00	0.00	0.00
2229	0.00	0.00	0.00	0.00	0.00	0.00
2230	0.00	0.00	0.00	0.00	0.00	0.00
2231	0.00	0.00	0.00	0.00	0.00	0.00
2232	0.00	0.00	0.00	0.00	0.00	0.00
2233	0.00	0.00	0.00	0.00	0.00	0.00
2234	0.00	0.00	0.00	0.00	0.00	0.00
2235	0.00	0.00	0.00	0.00	0.00	0.00
2236	0.00	0.00	0.00	0.00	0.00	0.00
2237	0.00	0.00	0.00	0.00	0.00	0.00
2238	0.00	0.00	0.00	0.00	0.00	0.00
2239	0.00	0.00	0.00	0.00	0.00	0.00
2240	0.00	0.00	0.00	0.00	0.00	0.00
2241	0.00	0.00	0.00	0.00	0.00	0.00
2242	0.00	0.00	0.00	0.00	0.00	0.00
2243	0.00	0.00	0.00	0.00	0.00	0.00
2244	0.00	0.00	0.00	0.00	0.00	0.00
2245	0.00	0.00	0.00	0.00	0.00	0.00
2246	0.00	0.00	0.00	0.00	0.00	0.00
2247	0.00	0.00	0.00	0.00	0.00	0.00
2248	0.00	0.00	0.00	0.00	0.00	0.00
2249	0.00	0.00	0.00	0.00	0.00	0.00
2250	0.00	0.00	0.00	0.00	0.00	0.00
2251	0.00	0.00	0.00	0.00	0.00	0.00
2252	0.00	0.00	0.00	0.00	0.00	0.00
2253	0.00	0.00	0.00	0.00	0.00	0.00
2254	0.00	0.00	0.00	0.00	0.00	0.00
					TOTAL	15.65

APPENDIX F

Service Losses and Recovery for Rocky Intertidal Habitat

October 2010

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

Table of Contents

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).

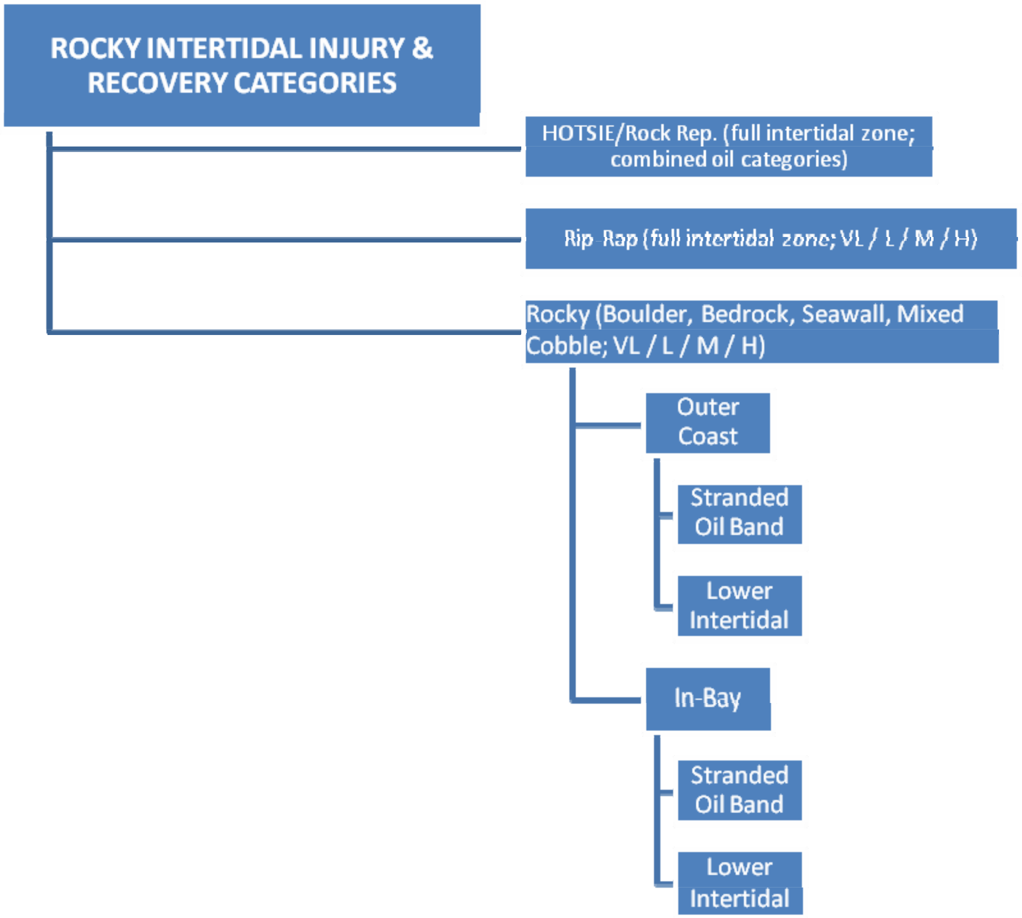

Figure 5. Rocky intertidal injury and recovery categories for the *Cosco Busan* incident

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

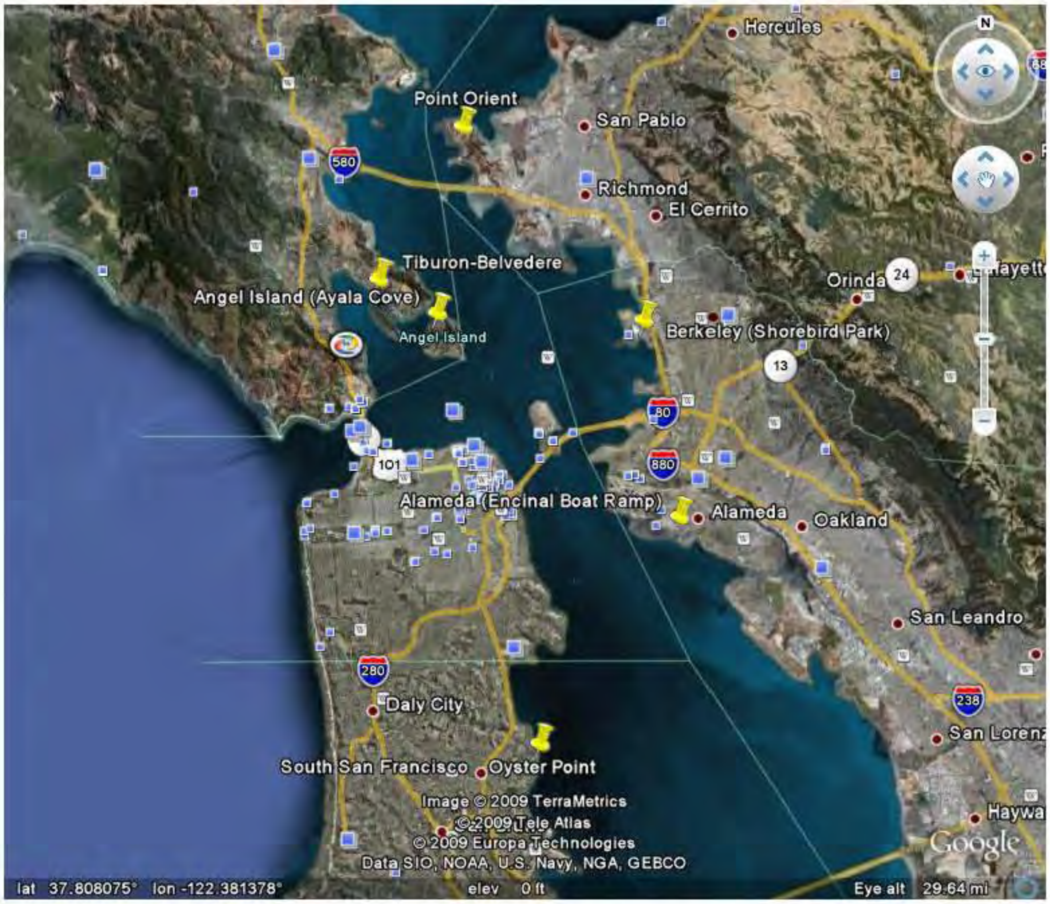

Figure 6. UCD native oyster long-term monitoring sites

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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IEc

Baseline Shoreline Use Estimates for the *Cosco Busan* Oil Spill Damage Assessment

December 30, 2010

prepared for:

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INTRODUCTION

On November 7, 2007, the *Cosco Busan* struck the Bay Bridge in San Francisco Bay, spilling approximately 58,000 gallons of intermediate fuel oil. The spill impacted a wide range of shoreline recreation sites throughout the Bay Area, including beaches, parks, piers, walking trails, and other locations. Many of these recreation sites were temporarily closed to the public or had posted health advisories during the post-spill time period.

In November 2008, approximately one year after the spill and after all closures and health advisories had been lifted, Industrial Economics, Incorporated (IEc) collected data on shoreline recreation at select locations throughout the Bay area. The goal of the data collection effort was to gather data that could be used to develop estimates of baseline visitor use throughout the spill impact period, from November 2007 to June 2008. Baseline visitor use is the amount of shoreline recreation that would have been present if the spill had not occurred. The baseline visitor use estimates served as inputs in a separate analysis that assessed shoreline use losses due to the spill.

The data collection effort focused on a wide range of activities pursued by visitors at coastal locations, including swimming, surfing, walking, exercising, biking, sightseeing, sunbathing, picnicking, and kite-boarding. Fishing and boating were excluded from the shoreline use data collection effort, as these two activities were addressed in separate analyses.

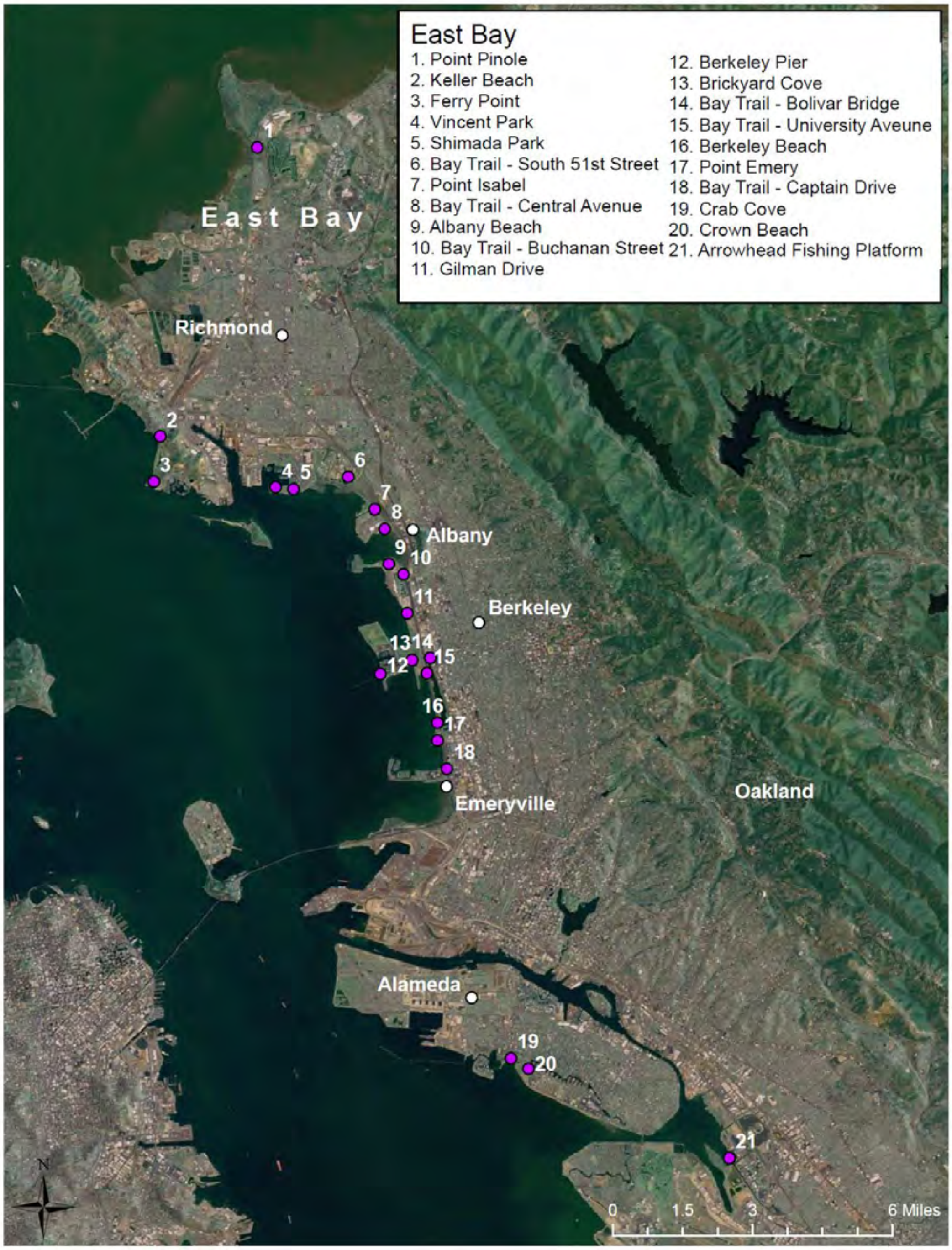
The shoreline sites selected for data collection are described in Exhibit 1. The sites are distributed throughout the San Francisco Bay area, including East Bay sites from Point Pinole in the north to Arrowhead Fishing Platform in the south, and Pacific Ocean sites from Stinson Beach in the north to Pacifica Pier in the south (Exhibit 2). Sites were selected based on the anticipated magnitude of recreational use losses. Specific selection criteria included expected number of visitors, presence of closures or advisories, and proximity to shoreline areas that were oiled during the spill.

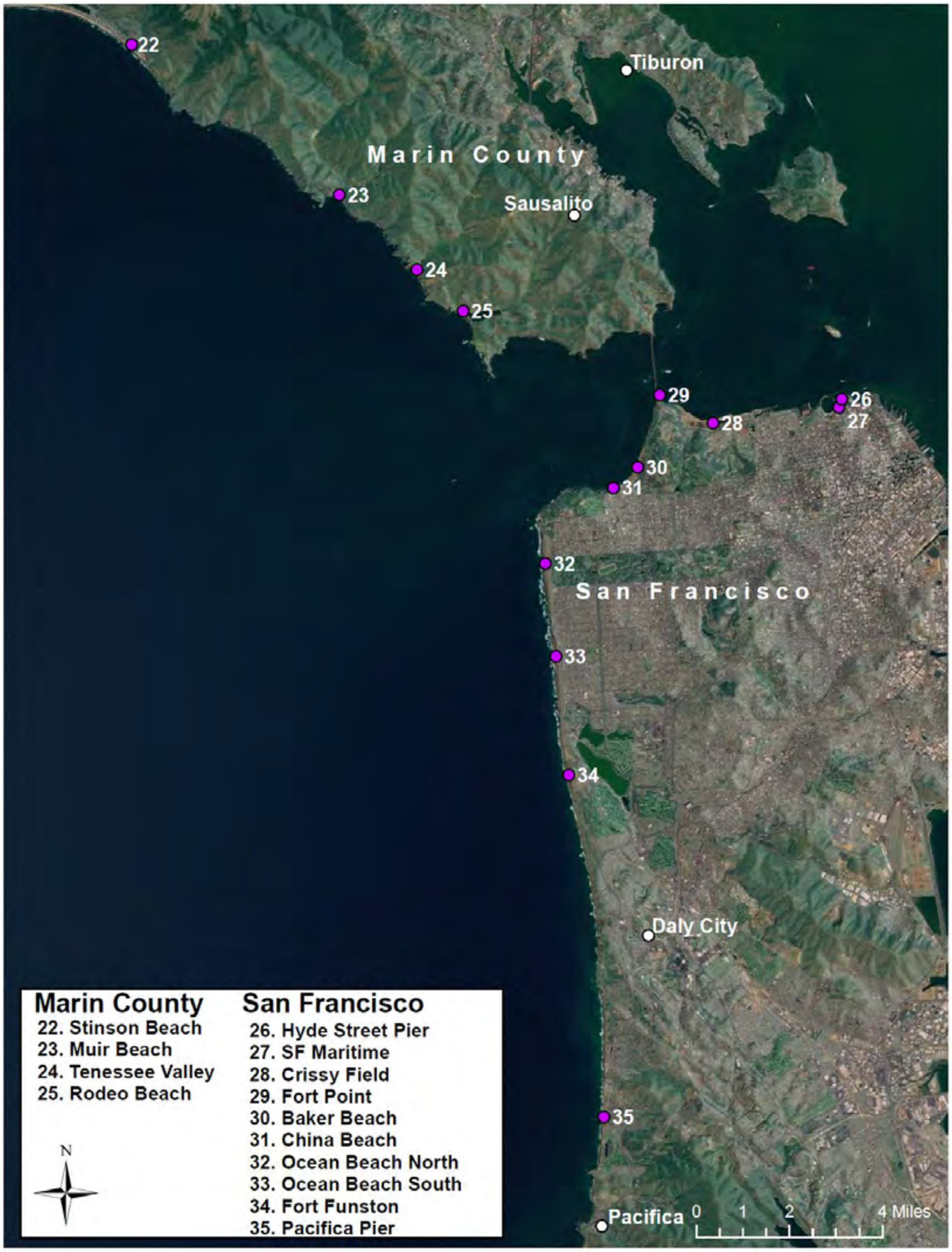
The remainder of this report describes in detail the development of baseline visitation estimates for shoreline use. After describing the general methodology and outlining the steps involved in the calculations, each of the steps is described in detail and final estimates of baseline use are presented. The report does not discuss the impacts of the spill on baseline visitation, nor does it develop estimates of economic losses associated with these impacts.

EXHIBIT 1: SHORELINE USE DATA COLLECTION SITES

COUNTY	SITE	DESCRIPTION
Marin	Stinson Beach	Beach
	Muir Beach	Beach
	Tennessee Valley	Bike path and beach
	Rodeo Beach	Beach
San Francisco	Hyde Street Pier	Pier
	San Francisco Maritime	Pier, beach, and bike path
	Crissy Field	Pier, beach, and bike/walking paths
	Fort Point	Bike/walking path
	Baker Beach	Beach
	China Beach	Beach
	Ocean Beach North	Beach and promenade
	Ocean Beach South	Beach and overlook/bluff
	Fort Funston	Beach and walking paths
San Mateo	Pacifica Pier	Pier
Contra Costa	Point Pinole	Pier and walking paths
	Keller Beach	Beach and picnic area
	Ferry Point	Pier
	Vincent Park	Pier and picnic area
	Shimada Friendship Park	Picnic area
	Point Isabel	Walking paths
Alameda	Albany Beach	Beach, walking paths
	Berkeley Pier	Pier
	Gilman Drive	Sightseeing area
	Brickyard Cove	Walking paths
	Berkeley Beach	Beach and sightseeing area
	Point Emery	Sightseeing area
	Bay Trail	Bike path
	Crown Beach	Beach and bike path
	Crab Cove	Beach and bike path
	Arrowhead Fishing Platform	Fishing platform at MLK Jr. park

EXHIBIT 2: DATA COLLECTION LOCATIONS





22
Tiburon
Marin County
23
Sausalito
24
25
29
28
26
27
30
31
32
San Francisco
33
34
Daly City
Marin County
22. Stinson Beach
23. Muir Beach
24. Tenessee Valley
25. Rodeo Beach
San Francisco
26. Hyde Street Pier
27. SF Maritime
28. Crissy Field
29. Fort Point
30. Baker Beach
31. China Beach
32. Ocean Beach North
33. Ocean Beach South
34. Fort Funston
35. Pacifica Pier
35
N
Pacifica
0 1 2 4 Miles

OVERVIEW OF METHODOLOGY

At each site, field personnel were stationed at entrances on four days in November 2008 to obtain counts of completed trips.[1] In addition, an automated vehicle or pedestrian counter was associated with each site to provide a "visitation index" for every day in November 2008. This daily visitation index was expected to be proportional to visitation at the site. The relationship between the visitation index (i.e., the automated vehicle or pedestrian counts) and the direct visitor estimates on the four sampled days was then used to estimate baseline visitation, after incorporating adjustments for differences in weather between November 2008 and the spill impact period.

The four steps used to calculate baseline visitation estimates are described below:

Step 1: Obtaining a Daily Visitation Index: Automated vehicle and pedestrian counters were deployed at site entrances to establish a daily index of visitation for each site throughout November 2008. At sites with multiple entrances, counters were deployed in locations that were expected to provide a daily count that would be highly correlated with visitation.

Step 2: Predicting the Daily Visitation Index for the Spill Impact Period: Site-specific regression models were used to predict the visitation index for every day of the spill impact period (November 2007 to June 2008). These models used observed variation in visitation index levels throughout November 2008 to estimate the parameters of the relationship between the visitation index, weather, and type of day (i.e., weekday or weekend/holiday). This relationship was then used, in combination with weather data from the spill impact period, to predict visitation index levels under baseline conditions.

Step 3: Relating the Visitation Index to Actual Visitation: Field personnel were deployed at site entrances on four days (two weekdays and two weekend days) in November 2008 to count completed trips to each site. For each site and each type of day (weekdays and weekend days) the total trip estimate was divided by the number of vehicles or pedestrians recorded on the automated counters to provide a trip/index ratio. This ratio represents the number of visitors that recreate at a site every time the automated counter records a visit. Ratios vary by site for a variety of reasons, but are most commonly due to parking conditions or because more than one person often travels to a site in a single vehicle.

Step 4: Calculating Baseline Visits: The results of Steps 2 and 3 are used to estimate baseline visitation during the spill impact period. That is, for each site

[1] On-site visitor counts were not obtained at five of the sites: Stinson Beach, Muir Beach, Hyde Street Pier, Fort Point, and Fort Funston. For these sites, information from other nearby sites was combined with on-site vehicle/pedestrian counts to estimate visitation (see later discussion).

and for every day of the spill impact period, baseline visitation is estimated by multiplying the trip/index ratio by the predicted visitation index.

Two key components of the methodology are (1) counting visitors at site entrances and (2) the use of ratio estimation. Counting visitors at site entrances/exits ensures that only completed trips are counted. While it is possible to count visitors on site while recreational activities are on-going (e.g., counting individuals on a beach), converting these on-site visitor counts to trip estimates requires data on trip durations, which typically must be obtained through visitor interviews.

Ratio estimation allows for efficient data collection by taking advantage of the relationship between the variable of interest (trips) and an auxiliary variable (vehicle/pedestrian counts), where data on the auxiliary variable is substantially less expensive to obtain.[2] In the current application, automated vehicle/pedestrian counters are placed at the study sites for an extended period of time. Then, visitor use is directly estimated on a small number of days for comparison to the automated counts. The ratio of direct visitor use estimates to automated counts indicates how many people use the site for each vehicle or pedestrian recorded by the automated counter.

The overall approach can be illustrated through a simple example, focusing on visitation at a hypothetical beach during a two-week period in November 2008. Suppose an automated vehicle counter placed at the entrance to the beach parking lot provides daily vehicle counts from November 10 to 23, 2008 (Exhibit 3). These vehicle counts serve as an index of visitation for the site. During four days of this two-week period (a Thursday, Friday, Saturday, and Sunday), field personnel are placed at the site from dawn to dusk and observe 250, 550, 1,450, and 950 individuals completing trips to the site, respectively. The corresponding vehicle counts for these four days are 150, 350, 700, and 500. The weekday trip/index ratio would then be calculated as 1.6 = (250 + 550) ÷ (150 + 350) and the weekend trip/index ratio would be calculated as 2.0 = (1,450 + 950) ÷ (700 + 500). Visitation on the remaining days in the two-week period would be estimated by multiplying the weekday vehicle counts by 1.6 and the weekend vehicle counts by 2.0 (see Exhibit 3).

The estimation approach that was actually implemented was somewhat more complex than the approach presented in this example, as the index values for the spill impact period were unknown (the vehicle and pedestrian counters were not in place during this period). As a result, as we describe in Step 2, regression techniques were used to *predict* these index values before applying the appropriate trip/index ratio.

The remainder of the report describes each of the four steps of the methodology in greater detail, with intermediate results presented after each step.

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[2] Ratio estimation is described in detail in Cochran (1977) and Lohr (1999). The current approach departs slightly from traditional ratio estimation in that the days chosen for on-site counts were not randomly selected.

EXHIBIT 3: ILLUSTRATION OF ESTIMATION METHODOLOGY

DATE	VISITATION INDEX (VEHICLE COUNTS)	TRIP COUNTS	TRIP/INDEX RATIO	PREDICTED TRIPS[a]
11/10/08 (Monday)	200	--	1.6	320
11/11/08 (Tuesday)	150	--	1.6	240
11/12/08 (Wednesday)	300	--	1.6	480
11/13/08 (Thursday)	150	250	1.6	240
11/14/08 (Friday)	350	550	1.6	560
11/15/08 (Saturday)	700	1,450	2.0	1,400
11/16/08 (Sunday)	500	950	2.0	1,000
11/17/08 (Monday)	200	--	1.6	320
11/18/08 (Tuesday)	400	--	1.6	640
11/19/08 (Wednesday)	200	--	1.6	320
11/20/08 (Thursday)	350	--	1.6	560
11/21/08 (Friday)	250	--	1.6	400
11/22/08 (Saturday)	450	--	2.0	900
11/23/08 (Sunday)	650	--	2.0	1,300

Note:
[a] – Although trip predictions are presented for all days in the two-week period, direct trip counts are clearly preferred, when they are available (i.e., 11/13/08 to 11/16/08). Direct trip counts are not available for the spill impact period.

OBTAINING A DAILY VISITATION INDEX

The first step in estimating baseline visitation involves establishing an index of visitation at each site for all days in November 2008. These visitation indices were established using data from existing National Park Service (NPS) vehicle counters and from new vehicle/pedestrian counters deployed for the current effort.

The daily visitation index used for each site is presented in Exhibit 4, and the locations of all automated counters are depicted in Attachment A. In selecting a daily visitation index for each site, the primary criterion was that the index be strongly correlated with visitation at the site. Thus, whenever possible, vehicle or pedestrian counts at a site's main entrance served as the site's visitation index. At some locations, the collection of appropriate automated count data was difficult or infeasible. For example, the parking lot at China Beach does not have a well-established entry or exit lane. At these locations, data from vehicle or pedestrian counters deployed at nearby sites with similar visitor activities were used to develop visitation indices.

Daily Visitation Index for Automated Counters with Time Stamp Data Recorders

Fifteen automated counters with time stamp data recorders were installed to gather data for the site-specific visitation indices throughout November 2008. Eleven of these automated counters were vehicle counters, while four were infrared pedestrian counters.

Both the pedestrian and the vehicle counters provided daily totals for the 7:00 a.m. to 5:30 p.m. time period (hereafter "daytime counts"), which corresponds exactly to the time period covered by the on-site trip counts by field personnel.

Ten of the vehicle counters were magnetic field counters and one (at Rodeo Beach) was an existing inductive loop counter that had been installed and used by NPS to count vehicles prior to the current effort. The magnetic field counters were self-contained devices placed in waterproof containers and deployed a few feet from the edge of the pavement at each site. When a vehicle passed within a specified distance of the counter, the counter would detect changes in the background magnetic field, and the vehicle would be tallied. The effective range of the counter was adjusted and tested at each location.

The four pedestrian counters were attached to railings alongside trails or piers, with an infrared scope pointing perpendicular to the primary direction of foot/bicycle traffic. When a pedestrian passed by the counter, it would detect the infrared signature associated with a warm, moving object, and a person would be counted.

Daily Visitation Index for Automated Counters without Time Stamp Data Recorders

Ten existing inductive loop vehicle counters without time stamp data recorders were also used to gather data for the site-specific visitation indices. These counters had been installed and used by NPS to count vehicles prior to the current effort, and they simply maintained cumulative counts of total vehicles at each location. In order to develop a count for a specific time period at a given location, the counter needed to be read by field personnel at the beginning and end of the time period, with the difference between the two readings providing the desired tally. As a result, 24-hour counts were developed for these counters by having field personnel read the counters at the same time every evening throughout November 2008.

As on-site trip counts were completed only during daytime hours (from 7:00 a.m. to 5:30 p.m.), these 24-hour counts must be converted to daytime counts to establish appropriate visitation indices. Daytime counts were obtained on four days (two weekdays and two weekend days) at six counter locations (Crissy Field East, Crissy Field West, Baker Beach, Ocean Beach Balboa, Ocean Beach Fulton, and Ocean Beach Sloat) by reading the counters at 7:00 a.m. and 5:30 p.m. The ratios of daytime counts to 24-hour counts observed at these six locations were then used to convert all 24-hour counts to daytime counts. For sites where daytime counts were not obtained, ratios from similar sites were used to convert 24-hour counts to daytime counts. Specifically, the Baker Beach ratio was applied to Muir Beach, Tennessee Valley, and Fort Funston.

The visitation index values for each site are presented in Attachment B for all days in November 2008.

Sites with Monthly Visitation Index

Daily visitation indices were not established for three of the sites: Stinson Beach, Hyde Street Pier, and Fort Point. At these locations, a monthly visitation index was developed using data from pre-existing NPS vehicle/pedestrian counters.

EXHIBIT 4: SOURCE OF VISITATION INDEX FOR EACH SITE

SITE	SOURCE OF VISITATION INDEX
Marin	
Stinson Beach	Vehicle counter at entrance to parking lot[a]
Muir Beach	Vehicle counter at entrance to parking lot
Tennessee Valley	Vehicle counter on Tennessee Valley Road approximately one mile northeast of parking lot entrance
Rodeo Beach	Vehicle counter at entrance to parking lot[b]
San Francisco	
Hyde Street Pier	Pedestrian counter at entrance to pier[a]
San Francisco Maritime	Vehicle counter at entrance to Crissy Field East parking lot[c]
Crissy Field	Vehicle counters at entrances to Crissy Field East and West parking lots (sum of two counter tallies)
Fort Point	Vehicle counter at entrance to parking lot[a]
Baker Beach	Vehicle counter at entrance to parking lot
China Beach	Vehicle counter at entrance to Baker Beach parking lot[c]
Ocean Beach North	Vehicle counters at entrances to Ocean Beach parking lots at Balboa Steet and Fulton Street (sum of two counter tallies)
Ocean Beach South	Vehicle counter at entrance to Ocean Beach parking lot at Sloat Boulevard
Fort Funston	Vehicle counter at entrance to parking lot
San Mateo	
Pacifica Pier	Pedestrian counter at entrance to pier[b]
Contra Costa	
Point Pinole	Vehicle counter at parking lot entrance[b]
Keller Beach	Vehicle counter at entrance to Ferry Point parking lot[b,c]
Ferry Point	Vehicle counter at parking lot entrance[b]
Vincent Park	Vehicle counter at parking lot entrance[b]
Shimada Friendship Park	Vehicle counter at entrance to Vincent Park parking lot[b,c]
Point Isabel	Vehicle counters at parking lot entrances (sum of two counter tallies) [b]
Alameda	
Albany Beach	Vehicle counter at parking lot entrance[b]
Berkeley Pier	Pedestrian counter at entrance to pier[b]
Gilman Drive	Vehicle counter at entrance to Point Emery parking lot[b,c]
Brickyard Cove	Vehicle counter at entrance to Point Emery parking lot[b,c]
Berkeley Beach	Vehicle counter at entrance to Point Emery parking lot[b,c]
Point Emery	Vehicle counter at entrance to Point Emery parking lot[b]
Bay Trail	Pedestrian counter at Bolivar Bridge[b]
Crown Beach	Vehicle counter at entrance to parking lot[b]
Crab Cove	Vehicle counter at entrance to parking lot[b]
Arrowhead Fishing Platform	Vehicle counter at entrance to main parking lot[b]

Notes:
[a] - A monthly (rather than daily) visitation index was established for this site.
[b] - Daytime counts were obtained directly from time stamp data recorders at this site.
[c] - The collection of automated count data was difficult or infeasible at this site. As a result, the visitation index is derived from a nearby site that is expected to have similar visitor activities (see discussion in text).

PREDICTING THE DAILY VISITATION INDEX FOR THE SPILL IMPACT PERIOD

The second step in estimating baseline visitation is to predict the baseline visitation indices for every day of the spill impact period, November 2007 to June 2008. That is, site-specific daily visitation indices for November 2008 calculated in Step 1 must be adjusted for differences in temperature, precipitation, and type of day (i.e., weekend/holiday vs. weekday) to obtain predicted baseline daily visitation indices for the entire spill impact period. These predicted visitation indices will be linked to actual visitation using the trip/index ratios calculated in Step 3.

Site-Specific Regression models

The daily visitation index data from November 2008 were used to estimate the parameters of a series of site-specific**,** semilog regression models.[3] The dependent variable in each of the models is the natural logarithm of the vehicle or pedestrian count for the location on day *t*, which we denote $\ln c_t$. The independent variables are daily high temperature (*TEMP*), total daily precipitation (*PPT*), and a binary variable for weekdays (i.e., non-weekends/holidays), *WEEKDAY*.

The regression model for each location is specified as:

$$\ln c_t = \beta_0 + \beta_1 TEMP_t + \beta_2 PPT_t + \beta_3 WEEKDAY_t + \varepsilon_t$$

Separate models are estimated for each location because the mix of visitor activities pursued differs across sites, and the impact of weather and type of day on visitation is therefore likely to vary across locations.

The estimated parameters from each regression model are combined with daily weather data from the spill impact period to predict vehicle or pedestrian counts on each day of the spill impact period.[4] In determining these predicted counts, the binary weekday variable is adjusted as appropriate for every day of the spill impact period, depending on the dates of the weekends and holidays.

Weather data were obtained from Weather Underground (http://www.wunderground.com), a service that compiles information from weather stations around the world. We matched each site to one of three weather stations (San Francisco -- KCASANFR63, Berkeley -- KCABERKE7, or Pacifica -- KCAPACIF4) based on geographic location and proximity to the ocean. Crissy Field was matched to the San Francisco station; all other Marin County, San Francisco, and San Mateo County

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[3] The semilog form ensures that predicted counts will be positive, which is consistent with site data. We also estimated the regression models in linear form, with results similar to those obtained using semilog models.

[4] With the semi-log specification, taking the exponential of the predicted logged count results in the median of the conditional count distribution. In order to recover the mean, we multiply the exponential of the predicted logged count by $\exp\left(\hat{\sigma}^2/2\right)$:

$$\hat{c}_t = \exp\left(\hat{\beta}_0 + \hat{\beta}_1 temperature_t + \hat{\beta}_2 precipitation_t + \hat{\beta}_3 weekday_t\right) * \exp\left(\frac{\hat{\sigma}^2}{2}\right)$$

sites were matched to the Pacifica station; and all Contra Costa and Alameda sites were matched to the Berkeley station. The daily temperature and precipitation data from the matched station were used to represent weather conditions at the location.

Estimation Results

The estimated coefficients for each of the regression models are presented in Attachment C. The coefficients are generally highly significant, with 17 of the 21 models explaining over 60 percent of the variation in the logged vehicle/pedestrian counts, and half of the models (11 of the 21) explaining over 80 percent of the variation in the logged vehicle/pedestrian counts. All of the temperature coefficients are positive, all of the precipitation coefficients are negative, and all of the weekday coefficients are negative, as expected. With a semilog model, the coefficients are interpreted as the percentage change in counts due to a one-unit increase in the independent variable. Thus, the estimated temperature coefficient of 0.03 for Muir Beach indicates that a one-degree increase in temperature is associated with a three percent increase in predicted counts.

Predicted Daily Visitation Index

The predicted visitation index for each location and month (summed across all days) is presented in Attachment D for the entire spill impact period. For comparison, Attachment D also presents the actual visitation index for November 2008.

Note that while the models are estimated using data from November, predictions are obtained for the entire November to June time period. We have greater confidence in the predictions for November than for other months, as (1) weather conditions from December to June may lie outside the range of the data used to estimate the model and (2) factors unrelated to weather and type of day may cause visitation in other months to differ, on average, from November visitation (e.g., school vacations, seasonal differences in outdoor activities, or special events).

Predicted Visitation at NPS Sites with Monthly Visitation Index

At NPS sites with monthly (rather than daily) visitation indices (Stinson Beach, Hyde Street Pier, and Fort Point), the predicted monthly visitation for the spill impact period was determined by averaging the value of the index over a six-year period: the five years immediately preceding the spill and one year following the spill.

RELATING THE VISITATION INDEX TO ACTUAL VISITATION

The third step in estimating baseline visitation is to estimate the ratio of completed trips to the daily visitation index (hereafter the "trip/index ratio"). Recall that this ratio is required to convert our predicted visitation index to an estimate of trips. Separate estimates are produced for each site and for each type of day (weekdays and weekend days). The calculation of site-specific daily visitation indices was described above under Step 1. This section describes the methodology used to estimate completed trips to each site for a sample of days in November 2008, and it presents the final trip/index ratios.

Methodology for Estimating Trips

Trained field personnel were deployed at site entrances on four days (two weekdays and two weekend days) in November 2008 to count completed trips to each site. The count locations for each site are provided in Attachment A. Counts were conducted from November 7 to 10 (Friday to Monday) at East Bay sites and from November 13 to 16 (Thursday to Sunday) at all other locations. The counts were conducted from 7:00 a.m. to 5:30 p.m. on each day, covering nearly all of the daylight hours.

Visitor counts were maintained on a tally sheet where the field personnel recorded all adults and children leaving the site. Anglers and park personnel were tallied separately from other visitors so that they could be removed from the counts. Anglers were identified based on the equipment that they carried (rather than interviews), and park personnel were identified based on their uniforms/vehicles. The duration of any breaks taken by field personnel were recorded directly on the tally sheet.

Trip estimation methodologies differed somewhat across sites due to differences in the number of entrances, visitation levels, and other site-specific factors. We describe the primary approach and two common variations below. The sampling approach for each site is summarized in Exhibit 5, with additional details provided in Attachment E.

Many of the targeted sites had a single entrance, so that daily trip estimates were developed by summing the tallies at that entrance and adjusting for any missed time periods (e.g., breaks). Missed time periods were addressed by dividing the total count for each day by the proportion of the day during which counts were conducted. For example, if field personnel took occasional breaks that totaled 5% of the monitored time period, then the total count for the day would be divided by 0.95 to obtain the trip estimate for that day.

At sites with multiple entrances (e.g., entrances to Crown Beach from Shoreline Drive), interviewers rotated systematically among these entrances throughout the day (e.g., moving to a different entrance every hour), with the starting location randomly selected on the first day. At these sites, the trip estimate was obtained by adjusting the counts for any breaks (as described above), summing the adjusted counts, and multiplying by the number of entrances.[5]

At several smaller sites (e.g., Vincent Park and Shimada Friendship Park) trip counts were conducted in tandem with a nearby site: a single person rotated systematically between the two sites (e.g., moving to a different location every two hours), with the starting location randomly selected on the first day and alternating every day thereafter. At these sites, the daily trip estimate was obtained by adjusting the counts for any breaks (as described above), summing the adjusted counts, then dividing by the proportion of the day during which counts were conducted at the site. For example, if counts were

[5] This approach treats the counts obtained during each time period as a random sample from the set of entrances, and the count is assumed to represent completed visits at all of the entrances during that particular time period.

conducted every other hour at a given site, the adjusted counts would be summed and divided by 0.5 to estimate the daily count.[6]

The unique nature of several sites necessitated more tailored estimation approaches:

- **San Francisco Maritime Bike Path:** At San Francisco Maritime National Historic Park, a short section of bike path passes along the shore next to the beach, then continues past the park, entering Crissy Field after several miles. The path is commonly used by bikers to tour the shoreline area between San Francisco Maritime and the Golden Gate Bridge. In order to avoid double-counting bikers visiting San Francisco Maritime *and* Crissy Field, bikers were omitted from the counts at this location. Walking/jogging visits on the path were estimated by (1) counting walkers/joggers passing by a single location in one direction (alternating directions every hour) (2) doubling the single-direction counts to estimate the number of walkers/joggers passing by the location in either direction, (3) interviewing a sample of walkers/joggers passing by this location to determine the number of times each visitor passed by that point during his or her trip (number of "crossings"), and (4) dividing the count by the average number of crossings.

- **Bay Trail:** Bay trail visitation was estimated by counting visitors leaving the section of the Bay Trail that stretches from Vincent Park in the north to Emeryville Beach in the south. Visitors were only counted at locations where a departure was likely to represent the end of a visit to the trail. This generally included departures at the northern and southern ends of the trail, departures at parking lots along the trail, and departures towards the residential neighborhoods to the east of the trail.

  At a subset of the Bay Trail locations (Vincent Park, Gilman Street, Brickyard Cove, Berkeley Beach, and Point Emery), field personnel were already stationed on site to count visits to adjacent coastal parks and beaches. At these locations, field personnel maintained separate tallies of Bay Trail departures. The methodology for estimating Bay Trail visits at these locations was identical to the methodology for estimating visits to the adjacent park/beach.

  Six additional Bay Trail departure locations were monitored by field personnel. At Bolivar Bridge, a major Bay Trail access point, departures were counted continuously by field personnel on all sampling days. At the remaining five locations (51st Street, Central Avenue, Buchanan Street, University Avenue, and Frontage Road at Shorebird Park), field personnel rotated through the locations on every sampling day, counting departures at each location during a single, two-hour time period. Daily departures were estimated at each location by dividing each two-hour count by an estimate of the proportion of daily visitation

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[6] This approach treats the periodic counts at the site as a random sample of time periods, and the sample is assumed to represent completed visits to the site during all time periods.

represented by that two-hour period. This proportion was estimated using data from the automated pedestrian counter at Bolivar Bridge.

- **Sites without On-Site Visitor Counts:** At five NPS sites (Stinson Beach, Muir Beach, Hyde Street Pier, Fort Point, and Fort Funston), on-site visitor counts were not conducted during the November 2008 effort. Trip/index ratios at four of these sites were transferred from sites with similar activities. The trip/index ratio from Rodeo Beach was transferred to Stinson and Muir beaches, the trip/index ratio from Point Isabel was transferred to Fort Funston (both parks are popular with dog walkers). For Fort Point, counts were calculated as the average monthly one-way car counts on the Fort Point car counter for 2002-2006 and 2008, multiplied by the average number of individuals in each exiting vehicle at Crissy West Bluff parking lot. At the fifth site, Hyde Street Pier, the trip/index ratio was set to one, as the visitation index is from an NPS count of all visitors to the pier.

The final trip estimates for every site and sampling day are provided in Exhibits 6 and 7.

EXHIBIT 5: OVERVIEW OF TRIP ESTIMATION METHODOLOGY FOR EACH SITE

SITE	TRIP ESTIMATION METHODOLOGY
Marin	
Stinson Beach	No visitor counts; transfer trip/index ratio from Rodeo Beach.
Muir Beach	No visitor counts; transfer trip/index ratio from Rodeo Beach.
Tennessee Valley	Count all departures.
Rodeo Beach	Count all departures.
San Francisco	
Hyde Street Pier	No visitor counts; trips obtained directly from NPS counts.
San Francisco Maritime	Alternate hourly between counting departures from Municipal Pier and Aquatic Park beach. Methodology for walking/biking path described in text.
Crissy Field	Count all departures at East Beach parking lot, West Bluff parking lot, and east end of promenade. Alternate hourly between counting departures at Long Avenue and at trail near East Beach lot. Rotate every half hour among the four trails crossing the center of Crissy Field, counting all departures.
Fort Point	No visitor counts; use car counts from Fort Point and average number of individuals in each exiting vehicle at Crissy West Bluff parking lot.
Baker Beach	Alternate hourly between counting departures at the parking lot entrance and at the Sand Ladder Trail.
China Beach	Count all departures.
Ocean Beach North	Divide promenade into three sections, with one field staffperson covering each section. Rotate every half hour among four or five stations within the section, counting all departures. Divide area between Lincoln Way and Sloat into eight sections. Rotate every hour among the sections, counting all departures.
Ocean Beach South	Alternate hourly between counting departures at Sloat Boulevard and at Second Overlook.
Fort Funston	No visitor counts; transfer trip/index ratio from Point Isabel.

SITE	TRIP ESTIMATION METHODOLOGY
San Mateo	
Pacifica Pier	Count all departures.
Contra Costa	
Point Pinole	Count all departures.
Keller Beach	Count all departures.
Ferry Point	Count all departures.
Vincent Park	Alternate hourly between Vincent and Shimada Friendship Park, counting all departures.
Shimada Friendship Park	Alternate hourly between Vincent and Shimada Friendship Park, counting all departures.
Point Isabel	Count all departures at Rydin Road and Isabel Street parking lots.
Alameda	
Albany Beach	Count all departures.
Berkeley Pier	Count all departures.
Gilman Drive	Alternate hourly between Gilman Drive and Brickyard Cove, counting all departures.
Brickyard Cove	Alternate hourly between Gilman Drive and Brickyard Cove, counting all departures.
Berkeley Beach	Alternate hourly between Berkeley Beach and Point Emery, counting all departures.
Point Emery	Alternate hourly between Berkeley Beach and Point Emery, counting all departures.
Bay Trail	Count all departures at Bolivar Bridge. Rotate every two hours among five different access points, counting all departures. Maintain separate counts of Bay Trail departures while sampling at Vincent Park, Gilman Drive, Brickyard Cove, Berkeley Beach, and Point Emery. Estimation methodology described in text.
Crown Beach	Count all departures from main parking lot on Westline Drive. Rotate every two hours among five locations along Shoreline Drive, counting all departures.
Crab Cove	Count all departures.
Arrowhead Fishing Platform	Count all departures.

EXHIBIT 6: DAILY TRIP ESTIMATES FOR FOUR SAMPLING DAYS – MARIN, SAN FRANCISCO, AND SAN MATEO SITES

SITE	THURSDAY 11/13/08	FRIDAY 11/14/08	SATURDAY 11/15/08	SUNDAY 11/16/08
Marin				
Stinson Beach[a]	n/a	n/a	n/a	n/a
Muir Beach[a]	n/a	n/a	n/a	n/a
Tennessee Valley[b]	505	505	1,501	1,501
Rodeo Beach	811	853	2,744	2,074
San Francisco				
Hyde Street Pier	n/a	n/a	n/a	n/a
San Francisco Maritime	4,504	4,748	9,005	8,306
Crissy Field	5,955	7,305	17,294	15,641
Fort Point	n/a	n/a	n/a	n/a
Baker Beach	840	1,331	3,949	3,635
China Beach	151	314	806	717
Ocean Beach – North	4,148	8,262	18,834	18,713
Ocean Beach – South	556	1,610	2,275	3,521
Fort Funston[a]	n/a	n/a	n/a	n/a
San Mateo				
Pacifica Pier	211	300	1,280	1,196

Notes:
[a] – No trip counts were obtained for this site. The trip/index ratio was transferred from a site with similar activities.
[b] – At Tennessee Valley, trip estimates were obtained for two days (11/14/08 and 11/15/08) rather than four. The estimate obtained on 11/14/08 was used for 11/13/08, and the trip estimate obtained on 11/15/08 was used for 11/16/08.

EXHIBIT 7: DAILY TRIP ESTIMATES FOR FOUR SAMPLING DAYS – CONTRA COSTA AND ALAMEDA SITES

SITE	FRIDAY 11/7/08	SATURDAY 11/8/08	SUNDAY 11/9/08	MONDAY 11/10/08
Contra Costa				
Point Pinole	179	214	200	428
Keller Beach	59	57	39	116
Ferry Point	46	32	66	122
Vincent Park	124	104	67	239
Shimada Friendship Park	71	123	131	179
Point Isabel	1,435	1,354	1,890	3,168
Alameda				
Albany Beach	265	220	285	558
Berkeley Pier	209	181	364	761
Gilman Drive	31	28	227	57
Brickyard Cove	37	53	47	59
Berkeley Beach	103	118	65	137
Point Emery	113	117	154	146
Bay Trail	853	633	914	1,718
Crown Beach	717	637	655	1,125
Crab Cove	166	127	151	286
Arrowhead Fishing Platform	54	61	18	53

Estimated Trip/Index Ratios

For each site and each type of day the total trip estimate was divided by the total visitation index on the two count days to estimate the trip/index ratio. This provides weekday and weekend estimates of the trip/index ratio for each site (Exhibit 8).

EXHIBIT 8: SITE-SPECIFIC TRIP/INDEX RATIOS

SITE	WEEKDAY RATIO[a]	WEEKEND RATIO[a]
Marin		
Stinson Beach[b]	1.25	1.76
Muir Beach[b]	1.25	1.76
Tennessee Valley	1.01	1.44
Rodeo Beach	1.25	1.76
San Francisco		
Hyde Street Pier[c]	1.00	1.00
San Francisco Maritime	3.72	3.68
Crissy Field	3.49	4.63
Fort Point[d]	2.80	2.80
Baker Beach	1.51	2.17
China Beach	0.31	0.44
Ocean Beach – North	6.35	8.78
Ocean Beach - South	1.11	2.19
Fort Funston[e]	1.13	1.43
San Mateo		
Pacifica Pier	0.53	0.95
Contra Costa		
Point Pinole	0.62	0.87
Keller Beach	0.65	0.66
Ferry Point	0.44	0.83
Vincent Park	0.45	0.56
Shimada Friendship Park	0.37	0.61
Point Isabel	1.13	1.43
Alameda		
Albany Beach	0.77	0.74
Berkeley Pier	0.91	1.22
Gilman Drive	0.11	0.72
Brickyard Cove	0.18	0.25
Berkeley Beach	0.43	0.45
Point Emery	0.45	0.71
Bay Trail	2.72	3.59
Crown Beach	5.10	5.21
Crab Cove	1.85	3.51
Arrowhead Fishing Platform	0.64	0.34

Notes:

[a] – The trip/index ratios are not required to be greater than one, as they do not necessarily represent the number of visitors per vehicle. Rather, they represent the number of visitors at the site divided by the value of the visitation index. Although this index is expected to be correlated with visitation, it does not necessarily equal the number of vehicles that the counted visitors used to access the site. In some cases, for example, the index is transferred from a nearby site (see Exhibit 4).

[b] – Trip/index ratio transferred from Rodeo Beach.

[c] – Trip/index ratio for Hyde Street Pier set equal to one, because daily visitation estimates were obtained directly from the National Park Service.

[d] – Trip/index ratio transferred from persons-per-vehicle counts at Crissy West Bluff parking lot.

[e] – Trip/index ratio transferred from Point Isabel, another park popular with dog walkers.

CALCULATING BASELINE VISITS

The final step in the estimation process is to combine the visit/index ratio for each site with the predicted daily visitation indices to estimate daily baseline visitation. Specifically, for every day of the spill impact period, daily baseline visitation for each site is estimated by multiplying the predicted visitation index (calculated in Step 2) by the weekday or weekend visit/index ratio (calculated in Step 3).

As these daily baseline visitation estimates exclude visits outside of the daytime period covered by the on-site count effort (i.e., 7:00 a.m. to 5:30 p.m.), the estimates are adjusted upwards to account for night-time visitation. At each site, the proportion of the 24-hour automated vehicle/pedestrian counts attributable to night-time visits is estimated separately for weekdays and weekends using the automated counter data from November 2008. These night-time proportions range from a low of zero at several sites with entry gates that are closed at night (e.g., Baker Beach) to a high of 0.33 at Berkeley Pier on weekdays. The daily baseline visitation estimates are divided by one minus the night-time proportion to estimate total daily visitation.

Exhibit 9 presents baseline visitation estimates for each site and for every month of the spill impact period. Total baseline visitation across all sites ranges from a low of 756,293 in January 2008 to a high of approximately 1,094,522 in November 2007.

EXHIBIT 9: BASELINE TRIP ESTIMATES[a]

SITE	NOVEMBER 2007	DECEMBER 2007	JANUARY 2008	FEBRUARY 2008	MARCH 2008	APRIL 2008	MAY 2008	JUNE 2008
Marin								
Stinson Beach	18,328	14,888	10,043	10,228	12,639	12,304	13,529	13,296
Muir Beach	13,115	11,147	8,099	8,318	9,949	9,575	10,603	10,371
Tennessee Valley	19,536	18,273	13,019	13,377	17,084	16,173	17,825	17,410
Rodeo Beach	32,045	28,405	22,527	22,841	25,963	24,757	27,264	26,599
San Francisco								
Hyde Street Pier	27,911	21,053	14,977	17,396	21,822	15,852	26,607	29,254
San Francisco Maritime	118,754	94,136	82,955	93,509	110,491	111,809	123,302	143,825
Crissy Field	210,926	174,416	151,375	164,769	194,513	192,449	210,811	236,542
Fort Point	72,666	52,153	58,267	56,252	60,872	60,859	81,245	89,934
Baker Beach	32,447	23,796	17,722	18,944	20,868	21,021	23,731	22,874
China Beach	6,576	4,824	3,598	3,852	4,241	4,272	4,829	4,652
Ocean Beach - North	265,865	217,047	172,268	177,452	194,140	188,772	209,455	204,235
Ocean Beach - South	51,166	46,475	37,690	37,676	42,353	40,027	44,044	42,844
Fort Funston	36,748	33,755	26,908	27,218	31,445	29,867	32,727	31,910
San Mateo								
Pacifica Pier	15,462	13,724	10,161	10,152	12,062	11,384	12,625	12,294
Contra Costa								
Point Pinole	7,344	6,781	6,040	6,332	7,301	6,987	7,559	7,573
Keller Beach	1,982	1,797	1,610	1,723	1,988	1,923	2,068	2,080
Ferry Point	1,848	1,733	1,478	1,525	1,805	1,685	1,857	1,842
Vincent Park	3,862	3,254	2,948	3,152	3,672	3,601	3,967	4,208
Shimada Friendship Park	3,731	3,159	2,821	2,968	3,494	3,389	3,736	3,947
Point Isabel	54,605	48,674	42,846	45,394	53,187	51,007	55,770	56,944
Alameda								
Albany Beach	9,941	8,365	7,438	8,071	9,510	9,296	10,234	10,795
Berkeley Pier	14,917	11,626	9,094	10,265	13,553	13,230	14,555	15,751
Gilman Drive	2,785	2,539	2,119	2,074	2,525	2,293	2,574	2,594
Brickyard Cove	1,611	1,415	1,279	1,358	1,568	1,523	1,663	1,722
Berkeley Beach	3,451	3,006	2,764	2,978	3,405	3,349	3,638	3,786
Point Emery	4,328	3,815	3,423	3,607	4,184	4,041	4,422	4,569
Bay Trail	31,263	23,850	20,387	23,482	29,065	28,999	32,309	35,355
Crown Beach	25,198	19,680	17,725	20,159	23,845	23,983	26,849	29,417
Crab Cove	4,846	4,103	3,691	3,902	4,569	4,450	4,904	5,185
Arrowhead Fishing Platform	1,267	1,081	1,022	1,136	1,280	1,287	1,389	1,461
Overall Total[b]	**1,094,522**	**898,969**	**756,293**	**800,108**	**923,395**	**900,165**	**1,016,090**	**1,073,268**

Notes:

[a] - Fishing and boating are excluded from these estimates, as these two activities were addressed in separate analyses.

[b] - Totals may not sum due to rounding.

EXAMPLE CALCULATION

This section demonstrates the approach used to calculate baseline visitation using Albany Beach as an example.

Daily Visitation Index

An automated vehicle counter was deployed at the Albany Beach parking lot entrance throughout the month of November, 2008. This vehicle counter provides a daily count of vehicles entering Albany Beach between 7:00 a.m. and 5:30 p.m.

Predicted Daily Visitation Index

Using regression techniques, the data from this vehicle counter are used to predict vehicle counts for each day of the spill impact period. For example, the regression using November 2008 data indicates that the following relationship holds between vehicle counts (*Count*), daily high temperature (*Temp*), daily total precipitation (*PPT*), and type of day (*Weekday*), where *Weekday* equals one on weekdays and zero on weekend days or holidays:

$$\ln(Count) = 5.12 + 0.02(Temp) - 2.53(PPT) - 0.59(Weekday)$$

This relationship can be used to predict counts for every day of the spill impact period. For example November 10, 2007 was a Saturday with a high temperature of 58.9 degrees and 0.17 inches of precipitation. Therefore, the predicted count for that day is:

$$360 = \exp(5.12 + 0.02x58.9 - 2.53x0.17 - 0.59x0)x1.017$$

The final adjustment of 1.017 allows us to obtain the mean rather than the median of the predicted count, which is a random variable (see Footnote 4).

Trip/Index Ratio

The trip/index ratio is calculated based on trip estimates and vehicle counts at Albany Beach from November 7 to 10, 2008 (Exhibit 10). The trip estimates for these four days were 265 (Friday), 285 (Saturday), 558 (Sunday), and 220 (Monday). The vehicle counts on these four days were 389 (Friday), 443 (Saturday), 671 (Sunday), and 255 (Monday).[7] Thus, the daily trip/index ratios were 0.68 (Friday), 0.64 (Saturday), 0.83 (Sunday), and 0.86 (Monday). The average weekday ratio is 0.77 and the average weekend ratio is 0.74.

[7] Vehicle counts are higher than trip estimates because many vehicles entering the Albany Beach parking lot do not bring visitors to the site. Persons driving to the Albany Beach parking lot can walk or bike to other locations in the area, they can sit in their cars (i.e., to read or listen to music), or they can simply turn around and leave the parking lot without stopping.

EXHIBIT 10: ALBANY BEACH TRIP/INDEX RATIO CALCULATION

	WEEKDAY		WEEKEND	
	NOVEMBER 7	NOVEMBER 10	NOVEMBER 8	NOVEMBER 9
2008 Trip Estimates	265	220	285	558
2008 Automated Counts	389	255	443	671
Trip/Index Ratio	0.68	0.86	0.64	0.83
	0.77		0.74	

Baseline Visits

The predicted daily visitation indices are multiplied by the appropriate trip/index ratio (weekend or weekday) and divided by the proportion of daytime visits to estimate baseline visits for every day of the spill impact period. For example, baseline visits for November 10, 2007 (a weekend) are calculated as:

$$283 = \frac{360x0.74}{0.94}$$

where 0.94 is the proportion of visitation that occurs between 7:00 a.m. and 5:30 p.m. on weekends.

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Lohr, Sharon L. 1999. *Sampling: Design and Analysis*. Duxbury (Pacific Grove, California).

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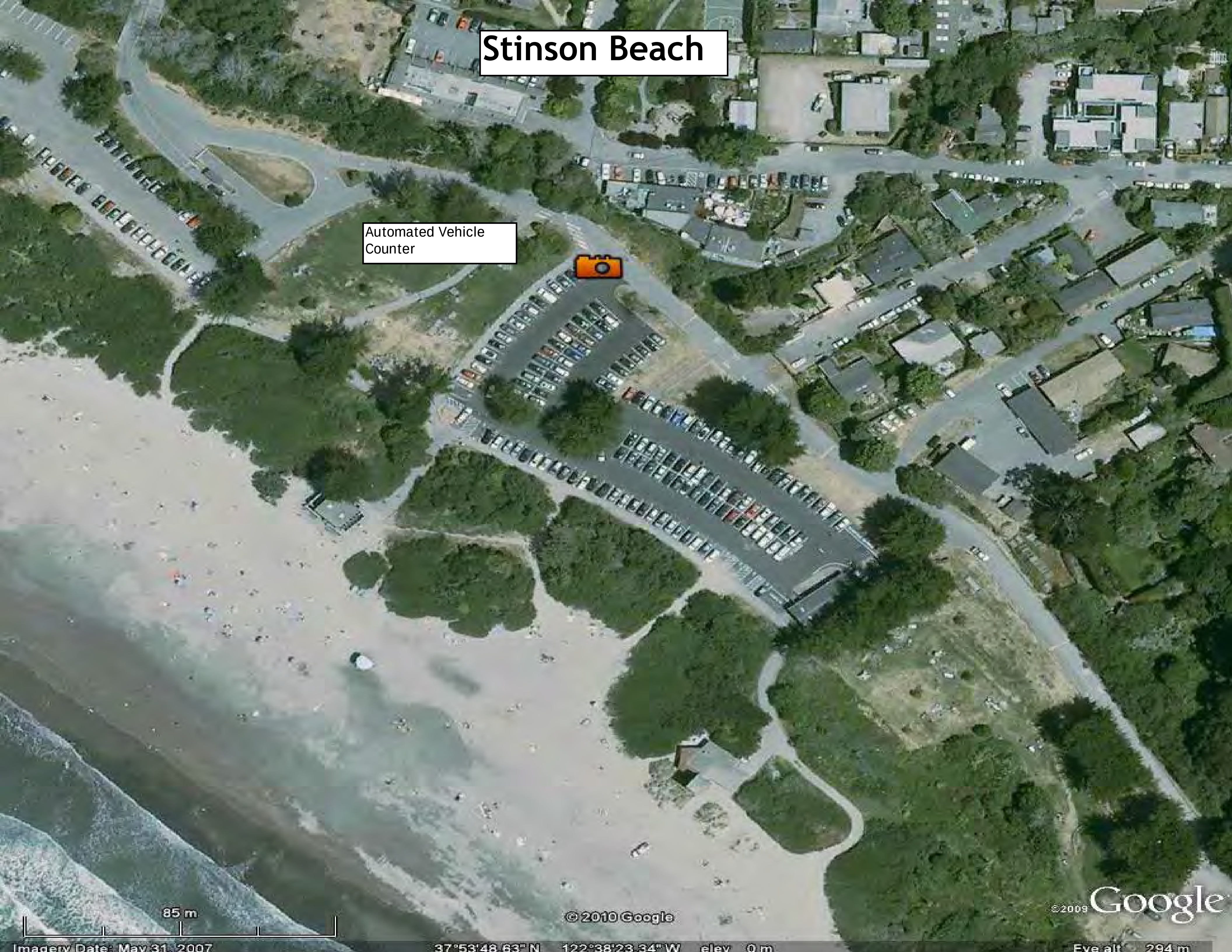
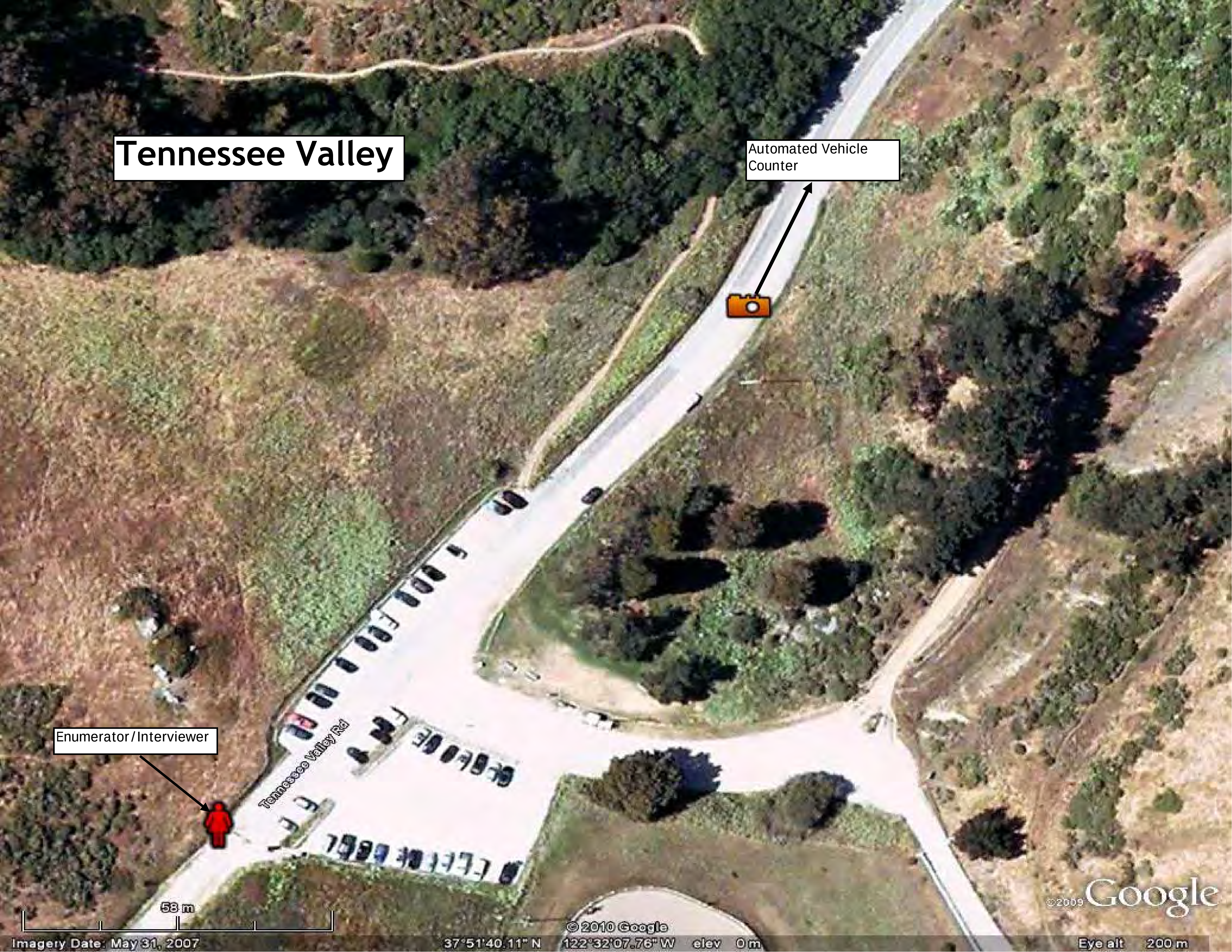
ATTACHMENT A: AUTOMATED COUNTER AND STAFF COUNTER LOCATIONS



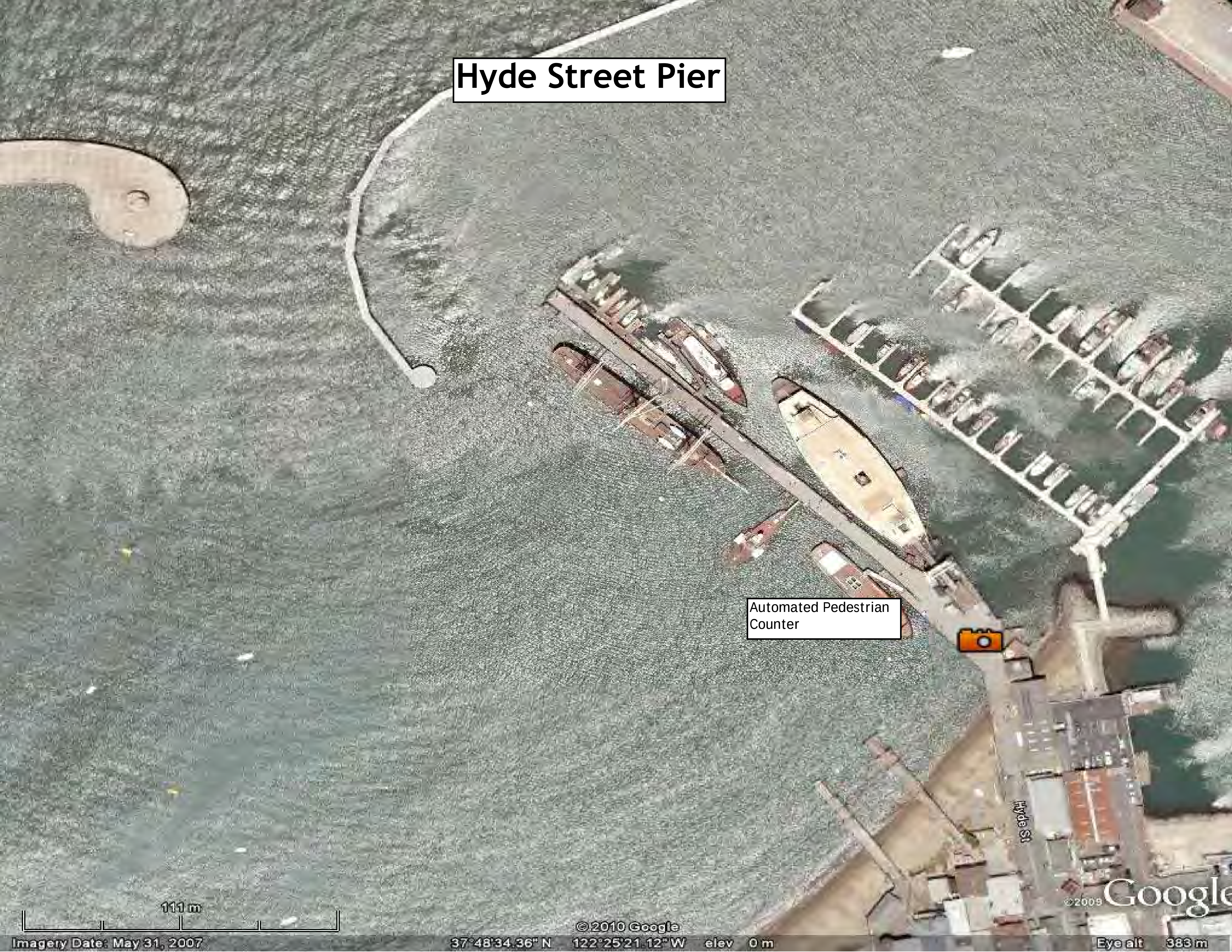
Stinson Beach
Automated Vehicle Counter
85 m
© 2010 Google
©2009 Google
Imagery Date: May 31, 2007
37°53'48.63" N 122°38'23.34" W elev 0 m
Eye alt 294 m


Muir Beach
Automated Vehicle Counter
75 m
© 2010 Google
©2009 Google
Imagery Date: May 31, 2007
37°51'39.11" N
122°34'32.07" W
elev 0 m
Eye alt 259 m



Tennessee Valley
Automated Vehicle Counter
Enumerator/Interviewer
Tennessee Valley Rd
58 m
©2009 Google
© 2010 Google
Imagery Date: May 31, 2007
37°51'40.11" N
122°32'07.76" W
elev 0 m
Eye alt 200 m

Rodeo Beach
Enumerator
Automated Vehicle Counter
178 m
© 2010 Google
©2009 Google
Imagery Date: May 31, 2007
37°49'54.91" N 122°32'06.68" W elev 0 m
Eye alt 615 m


Hyde Street Pier
Automated Pedestrian Counter
Hyde St
©2009 Google
111 m
© 2010 Google
Imagery Date: May 31, 2007
37°48'34.36" N 122°25'21.12" W elev 0 m
Eye alt 383 m

San Francisco Maritime Beach & Promenade
Enumerator
Enumerator/Interviewer
Beach St
60 m
© 2010 Google
Google

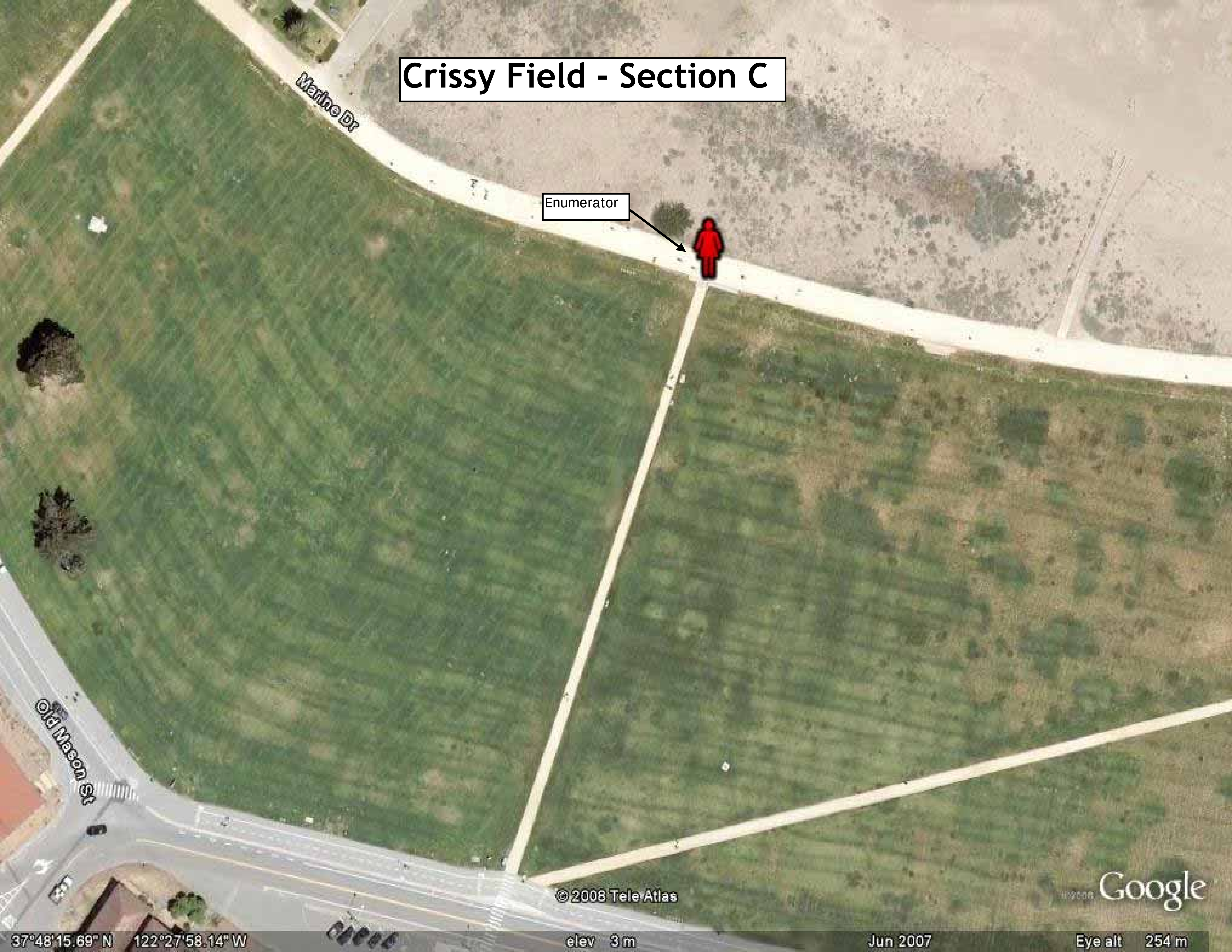
San Francisco Maritime - Municipal Pier

Crissy Field East Beach Parking Lot
Interviewer
Automated Vehicle Counter
Enumerator
47 m
© 2010 Google
©2009 Google
Imagery Date: May 31, 2007
37°48'21.20" N
122°27'03.95" W
elev 0 m
Eye alt 174 m

Crissy Field East Promenade

Crissy Field - Section A


Crissy Field - Section B
Enumerator
Marine Dr
Old Mason St
© 2008 Tele Atlas
Google
37°48'14.70" N
122°27'47.01" W
elev 3 m
Jun 2007
Eye alt 370 m


Crissy Field - Section C
Marine Dr
Enumerator
Old Mason St
© 2008 Tele Atlas
Google
37°48'15.69" N
122°27'58.14" W
elev 3 m
Jun 2007
Eye alt 254 m

Crissy Field - Section D


Crissy Field - Trail Section A
Enumerator
Fort Point Entrance
© 2010 Google
Google

Crissy Field - Trail Section B


Crissy Field West Bluff Parking Lot
Interviewer
Automated Vehicle Counter
Enumerator
63 m
© 2010 Google
©2009 Google
Imagery Date: May 31, 2007
37°48'25.11" N
122°28'10.66" W
elev 0 m
Eye alt 227 m


Fort Point
Marine Dr
Battery East Rd
Automated Vehicle Counter
1
Long Ave
Hamilton St
Cranston Rd
Image © 2010 TerraMetrics
© 2010 Google
©2009 Google
195 m
Imagery Date: May 31, 2007
37°48'35.10" N 122°28'24.64" W elev 0 m
Eye alt 675 m

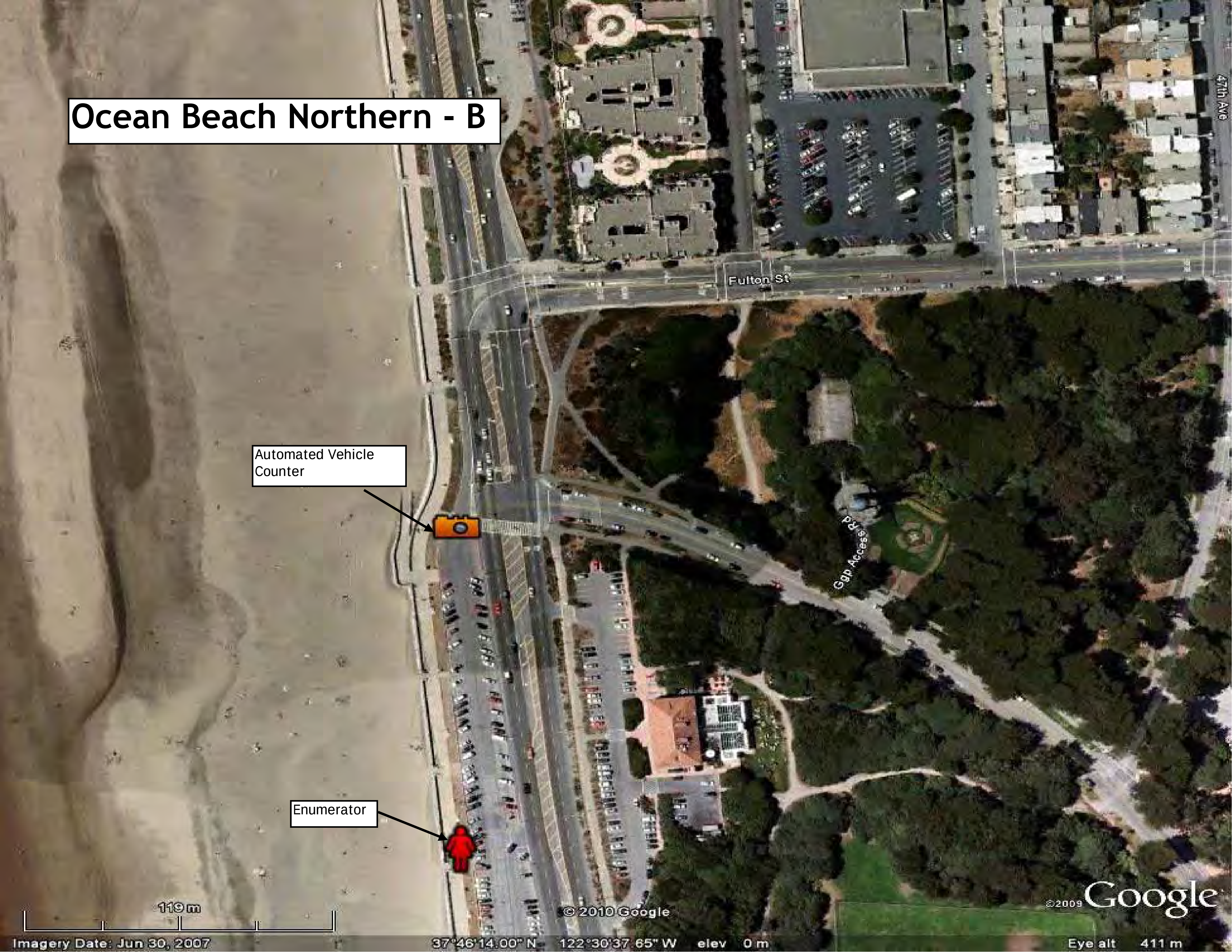

Baker Beach Parking Lot
Automated Vehicle Counter
Enumerator
98 m
© 2010 Google
©2009 Google
Imagery Dates: May 31, 2007 - Jun 30, 2007
37°47'29.46" N
122°29'00.00" W
elev 0 m
Eye alt 339 m


Baker Beach - Sand Ladder Parking Area
Enumerator
22 m
© 2010 Google
©2009 Google
Imagery Date: May 31, 2007
37°47'46.53" N
122°28'47.43" W
elev 0 m
Eye alt 77 m


China Beach
Enumerator
32 m
© 2010 Google
Imagery Date: Jun 30, 2007
37°47'15.90" N
122°29'27.23" W
elev 0 m
Eye alt 110 m
©2009 Google


Ocean Beach Northern - A
Automated Vehicle Counter
Enumerator
Anza St
Sutro Heigh
Balboa St
Great Hwy
Cabrillo St
La Playa St
48th Ave
152 m
Imagery Date: Jun 30, 2007
©2010 Google
37°46'30.67" N 122°30'43.85" W elev 0 m
©2009 Google
Eye alt 525 m

Ocean Beach Northern - B




Ocean Beach Northern - C
Enumerator
John F Ken
South Dr
© 2008 Tele Atlas
©2008 Google
37°45'58.45" N 122°30'36.50" W
elev 5 m
Jul 2007
Eye alt 513 m

Enumerators
Ocean Beach Central Section
Martin Luther King Jr Dr
Lincoln Way
36th Ave
Noriega St
Taraval St
Sunset Blvd
Image © 2010 TerraMetrics
© 2010 Google
©2009 Google
900 m


Ocean Beach - Sloat Parking Lot
Enumerator
Enumerator
Automated Vehicle Counter
Great H
52 m
© 2010 Google
©2009 Google
Imagery Date: Jun 30, 2007
37°44'08.37" N
122°30'25.70" W
elev 0 m
Eye alt 180 m


Ocean Beach - Second Overlook Parking Lot
Enumerator
Enumerator
Armory Rd
Great Hwy (Closed winters)
Great Hwy
68 m
© 2010 Google
©2009 Google
Imagery Date: Jun 30, 2007
37°43'52.22" N
122°30'24.53" W
elev 0 m
Eye alt 235 m


Fort Funston
Automated Vehicle Counter
Fort Funston Rd
104 m
© 2010 Google
Google
Imagery Date: Jun 30, 2007
37°42'53.39" N 122°30'06.30" W elev 0 m
Eye alt 361 m


Pacifica Pier
Enumerator
Automated
Pedestrian Counter
133 m
© 2010 Google
©2009 Google
Imagery Date: Jun 30, 2007
37°38'02.66" N 122°29'44.43" W elev 0 m
Eye alt 459 m

Point Pinole


Keller Beach
Enumerator
35 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°55'15.32" N
122°23'10.88" W
elev 0 m
Eye alt 121 m


Ferry Point
Automated Vehicle Counter
Enumerator
Image © 2010 TerraMetrics
© 2010 Google
©2009 Google
116 m
Imagery Date: Oct 2, 2009
37°54'36.11" N 122°23'23.06" W elev 0 m
Eye alt 441 m


Vincent Park
Automated Vehicle Counter
Enumerator/Interviewer
34 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°54'31.55" N
122°21'01.18" W
elev 0 m
Eye alt 119 m


Shimada Friendship Park
Enumerator
35 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°54'29.72" N 122°20'40.78" W elev 0 m
Eye alt 136 m

Point Isabel Parking Lot North
Enumerator/Interviewer
Automated Vehicle Counter
52 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°54'11.63" N
122°19'12.81" W
elev 0 m
Eye alt 181 m

Point Isabel Parking Lot West


Albany Beach
Enumerator/Interviewer
Automated Vehicle Counter
Albany Bulb
Albany Plateau
Albany Beach
Image © 2010 TerraMetrics
© 2010 Google
284 m
©2009 Google
Imagery Date: Oct 2, 2009
37°53'19.84" N 122°19'10.21" W elev 0 m
Eye alt 1.07 km


Berkeley Pier
Automated Pedestrian Counter
Enumerator
49 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°51'47.20" N
122°19'03.75" W
elev 0 m
Eye alt 169 m


Gilman Drive
Enumerator
Harrison St
Park Way
Buchanan St
Gilman St
Eastshore Fwy
Eastshore Hwy
Frontage Rd
80
580
2nd
Image © 2008 TerraMetrics
© 2008 Tele Atlas
Google
N


Brickyard Cove
Enumerator
Brickyard Cove
161 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°51'53.12" N
122°18'16.63" W
elev 0 m
Eye alt 558 m

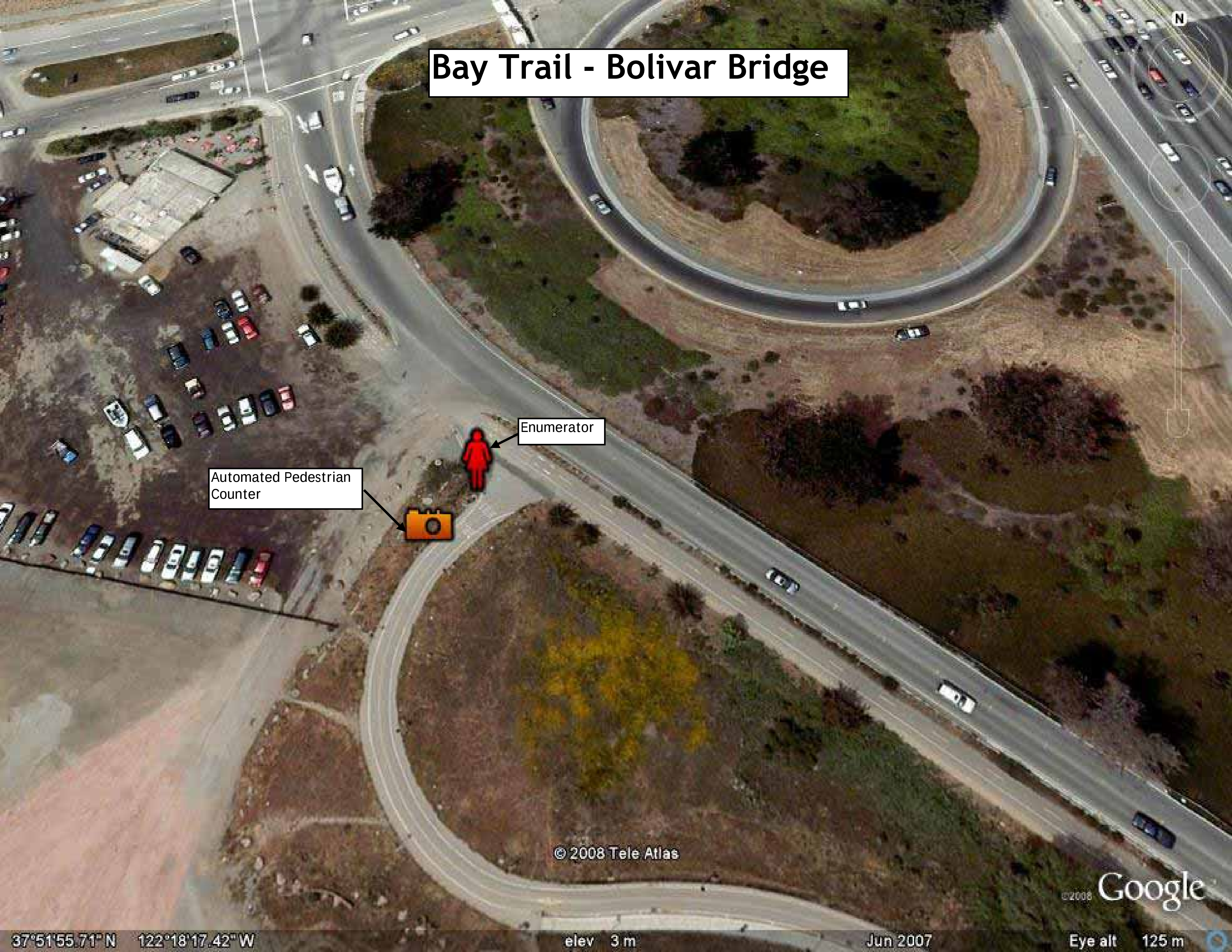
Berkeley Beach
Enumerator
44 m
© 2010 Google
©2009 Google
G-66
Imagery Date: Oct 2, 2009
37°51'04.30" N
122°18'00.45" W
elev 0 m
Eye alt 151 m


Point Emery
Enumerator
Automated Vehicle Counter
33 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°50'46.67" N
122°18'01.12" W
elev 0 m
Eye alt 121 m

Bay Trail - South 51st Street

Bay Trail - Central Avenue

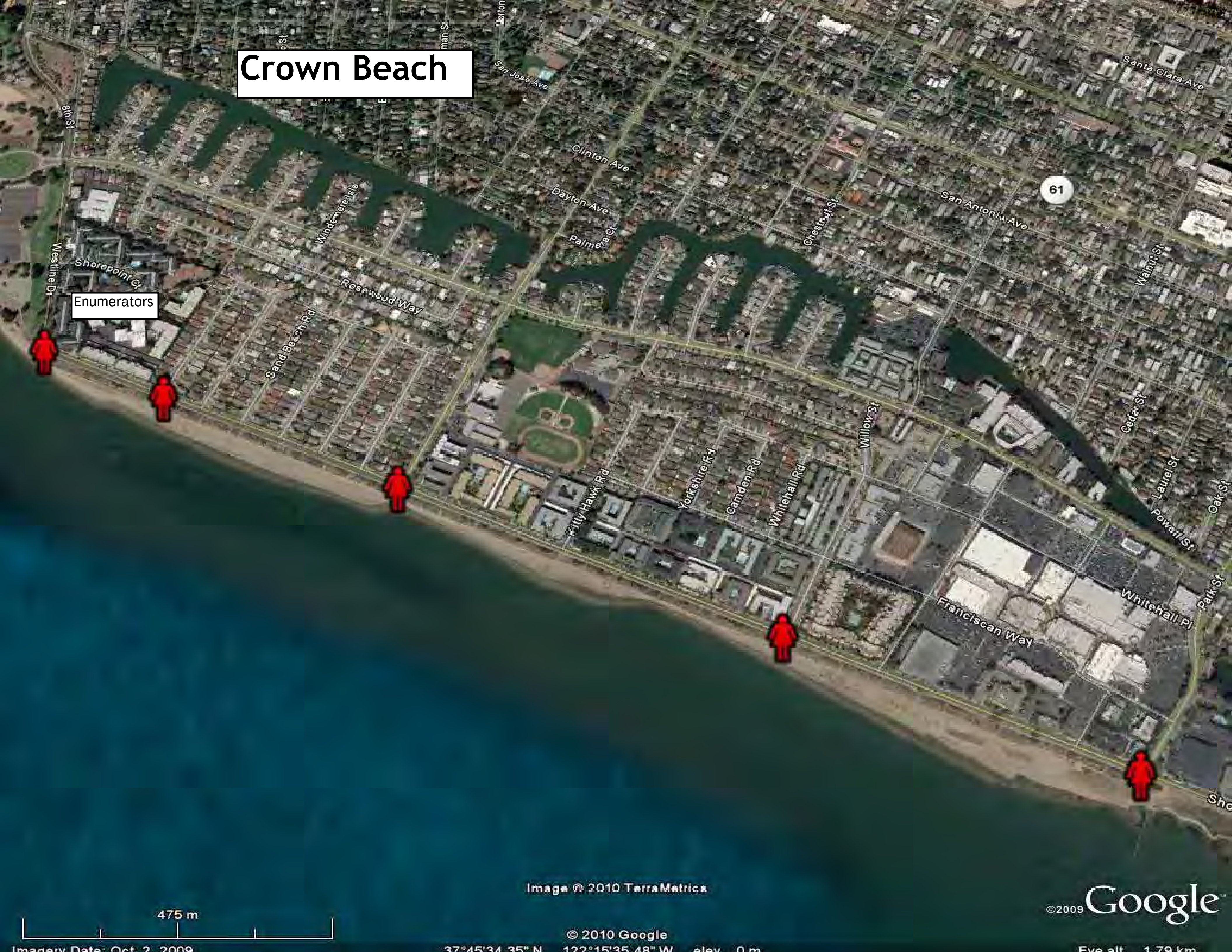
Bay Trail - Buchanan Street
Enumerator
© 2008 Tele Atlas
Google
37°53'18.66" N 122°18'33.63" W
elev 3 m
Jun 2007
Eye alt 143 m
N


Bay Trail - Bolivar Bridge
Enumerator
Automated Pedestrian Counter
© 2008 Tele Atlas
©2008 Google
37°51'55.71" N 122°18'17.42" W
elev 3 m
Jun 2007
Eye alt 125 m
N

Bay Trail - University Avenue
Enumerator
Frontage Rd
University Ave
© 2008 Tele Atlas
Google
37°51'59.60" N
122°18'20.42" W
elev 4 m
Jun 2007
Eye alt 170 m
N

Bay Trail - Captain Dr. at Frontage Rd.

Crown Beach Westline Drive Parking Lot
Enumerator/Interviewer
Automated Vehicle Counter
50 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°45'55.71" N
122°16'19.02" W
elev 0 m
Eye alt 172 m


Crown Beach
Enumerators
Santa Clara Ave
San Jose Ave
Clinton Ave
Dayton Ave
San Antonio Ave
61
Palmera Ct
Chestnut St
Walnut St
Shorepoint Ct
Westline Dr
8th St
Rosewood Way
Sand Beach Rd
Kitty Hawk Rd
Yorkshire Rd
Camden Rd
Whitehall Rd
Willow St
Cedar St
Laurel St
Oak St
Powell St
Park St
Whitehall Pl
Franciscan Way
Image © 2010 TerraMetrics
475 m
© 2010 Google
©2009 Google


Crab Cove
Automated Vehicle Counter
Enumerator/Interviewer
Crab Cove
© 2010 Google
©2009 Google
66 m
Imagery Date: Oct 2, 2009
37°46'09.45" N
122°16'38.16" W
elev 0 m
Eye alt 227 m

Arrowhead Fishing Platform
Enumerator
Automated Vehicle Counter
68 m
© 2010 Google
©2009 Google
Imagery Date: Oct 2, 2009
37°44'31.70" N
122°12'31.23" W
elev 0 m
Eye alt 236 m

ATTACHMENT B

GGNRA AND PACIFICA PIER

DATE	MUIR BEACH	TENNESSEE VALLEY	RODEO BEACH	CRISSY FIELD EAST	CRISSY FIELD WEST	BAKER BEACH	OCEAN BEACH - NORTH	OCEAN BEACH - SOUTH	FORT FUNSTON	PACIFICA PIER
11/1/2008	--	--	372	566	447	315	758	531	466	232
11/2/2008	282	175	563	1,141	736	538	933	768	1,173	933
11/3/2008	174	179	389	616	326	268	501	505	662	227
11/4/2008	171	316	438	879	438	343	536	536	696	292
11/5/2008	160	346	414	850	405	324	616	903	748	351
11/6/2008	302	373	499	1,056	490	508	866	1,041	864	513
11/7/2008	237	477	554	1,191	572	597	846	1,040	926	500
11/8/2008	266	516	452	965	710	490	864	885	834	729
11/9/2008	206	499	1,021	1,854	1,006	815	1219	831	1,453	723
11/10/2008	596	821	492	941	502	406	712	700	822	417
11/11/2008	187	484	534	1,044	531	387	725	764	915	654
11/12/2008	110	372	446	845	423	301	568	745	687	232
11/13/2008	205	460	581	1,096	624	516	751	855	853	416
11/14/2008	250	549	776	1,429	644	952	1152	1,031	1,025	548
11/15/2008	843	1,064	1,523	2,460	1,273	1,814	2095	1,478	1,828	1,324
11/16/2008	742	1,026	1,204	2,247	1,133	1,675	2182	1,241	1,865	1,290
11/17/2008	135	267	498	1,181	531	638	1128	1,077	897	507
11/18/2008	182	509	385	766	435	305	555	698	635	316
11/19/2008	100	298	423	670	398	303	501	620	681	283
11/20/2008	95	350	434	826	411	335	612	665	702	390
11/21/2008	205	487	589	972	549	464	671	777	866	385
11/22/2008	437	755	790	1,518	861	690	1345	983	1,197	985
11/23/2008	471	978	988	1,720	892	855	1562	1,158	1,621	1,082
11/24/2008	178	296	451	744	439	354	760	927	764	380
11/25/2008	123	276	435	668	387	309	809	842	638	261
11/26/2008	107	201	410	462	340	267	708	764	482	206
11/27/2008	--	--	703	1,054	596	482	911	834	1,038	639
11/28/2008	389	580	729	1,076	800	550	1060	948	1,001	742
11/29/2008	568	831	1,066	1,531	938	837	1534	1,121	1,425	1,373
11/30/2008	556	915	1,282	1,783	950	1,025	1695	1,197	1,597	344
Total	**8,277**	**14,401**	**19,440**	**34,152**	**18,790**	**17,662**	**29,175**	**26,466**	**29,361**	**17,273**

Note: the values in this table are not visitation estimates. They are index values that were used in developing the visitation estimates presented in Exhibit 9.

EAST BAY

DATE	POINT PINOLE	FERRY POINT	VINCENT PARK	POINT ISABEL	ALBANY BEACH	BERKELEY PIER	POINT EMERY	BAY TRAIL	CROWN BEACH	CRAB COVE	ARROW-HEAD
11/1/2008	120	33	--	615	271	40	117	56	82	38	35
11/2/2008	364	168	--	1,745	618	524	196	381	158	59	133
11/3/2008	241	54	--	660	156	35	140	96	79	49	64
11/4/2008	339	87	--	1,054	243	149	223	249	139	76	85
11/5/2008	287	80	--	1,087	320	136	187	213	103	60	91
11/6/2008	364	88	--	1,125	399	255	241	202	158	--	86
11/7/2008	285	87	243	1,322	389	200	270	261	157	75	82
11/8/2008	248	87	210	1,466	443	301	187	222	110	43	136
11/9/2008	460	135	297	2,026	671	620	246	469	252	82	96
11/10/2008	350	89	271	1,160	255	233	249	211	113	87	99
11/11/2008	386	115	232	1,348	379	378	216	287	148	54	86
11/12/2008	291	94	200	705	330	131	203	186	133	46	45
11/13/2008	325	100	217	1,104	372	236	242	249	194	75	73
11/14/2008	326	100	196	1,295	432	308	210	299	168	56	60
11/15/2008	447	88	320	1,919	763	815	285	449	265	116	156
11/16/2008	505	131	386	2,254	836	724	326	551	277	85	169
11/17/2008	352	137	219	1,195	289	257	222	245	180	59	104
11/18/2008	368	90	211	1,056	243	139	215	211	191	81	63
11/19/2008	294	93	161	1,007	308	142	180	144	112	57	70
11/20/2008	309	62	167	958	349	182	200	171	129	60	65
11/21/2008	316	94	188	1,298	435	275	210	251	146	48	54
11/22/2008	334	125	321	2,048	614	655	237	405	187	72	83
11/23/2008	377	104	246	2,107	705	822	253	461	236	64	102
11/24/2008	281	95	158	1,100	253	162	169	152	138	64	59
11/25/2008	340	53	121	1,053	222	151	167	121	115	64	71
11/26/2008	224	56	148	769	256	70	141	82	72	27	62
11/27/2008	237	109	135	1,113	415	603	152	257	151	36	41
11/28/2008	381	86	146	1,285	445	577	185	210	118	36	51
11/29/2008	358	159	282	1,688	527	783	215	388	172	81	84
11/30/2008	478	147	308	1,957	622	787	251	522	172	81	87
Total	**9,987**	**2,946**	**5,383**	**39,512**	**12,560**	**10,688**	**6,328**	**7,995**	**4,655**	**2,076**	**2,492**

Note: the values in this table are not visitation estimates. They are index values that were used in developing the visitation estimates presented in Exhibit 9.

ESTIMATED REGRESSION COEFFICIENTS[a]

LOCATION	NO. OF OBSERVATIONS	R^2	ESTIMATED COEFFICIENTS[b]			
			CONSTANT	TEMP	PRECIPITATION	WEEKDAY
Muir Beach	28[a]	0.61	4.05***	0.03***	-2.30	-0.71***
Tennessee Valley	28[a]	0.48	5.25***	0.02*	-4.12*	-0.48**
Rodeo Beach	30	0.80	5.18***	0.02***	-1.15***	-0.51***
Crissy Field East	30	0.90	5.22***	0.03***	-0.64***	-0.48***
Crissy Field West	30	0.90	5.32***	0.02***	-0.44***	-0.58***
Baker Beach	30	0.87	3.72***	0.05***	-1.26***	-0.51***
Ocean Beach – North	30	0.89	5.00***	0.03***	-0.72***	-0.49***
Ocean Beach - South	30	0.73	5.53***	0.02***	-0.85***	-0.17***
Fort Funston	30	0.89	5.87***	0.02***	-1.41***	-0.48***
Pacifica Pier	30	0.80	5.10***	0.03***	-1.76***	-0.80***
Point Pinole	30	0.61	5.33***	0.01*	-2.85***	-0.11
Ferry Point	30	0.63	4.18***	0.01	-3.51***	-0.26***
Vincent Park	24[a]	0.50	4.22***	0.02***	-1.59	-0.27**
Point Isabel	30	0.80	6.59***	0.01***	-2.90***	-0.43***
Albany Beach	30	0.82	5.12***	0.02***	-2.53***	-0.59***
Berkeley Pier	30	0.93	4.74***	0.03***	-8.46***	-1.14***
Point Emery	30	0.67	4.43***	0.02***	-1.97***	-0.06
Bay Trail	30	0.80	4.24***	0.03***	-5.08***	-0.44***
Crown Beach	30	0.75	3.51***	0.03***	-2.51***	-0.24***
Crab Cove	29[a]	0.34	2.86***	0.02**	-1.55*	-0.01
Arrowhead Fishing Platform	30	0.34	3.51***	0.02*	-2.06**	-0.21*

Notes:
[a] - The following days were excluded from the model at the sites indicated:

- Tennessee Valley and Muir Beach on Nov. 1 and 27 (no staff assigned);
- Vincent Park on Nov. 1-6 (City of Richmond installed counter on Nov. 6); and,
- Crab Cove on November 6 (outlier due to cross country meet).

[b] - *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

ATTACHMENT D

PREDICTED VISITATION INDEX FOR SPILL IMPACT PERIOD[a,b]

SITE	ACTUAL COUNTS - 2008	PREDICTED COUNTS – NOVEMBER 2007 TO JUNE 2008							
	NOVEMBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
Stinson Beach	7,773	11,477	9,299	6,422	6,665	8,130	7,941	8,788	8,615
Muir Beach	8,277	8,553	7,235	5,397	5,648	6,668	6,461	7,161	7,006
Tennessee Valley	14,401	15,114	13,979	10,298	10,800	13,505	12,951	14,146	13,880
Rodeo Beach	19,440	19,035	16,795	13,610	14,004	15,786	15,197	16,658	16,295
Hyde Street Pier	23,788	27,911	21,053	14,977	17,396	21,822	15,852	26,607	29,254
Crissy Field East	34,152	29,636	23,526	20,667	23,241	27,499	27,786	30,620	35,675
Crissy Field West	18,790	16,855	14,660	13,056	13,896	16,025	15,687	17,100	18,372
Fort Point	18,948	25,952	18,626	20,810	20,090	21,740	21,736	29,016	32,119
Baker Beach	17,662	17,416	12,817	9,756	10,652	11,663	11,735	13,497	12,893
Ocean Beach – North	29,175	28,708	23,432	18,972	19,881	21,637	21,164	23,558	22,950
Ocean Beach – South	26,466	26,565	23,866	20,290	20,916	23,131	22,416	24,267	23,804
Fort Funston	29,361	28,871	26,384	21,405	21,884	25,091	24,037	26,184	25,607
Pacifica Pier	17,273	16,781	14,773	11,340	11,616	13,566	12,984	14,319	13,992
Point Pinole	9,987	10,120	9,193	8,397	8,970	10,214	9,957	10,635	10,732
Ferry Point	2,946	2,965	2,688	2,410	2,581	2,977	2,881	3,096	3,115
Vincent Park	5,383	6,341	5,322	4,878	5,281	6,104	6,035	6,647	7,072
Point Isabel	39,512	38,921	34,454	30,679	32,830	38,210	36,947	40,228	41,209
Albany Beach	12,560	12,167	10,264	9,080	9,799	11,587	11,287	12,432	13,095
Berkeley Pier	10,688	10,122	7,834	6,195	7,057	9,246	9,060	9,994	10,830
Point Emery	6,328	6,327	5,500	5,078	5,493	6,266	6,182	6,706	6,987
Bay Trail	8,979	8,823	6,680	5,787	6,758	8,282	8,308	9,295	10,189
Crown Beach	4,655	4,561	3,561	3,209	3,652	4,318	4,344	4,864	5,330
Crab Cove	2,076	1,891	1,583	1,472	1,613	1,846	1,841	2,026	2,162
Arrowhead Fishing Platform	2,492	2,480	2,152	1,965	2,118	2,434	2,389	2,602	2,711

Notes:

[a] - The values in this table are not visitation estimates. They are index values that were used in developing the visitation estimates presented in Exhibit 9.

[b] – As described in the text, daily visitation indices were not available for three sites: Stinson Beach, Hyde Street Pier, and Fort Point. For these sites, the predicted visitation index was determined by averaging monthly counts from NPS automated counters over a six-year period: the five years immediately preceding the spill and one year following the spill.

ATTACHMENT E

SITE-SPECIFIC SURVEY APPROACHES

SITE	APPROACH
EAST BAY	
Point Pinole	On-site counts were conducted at the main parking lot to determine the number of visitors using the park. The counts were conducted from a vantage point near the shuttle stop that provided a view of all visitors leaving the park to enter the parking lot and all visitors leaving the park on the trail to the police station.
Miller/Knox – Keller Beach & Ferry Point	On-site counts were conducted at Keller Beach (beach) and Ferry Point (fishing pier) to determine the number of visitors exiting.
Vincent Park & Shimada Friendship Park	One field staff person alternated every hour between the two parks, with the initial location randomly selected on the first day of sampling and alternating every day thereafter. The last sampling period every day was 1 ½ hours long, from 4:00 to 5:30 p.m. • Vincent Park: On-site counts were conducted at the main parking lot to determine the number of visitors leaving the parking lot. Counts were separated into two categories: 1) departures from the parking lot and 2) departures from the park on the portion of the Bay Trail that runs along the north side of Peninsula Drive. • Shimada Park: On-site counts were conducted to determine the number of visitors and were separated into two categories: 1) departures from the Bay Trail and shoreline area, and 2) departures from the picnic area. For the visitors who are recorded as exiting the picnic area, field staff kept separate counts of visitors who used the shoreline during their visit and those who did not.
Eastshore State Park – Point Isabel	On-site counts were conducted at the two main parking lots. • At the Rydin Road lot, field staff stood at the parking lot entrance, counting all visitors leaving in vehicles, on bicycle, or on foot down Rydin Road. The individual posted at this location counted 1) number of departing vehicles, 2) number of people in each vehicle, and 3) number of departing walkers and bicyclists. • At the Isabel Street lot, field staff stood where the bike path crosses Isabel Street, and counted all visitors leaving in vehicles or on foot going east on Isabel Street.
Eastshore State Park – Albany Beach	On-site counts were conducted at the main parking lot. Field staff counted visitors exiting the park via the parking lot and via the path that runs along the northern side of Buchanan Street.
Berkeley Pier	On-site counts were conducted at the entrance to the pier to determine visitors leaving the pier.

SITE	APPROACH
Eastshore State Park – Gilman Drive & Brickyard Cove	On-site counts were conducted at the two parking areas to determine the number of visitors exiting the park. A single field staff person alternated every hour between the two parks, with the initial location randomly selected on the first day of sampling and alternating every day thereafter. The last sampling period of the day was 1 ½ hours long, from 4:00 to 5:30 p.m. • At Gilman Street, field staff counted visitors leaving the shoreline area. In addition, field staff maintained a separate count of visitors exiting the Bay Trail going east on Gilman Street. Field staff did not count individuals who exited the sports field located to the east of the parking lot. • At Brickyard Cove, field staff maintained separate counts of 1) visitors leaving the Brickyard Cove walking trails, and 2) visitors getting into their vehicles after leaving the Bay Trail.
Eastshore State Park – Berkeley Beach & Point Emery	On-site counts were conducted at the two parking lots to determine the number of visitors exiting. A single field staff person alternated every hour between the two parks, wit the initial location randomly selected on the first day of sampling and alternating every day thereafter. The last sampling period every day was 1 ½ hours long, from 4:00 to 5:30 p.m. Field staff maintained separate counts of visitors getting into their vehicles after leaving the Bay Trail.
Bay Trail	On-site counts were conducted at points where visitors exit the Bay Trail, including the pedestrian/bike bridge over I-80 at Bolivar Drive, several local avenues that intersect the Trail, and the southern/northern endpoints of the central portion of the Trail. There are five additional entry/exit points along the central section of the Bay Trail that are not already covered by sampling efforts: 51st Street, Central Avenue, Buchanan Street, University Avenue, and Frontage Road at Shorebird Park. On-site counts were conducted at each of these five sites for two hours a day. Field staff rotated through the five sites during the day, moving to a new site every two hours. The first site was randomly selected at the beginning of each day. Thereafter, the individual moved to the next closest site to the south, returning to the northernmost site after counting at the southernmost site. The final site on each sampling day was sampled for 2 ½ hours, from 3:00 to 5:30 p.m. • At the Bolivar Drive Bridge over I-80, on-site counts were conducted to determine the number of visitors leaving the Bay Trail. • 51st Street: Counted all individuals entering 51st Street from the Bay Trail. • Central Avenue: Counted all individuals leaving the Bay Trail (located both south of Central Avenue and east of Rydin Road) and heading east on Central Avenue. • Buchanan Street: Counted all individuals coming from the north on the Bay Trail and going under I-80 towards the east (either on Buchanan Street or on the bike trail located just north of Buchanan Street). • University Avenue: Counted all individuals leaving the Bay Trail (from the north or the south) and heading east on University Avenue over I-80. • Captain Drive at Frontage Road: Counted all individuals traveling south on the Bay Trail.

<table>
<tr><th>SITE</th><th>APPROACH</th></tr>
<tr><td>Crown Memorial State Park</td><td>On-site counts were conducted at three sites to determine the number of visitors exiting. In addition, on-site counts were conducted at the bike trail along Shoreline Drive. During each shift, three field personnel counted visitors leaving the Crab Cove and Crown Beach areas:
At the Crab Cove parking area, on-site counts were conducted at the parking lot to determine the number of visitors exiting the park towards McKay Avenue (including pedestrians and bikers).
At the large parking lot off of Westline Drive on-site counts and interviews were conducted at the parking lot. For the first 45 minutes of each hour, field staff counted 1) the number of departing vehicles, 2) the number of people in each vehicle, and 3) the number of walkers and bicyclists exiting the main entrance onto Westline Drive. (Interviews were conducted for the last 15 minutes of each hour).
There are five additional principal entry/exit points to Crown Beach along Shoreline Drive: at the northern end of Shoreline Drive where it intersects with Westline Drive, at Shell Gate Road, at Grand Street, at Willow Street, and at Park Street. On-site counts were conducted at each of these five sites to determine exits from the beach.
Field staff rotated through the five sites during the day, moving to a new site every two hours. The first site was randomly selected at the beginning of the first day. Thereafter, the individual moved to the next closest site to the south, returning to the northernmost site after counting at the southernmost site. The final site on each sampling day was sampled for 2 ½ hours, from 3:00 to 5:30 p.m.
Field staff maintained two separate departure counts: 1) visitors exiting the beach and 2) visitors exiting the paved path that is parallel to the beach. The counts for the paved path included all visitors crossing the road and entering the local neighborhoods from the paved path. In addition, at the northernmost location, field staff also counted all visitors exiting the path and heading north on Westline Drive. At the southernmost location, field staff counted all visitors who exited the path south of this location, including visitors crossing the road and those heading northeast on Broadway. The counts did not include visitors exiting the path to enter Crown Beach.</td></tr>
<tr><td>Arrowhead Fishing Platform (MLK Jr.)</td><td>On-site counts were conducted at the fishing pier to determine the number of visitors exiting the pier. Individuals who passed by the pier on the walking path, but that did not go onto the pier were not counted. Sampling at MLK Jr. was conducted between 8:00 a.m. and 5:30 p.m. because the fishing pier can not be accessed until park staff open the gate to the parking lot in the morning.</td></tr>
<tr><td colspan="2">SAN FRANCISCO, MARIN, SAN MATEO</td></tr>
<tr><td>Tennessee Valley</td><td>On-site counts were conducted at the parking lot to determine the number of visitors exiting the walking trail.</td></tr>
<tr><td>Rodeo Beach</td><td>On-site counts were conducted to determine the number of visitors exiting the beach. One person equipped with binoculars observed all Rodeo Beach departures from a single vantage point. Departures occurred at the parking lot at the end of Mitchell Road, at the pedestrian bridge, at the Rodeo Lagoon trail, and at the Battery Smith-Guthrie Trail. Departures into the parking lot were tallied as visitors came off the beach and crossed the line of logs along the southern edge of Mitchell Road. Field personnel kept separate counts for three groups of visitors: 1) school groups, 2) visitors departing directly into the parking lot at the end of Mitchell Road, and 3) visitors departing on the pedestrian bridge or on either of the two trails.</td></tr>
</table>

SITE	APPROACH

San Francisco Maritime	On-site counts were conducted at two separate areas:
	• At the stadium seating area just east of the Maritime Museum on-site counts and interviews were conducted. Interviews and counts were performed on an alternating schedule by a single person. For the first 45 minutes of each hour, field staff faced the lagoon and counted visitors passing along the promenade in one direction (either from west to east or from east to west). The counting direction alternated every hour, with the initial direction randomly selected on the first day of sampling and alternating every day thereafter. For the last 15 minutes of every hour, field staff conducted interviews with walkers passing along the promenade in the same direction as the most recent counting period.
	• At Municipal Pier and the beach at Aquatic Park, on-site counts were conducted to determine the number of visitors exiting.
	    o Departures from Municipal Pier were counted at the entrance to the pier.
	    o Departures from the beach at Aquatic Park were counted from a lamppost located near the midpoint of the beach. For ½ hour, field staff counted departures from the eastern half of the beach. Then, field staff counted departures from the western half of the beach for ½ hour.
	    o Field staff alternated every hour between the two sites, with the initial location randomly selected on the first day of sampling and alternating every day thereafter. The last sampling period every day was 1 ½ hours long, from 4:00 to 5:30 p.m.

Crissy Field	On-site counts were conducted at Crissy Field to determine the number of visitors using the waterfront area (i.e., waterfront promenade, pier, and beaches). During each shift, five field personnel counted visitors leaving the waterfront area of Crissy Field:
	• One person was stationed at the eastern border of Crissy Field on the promenade in a location that provided a view of the two trails exiting the park (one exiting at the northeast corner near the waterfront and one exiting via a diagonal path off of Mason Drive at the southeast corner).
	• One person was stationed at the one-way road used by vehicles to exit the East Beach parking lot. The individual posted at this location counted 1) number of departing vehicles, 2) number of people in each vehicle and, 3) number of departing walkers and bicyclists.
	• One person rotated among four promenade locations between the lagoon and the West Bluff parking lot:
	    o Near the northwest corner of the lagoon, where two paths leave the promenade heading towards Mason Street.
	    o At the promenade end of the path that runs perpendicular to Mason Street and ends at Battery Sherwood.
	    o At the promenade end of the path that begins just east of the NOAA building.
	    o At the promenade end of the path opposite the NOAA building.
	When at location A, field staff counted departures on both the diagonal path and the path that runs along the western edge of the lagoon. When at location D, the individual counted departures along the path opposite the NOAA building and any visitors leaving the waterfront area to head east on Mason Street. Visitors who spend time on the grassy field without entering the waterfront area were not counted. Field staff rotated through the four locations (A, B, C, D) during the day, moving to a new location every ½ hour. The first location was randomly selected on the first sampling day. Thereafter, field staff moved to the next closest location to the west, returning to the easternmost location (A) after counting at the westernmost location (D).
	• One person rotated every two hours between two locations:
	    o The intersection of the hiking trail descending from Battery East and Long Avenue.
	    o The trail intersection between the lagoon and the East Beach parking lot.

SITE	APPROACH
	When at location A, the person counted all walk-in and bike-in visitors exiting the waterfront area via Long Avenue or the hiking trail. When at location B, the person counted all visitors exiting the waterfront area (heading towards Mason Street) on the trails between the lagoon and the East Beach lot. The initial location was randomly selected on the first day of sampling and alternate every day thereafter. The final site on each sampling day was sampled for 2 ½ hours, from 3:00 to 5:30 p.m. • One person was stationed at the exit from the West Bluff parking lot. The individual posted at this location counted 1) number of departing vehicles, 2) number of people in each vehicle and, 3) number of departing walkers and bicyclists.
Baker Beach	On-site counts were conducted at two locations: • At the entrance to the main parking lot, on-site counts determined 1) number of departing vehicles, 2) number of people in each vehicle and, 3) number of departing walkers and bicyclists. • At the entrance to the Sand Ladder Trail, on-site counts determined the number of visitors exiting. Departures from the Sand Ladder Trail and the Coastal Trail were counted from a single vantage point where the Sand Ladder Trail meets Lincoln Boulevard. All departures were counted on a single form. Field staff alternated every two hours between counting departures at the main parking lot and counting departures at the Sand Ladder and Coastal Trails. The initial counting location was randomly selected on the first day of sampling and alternated every day thereafter. The final site on each sampling day was sampled for 2 ½ hours, from 3:00 to 5:30 p.m. On the two weekend days of the survey, the main parking lot filled to capacity and some vehicles that entered the parking lot subsequently exited without finding a parking space, then re-entered the beach on foot. The enumerator located at the main entrance likely counted a portion of the individuals exiting the main parking area on two occasions – once when they exited the parking lot in their vehicle and once when they exited the parking lot on foot. When calculating the counts at this site on these days, we adjust our counts to remove potential extra counts.
China Beach	On-site counts were conducted to determine the number of visitors exiting the beach.

Ocean Beach	On-site counts were conducted to determine the number of visitors exiting the beach. During each shift, six field personnel counted visitors completing trips to Ocean Beach:
	• In the northern section, on-site counts were conducted from 14 subsections between the Cliff House and Lincoln Way. The fourteen subsections were divided into three contiguous groups, each with dedicated field staff:
	  o The first group (A) consisted of the four northern subsections, from Stairwell 1 to Stairwell 8.
	  o The second group (B) consisted of the five central subsections, from Stairwell 9 to Stairwell 18.
	  o The third group (C) consisted of the five southern subsections, from Stairwell 19 to Stairwell 28.
	
	Field staff were stationed at the southernmost stairwell in the subsection being counted. They looked north along the boardwalk during the ½ hour counting period and recorded all departures from the beach via the two stairwells in the subsection. In addition, field staff counted all visitors exiting the boardwalk/promenade that is parallel to Ocean Beach. This included separate counts of a) all departures from the beach via the two stairwells and b) all departures from the boardwalk to the parking lot. In the northernmost subsection, counts for (b) also included all visitors exiting the boardwalk heading north towards the Cliff House. In the southernmost subsection, counts for (b) also included all visitors exiting the boardwalk heading south towards Lincoln Way. The section of boardwalk that was monitored stretched from the counter's position just south of a stairwell to a point just south of the third stairwell north of the counter. For example, when monitoring departures from Stairwells 3 and 4, the counter observed

<table>
<tr><th>SITE</th><th>APPROACH</th></tr>
<tr><td></td><td>
boardwalk departures from just south of Stairwell 4 to just south of Stairwell 2. The northern boundary of the monitored section was marked with traffic cones.
Field staff assigned to each group (A, B, or C) rotated through that group's subsections during the day, moving to a new subsection every ½ hour. The initial subsection for each group was randomly selected on the first sampling day. Thereafter, field staff moved to the next closest subsection to the south, returning to the northernmost subsection after counting at the southernmost subsection.

In the central section (grouped with the northern section in the visitation estimates in the main body of the report), on-site counts were conducted at eight access points between Lincoln Way and Sloat Boulevard. The eight access points were: Lincoln Street, Judah Street, Lawton Street, Noriega Street, Pacheco Street, Rivera Street, Taraval Street, and Vicente Street. Field staff rotated through the eight access points during the day, moving to a new access point every hour. The first access point was randomly selected on the first sampling day. Thereafter, field staff moved to the next closest access point to the south, returning to the northernmost access point after counting at the southernmost access point. The final access point on each day was counted for 1 ½ hours, from 4:00 p.m. to 5:30 p.m.
In the southern section, on-site counts were conducted at the Sloat Boulevard and Second Overlook parking lots. Field staff generated counts of a) all departures from the beach via the two stairwells and b) all departures from the overlook area (bluff) to the parking lot.

At Sloat one field staff was stationed on the beach at the base of the path that ascends to the parking lot. This individual counted all visitors exiting the beach. A second field staff was stationed on the bluff between the parking lot and the beach. This individual counted all visitors exiting the bluff to the parking lot.
At Second Overlook parking one field staff was stationed on the bluff near the northern end of the parking lot. This individual looked south along the bluff to a point defined by a traffic cone and recorded all departures from the beach via the paths leading up from the beach within this zone. In addition, this individual counted all visitors exiting the bluff between the parking lot and the beach in this same area. A second field staff was stationed on the bluff at the traffic cone. This individual looked south along the bluff in the remainder of the parking area and record all departures from the beach via the paths leading up from the beach. In addition, this individual counted all visitors exiting the bluff between the parking lot and the beach in this same area.

Field staff alternated every hour between the two parking lots, with the initial location randomly selected on the first day of sampling and alternating every day thereafter. The last sampling period every day was 1 ½ hours long, from 4:00 p.m. to 5:30 p.m.
</td></tr>
<tr><td>Pacifica Pier</td><td>On-site counts were conducted at the entrance to the pier to determine the number of visitors exiting the pier.</td></tr>
</table>

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Recreational Fishing Damages Due to the *Cosco Busan* Oil Spill

30 December 2010

prepared for:

Cosco Busan Natural Resource Damage Assessment

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INTRODUCTION

On November 7, 2007, the *Cosco Busan* struck the Bay Bridge in San Francisco Bay, spilling approximately 58,000 gallons of intermediate fuel oil. Seven days later, on November 14, the State of California closed the commercial and recreational marine fisheries from Point Reyes to San Pedro Point, including San Francisco Bay and all areas within three nautical miles of the outer coast (Exhibit 1; CADFG, 2007). The closure was lifted on November 29, 2007, and the following advisory was issued: "It is possible that residual oil may remain on the water over the next several months. Recreational and commercial fishers should avoid exposure of their take to these residual pockets."

This report describes the calculation of economic losses to recreational anglers due to the *Cosco Busan* spill. The losses estimated in this report are based on the economic concept of consumer surplus (USDOI, 1987). An angler's consumer surplus from a fishing trip represents the difference between (1) the maximum amount that the angler would be willing to pay for the trip and (2) the amount that the angler actually paid for the trip (in gasoline, bait, etc.). Thus, consumer surplus is a measure of the net economic value of a fishing trip, after all expenses have been paid.

The analysis was conducted in two stages. First, publicly available data from the California Recreational Fisheries Survey are used to estimate the number of fishing days lost due to the spill. Second, a published study from the economics literature is used to estimate the value of a fishing day. Total damages are estimated by multiplying the number of lost fishing days by the value of a fishing day.

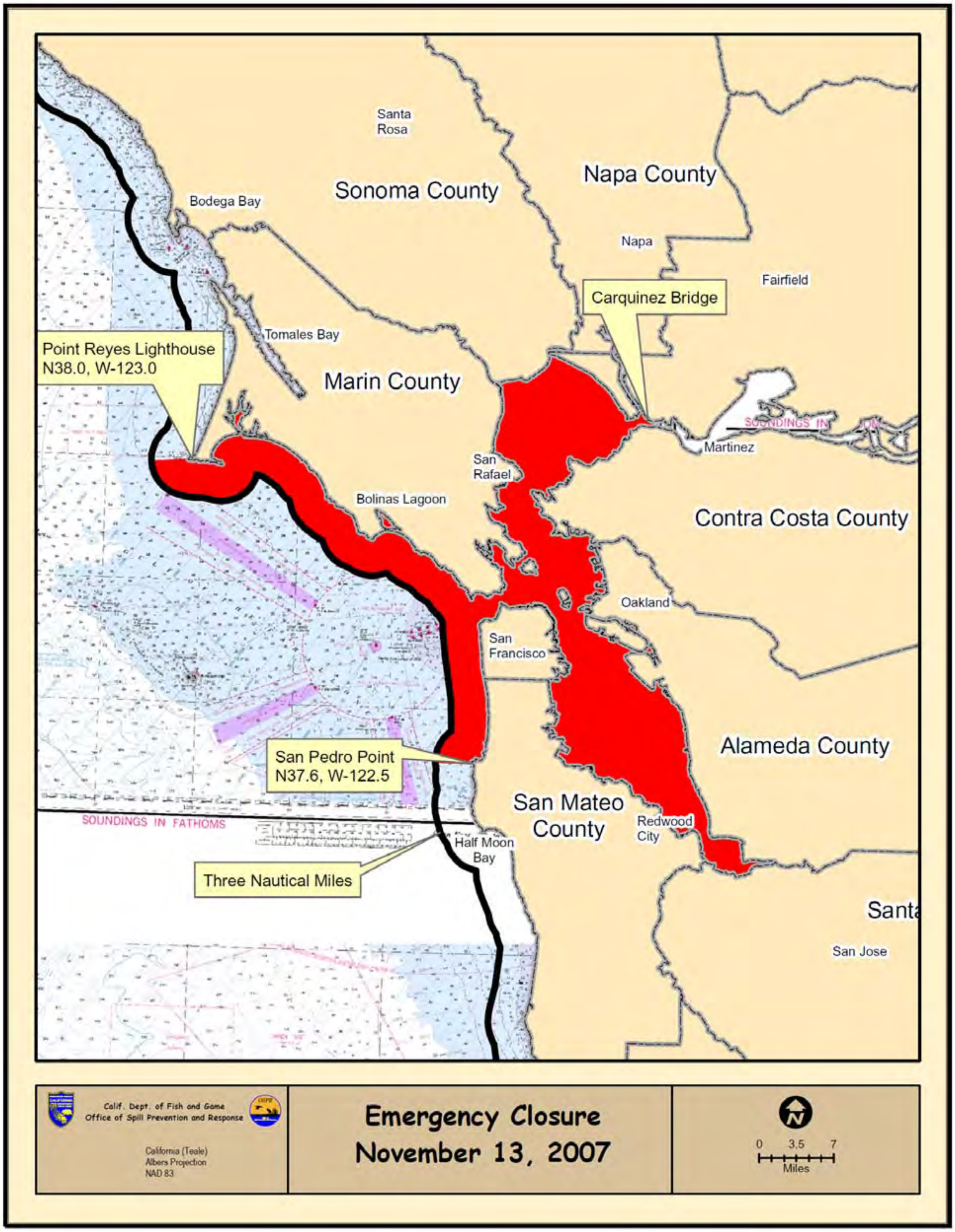
LOST FISHING DAYS

Fishing pressure estimates from the California Recreational Fisheries Survey (CRFS) are used to determine the number of lost fishing days.[1] The CRFS program uses a combination of access point surveys, telephone interviews with licensed anglers, and telephone interviews with licensed charter boat operators to develop monthly saltwater fishing pressure estimates for all coastal regions in California (PSMFC 2006). The CRFS estimates for the San Francisco Bay area are used in the current analysis. These estimates include all saltwater recreational angling within three miles of the coast from Sonoma County to San Mateo County, including all fishing within San Francisco Bay.

Lost fishing days are calculated by comparing fishing pressure in the San Francisco Bay area during the post-spill time period to fishing pressure during a reference period designated as "baseline." The post-spill time period is November 2007 to January 2008. This time period extends somewhat beyond the time period of the official closure because some anglers may have avoided the fishery even after the closure was lifted due to lingering concerns about spill-related impacts.

[1] CRFS estimates were obtained from http://www.recfin.org/forms/est2004.html.

EXHIBIT 1: RECREATIONAL FISHING CLOSURE AREA



The baseline time period was selected to reflect the level of fishing pressure that would have existed in the San Francisco Bay area if the spill had not occurred. Specifically, fishing pressure estimates from two years prior to the spill (November 2005 to January 2006), one year prior to the spill (November 2006 to January 2007), and one year after the spill (November 2008 to January 2009) were used to represent baseline conditions. Multiple years were used in the analysis to minimize the impact of anomalous fishing conditions during any particular year.[2] Pressure estimates from more than two years before the spill were not utilized because two changes in CRFS estimates occurred in 2005, making it difficult to compare pre-2005 estimates with estimates from 2005 and later: (1) the methodology used to develop fishing pressure estimates was modified and (2) the geographic region covered by the San Francisco Bay area estimates was changed.

The CRFS estimates of San Francisco Bay area fishing pressure for the post-spill and baseline time periods are summarized in Exhibit 2. Separate estimates are provided for boat fishing and shore fishing. Boat fishing is defined as fishing from private, rental, party, or charter boats. Boat fishing estimates were obtained by summing CRFS "private and rental" and "commercial passenger fishing vessel" estimates. Shore fishing is defined as fishing that occurs from the shore either on man-made structures such as piers and docks, or from natural areas such as beaches or banks. Shore fishing estimates were obtained by summing CRFS "man-made structures" and "beach and bank" estimates. Since the CRFS fishing pressure estimates for man-made structures only include fishing that occurs during daylight hours, the man-made structure estimates were adjusted to account for night fishing. The night fishing adjustment is derived from automated pedestrian counter data at Berkeley and Pacifica piers, which indicate that approximately 21 percent of visitation at these sites occurred between 5:30 p.m. and 7:00 a.m.

Estimates of lost fishing days are presented in Exhibit 2. For the November 2007 to January 2008 time period, there were an estimated 58,500 lost shore fishing days and 11,000 lost boat fishing days due to the spill. Fifty-four percent of the lost fishing days occurred in November 2007, 27 percent occurred in December 2007, and 19 percent occur in January 2008.

[2] Although weather conditions in January 2008 appeared to have been somewhat worse than average, a related analysis indicates that the adverse weather in January 2008 is unlikely to have had a significant impact on baseline fishing trips (see Attachment A).

EXHIBIT 2. SALTWATER RECREATIONAL FISHING DAYS IN SAN FRANCISCO AREA (THOUSANDS)

	BASELINE PERIOD				POST-SPILL PERIOD	LOST FISHING DAYS
	TWO YEARS PRE-SPILL	ONE YEAR PRE-SPILL	ONE YEAR POST-SPILL	AVERAGE		
Shore Fishing[a]						
November	37.8	35.2	66.0	46.3	16.0	30.3
December	27.9	20.7	40.8	29.8	13.2	16.6
January	26.0	29.3	21.5	25.6	13.9	11.6
TOTAL:						**58.5**
Boat Fishing[b]						
November	16.3	8.6	7.9	10.9	3.7	7.2
December	5.7	5.4	3.7	4.9	2.9	2.1
January	3.7	5.4	5.0	4.7	2.9	1.8
TOTAL:						**11.0**

Notes:
[a] – Shore fishing estimates calculated as sum of CRFS estimates for man-made structures and beach/bank, after dividing man-made structure estimates by 0.79 to account for night fishing (see text).
[b] – Boat fishing estimates calculated as sum of CRFS estimates for private/rental and commercial passenger fishing vessel modes.

VALUE PER FISHING DAY

The economic value of a fishing day is obtained from a study of saltwater fishing in Southern California by Kling and Thomson (1996). Kling and Thomson obtain data on saltwater fishing trips taken by randomly selected households in eight Southern California counties, and they estimate several different logit site choice models using various model specifications and nesting structures. Similar to CRFS data, all fishing trips in the Kling and Thomson dataset are categorized into one of four modes: beach, pier, charter boat, or private boat.

Our analysis uses welfare measures associated with the author-preferred model specification and the two nesting structures that group sites by fishing mode (i.e., Models A and B in Table 4 of Kling and Thomson). There are six separate welfare measures reported for each of these two nesting structures, one each for eliminating the fishing sites associated with the four fishing modes, one for eliminating all shore fishing sites, and one for eliminating all boat fishing sites. Our analysis focuses on the latter two welfare measures, as they more closely mimic the broad closure that was in place after the *Cosco Busan* spill.

The estimated loss associated with eliminating shore fishing sites ranges from $6.36 to $11.18 per choice occasion, while the estimated loss associated with eliminating boat fishing sites ranges from $24.19 to $43.02 per choice occasion. Converting to November 2009 dollars and averaging the results from the two nesting structures, this is equivalent to $15.30 per choice occasion for eliminating shore fishing sites and $58.62 per choice occasion for eliminating boat fishing sites.

Two additional adjustments were made to the value estimates from Kling and Thomson before using the estimates to evaluate losses due to the spill:

- **Fishing Day Value Adjustment:** As with many logit site choice models in the environmental economics literature, Kling and Thomson present loss estimates *per choice occasion*. Per choice occasion losses average losses across all fishing trips, including trips taken by anglers who do not visit the closed fishing site(s). When transferring the loss estimates to a new situation, these per choice occasion loss estimates must either be (1) applied to all fishing trips taken to the local area, including those taken to substitute sites (2) converted to trip values and applied only to "lost" trips, or trips diverted from the closed sites.

  As lost trip estimates have been developed for the current analysis, the Kling and Thomson loss estimates must be converted to trip values. The conversion is implemented by dividing each choice occasion loss estimate by the fraction of trips taken to the sites that were closed in the loss scenario (Attachment B). Twenty-six percent of the fishing trips in the Kling and Thomson dataset were taken to shore fishing sites, and the remaining 74 percent of the trips were taken to boat fishing sites (Kling, 2009). Thus, the choice occasion loss for shore fishing is divided by 0.26 and the choice occasion loss for boat fishing is divided by 0.74 to obtain fishing day values. The final values after the conversion are $58.84 per shore fishing day and $79.21 per boat fishing day.

- **Travel Cost Adjustment:** The costs associated with travel are directly related to the losses estimated by the Kling and Thompson model, as angler losses are related to the cost of traveling to an alternative fishing site when the closed site is unavailable. In determining travel costs, Kling and Thomson use 60 percent of each angler's wage rate as a proxy for the opportunity cost of travel time. This differs from the approach used in many travel cost studies in the literature, where one-third of the wage rate is applied. Thus, the fishing day values are adjusted to reflect the standard approach in the literature. The adjustment involves calculating the ratio of two per-mile travel costs: (1) average cost when one-third the wage rate is used as the opportunity cost of time ($0.46/mile) and (2) average cost when 60 percent of the wage rate is used as the opportunity cost of time ($0.72/mile). The final ratio (0.64 = $0.46 ÷ $0.72) is multiplied by the fishing day values to obtain the adjusted values. The adjusted fishing day values are $37.49 per day for shore fishing and $50.48 per day for boat fishing.

TOTAL ESTIMATED DAMAGES

Total damages are estimated by combining information on lost fishing days with information on the value of a fishing day. Shore fishing damages are calculated by multiplying estimated lost shore fishing days by the value of a shore fishing day, and boat fishing damages are calculated by multiplying estimated lost boat fishing days by the value of a boat fishing day. Both damage estimates are inflated using a 3% annual discount rate to reflect the two-year period between the spill and the calculation of damages. The final damage estimates are $2.3 million for shore fishing and $0.6 million for boat fishing, or a total of $2.9 million in recreational fishing damages (Exhibit 3).

EXHIBIT 3. SUMMARY OF RECREATIONAL FISHING DAMAGES

	LOST FISHING DAYS (THOUSANDS)	FISHING DAY VALUE (2009 DOLLARS)	TOTAL DAMAGES (MILLIONS)	TOTAL DAMAGES WITH INTEREST[A] (MILLIONS)
Shore Fishing	58.5	$37.49	$2.19	$2.33
Boat Fishing	11.0	$50.48	$0.56	$0.59
TOTAL:			$2.75	$2.92

Notes:

[a] – Reflects two years of interest (i.e., 2007 to 2009) at a 3% discount rate.

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ATTACHMENT A:

ANALYSIS OF IMPACT OF ADVERSE WEATHER IN JANUARY 2008

Given the large amount of precipitation in January 2008, the possibility that the observed decline in fishing pressure during that month may have been weather related warrants consideration. First, however, one needs to establish that precipitation does in fact have a significant impact on saltwater fishing activity in the San Francisco Bay area. To investigate this issue, fishing trips (monthly CRFS estimates from January 2005 to February 2009) are regressed on precipitation (as measured at Oakland Airport), allowing for separate effects during the winter (December, January, and February) and non-winter months, and controlling for other factors that may potentially impact fishing pressure.

The form of the regression is as follows:

$$\ln(Trips_t) = \beta_0 + \beta_1 W_t * PPT_t + \beta_2 (1 - W_t) * PPT_t + \beta_3 Temp_t + \beta_4 Trend_t + \sum_{i=1}^{11} \alpha_i Month_{it} + \delta_1 Nov07_t + \delta_2 Dec07_t + \delta_3 Jan08_t + \varepsilon_t$$

where:

$Trips_t$	=	Fishing trips (in thousands) to San Francisco Bay area in month *t* (sum across all modes)
W_t	=	Indicator (0/1) variable for winter months (December, January, February)
PPT_t	=	Total precipitation in month *t* as measured at the Oakland Airport
$Temp_t$	=	Average high temperature in month *t* as measured at the Oakland Airport
$Trend_t$	=	Number of months since January 2005
$Month_{it}$	=	Indicator (0/1) variable for each of the twelve months (January omitted)
$Nov07_t$	=	Indicator (0/1) variable for November 2007
$Dec07_t$	=	Indicator (0/1) variable for December 2007
$Jan08_t$	=	Indicator (0/1) variable for January 2008

As diagnostic tests indicated the potential presence of autocorrelation,[3] the Prais-Winsten generalized least squares estimation method was used, which assumes that the errors

[3] The Durbin-Watson test was inconclusive, while the Breusch-Godfrey test for first-order serial correlation was significant at the 5% level.

follow a first-order autoregressive process.[4] The estimation results are presented in Exhibit A-1. The results indicate that precipitation has a highly significant impact on fishing pressure during the summer months ($\hat{\beta}_2 = -0.092,\ t$ = -2.16) but the impact is near zero during the winter months ($\hat{\beta}_1 = -0.011,\ t$ = -0.34). Thus, it appears that a weather-related adjustment to January 2008 baseline fishing pressure is unnecessary.

EXHIBIT A-1: ESTIMATION RESULTS

VARIABLE	COEFFICIENT	T-STATISTIC
Winter x PPT	-0.01	-0.34
Non-Winter x PPT	-0.09	-2.16
Temp	-0.01	-0.69
Trend	-0.01	-2.15
FEB	0.37	2.43
MAR	0.84	3.14
APR	1.20	4.35
MAY	1.51	4.70
JUN	1.60	4.44
JUL	1.95	5.06
AUG	1.69	4.56
SEP	1.66	4.40
OCT	1.11	3.15
NOV	0.92	3.44
DEC	0.20	1.07
Nov 2007	-0.77	-2.91
Dec 2007	-0.40	-1.40
Jan 2008	-0.06	-0.17
Constant	4.40	3.60

ρ = 0.54
r^2 = 0.83
n = 50
Dependent variable = ln(*trips*)

[4] That is, we assume that $\varepsilon_t = \rho\varepsilon_{t-1} + u_t$.

This attachment summarizes the approach to transferring results from Kling and Thomson (1996) to estimate recreational fishing losses.

The analysis uses CRFS data to estimate the number of fishing trips displaced as a result of the closure (T). Recreational fishing losses (L) are calculated by multiplying the T displaced trips by an estimate of the loss per displaced trip (L_d):

$$L = T \; x \; L_d$$

The estimate of the loss per displaced trip is derived from Kling and Thomson (1996). Let T_1 represent the number of trips taken under baseline conditions to the closed sites in the Kling and Thomson model, and let T_2 represent the number of trips to all other sites in the model under baseline conditions. Thus, $T_1 + T_2$ represents the total number of "choice occasions" in the model. The loss estimates reported in the study (L_c) are equal to the total losses divided by the number of choice occasions:[5]

$$L_c = \frac{L}{T_1 + T_2}$$

$T_1 + T_2$ represents the total number of trips to all sites, so L_c is the loss per *choice occasion*. However, we are interested in an estimate of the loss per *displaced trip*:

$$L_d = \frac{L}{T_1}$$

To derive L_d, it is necessary to convert L_c from Kling and Thomson into an estimate for each displaced trip. This is done by dividing L_c by the fraction of trips to the closed sites:

$$L_d = \frac{L_c}{\left(\frac{T_1}{T_1 + T_2}\right)}$$

$$= \frac{\frac{L}{T_1 + T_2}}{\left(\frac{T_1}{T_1 + T_2}\right)}$$

$$= L/T_1$$

[5] Equation 6 on page 105 of Kling and Thomson is a per choice occasion measure of compensating variation, and the estimates presented in the tables are per choice occasion measures of welfare losses (see third sentence of third complete paragraph on page 107).

Recreational Boating Damages Due to the *Cosco Busan* Oil Spill

30 November 2010

prepared for:

Cosco Busan Natural Resource Damage Assessment

prepared by:

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INTRODUCTION

On November 7, 2007, the *Cosco Busan* struck the Bay Bridge in San Francisco Bay, spilling approximately 58,000 gallons of intermediate fuel oil. The oil spill resulted in closures of marinas, oiling of vessels, and the disruption of recreational boating activity. In addition, the State of California closed the marine fishery within three nautical miles of the outer coast from Point Reyes to San Pedro Point, including San Francisco Bay.

The Trustees retained Industrial Economics, Incorporated (IEc) to estimate the magnitude of impacts to recreational boaters. Our analysis relies on existing information combined with site-specific data collected in response to the oil spill. This report summarizes our approach for estimating impacts to recreational boaters based on these data.

IEc estimated recreational boating impacts in three stages:

1) We estimated baseline boating activity. Baseline represents the number of boating trips that would have occurred in the absence of the oil spill.

2) We estimated the number of boating trips that were lost due to the spill. Impacted trips equal the difference between baseline trips and the number of boating trips that were actually taken during the oil spill impact period.

3) We estimated the economic value associated with the lost trips.

We describe each component of the analysis below.

ESTIMATING BASELINE TRIPS

IEc estimated baseline boating activity based on data collected during an on site study conducted from November 14 – 17, 2009. IEc sampled boating activity at 10 marinas located throughout San Francisco Bay. Marinas were selected for inclusion in the sampling effort based on location within the Bay, the presence of vantage points for observing boats entering the marina, number of slips, and receipt of permission to conduct on-site sampling. As part of the sampling effort, we recorded the number of boat trips and classified various attributes of those trips. Data were obtained by direct observation of boating activity and through interviews with a sample of boaters. Exhibit 1 summarizes information about the location and sampling methodology for each marina included in the study. Attachment A summarizes the survey methodology.

EXHIBIT 1: MARINA SAMPLING LOCATIONS

MARINA	LOCATION	NUMBER OF SLIPS	COUNT	INTERVIEW
1. Loch Lomond Marina	San Rafael	512	Yes	Yes
2. Marina Bay Yacht Harbor	Richmond	850	Yes	Yes
3. Berkeley Marina	Berkeley	1,100	Yes	Yes
4. Richardson Bay Marina	Sausalito	221	No	Yes
5. Clipper Yacht Harbor	Sausalito	700	Yes	No
6. Ballena Isle Marina	Alameda	515	Yes	No
7. Grand Marina	Alameda	400	No	Yes
8. San Francisco Marina Yacht Harbor	San Francisco	686	Yes	Yes
9. Brisbane Marina	Brisbane	574	Yes	Yes
10. Redwood City Yacht Harbor	Redwood City	185	Yes	Yes

DEVELOPING BASELINE USE FROM SURVEY DATA

We used the 2009 data to estimate boating activity that would have occurred in the absence of the oil spill. However, since we collected the 2009 on-site survey data over a limited period of time and at a subset of the marinas in San Francisco Bay, we addressed several gaps in the data. Specifically, we accounted for (1) un-sampled days of the week, (2) weather, and (3) un-sampled marinas. In addition, we account for differences in marina-specific attributes such as marina size and other factors that may affect the number of boating trips. Below, we describe the primary adjustments we made to the on-site study data to facilitate application of survey results throughout the Bay.

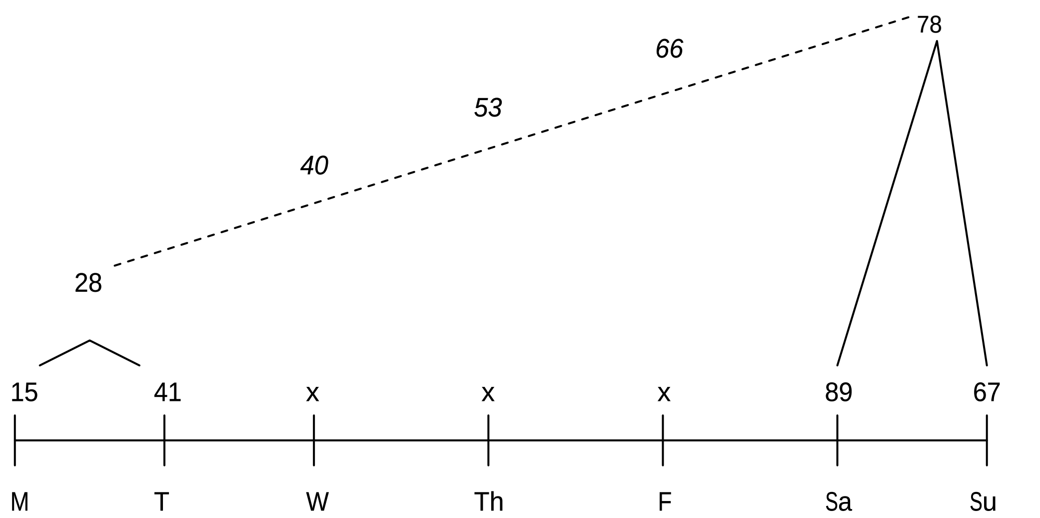
Un-Sampled Days of the Week

The 2009 study collected data on four consecutive days: Saturday, Sunday, Monday, and Tuesday. Since we did not sample on Wednesday, Thursday, or Friday, we evaluated how to account for the un-sampled days. Based on a review of the 2009 data and scoping surveys conducted in 2008, we adjusted the data to reflect expected changes in activity on each day of the week. Specifically, we estimated daily use at each marina under the assumption that boating activity was lowest on Monday and Tuesday and highest on Saturday and Sunday. Next, we fitted a linear model to the 2009 data to estimate boating activity on Wednesday, Thursday, and Friday.[1] Exhibit 2 provides an example of how

[1] As part of the 2008 shoreline survey, the Trustees conducted a limited scoping survey of boating activity at Richmond Marina and Berkeley Marina. The survey was conducted on Friday, Saturday, Sunday, and Monday (November 7-10). Consistent with the results of the 2009 survey, boating activity was the lowest on Monday and highest on Saturday and Sunday. The 2008 data show boating activity on Friday was about 20 percent lower than the weekend average and approximately three times greater than the number of trips observed on Monday. These results are

this adjustment accounts for expected variation in boating activity for each day of the week. We performed this adjustment for each marina included in the 2009 on-site study.

EXHIBIT 2: EXAMPLE OF LINEAR EXTRAPOLATION OF TRIP COUNTS - SAN FRANCISCO MARINA, PEOPLE ON SAILBOATS



Weather

All other things being equal, more boating activity occurs when weather conditions are favorable. Since the weather during 2009 differed from the weather that occurred during the oil spill impact period, it is necessary to adjust the on-site counts to account for this difference.

Using data from IEc's 2008 shoreline survey, we estimate how shoreline visitation varies with changes in weather and day of the week.[2] This involves predicting visitation in both 2007 and 2009. Next, we match comparable days in 2007 and 2009 and calculate an associated weather ratio for each day during the spill impact period. Exhibit 3 provides the weather adjustment developed for the boating analysis.

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consistent with data collected in 2009 and support the use of a linear extrapolation model. The 2008 survey data are not used directly in our analysis of boating impacts due to the limited number of sites surveyed and slight differences in the survey methodology. Both sites included in the 2008 study were re-sampled in 2009 to ensure consistency with the data obtained from the other study sites.

[2] See Appendix G. *Baseline Shoreline Use Estimates for the Cosco Busan Oil Spill Damage Assessment* October 31, 2010.

EXHIBIT 3: WEATHER ADJUSTMENT

DATE 2009	PREDICTED COUNTS 2009	DATE 2007	PREDICTED COUNTS 2007	WEATHER RATIO
November 11	14,290	November 7	7,390	0.52
November 12	8,158	November 8	8,000	0.98
November 13	8,016	November 9	9,045	1.13
November 14	13,157	November 10	6,402	0.49
November 15	13,942	November 11	13,253	0.95
November 16	8,958	November 12	15,126	1.69
November 17	8,352	November 13	9,600	1.15
November 18	7,984	November 14	11,543	1.45
November 19	8,672	November 15	8,631	1.00
November 20	3,231	November 16	8,016	2.48
November 21	12,356	November 17	12,797	1.04
November 22	12,388	November 18	13,531	1.09
November 23	9,219	November 19	8,373	0.91
November 24	10,295	November 20	8,527	0.83
November 25	10,745	November 21	9,624	0.90
November 26	15,068	November 22	15,136	1.00
November 27	11,046	November 23	18,038	1.63
November 28	15,949	November 24	14,052	0.88
November 29	17,145	November 25	14,391	0.84
November 30	9,433	November 26	8,942	0.95
December 1	9,064	November 27	9,498	1.05
December 2	6,888	November 28	9,717	1.41
December 3	7,697	November 29	8,523	1.11
December 4	7,329	November 30	7,241	0.99
December 5	11,618	December 1	11,707	1.01
December 6	8,608	December 2	13,454	1.56
December 7	5,113	December 3	9,628	1.88
December 8	6,425	December 4	6,092	0.95
December 9	6,090	December 5	8,181	1.34
December 10	5,588	December 6	6,172	1.10
December 11	4,930	December 7	6,331	1.28

Note: Yellow highlighting indicates weekend days and holidays

Un-Sampled Marinas

IEc's 2009 on-site study collected data at 10 marinas located through San Francisco Bay. To develop an estimate of baseline boating activity, we assume that marinas that are closely located to one another exhibit similar rates of use. Therefore, we apply the trip rates observed at sampled marinas to unsampled marinas that are located in the same area. Exhibits 4 and 5 detail the marina groupings.

EXHIBIT 4: MAP OF BAY AREA MARINA GROUPINGS

EXHIBIT 5: BAY AREA MARINA GROUPINGS

GROUP NAME	SURVEYED MARINA	ASSOCIATED MARINAS
North Marin County	Loch Lomond Marina	Lowrie Yacht Harbor Marin Yacht Club San Rafael Yacht Harbor Martinez Marina Vallejo Municipal Marina
South Marin County	Clipper Yacht Harbor	Galilee Harbor Sausalito Marine Harbor Presidio Yacht Club Marina Corinthian Yacht Club Pelican Yacht Harbor Arques Shipyard & Marina Marina Plaza Yacht Harbor Schoonmaker Marina San Francisco Yacht Club Paradise Cay Yacht Harbor Richardson Bay Marina Sausalito Yacht Harbor
San Francisco	San Francisco Marina	Treasure Island Marina Pier 39 Marina SBC Park Marina (Pier 38) South Beach Harbor
South Central San Francisco	Brisbane Marina	Oyster Cove Marina Oyster Point Marina Park Coyote Point Marina
South San Francisco	Redwood City Yacht Harbor	Redwood Landing Marina Bair Island Marina Docktown Pete's Yacht Harbor Peninsula Marina
North East Bay	Berkeley Marina/Marina Bay Yacht Harbor	Richmond Yacht Harbor Channel Marina Point San Pablo Yacht Harbor Brickyard Cove Marina Emery Cove Marina Emeryville Marina

GROUP NAME	SURVEYED MARINA	ASSOCIATED MARINAS
South East Bay	Ballena Isle Marina	Portobello Marina Mariner Square North Basin Union Point Basin Fifth Avenue Marina Embarcadero Cove Marina Central Basin Jack London Square Marina Oakland Yacht Club Pacific Marina San Leandro Marina Grand Marina Fortman Marina Alameda Marina Marina Village Yacht Harbor Fernside Marina

Marina-Specific Adjustments

As described above, we used data from sampled marinas to estimate boating activity associated with unsampled locations. In addition to the adjustments outlined above, we normalized the data to account for marina-specific differences that affect trip rates as follows:

- The physical size of a marina significantly affects the number of boats that complete trips on any given day. When estimating the number of boating trips at one marina based on data from another marina, it is important to account for the size of each marina. We adjusted for marina size by calculating the number of trips per slip for the sampled marinas. The resultant trip *rate* is then used to estimate the total number of boat trips at other marinas in the same vicinity, where the total number of boat trips for marina *i* equals the applicable trip rate multiplied by the number of slips at marina *i*.
- Marinas that have boat ramps will have higher trip rates relative to marinas that do not have boat ramps. To account for this difference, we sampled trip rates at marinas with boat ramps and recorded any vessels that used the boat ramp at the completion of their trip. We adjusted the trip rate when applying sample data across marinas that have dissimilar vessel access options.
- Many marinas in San Francisco Bay are occupied to capacity. However, a survey of marinas in the northern and southern sections of the Bay indicates some marinas have slips available for rent. Where data indicated that slips were available, we adjusted the trip estimate for the marina to reflect the number of occupied slips.

Attachment B provides the trip rates for each marina and each day for the period November 7 to December 7, 2007.

BASELINE RESULTS

Using data from the 2009 survey in conjunction with the adjustments described above, we estimate the number of boating trips that would have occurred in the absence of the spill. We estimate baseline activity for the period November 7 to December 7, 2007. Our estimate reflects the total number of individuals participating in sail-boating, motor-boating, and other types of boating originating from marinas. Exhibit 6 summarizes baseline boating trips by mode.

EXHIBIT 6: BASELINE BOAT TRIPS - NOVEMBER 7 - DECEMBER 7, 2007

	ESTIMATED BOATING TRIPS	LESS BOAT-BASED ANGLERS[a]	BASELINE BOATING TRIPS
Sailboats	30,996	NA	30,996
Motorboats	32,693	(10,184)	22,509
Other	288	NA	288
Total	**63,172**	**(10,184)**	**53,793**

a Boat-based anglers have been removed from the baseline trip estimate because impacts to anglers are addressed through a separate analysis. Data for this adjustment were obtained from the California Recreational Fishing Survey for November and December 2005 and 2006, and are adjusted to account for the fraction of each month affected by the oil spill.

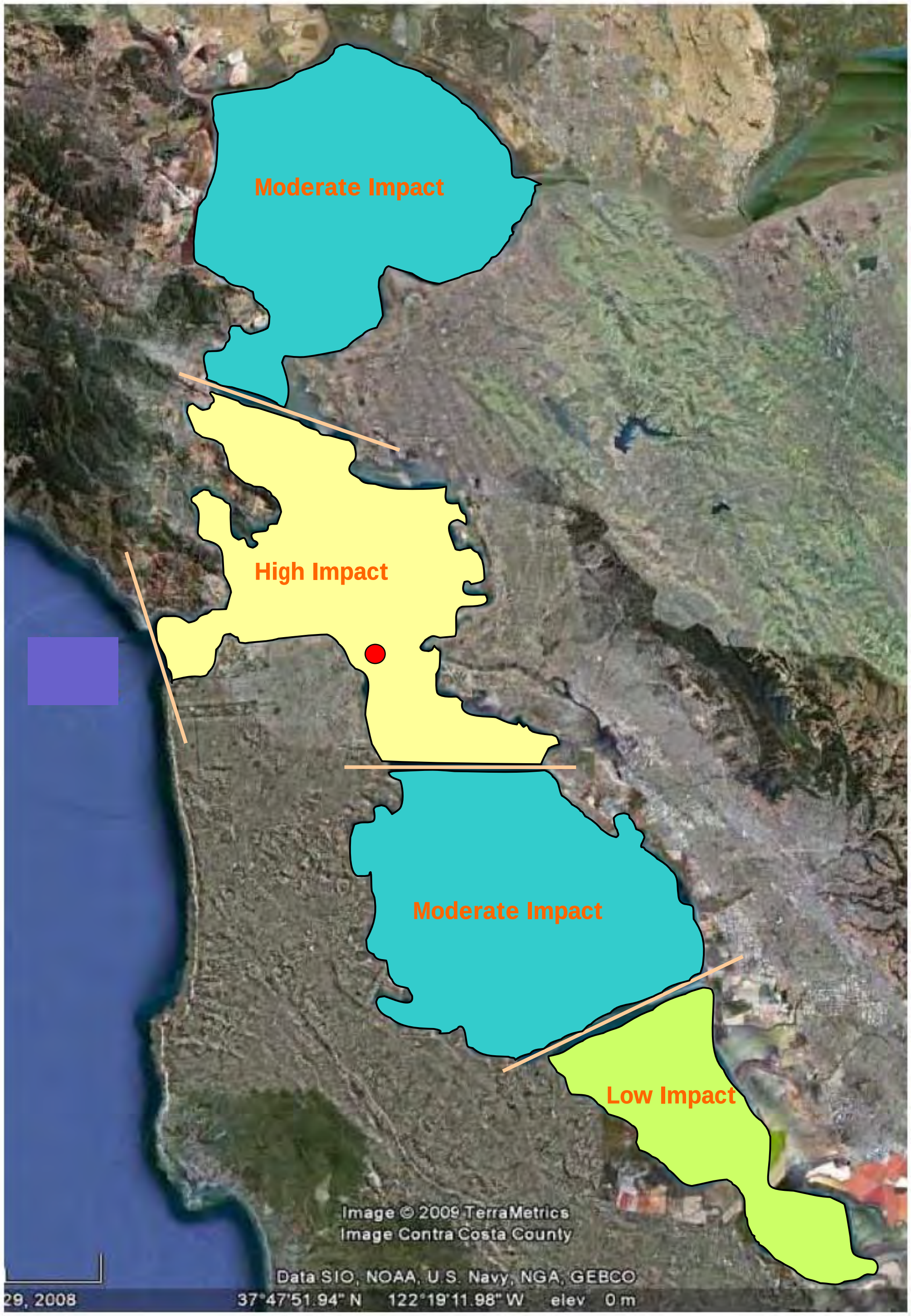
ESTIMAING SPILL-IMPACTED TRIPS

We estimate the change in boating trips for 30-days following the spill based on information such as marina closures, regatta cancellations, and data that describe the distribution of oil on shorelines. The process for determining the number of lost boating trips consists of estimating the severity of impacts in different parts of the Bay and calculating the reduction in boating trips from baseline in each area. We also make marina-specific adjustments where appropriate to account for boating impacts that were not accounted for in the baseline data. We describe each step in the analysis below.

IMPACTS

Within San Francisco Bay, oil from the *Cosco Busan* spread throughout the central portion of the Bay and north to Point Pinole. The oil also spread out of the Bay north and south along the outer coast. Based on spill records and other information gathered subsequent to the spill, we divided the Bay into three impact areas for boaters. The impact areas – designated Low, Moderate, and High – generally reflect the severity of oiling throughout the Bay and the associated reactions of boaters and marina operators in each area. Exhibit 7 depicts the impact areas.

EXHIBIT 7: IMPACT AREAS



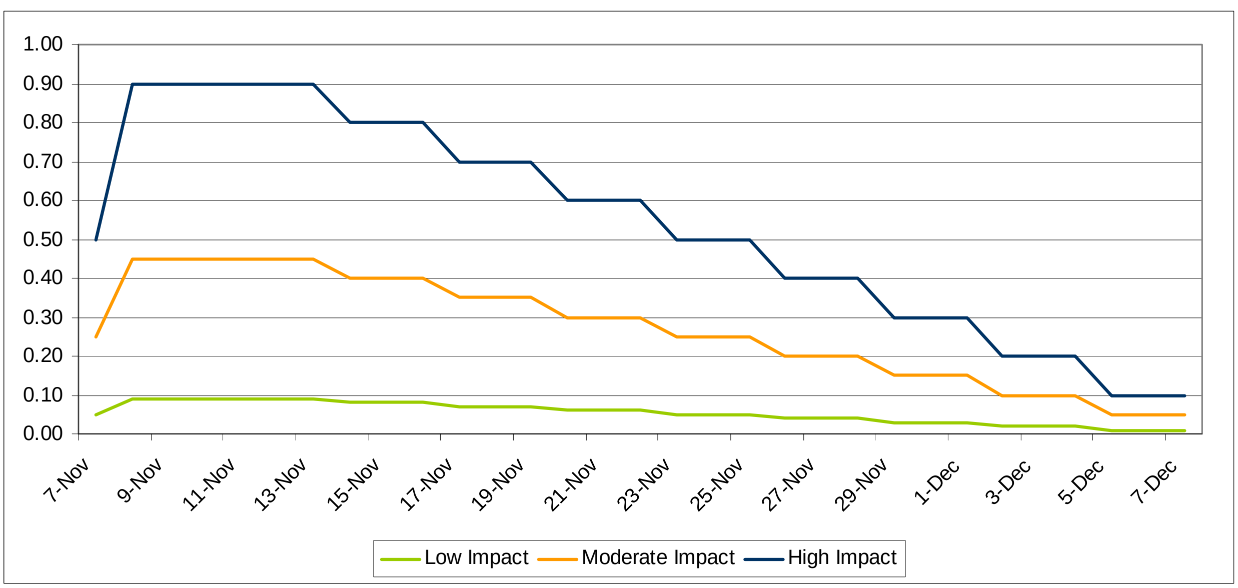
● *Cosco Busan* point of impact with Bay Bridge (approximate)

For each impact area, we derived a loss function that reflects available information on oil spill impacts. The greatest impacts occurred in the central section of the Bay due to the presence of oil in and on the water and associated response activities. During the first several days of the spill, several marinas in the central section of the Bay were physically closed due by containment boom and many of these marinas remained closed through November 15. Similarly, several scheduled sailing events in the central portion of the Bay were cancelled as a result of the spill. During this initial period, boaters in the central section of the Bay were also faced with the added expense of cleaning their hulls if oil was encountered on a trip. Once oil was no longer present on the surface of the water and marinas were reopened, we expect boating activity to steadily increase until it reached baseline levels. In comparison, little oil reached the northern section of the Bay, and no oil was found in southern section. Boaters in these areas continued to have access to recreational opportunities, but they likely reduced the frequency of their trips due to widespread media coverage or they may have modified their trips to avoid oiled areas. As a result, we expect relatively modest impacts to boating activity in these areas, with a gradual return to normal activity levels over time.

Losses were calculated for the period of November 7 to December 7, 2007. The impact functions are described below and are shown in Exhibit 8.

- **High Impact:** The high impact function reflects the most severely impact portion of the Bay. This function starts with a 50 percent loss of boating activity on November 7th, followed by a loss of 90 percent for November 8th through the 13th. Starting November 14th, the loss decreases by 10 percent every three days.
- **Moderate Impact:** The moderate impact function follows the same pattern as the high impact category, but is always 50 percent of the value associated with the high impact function.
- **Low Impact:** The low impact function follows the same pattern as the high impact category, but is always 10 percent of the value associated with the high impact function.

EXHIBIT 8: LOSS FUNCTIONS BY IMPACT CATEGORY



As part of our 2009 on-site study, survey respondents provided information on which area of the Bay they visited on their trip. Based on these results, we determine the number of boat trips for each marina that fall into each impact category. Exhibit 9 provides the allocation of boating trips by area visited.

EXHIBIT 9: FRACTION OF TRIPS IN EACH IMPACT CATEGORY

	LOW IMPACT	MODERATE IMPACT	HIGH IMPACT
North Marin County	0.0%	31.3%	68.8%
South Marin County	0.0%	0.0%	100.0%
San Francisco	0.0%	0.0%	100.0%
South Central San Francisco	0.0%	50.0%	50.0%
South San Francisco	77.8%	18.5%	3.7%
North East Bay	0.0%	0.0%	100.0%
South East Bay	0.0%	0.0%	100.0%
% of Total Trips	**3.6%**	**8.9%**	**87.5%**

For each marina, we calculate the number of lost trips on any given day as the product of that day's baseline trips, the fraction of trips to each impact area, and the applicable value from the loss function.

MARINA-SPECIFIC ADJUSTMENTS

While most of the boating impacts can be determined using the data collected in 2009, several spill-related effects associated with specific marinas were observed in 2007. These impacts are accounted for separately to ensure that observations made concurrently with the spill are accurately represented in the boating analysis. Where appropriate, the 2009 on-site study was designed to avoid potential double-counting of these marina-specific impacts. The following marina-specific adjustments are included in the estimate of impacted boating trips:

- In 2007, we contacted several sailing and boating clubs within San Francisco Bay to determine if the spill had impacted club activities. Some of these organizations reported that specific activities planned by the club were cancelled as a result of the spill. Following a survey of potentially affected organizations, we estimate that 805 marina-specific sailboat trips were lost in November 2007. None of the organizations we contacted reported spill-related impacts in December.

- The Berkeley Racing and Canoe Center provides opportunities for individuals to participate in dragon boat racing and excursions. During the spill, the Berkeley Mariana was closed and the Center cancelled its regularly scheduled dragon boat activities. To evaluate potential impacts to individuals engaged in dragon boating, we collected on-site data to determine the number of impacted trips. Based on these data and information on the frequency of dragon boat activity obtained from the organization and its web site, we estimate that 288 dragon boat trips were lost in November 2007.

LOST TRIPS RESULTS

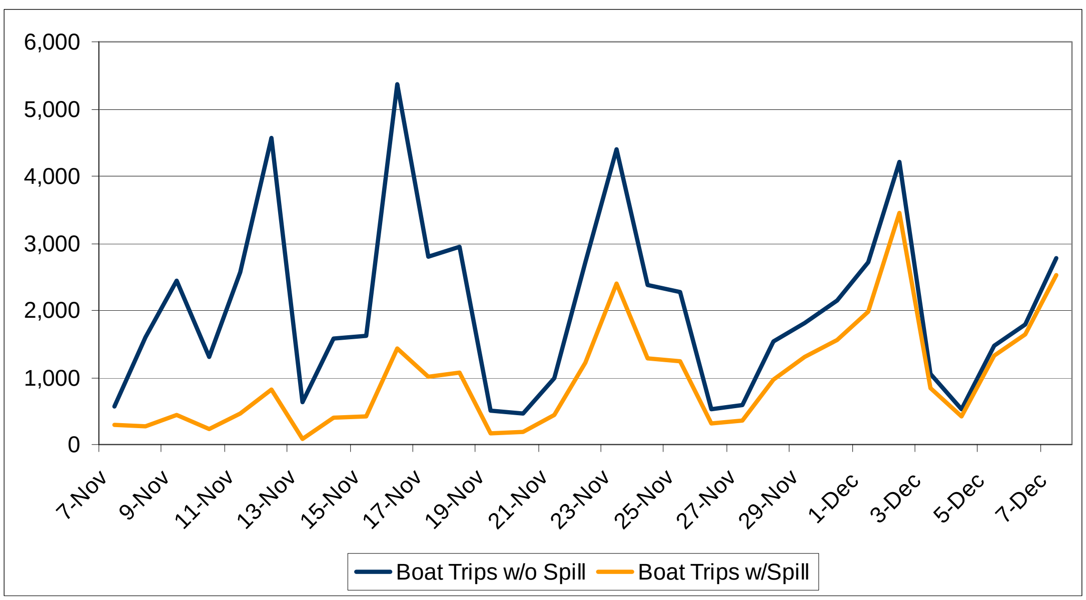
Using data from the 2009 survey in conjunction with the adjustments described above, we estimate the number of boating trips that were lost as a result of the spill. We estimate lost trips for the period November 7 to December 7, 2007. Our estimate reflects the total number of individuals participating in sail-boating, motor-boating, and other types of boating originating from marinas. Exhibit 10 summarizes lost trips by mode. Exhibit 11 shows estimated boating activity with and without the spill.

EXHIBIT 10: TOTAL LOST BOAT TRIPS - NOVEMBER 7 - DECEMBER 7, 2007

	ESTIMATED LOST TRIPS	LESS BOAT-BASED ANGLERS[a]	TOTAL LOST TRIPS
Sailboats	15,748	NA	15,748
Motorboats	17,314	(6,763)	10,551
Other	288	NA	288
Total	**33,350**	**(6,763)**	**26,587**

a Boat-based anglers have been removed from the baseline trip estimate because impacts to anglers are addressed through a separate analysis. See Exhibit 6.

EXHIBIT 11: BOAT TRIPS



VALUATION We estimate the dollar value of lost boating trips based on benefit transfer. Benefit transfer is the process of adopting trip values from existing literature to fit the conditions associated with the site, activity, and incident of interest. Multiplying the reduction in trips by the loss per trip yields the total loss in dollars. This approach is based on the economic principle of consumer surplus, which measures changes in value associated with changes in the supply and demand of goods and services. The benefit transfer methodology has been used to assess recreational damages in several past oil pills.

To determine the appropriate value to use for the assessment, we reviewed literature on ocean-based sailing and motor-boating. However, due to the small number of studies that evaluate ocean-based boating, we also reviewed the valuation literature for motor boating, canoeing, and other types of boating on lakes and rivers. Based on our review, we selected values from a 2005 study authored by John Loomis. This report compiles consumer surplus estimates for a wide range of outdoor activities, including motor-boating. Loomis reports a mean value of $52.23 per day for motor-boating ($2009).

The specific studies that underlie the values reported in Loomis (2005) differ from San Francisco Bay boating in a number of ways. Primary among the differences is that most of the boating activity reported in the literature occurs on inland lakes and rivers. In addition, the boats are typically smaller than those found in San Francisco Bay and none of the studies expressly evaluates oceangoing sailboats. Despite these limitations, Loomis (2005) offers useful guidance regarding the range of values that one might expect to find if an original study was conducted in San Francisco Bay. Specifically, we estimate that recreational sail-boating and motor-boating in San Francisco Bay has a value of $78 per trip, or 150 percent of the consumer surplus reported in Loomis (2005). We estimate the value of dragon boat trips to be similar to the $52 per trip reported by Loomis (2005). The upward adjustment from Loomis (2005) reflects the factors outlined above plus a premium that reflects San Francisco Bay's unique boating conditions.

Exhibit 12 summarizes the total damages associated with spill-related impacts to boating. Total damages are calculated by multiplying the present value lost trips by a per trip value for sailboats, motorboats, and other trips. The present value of the lost trips is calculated by applying a three percent discount rate to the 2007 lost trips.

EXHIBIT 12: SUMMARY OF BOATING IMPACTS

	LOST TRIPS NOV-DEC 2007	PRESENT VALUE LOST TRIPS (NOVEMBER 2009)	VALUE PER TRIP	TOTAL DAMAGES
Sailboats	15,748	16,707	$78	$1,228,336
Motorboats	10,551	11,193		$822,962
Other	288	306	$52	$14,976
Total	**26,587**	**28,206**		**$2,066,274**

REFERENCES

Loomis, J. 2005. Updated Outdoor Recreation Use Values on National Forests and Other Public Lands. United States Department of Agriculture, U.S. Forest Service. General Technical Report PNW-GTR-658.

ATTACHMENT A

2009 ON-SITE STUDY METHODOLOGY

SURVEY METHODOLOGY

The overall goal of the 2009 sampling effort was to record the number of boat trips for each marina included in the sample and to classify various attributes of those trips. During the sampling period, each vessel returning to the marina was observed by field staff. Field staff also conducted brief interviews with a sample of visitors to characterize boating activity.

Visitor Counts

On each sampling day, field staff recorded each vessel that entered the marina from the Bay. The counts were conducted in two shifts covering 7:00 a.m. to 5:30 p.m. The first shift covered five hours, from 7:00 a.m. to 12:00 p.m. The second shift covered 5 ½ hours, from 12:00 p.m. to 5:30 p.m. Observers recorded each vessel as it entered the marina, classifying each by vessel type. Vessels were classified as sailboats, motorboats, personal watercraft or kayaks. In addition, commercial work boats such as Coast Guard, harbor maintenance and law enforcement/marina staff vessels were identified. The number of visible individuals on each vessel was recorded and classified as "Adults" (age 13 and over) and "Children" (infant to age 12). Age classifications were based on visual identification by survey staff.

Visitor Interviews

We conducted interviews at eight marinas: Loch Lomond, Marina Bay, Richardson, Berkeley, San Francisco, Grand, Brisbane, and Redwood City Marinas. Visitor interviews were conducted with one member of each party that departed the marina after completion of a boating trip. When possible, the interview was conducted with the vessel owner or captain. Interviews were conducted in one shift per day starting at 9:00 a.m. and ending at 5:00 p.m.

Interviews consisted of several brief questions designed to characterize various attributes associated with the just-completed trip and the respondents' general boating activity. Specific information obtained during the interviews includes:

- Areas visited on the just-completed trip;
- Duration of the just-completed trip;
- Number of adults and children on the vessel;
- Type of vessel;
- Length of vessel;
- Number of trips on the vessel in the last 12 months;
- Length of time the individual has kept their vessel at the marina;
- Monthly slip fee (if applicable); and
- Zip code.

ATTACHMENT B

MARINA-SPECIFIC TRIP RATES

EXHIBIT B1: ESTIMATED SAILBOAT TRIP RATES NOVEMBER 7 - DECEMBER 7, 2007

DATE 2007	AREA 1 LOCH LOMOND MARINA	AREA 2 CLIPPER YACHT HARBOR	AREA 3 SF MARINA & YACHT HARBOR	AREA 4 BRISBANE MARINA	AREA 5 REDWOOD CITY YACHT HARBOR	AREA 6 BERKELEY MARINA & MARINA BAY	AREA 7 BALLENA ISLE MARINA
Wed, 7-Nov	0.0046	0.0124	0.0343	0.0187	0.0314	0.0240	0.0069
Thur, 8-Nov	0.0129	0.0372	0.0852	0.0467	0.1154	0.0716	0.0229
Fri, 9-Nov	0.0196	0.0586	0.1211	0.0667	0.1971	0.1125	0.0377
Sat, 10-Nov	0.0105	0.0320	0.0622	0.0344	0.1127	0.0615	0.0212
Sun, 11-Nov	0.0205	0.0626	0.1215	0.0672	0.2201	0.1201	0.0414
Holiday, 12-Nov	0.0364	0.1112	0.2159	0.1194	0.3910	0.2133	0.0735
Tue, 13-Nov	0.0055	0.0115	0.0527	0.0282	0.0045	0.0227	0.0036
Wed, 14-Nov	0.0130	0.0347	0.0959	0.0522	0.0879	0.0671	0.0192
Thur, 15-Nov	0.0131	0.0378	0.0864	0.0474	0.1172	0.0727	0.0232
Fri, 16-Nov	0.0431	0.1287	0.2663	0.1468	0.4333	0.2474	0.0830
Sat, 17-Nov	0.0223	0.0682	0.1324	0.0732	0.2398	0.1309	0.0451
Sun, 18-Nov	0.0235	0.0719	0.1397	0.0772	0.2529	0.1380	0.0475
Mon, 19-Nov	0.0043	0.0091	0.0416	0.0223	0.0035	0.0180	0.0029
Tue, 20-Nov	0.0040	0.0083	0.0380	0.0203	0.0032	0.0164	0.0026
Wed, 21-Nov	0.0080	0.0215	0.0594	0.0323	0.0545	0.0416	0.0119
Holiday, 22-Nov	0.0216	0.0661	0.1284	0.0710	0.2326	0.1269	0.0437
Holiday, 23-Nov	0.0352	0.1075	0.2088	0.1154	0.3781	0.2063	0.0711
Sat, 24-Nov	0.0190	0.0580	0.1127	0.0623	0.2040	0.1113	0.0384
Sun, 25-Nov	0.0181	0.0553	0.1073	0.0593	0.1944	0.1060	0.0365
Mon, 26-Nov	0.0045	0.0095	0.0434	0.0233	0.0037	0.0187	0.0030
Tue, 27-Nov	0.0050	0.0105	0.0480	0.0257	0.0041	0.0207	0.0033
Wed, 28-Nov	0.0127	0.0338	0.0936	0.0509	0.0858	0.0655	0.0187
Thur, 29-Nov	0.0146	0.0420	0.0962	0.0527	0.1304	0.0809	0.0258
Fri, 30-Nov	0.0171	0.0513	0.1061	0.0584	0.1725	0.0985	0.0330
Sat, 1-Dec	0.0217	0.0663	0.1288	0.0712	0.2333	0.1273	0.0439
Sun, 2-Dec	0.0337	0.1029	0.1998	0.1105	0.3619	0.1975	0.0680
Mon, 3-Dec	0.0090	0.0189	0.0863	0.0462	0.0073	0.0372	0.0059
Tue, 4-Dec	0.0045	0.0095	0.0434	0.0233	0.0037	0.0188	0.0030
Wed, 5-Dec	0.0121	0.0322	0.0891	0.0485	0.0817	0.0624	0.0178
Thur, 6-Dec	0.0145	0.0419	0.0959	0.0526	0.1300	0.0807	0.0258
Fri, 7-Dec	0.0223	0.0666	0.1379	0.0760	0.2243	0.1280	0.0429

EXHIBIT B2: ESTIMATED MOTORBOAT TRIP RATES NOVEMBER 7 - DECEMBER 7, 2007

DATE 2007	AREA 1 LOCH LOMOND MARINA	AREA 2 CLIPPER YACHT HARBOR	AREA 3 SF MARINA & YACHT HARBOR	AREA 4 BRISBANE MARINA	AREA 5 REDWOOD CITY YACHT HARBOR	AREA 6 BERKELEY MARINA & MARINA BAY	AREA 7 BALLENA ISLE MARINA
Wed, 7-Nov	0.02708	0.01488	0.04051	0.00416	0.01006	0.02336	0.01258
Thur, 8-Nov	0.07687	0.04932	0.09980	0.01013	0.03434	0.06524	0.03428
Fri, 9-Nov	0.11781	0.08105	0.14126	0.01424	0.05708	0.09916	0.05143
Sat, 10-Nov	0.06347	0.04543	0.07231	0.00726	0.03219	0.05315	0.02735
Sun, 11-Nov	0.12399	0.08874	0.14127	0.01418	0.06288	0.10384	0.05342
Holiday, 12-Nov	0.22024	0.15764	0.25095	0.02518	0.11170	0.18445	0.09490
Tue, 13-Nov	0.03029	0.00832	0.06312	0.00660	0.00447	0.02738	0.01576
Wed, 14-Nov	0.07572	0.04159	0.11326	0.01162	0.02812	0.06531	0.03518
Thur, 15-Nov	0.07802	0.05006	0.10129	0.01028	0.03485	0.06621	0.03479
Fri, 16-Nov	0.25904	0.17820	0.31060	0.03131	0.12550	0.21803	0.11308
Sat, 17-Nov	0.13509	0.09669	0.15392	0.01545	0.06851	0.11314	0.05821
Sun, 18-Nov	0.14247	0.10197	0.16233	0.01629	0.07225	0.11932	0.06139
Mon, 19-Nov	0.02393	0.00658	0.04988	0.00522	0.00353	0.02163	0.01245
Tue, 20-Nov	0.02182	0.00600	0.04549	0.00476	0.00322	0.01973	0.01136
Wed, 21-Nov	0.04691	0.02577	0.07017	0.00720	0.01742	0.04046	0.02179
Holiday, 22-Nov	0.13102	0.09378	0.14929	0.01498	0.06645	0.10973	0.05645
Holiday, 23-Nov	0.21299	0.15245	0.24269	0.02436	0.10802	0.17838	0.09178
Sat, 24-Nov	0.11492	0.08225	0.13094	0.01314	0.05828	0.09624	0.04952
Sun, 25-Nov	0.10948	0.07836	0.12474	0.01252	0.05553	0.09169	0.04717
Mon, 26-Nov	0.02498	0.00686	0.05206	0.00544	0.00368	0.02258	0.01300
Tue, 27-Nov	0.02761	0.00759	0.05755	0.00602	0.00407	0.02496	0.01437
Wed, 28-Nov	0.07388	0.04059	0.11052	0.01134	0.02744	0.06372	0.03433
Thur, 29-Nov	0.08680	0.05570	0.11269	0.01144	0.03878	0.07367	0.03871
Fri, 30-Nov	0.10316	0.07097	0.12369	0.01247	0.04998	0.08683	0.04503
Sat, 1-Dec	0.13143	0.09407	0.14976	0.01503	0.06666	0.11007	0.05663
Sun, 2-Dec	0.20386	0.14592	0.23228	0.02331	0.10339	0.17073	0.08784
Mon, 3-Dec	0.04962	0.01363	0.10341	0.01081	0.00732	0.04485	0.02582
Tue, 4-Dec	0.02498	0.00686	0.05207	0.00545	0.00368	0.02258	0.01300
Wed, 5-Dec	0.07035	0.03865	0.10524	0.01080	0.02613	0.06068	0.03269
Thur, 6-Dec	0.08658	0.05556	0.11240	0.01141	0.03868	0.07348	0.03861
Fri, 7-Dec	0.13408	0.09224	0.16077	0.01621	0.06496	0.11286	0.05853

STRATUS CONSULTING

Appendix J
Damage Estimate for Shoreline Recreation

Prepared for:

Cosco Busan Natural Resource Damage Assessment

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Damage Estimate for Shoreline Recreation

Prepared for:

Cosco Busan Natural Resource Damage Assessment

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SC12217

J. Damage Estimate for Shoreline Recreation

This appendix describes the assessment of losses associated with impacts to shoreline recreation from the Cosco Busan oil spill. The term "impacts to shoreline recreation" refers to any change in the shoreline-related recreation choices people made in response to the spill. The changes people made could have included taking fewer shoreline recreation trips, recreating at different shoreline sites, or participating in different shoreline recreation activities. When people change their behavior as a result of the spill, this leads to a loss. The loss associated with the impacts is equal to the decline in the value of shoreline recreation in the San Francisco Bay Area (hereafter, Bay Area) attributable to the spill or to the amount the public would have been willing to pay to prevent the effects of the spill on Bay Area recreation.

The methods described in this appendix address shoreline recreational activities such as sunbathing, swimming, surfing, strolling, sightseeing, exercise, and wildlife viewing. The analysis does not evaluate fishing or boating losses, which are addressed in Appendix H and Appendix I, respectively. This appendix begins with an overview of the overall approach to shoreline damage estimation. Following the overview, the main elements of the shoreline assessment are described, including a telephone survey of Bay Area residents about their shoreline recreation and effects of the spill; methods for estimating the number of recreation trips lost due to the spill; methods for valuing lost trips; and results of the analysis, including an estimate of shoreline recreation damages.

J.1 Overall Damages Approach

The value of shoreline recreation-related losses attributable to the Cosco Busan oil spill was estimated using a telephone survey of Bay Area residents. The shoreline recreation survey asked residents about their recreation trips to shoreline sites in the Bay Area and about the impact of the spill on their recreation trips. Data from the survey were used to estimate an economic model of shoreline recreation, and this model was then used to estimate the lost value associated with impacts to recreation. The assessment of recreational losses involved three steps: (1) estimating the number of shoreline trips that would have been taken to shoreline sites in the Bay Area under baseline conditions; (2) estimating the decline in the number of shoreline recreation trips attributable to the spill, or the number of "lost trips"; and (3) estimating the value of a lost trip, which was multiplied by the total number of lost trips to calculate total damages.

The first step in estimating shoreline recreation damages involved calculating the number of shoreline recreation trips that would have been taken to Bay Area sites in November 2007 and subsequent months in the absence of the spill. Methods for estimating trips under baseline conditions relied on onsite sampling that was conducted in November 2008 at a selection of sites throughout the Bay Area. The onsite sampling effort is described in Appendix G. The onsite sampling included most sites with significant levels of recreation activity. A statistical model was developed that estimated the relationship between the number of recreation trips at each site where sampling occurred and variables that influence recreation, including weather variables and a variable distinguishing weekdays and weekend days. The statistical model was used to estimate baseline trips to the sampled sites from November 2007 to June 2008 using the appropriate data for weather and weekday/weekends.

The assessment area for the shoreline recreation study was geographically larger than the onsite sampling area and included many sites that were not part of the onsite sampling effort. Specifically, the assessment area extended from Dillon Beach north of San Francisco to San Gregorio Beach south of Half Moon Bay, California. The telephone survey of Bay Area residents provided information on the number of trips taken to sites where onsite sampling did not occur. Using the telephone survey data, a ratio was calculated by dividing the total number of trips reported by survey respondents to all assessment-area sites by the number of trips reported by survey respondents to sites specifically included in the onsite sampling effort. This ratio was multiplied by the number of baseline trips estimated from the onsite sampling, resulting in an estimate of the total number of baseline trips to sites throughout the assessment area.

The number of lost trips was estimated using the estimate of baseline trips combined with information on spill impacts to recreation derived from the telephone survey. The term “lost trips” refers to the decline in the number of shoreline recreation trips attributable to the spill. The telephone survey asked respondents to specify the number of trips they typically take each month throughout the year and also asked how many fewer trips they took because of the spill. This information was used to estimate lost trips as a percent of baseline trips for those people responding to the survey. This percentage was multiplied by the total number of baseline trips to sites throughout the assessment area to estimate the total number of lost trips attributable to the spill.

The value of lost trips was estimated using a travel-cost model developed from telephone survey data. Survey respondents were asked to report the destination of several of their recent shoreline recreation trips. The trips were selected to be representative of the recreation choices of Bay Area residents under baseline conditions. Information on trips was used to develop a multiple-site travel-cost model for shoreline recreation in the Bay Area. A travel-cost model analyzes the costs people are willing to incur to reach recreation sites and estimates the amount that people are willing to pay for access to recreation sites under baseline conditions. The baseline recreation model was then adjusted to represent spill conditions. The adjusted model accounted for information about spill impacts to recreation obtained from the telephone survey. A comparison of the baseline and adjusted models was used to estimate the value for trips lost due to the spill.

Total damages were estimated by multiplying the number of lost trips by the value per lost trip. The total estimated number of lost trips was 984,451, and the average estimated value per lost trip was $18.25 in 2007 dollars. Total estimated damages were $18.0 million in 2007 dollars. Accounting for discounting and inflation since November 2007, the total estimated present value of shoreline damages in January 2010 was $20.2 million. As noted earlier, this damage estimate does not include losses associated with boating, boat-based fishing, or shore fishing but evaluates impacts to all other shoreline recreation trips.

J.2 The Bay Area Shoreline Recreation Survey

The shoreline recreation survey was used to collect data to support two objectives: to estimate the number of trips lost due to the Cosco Busan oil spill and to develop a travel-cost model for estimating the value of lost trips. This section describes the design of the survey, including an overview of the questions included in the survey instrument; implementation of the survey, including pretesting of the survey instrument, development of the sample, the number of completed interviews, and the response rate; and the calculation of statistical weights to ensure the data collected were representative of the Bay Area population. A copy of the survey instrument is provided in Attachment 1.

J.2.1 Survey instrument

The survey was divided into four sections. The first three sections included questions about respondents' recreation trips to shoreline sites in the Bay Area. Only respondents who had visited shoreline sites for recreation at least once in the 12 months prior to the interview were asked questions from the first three sections of the survey. The final section of the survey included questions about respondents' demographic characteristics. All respondents were asked the demographic questions.

The first section of the survey asked respondents to report specific information about a representative selection of up to three of their recent shoreline recreation trips.[1] Respondents were asked only about trips that occurred during the three months prior to the time of the interview. Also, respondents were asked only about single-day trips, in other words, trips that

1. Information about a representative selection of trips was obtained using a series of questions that varied depending on the pattern of trips reported by each respondent over the previous three months. The questions elicited information about at least one trip for each of the months in which the respondent took trips, ensuring a representative distribution of the respondent's trips across time. The questions also required respondents to provide information about either their first or last trip in a given month, a method resulting in probabilities of selection that were believed to be uncorrelated with any features of the trip, such as activity or destination. An example of this method of selecting trips could involve a respondent who took two trips during the month of the interview, three trips in the month prior to the interview, and no trips in the month before that. This respondent would be asked to report details about his or her most recent trip, as well as details about the first and last trip in the month prior to the interview.

lasted one day or less and did not involve an overnight stay away from home. The information reported about each trip included the date of the trip, the destination of the trip, the number of people who accompanied the respondent on the trip, the activities the respondent engaged in during the trip, and whether the respondent traveled to the shoreline site by car. The survey was administered between June 2008 and August 2008, and the trips reported by respondents in the first section of the survey occurred between April 2008 and August 2008.

The second section of the survey asked respondents to report the number of trips they typically take during each month of the year. This section also included a question asking whether respondents typically went to the same shoreline sites and engaged in the same types of shoreline activities during November and December as they did during the three months prior to the time of the interview. The purpose of this question was to determine whether the recreation choices reported in the first section of the survey were representative of the recreation choices respondents typically made during November and December, the months when the most significant spill impacts to recreation were likely to have occurred.

The third section of the survey included questions asking respondents about effects of the oil spill on their recreation choices. The questions asked if respondents stopped going to certain shoreline sites because of the spill or if they went less often to certain sites because of the spill. If respondents stopped going to certain sites or went to certain sites less often, they were asked to identify the affected sites. They were also asked how many fewer trips they took to the affected sites because of the spill and whether on those occasions they went to other shoreline sites instead.

The final section of the survey collected information about the demographic characteristics of respondents. These included the respondent’s age; the number of people living in the respondent’s household; the number of children under the age of 16 living in the respondent’s household; the number of people in the respondent’s household who were members of the respondent’s family; and the number of landline telephone numbers in the respondent’s household. The demographic characteristics also included the highest level of education the respondent achieved; whether the respondent was Hispanic; the respondent’s race; whether the respondent spoke a language other than English at home and, if so, which language; the respondent’s family income; and the respondent’s gender. The final section of the survey also asked the respondent’s zip code.

J.2.2 Survey design and implementation

The telephone survey was conducted from June 2008 to August 2008 with a sample of residents in five Bay Area counties. Implementation of the survey in the period 8 to 10 months after the spill was believed to be soon enough to allow for the accurate recollection of spill effects by survey respondents but late enough to allow for recovery from the spill and the collection of recreation data under baseline conditions. Those eligible to be surveyed (the sample frame) included all residents of San Francisco County who were 16 years or older at the time of the survey and who had a landline telephone. It also included residents 16 years or older with a landline telephone living in parts of Marin, Contra Costa, Alameda, and San Mateo counties. The geographic area included in the sample frame is shown in Figure J.1. This area includes 104 zip codes and 2.4 million people.

The survey company Fleischman Field Research in San Francisco was retained to implement the survey. A series of training sessions were held with interviewers to rehearse the interview process and address any questions about the survey instrument. An initial 65 interviews were conducted for pretesting the survey instrument. During the pretest phase, members of the research team listened to the interviews as they were in progress and noted any difficulties in the interview script or other aspects of survey implementation. During the pretest phase, researchers clarified certain aspects of the survey approach with interviewers, for example, that recreational activities at beach or waterfront areas included only those activities whose primary purpose was the use of public shore resources and did not include activities such as dining at a seaside restaurant. During the pretest phase, researchers concluded that all aspects of the survey were working well, and no changes were made to the survey instrument or approach.

The telephone survey was conducted using random-digit dial (RDD) methods. A stratified random sample of landline phone numbers for the designated geographic area was obtained from Survey Sampling International (SSI). The approach to stratification involved dividing the geographic area sampled into two zones: areas within San Francisco and areas outside San Francisco. Telephone numbers within San Francisco were sampled at a higher rate than telephone numbers outside San Francisco to ensure that the final sample of completed interviews was evenly split between the two zones. This approach allowed losses for residents within San Francisco and losses for residents outside San Francisco to be estimated with equal precision.

The total sample included 22,449 phone numbers. Of these, 12,231 were determined to be ineligible, including disconnected numbers, business numbers, and fax numbers. The remaining sample consisted of 10,218 eligible numbers. Each eligible landline number is associated with a particular household. In order to ensure that an interview was conducted with a randomly selected individual within each household, interviewers asked to speak with the person in the household 16 years old or older who most recently had a birthday. Interviews were completed with 1,339 respondents, resulting in a response rate of 13.1%. An additional 27 respondents were eliminated from the sample during the weighting process so that characteristics of sample respondents could be matched to statistics from the U.S. Census (described below). The final sample used in the analysis included the remaining 1,312 respondents.

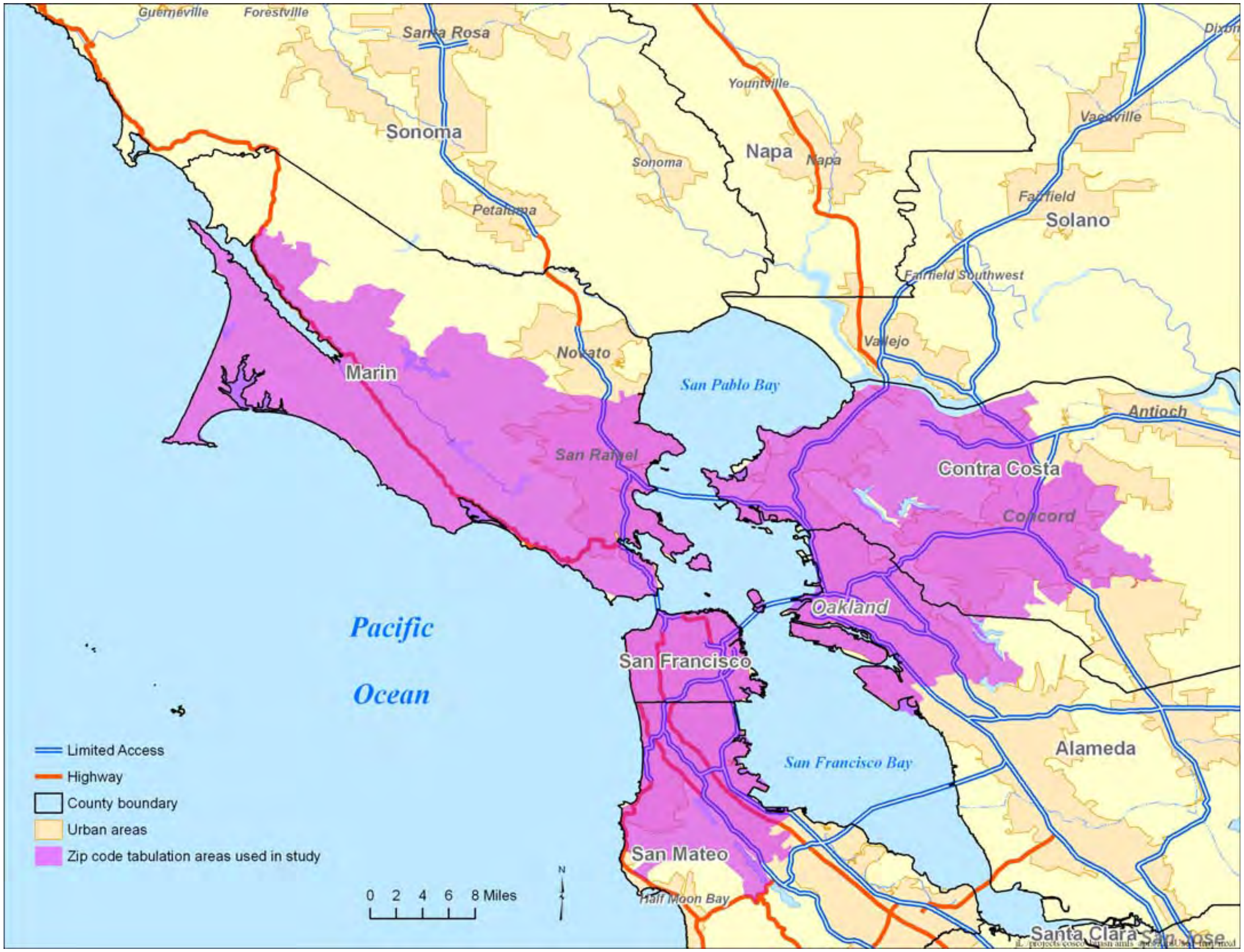

Figure J.1. Geographic area included in the sample frame.

J.2.3 Weighting survey responses

Prior to using the telephone survey data for estimating lost trips or developing a travel-cost model, survey responses were weighted to ensure that the sample was representative of residents in the target area of the survey (as shown in Figure J.1). Statistical weights were calculated to account for three factors. First, design weights compensated for unequal sample-selection probabilities that arose from the use of landline telephone numbers as the mode of contact for the survey. This ensured that differences in the number of landlines per household would not introduce bias in survey results. Second, population weights were developed to match the survey sample to population controls derived from the U.S. Census. This compensated for the oversampling of San Francisco residents that occurred in the implementation of the survey and ensured that all residents of various geographic regions and various demographic and socioeconomic groups were equitably represented in the analysis of recreation losses.

Design weights to compensate for unequal sample-selection probabilities across respondents were calculated as the inverse of the sample-selection probability for each respondent. Sample-selection probabilities were calculated as the number of landlines in the respondent’s home divided by the number of adults in the respondent’s household. The number of adults in the household was calculated as the total number of people in the household minus the number of children in the household. For the purpose of calculating the weights, the number of landlines in a household was truncated at two and the number of adults in a household was truncated at three.

To calculate population weights for use in matching the sample to the U.S. Census, respondents and their corresponding design weights were divided into 16 groups or “subclasses.” The 16 subclasses were defined by the set of unique combinations associated with four binary variables ($2^n = 2^4 = 16$). The four binary variables were age, which was divided into those 18 to 44 years old and those 45 and older; gender, which consisted of male and female; education, which was divided into those with an associate’s degree or lower and those with a bachelor’s degree or higher; and zone of residence, which was divided between those living in and outside San Francisco. For example, one subclass of observations was defined by the group of respondents who were between 18 and 44 years old, were male, had completed an associate’s degree or less, and lived in San Francisco. At this stage, 27 observations were removed so that respondents 16 or 17 years old were eliminated from the sample. This was necessary to develop the population weights because the U.S. Census reports separate statistics for those 18 and older in the relevant geographic area but not for those 16 and older.

Note that of the 16 subclasses, one contained a small number of observations and was therefore combined with another subclass. Specifically, the subclass defined by respondents who were between 18 and 44 years old, were male, had completed an associate’s degree or less, and lived outside San Francisco had a small number of observations. This subclass was combined with the subclass of people who were between 18 and 44 years old, were female, had completed an associate's degree or less, and lived outside San Francisco. This resulted in a total of 15 subclasses used in the final calculation of weights.

The population weighting procedure involved calculating weights that, when multiplied by the sample-selection weights previously calculated, allowed the "sample proportions" for each of the 15 subclasses to match "control proportions" from the U.S. Census. Sample proportions for each subclass were calculated as the sum of the design weights for respondents in each subclass divided by the sum of design weights for all respondents. "Control proportions" were calculated using information from the U.S. Census. Specifically, control proportions were calculated as the portion of the target population belonging to each of 15 subclasses, according to U.S. Census data. The sample selection weights for each observation in a given subclass were then multiplied by the population weights, which were the ratio of the control proportion to the sample proportion for that subclass. After this population-weighting procedure, the relative size of each subclass in the weighted sample was equal to the relative size of each subclass in the target population.

A standard weight-trimming procedure was used to truncate the final weights at the second-largest value (Kish, 1992). In other words, there were several weights of equal value that were larger than any other weights in the sample, and these were set equal to the value of the second-largest weight in the sample. Finally, the weights were rescaled so that the sum of the weights equaled 1,312, which is the total number of observations in the final sample. The weighted data were used in the calculation of all results described below.

J.3 Estimating Lost Trips

The term "lost trips" refers to the decline in trips to sites where spill impacts to recreation occurred. For each lost trip, an individual either recreates at a shoreline site outside the affected area or engages in activities other than shoreline recreation. Estimating the number of lost trips at affected sites is important to the analysis because it is a measure of the severity of spill impacts to recreation that can be incorporated into the recreation valuation model. Specifically, the baseline recreation model was modified to reflect a decline in quality at affected sites, and the severity of the quality decline was adjusted until the model's estimate of lost trips at affected sites matched the information from the survey. As described further in Section J.4, a comparison of the spill-adjusted model to the baseline model can be used to estimate the loss in value attributable to the spill.

Quantifying lost trips involved several steps. First, the number of lost trips reported by survey respondents was estimated. This estimate was used to calibrate the baseline model to spill impacts, as described in Section J.4. Second, a percentage was calculated for survey respondents reflecting lost trips to affected sites as a proportion of baseline trips to all sites throughout the assessment area. Third, the total number of baseline trips by all recreators to all sites in the assessment area was estimated using results of the onsite sampling. Finally, the total number of lost trips by all recreators was calculated by multiplying the lost trips percentage by the total number of baseline trips. The extent of the area where spill impacts to recreation occurred is defined below. The assessment area includes all shoreline sites where respondents to the survey typically go for trips lasting a single day or less.

J.3.1 Lost trips reported by survey respondents

Questions in the telephone survey asked respondents whether they had taken any single-day recreation trips to shoreline sites in the Bay Area during the 12 months prior to the time of the interview. The survey also asked respondents whether they were aware of the oil spill that had occurred in San Francisco Bay in November 2007. Those respondents who took trips in the previous 12 months and who were aware of the oil spill were asked whether the spill caused them to stop going to certain sites or to go less often to certain sites in November 2007. Those respondents reporting effects from the spill were asked to identify the sites they avoided or went to less often and to report how many fewer trips they took to those sites because of the spill. For the times when they did not got to a particular site because of the spill, respondents were also asked whether they went to other shoreline recreation sites instead.

The responses to these questions were used to calculate lost trips for survey respondents during November 2007. The first step was determining the group of sites that were affected by the spill. For the purpose of calculating lost trips, a shoreline site was determined to be affected if at least two survey respondents indicated they took fewer trips to the site because of the spill. This approach to determining the geographic extent of spill impacts to recreation is conservative because any sites identified as impacted by only one person were excluded from the designated area and were assumed not to be affected.

For each respondent, the decline in trips to affected sites included all trips not taken to a given affected site because of the spill, net of any switching between affected sites. For example, if a respondent indicated that he or she avoided an affected site on three occasions but went to another site within the affected area on one of the occasions, this respondent was determined to have lost only two trips. Netting out any trips that involve switching between affected sites is important because switching between affected sites does not result in a decline in the total number of trips to the affected area. As noted above, the total decline in trips to affected sites is the key indicator of spill impacts to recreation used to calibrate the spill-adjusted valuation model. Switching from one affected site to another affected site occurred only rarely in the telephone survey data and likely resulted from differences in perception among respondents about spill impacts at particular sites. Lost trips to affected sites for each respondent were summed across respondents to calculate total lost trips in November 2007.

In addition to questions about spill impacts to recreation trips in November 2007, respondents were asked whether the number of their recreation trips had returned to normal following the spill. If the number of their trips had returned to normal by the time of the survey, respondents were asked in what month this happened. For each month after November and up to the month when the number of their trips returned to normal, respondents were asked how many times they would normally have gone to shoreline sites in the Bay Area but did not go because of the spill. The number of impacted trips reported in response to this last question was added across respondents to calculate a preliminary estimate of lost trips in each month after November. This preliminary estimate did not account for any switching between sites within the affected area. Since the survey did not obtain the relevant information for months after November, results for November were used to make the appropriate adjustment. Specifically, results for November indicated that the process of netting out any switching between sites led to a decline of about 5.2% in the estimated number of lost trips. An adjustment of 5.2% was therefore also applied in months after November to calculate the final estimate of lost trips in each month.

J.3.2 Lost trips as a percent of baseline trips

The estimate of lost trips for survey respondents was used to calculate the percentage decline in trips due to the spill relative to the number of trips respondents would have taken under baseline conditions. The number of baseline trips for respondents was estimated using information about the number of trips respondents typically take in a given month, as reported by respondents in the second section of the survey.

First, the number of lost trips for each respondent in a given month was compared to the number of trips the respondent typically took in that month. In some instances the number of lost trips exceeded the number of typical trips. In these instances the number of lost trips was truncated to be equal to the number of typical trips. Prior to truncation, the typical number of trips reported by each respondent for November 2007 was multiplied by 0.756 to estimate the typical number of trips on or after November 7, when the spill occurred.[2] Second, the truncated number of lost trips was added across respondents by month, and the typical number of trips was also added across respondents by month. The sum of typical trips represents an estimate of baseline trips in each month. Third, the total number of lost trips for all respondents was divided by the total number of typical trips for all respondents to estimate the percent decline in trips in a given month. Since the number of trips a respondent would have taken absent the spill may be greater than the typical number of trips a respondent takes, it is also possible for lost trips to exceed

2. The factor 0.756 was calculated using daily estimates of shoreline recreation trips under baseline conditions in November 2007 to sites included in the onsite counts (see Appendix G). The daily trip estimates reflected visitation to sites included in the onsite counts and were estimated using the model developed from the onsite counts.

typical trips. Truncating the number of lost trips to be less than or equal to the number of typical trips may therefore be conservative.

Table J.1 shows lost trips as a percent of baseline trips for November 2007 through June 2008. Lost trips were 38.1% of baseline trips for the period November 7 to November 30, 2007. This percentage declined to 16.0% in December 2007 and to 9.4% in January 2008. For the damage assessment, the period of spill impacts was assumed to extend from November 2007 to June 2008. The estimate of lost trips as a percent of baseline trips was 2.0% in June 2008, and any spill impacts to recreation after June were not included in the assessed losses.

Table J.1. Lost trips as a percent of baseline trips for survey respondents

Month	Lost trips	Baseline trips	Lost trips as percent of baseline trips
November 7–30, 2007	544	1,425	38.1%
December 2007	277	1,735	16.0%
January 2008	154	1,637	9.4%
February 2008	122	1,780	6.8%
March 2008	89	2,079	4.3%
April 2008	79	2,702	2.9%
May 2008	66	2,169	3.1%
June 2008	44	2,184	2.0%

J.3.3 Total baseline trips

The total number of baseline trips to shoreline sites in the assessment area was estimated using onsite sampling that involved counts of recreation trips at selected shoreline sites. Estimating total trips using information from the onsite sampling accounted for trips taken by tourists and other people who may live in places outside the coverage area of the telephone survey. It also represented a conservative estimate of total shoreline trips because, unlike the telephone survey, the onsite sampling accounted for trips to a precisely circumscribed area around each shoreline site. If some shoreline trips are taken to areas near a particular site but outside the site boundaries delineated in the onsite sampling, results of the onsite sampling would provide an underestimate of total baseline trips.

The calculation of total baseline trips involved two steps. The first step was to develop an estimate of total baseline trips to the specific sites that were included in the onsite sampling. The number of baseline trips to these sites was estimated using onsite counts conducted during November 2008. A model was developed to account for the influence of weekdays and weekend days on recreation activity and to adjust for differences in weather between November 2008 and the months for which baseline predictions were developed. Specifically, baseline trips to the selected sites were estimated for the period November 2007 to June 2008. The details of this estimation procedure and the adjustments for weather are described in Appendix G.

The second step in calculating total baseline trips involved adjusting the estimated number of baseline trips at sites included in the onsite sampling to account for sites that were not part of the onsite sampling. This adjustment relied on information from the telephone survey. As described below, information from the telephone survey was used to estimate baseline trips taken by survey respondents to sites throughout the Bay Area. The baseline trip estimates derived from the telephone survey included trips over a three-month period to 110 sites, including 25 sites that were part of the onsite sampling and 85 sites that were not part of the onsite sampling. Using information from the telephone survey, a ratio was calculated comparing baseline trips taken by survey respondents to all 110 sites in the assessment area to baseline trips taken by survey respondents to the 25 sites included in the onsite sampling. This ratio was 1.4. Multiplying the total number of baseline trips estimated from the onsite sampling by 1.4 resulted in an estimate of total baseline trips to all sites in the assessment area. Table J.2 shows the estimated total number of baseline trips to assessment area sites by month. The estimate of total baseline trips varied from a low of 1,058,810 trips in January 2008 to a high of 1,502,575 trips in June 2008.

Table J.2. Total baseline trips and total lost trips

Month	Total baseline trips	Lost trips as percent of baseline trips	Total lost trips
November 7–30, 2007	1,158,645	38.1%	441,918
December 2007	1,258,557	16.0%	201,179
January 2008	1,058,810	9.4%	99,308
February 2008	1,120,151	6.8%	76,551
March 2008	1,292,753	4.3%	55,024
April 2008	1,260,231	2.9%	36,907
May 2008	1,422,526	3.1%	43,597
June 2008	1,502,575	2.0%	29,967

J.3.4 Total lost trips

The total number of lost trips was estimated by multiplying the total number of baseline trips throughout the assessment area by the estimate of lost trips as a percent of baseline trips. Table J.2 shows the result of this calculation by month. The total number of lost trips declines from 441,918 in November 2007 to 29,967 in June 2008.

J.4 The Value per Lost Trip

The value per lost trip was calculated using a travel-cost model. The model was developed from information collected in the telephone survey about the frequency and destination of shoreline recreation trips taken by survey respondents. A travel-cost model is used to estimate the value of recreation trips based on information about the distance people travel and the costs they incur to reach recreation sites. The use of travel-cost models for assessing impacts to recreation (Herriges and Kling, 1999; Phaneuf and Smith, 2005) and recreational losses from oil spills (Hausman et al., 1995; English et al., 2009) is well established. The model was developed to represent recreation choices of Bay Area residents under baseline conditions. The model was then adjusted to represent spill conditions using information from the telephone survey about the geographic extent of spill impacts to recreation and the number of lost recreation trips attributable to the spill.

The following elements of the travel cost model and the techniques for estimating the value of lost trips are described below: (1) development of data for estimating a baseline model of shoreline recreation, including the number of trips to sites in the Bay Area, the cost of traveling to shoreline sites, and demographic variables; (2) the model specification, including the development of a site-choice and participation model and the use of alternative-specific constants to represent the quality of shoreline sites; (3) calibration of the model to information about spill impacts to recreation, including the geographic extent of spill impacts and the number of lost trips; and (4) use of the model to estimate the value per lost trip.

J.4.1 Data for estimating a baseline model

The travel-cost model was developed using information about respondents' reported trips within the three months prior to the time of the interview. As noted earlier, the survey was administered between June 2008 and August 2008, and the trips reported by respondents occurred between April 2008 and August 2008. Respondents were asked to report the number of trips they had taken to Bay Area shoreline sites during the month when the interview was administered, up to the date of the interview. Respondents were also asked to report the number of trips they took to Bay Area shoreline sites in each of the two months prior to the month when the interview was administered. Finally, respondents were asked to report the destination and other details of a representative selection of up to three of these trips.

For the purpose of developing the travel-cost model, the destinations of the selected trips were extrapolated to represent the destinations of all trips reported by each respondent. For example, a respondent might report specific information about two different trips in the months prior to the interview. The respondent might also report taking a total of six trips during the same period.[3] In this case the respondent was assumed to have taken three trips to each of the two destinations, for a total of six trips. The procedure was repeated for all respondents, and the results were used as the basis for a travel-cost model of trip destination and frequency. A model estimated in this way is unbiased, as long as the trips a respondent is asked to describe in detail do not systematically overrepresent certain shoreline destinations visited by the respondent. By adding baseline trips across individuals in the sample, this same procedure was also used to develop estimates of total baseline trips to each site in the assessment area.

The data required to develop a travel-cost model include travel distances between each respondent's place of residence and all shoreline sites included in the model. Distances were measured using PCMiler software. Distances were converted to travel cost using the sum of monetary expenses and time-related costs. Per-mile monetary expenses for driving were calculated as $0.21 per mile for gasoline and depreciation expenses divided by an average of 2.5 passengers per vehicle. The figure of $0.21 per mile was derived from a report of nationwide average driving costs for late 2007 published by the American Automobile Association. Per-mile time-related costs were calculated as family income divided by 2,000 hours per year, divided by 3 (for one-third hourly income), divided by 35 miles per hour. This approach to valuing the cost of time is common in the travel-cost literature (Train, 1998; Moeltner, 2003). Per-mile expenses for the cost of driving and the cost of time were multiplied by the round-trip driving distance from the resident's zip code to the shoreline site. The PCMiler program also provided information on tolls along each route, and these costs were added to per-mile costs to calculate the total cost of traveling to shoreline sites.

Respondents to a survey are often unwilling to report their income, and 40.0% of respondents to the shoreline recreation survey did not report their family income. A log-linear regression was used to impute incomes for those who did not provide this data so that income could be used in constructing the travel-cost variable as described above. For the 965 respondents who reported

3. The number of trips a respondent reported for the month during which the interview took place represented the respondent's recreation activity for the portion of the month that had elapsed prior to the interview. To ensure that each respondent's recreation activity was represented equally, this amount was adjusted to estimate the expected number of trips the respondent would take during the entire month. Specifically, the number of trips reported for the month of the interview was increased to equal the number of trips reported for the previous entire month, whenever the latter number was greater.

their family income, the natural log of family income was regressed on a constant term and five independent variables, including age (18–29, 30–44, 45–64, 65+); education (less than 9th grade, 9th grade to 12th grade, high school diploma, some college, associate's degree, bachelor's degree, graduate/professional degree); whether the respondent was Hispanic (no, yes, don't know, refused); race (white, black/African American, American Indian, Asian, Pacific Islander, other); and language spoken at home (English, Spanish, Chinese, Tagalog, Japanese, Vietnamese, other, no response). Income was imputed for the remaining 347 observations by taking the inverse natural log of the product of the estimated coefficients and the relevant demographic variables.

The remaining data required for the travel cost model were demographic characteristics. These were binary variables defined as follows: age (45 years old or older); education (bachelor's degree or higher); race (white); language spoken at home (English only); gender (female); and whether there were children living in the household. In each case the variable was set equal to one if the respondent could affirmatively be identified as part of the relevant group and to zero in all other cases, including those who did not provide a response to the relevant question.

J.4.2 Model specification

The shoreline recreation model is a site-choice and participation model, meaning it is able to predict changes in both the destination and frequency of recreation trips. The site-choice component is important for assessing spill impacts to recreation because it allows for the possibility that recreators switch to alternative recreation sites when the sites they would have used are affected by the spill. The participation component is important for assessing spill impacts to recreation because it allows for the possibility that people engage in activities other than shoreline recreation in response to the spill. Models that do not explicitly allow for substitution to other sites and other activities could result in a higher estimate of losses because such models may not fully account for the ability of recreators to mitigate spill-related losses.

Survey respondents identified 110 shoreline sites in the Bay Area where they take recreation trips. These include sites they visited in recent months and also included sites where they went less often during the period of the spill. It is difficult to include 110 sites in a travel-cost model because of the large number of model parameters required. It is common in the travel-cost literature to combine nearby sites to form a smaller number of aggregate shoreline destinations (Parsons and Needelman, 1992). For the Bay Area shoreline recreation model, the 110 individual sites were combined into groups to form 31 aggregate sites. The 110 individual sites and the 31 aggregate sites are shown in Attachment 2. Figure J.2 shows the aggregate sites with appropriate labels and also shows the individual sites as points within each aggregate site. Each aggregate site is named for the largest individual site it contains.

Figure J.2. Aggregate recreation sites.

The model structure used in the Bay Area shoreline recreation model was first developed as the "repeated-logit" model described in Morey et al. (1993). The specific form used for the Bay Area shoreline recreation model is described in detail as the "nested-logit" model in English (2008). This form includes a random-utility logit model of site choice, nested within a second logit model of trip frequency. As in English (2008), the quality and characteristics of recreation sites are described using site-specific constants. A specification relying on site-specific constants reduces bias in valuation results (Murdock, 2006) and is frequently applied in oil spill assessments (Hausman et al., 1995; English et al., 2004). In addition to site-specific constants, the model includes a variable representing the cost of travel to recreation sites, variables used in the trip-frequency model including a constant and demographic characteristics (age, education, race, children, language, and gender, as defined above), and a scale parameter used in the nested-logit specification. The statistical weights corresponding to each respondent were incorporated into the model using a weighted likelihood function.

The coefficients of the model are shown in Table J.3. The parameter for travel cost is negative, indicating that, all else equal, people are less likely to choose sites with higher travel cost. The 31 aggregate sites are listed in geographic sequence starting in the north and ending in the south. Each of the 31 aggregate sites includes more than one individual site, and the name used for the aggregate site is generally the name of the largest individual site within the aggregate group. The site-specific constants reflect the characteristics of the sites within each aggregate group. The length of available shoreline is an important site characteristic, which may explain why Ocean Beach has the largest site-specific constant. In the trip frequency model, a positive sign indicates that an increase in a particular variable is associated with less frequent recreation trips. Those who are older than 45, are female, or have children are less likely to take recreation trips to shoreline sites in the Bay Area.

J.4.3 Calibrating the model to information about spill impacts on recreation

The model of baseline recreation trips described above was adjusted to represent conditions during the period of spill impact. The decline in trips to shoreline sites during the period of the spill was assumed to be attributable to a decline in the quality of shoreline sites. Since the quality of shoreline sites is represented in the travel-cost model using site-specific constants, the model can be calibrated to spill impacts on recreation using adjustments to the site constants. A comparison of the calibrated model to the baseline model can then be used to estimate the lost value associated with the decline in the quality of shoreline sites. For November 2007, the site constants were modified to reflect the impact of the spill and the reduced number of trips taken to shoreline sites based on information from the telephone survey. The calibration of the model to spill impacts took into account the specific number of trips lost at each shoreline site. For months after November 2007, adjustments to the calibrated model reflected the declining severity of impacts over time.

Table J.3. Model coefficients

Variable	Coefficient	Standard error	*t*-statistic
Travel cost	-0.13	0.00	-61.39
Site constants			
Dillon Beach	7.08	1.60	4.43
Tomales Beach	7.17	1.58	4.53
Limantour Beach	6.98	1.53	4.57
Bolinas Beach	6.22	1.50	4.15
Stinson Beach	7.25	1.49	4.86
Muir Beach	4.47	1.61	2.78
Rodeo Beach	3.81	1.57	2.43
Marin Headlands	3.64	1.59	2.29
Sausalito/Angel Island	3.43	1.56	2.21
San Rafael	3.63	1.51	2.40
Carquinez	0.00		
San Pablo	1.19	1.84	0.65
Keller Beach	4.26	1.50	2.84
Point Isabel	5.96	1.50	3.99
Berkeley Marina	5.28	1.50	3.52
Alameda State Beach	5.97	1.49	4.00
Coyote Point	4.28	1.54	2.78
Mission Bay	2.65	1.63	1.63
Piers 1–45	5.72	1.51	3.80
Aquatic Park	4.55	1.50	3.03
Marina Green	3.65	1.51	2.42
Crissy Field Beach	6.50	1.50	4.33
Baker Beach	5.82	1.50	3.87
China Beach	4.62	1.51	3.07
Lands End Beach	4.56	1.51	3.03
Ocean Beach	7.79	1.50	5.19
Fort Funston	5.40	1.50	3.59
Sharp Park Beach	5.00	1.50	3.33
Pacifica Beach	6.87	1.50	4.57
Half-Moon Bay	6.71	1.53	4.39
San Gregorio Beach	5.40	1.76	3.07

Table J.3. Model coefficients (cont.)

Variable	Coefficient	Standard error	*t*-statistic
Trip frequency model			
Constant	5.66	0.43	13.21
Age	0.16	0.02	9.61
Education	-0.38	0.02	-23.80
Race	-0.18	0.02	-10.20
Children	0.37	0.03	14.62
Language	-0.86	0.02	-36.49
Gender	0.28	0.02	15.90
Nesting scale parameter	3.42	0.12	28.97

Questions in the telephone survey asked respondents about the number of trips they would have taken to shoreline sites in the Bay Area in November 2007 but did not take because of the spill. As described above, these questions were used to determine the number of lost trips for each respondent. Questions in the survey also asked respondents to identify which sites they avoided or went to less often. These questions were used to estimate the number of lost trips specifically associated with each shoreline recreation site. This was accomplished by allocating the lost trips for each respondent to each of the sites the respondent avoided or went to less often. The allocation accounted for the probability of visiting each site under baseline conditions as estimated by the travel-cost model. For example, a respondent might report taking 10 fewer trips because of the spill and might identify two sites that he or she avoided or went to less often. Each site identified would correspond to one of the aggregate sites used in the travel-cost model. The travel-cost model might estimate the relative probability of visiting each of the two aggregate sites as 0.7 and 0.3, respectively. In this case the estimate of this respondent's lost trips for the two sites would be 7 and 3, respectively. By adding up the site-specific estimates of lost trips across respondents, an estimate of lost trips for each of the 31 aggregate sites was obtained.

The estimate of lost trips for each of the aggregate sites in the model in November 2007 was used to calibrate the model to spill conditions. In the calibrated model, the number of trips to a given site must be equal to the number of baseline trips for the site less the number of lost trips for the site. A search procedure was used to find the appropriate 31 site-specific constants for the calibrated model that would satisfy this requirement. Prior to calibration, five sites (Dillon Beach, San Rafael, Coyote Point, Half Moon Bay, and San Gregorio Beach) were reported to be affected by fewer than three respondents; these sites were assumed to be unaffected. This threshold for aggregate sites is slightly higher than the threshold for individual sites used above, because each aggregate site combines lost trips from several individual sites and the number of lost trips at aggregate sites is therefore expected to be higher than the number of lost trips at individual sites. In the calibrated model, the most significant declines in recreation trips occurred at Stinson Beach, Ocean Beach, and Pacifica Beach. This was due, in part to, the severity of impacts to recreation at these sites and, in part, to the popularity of these beaches under baseline conditions.

The number of lost trips reported by survey respondents declined in each month after November 2007. This was assumed to be attributable to two factors. First, the number of sites affected by the spill may have declined over time. Second, the severity of recreational impacts at any given site may have declined over time. Both of these factors were accounted for in the calibration of the model to spill impacts in months after November.

The sites that continued to be affected by the spill in months after November 2007 were identified using information from survey respondents to develop an index of spill impacts. The first step was to sum up the estimated number of people who avoided a given site in a given month because of the spill. For months after November, questions in the survey did ask whether affected respondents continued to take fewer trips because of the spill but did not ask respondents to give specific information about which sites they avoided. It was therefore assumed that respondents who continued to be affected after November continued to avoid the same sites they had avoided in November. In other words, the first step in calculating the spill index for a given site was to sum up the total number of people who both avoided the site in November and who continued to take fewer trips in the relevant month because of the spill.

The estimated number of people who avoided each site in a given month was then normalized based on the typical level of use at each site. Specifically, the number of people who avoided a given site in each month was divided by the total number of trips taken to the site by survey respondents under baseline conditions. Normalizing the index by the typical number of trips to each site controlled for the fact that more popular sites were more likely to be identified as affected by survey respondents. Without normalizing in this way, popular sites could have had a high index indicating significant effects even if a small percentage of people who used the sites under baseline conditions reported avoiding the site during the spill.

To identify affected sites, the index of spill impacts for a given site in a given month was compared to a minimum threshold. Sites with an index exceeding the threshold were determined to be affected. The appropriate threshold was selected by comparing the index to actual recreation impacts in November, as determined above. Specifically, the threshold was set so that the set of affected sites as predicted by the index in November matched the set of sites where at least three people specifically indicated impacts had occurred. This threshold was then applied to all months after November. The spill impact index declined for most sites in most months, and the number of sites determined to be affected also declined. The sites designated as affected in each month are shown in Figure J.3. The number of sites identified as affected declined from 23 sites in November to 18 sites in December, 15 in January, 12 in February, 4 in March, 3 in April, 3 in May, and 1 in June.

For those sites that continued to be affected in each month, the severity of impacts at the sites was reflected in the spill-calibrated model using adjustments to the site constants. The spill-calibrated model for months after November satisfied two constraints. First, the site constants were adjusted each month to correctly reflect the total number of lost trips in each month. Unlike in November, the model was calibrated to total lost trips rather than the number of lost trips at each site, because site-specific losses were not available in months after November. Second, the relative severity of recreation impacts across sites as determined above for November 2007 was retained. Specifically, if the reduction in the site constant for the calibrated model relative to the baseline model was twice as great for one site relative to another site in November 2007, then the reduction was twice as great in all subsequent months, as long as both sites continued to be affected.

J.4.4 Value per lost trip

The value per lost trip was calculated for each month from November 2007 to June 2008 using a comparison between the baseline shoreline recreation model and the spill-calibrated model for each month. The value per lost trip was calculated as the loss in value estimated by the model divided by the number of lost trips in each month for all survey respondents. The loss in value was determined using the standard nested-logit formula for a change in consumer surplus given in Train (2003). The change in consumer surplus was calculated using the change in value of the site-specific constants in the spill-calibrated model relative to the baseline model.

The per-trip values for November 2007 through June 2008 are given in Table J.4. The values decline from $22.65 in November 2007 to $8.90 in June 2008. The values generally decline each month due to the declining number of sites affected by the spill. A decline in the number of sites affected corresponds to a lower per-trip loss because people avoiding the affected sites have a greater selection of alternative sites to visit and are therefore better able to mitigate losses. In some cases, the per-trip value increases modestly despite a decline in the number of affected sites because the sites that remain affected may be of higher value on average than the sites affected in the previous month. Differences in the value of individual sites are captured in the travel-cost model by differences in the distance people travel to reach the sites.

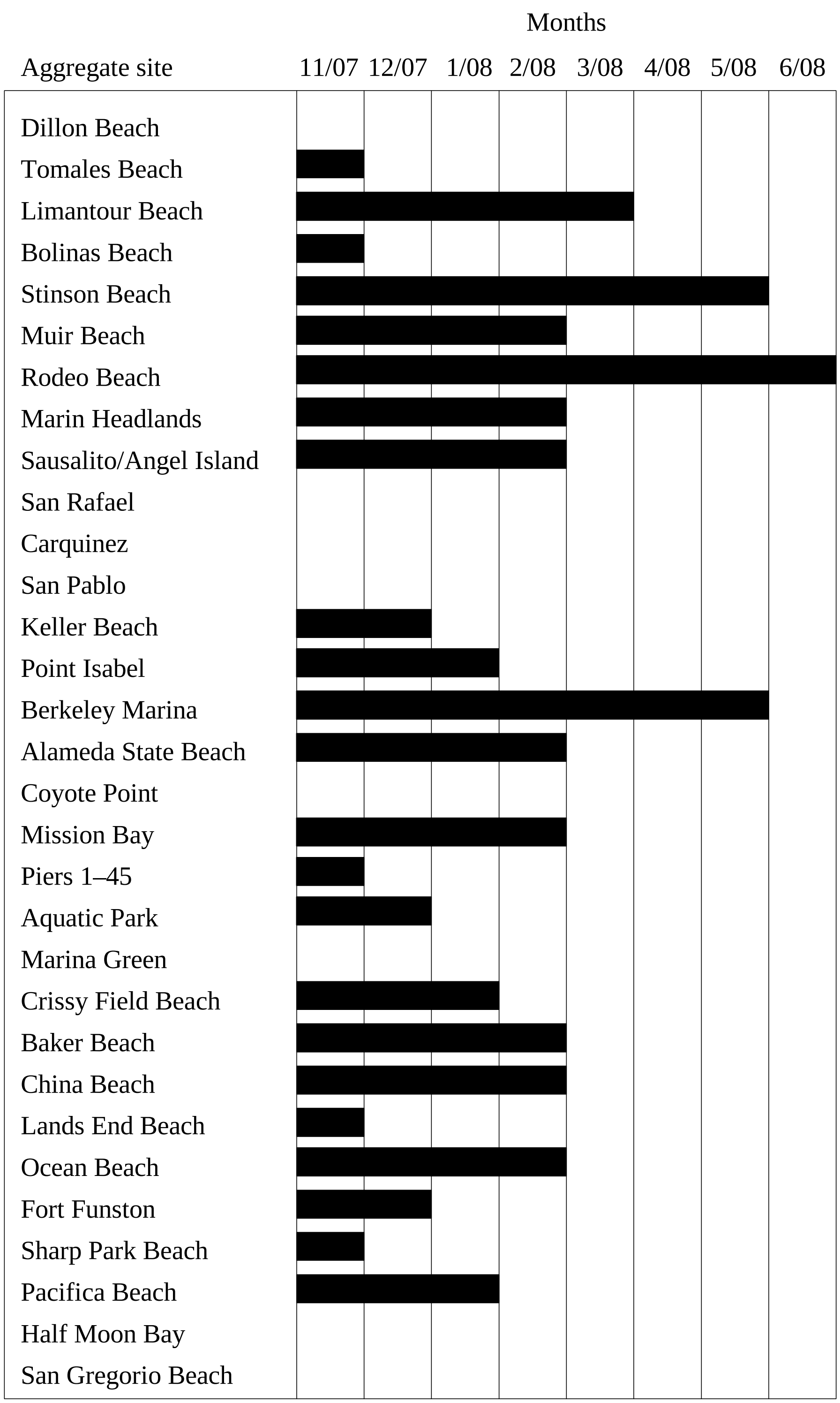

Figure J.3. Sites with impacted recreation visits by month.

Table J.4. Value per lost trip in 2007 dollars

Month	Value per lost trip
November 2007	$22.65
December 2007	$19.15
January 2008	$17.64
February 2008	$12.44
March 2008	$8.35
April 2008	$8.28
May 2008	$8.28
June 2008	$8.90

J.5 Summary of the Overall Damage Estimate

Table J.5 summarizes the result of the calculations described above. Amounts for baseline trips and lost trips and the value per lost trips are as reported above. Multiplying lost trips by the value per trip in each month results in a monthly estimate of losses. In 2007 dollars, total lost value declines from $10.0 million in November 2007 to $266,748 in June 2008. The total estimate of damages for the period from November 2007 to June 2008 is $18.0 million in 2007 dollars. To calculate the present value of shoreline recreation damages in January 2010, these amounts are adjusted for inflation using the monthly Consumer Price Index and adjusted for discounting using an annual 3% discount rate. As shown in the final column of Table J.5, the present value of damages in January 2010 was $20.2 million.

Table J.5. Summary of baseline trips, lost trips, and total damages

Month	Baseline trips	Lost trips as percent of baseline trips	Lost trips	Value per lost trip in November 2007 dollars	Lost value in November 2007 dollars	Present value of losses in January 2010
November 7–30, 2007	1,158,645	38.1	441,918	$22.65	$10,011,456	$11,351,008
December 2007	1,258,557	16.0	201,179	$19.15	$3,853,255	$4,343,775
January 2008	1,058,810	9.4	99,308	$17.64	$1,751,323	$1,962,069
February 2008	1,120,151	6.8	76,551	$12.44	$952,528	$1,062,133
March 2008	1,292,753	4.3	55,024	$8.35	$459,721	$509,348
April 2008	1,260,231	2.9	36,907	$8.28	$305,729	$337,010
May 2008	1,422,526	3.1	43,597	$8.28	$360,887	$394,656
June 2008	1,502,575	2.0	29,967	$8.90	$266,748	$288,322
Total	10,074,248		984,451		$17,961,646	$20,248,321

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Attachment 1. Shoreline Recreation Survey

SHORELINE USE TELEPHONE SURVEY

CATI instructions
INTERVIEWER INSTRUCTIONS
[Script insertions]

Hello, my name is **[name]** and I am calling on behalf of the city of San Francisco. We are conducting a survey about public lands and recreation in the San Francisco Bay Area. The survey will help the city and other government officials manage beaches more effectively. The survey is anonymous, and takes about 10 minutes. May I begin?

IF ENGLISH DOES NOT APPEAR TO BE PRIMARY LANGUAGE:

Q0: Do you prefer to do the survey in English, or another language?
1 English) ***Continue, below***

2 Spanish)
3 Mandarin)
4 Cantonese)
5 Tagalog)
For any of these languages:
Please hold while I transfer you to another interviewer
OR
We will try to contact you again later. Thank you for your time.

6 Other) ***terminate***

Terminate: Sorry for the interruption. Thank you for your time.

L1: Your telephone number was randomly selected. In order to ensure our survey is representative, we need to interview the person 16 years or older living there who most recently had a birthday. Are you the person 16 years or older who most recently had a birthday?
1 Yes) ***Go to Q1***
2 No

L1A: May I speak with that person?
1 Yes) ***Go to L1B***
2 No) IF RESPONDENT IS NOT AVAILABLE OR IT IS NOT A GOOD TIME FOR AN INTERVIEW, SET UP A CALL BACK ***(terminate)***

L1B: (WHEN PERSON ANSWERS)

Hello, my name is **[name]** and I am calling on behalf of the city of San Francisco. We are conducting a survey about beaches in the San Francisco Bay Area. It will help the city and other government officials manage beaches more effectively. In order to ensure our survey is representative, we have asked to speak with you since you were picked randomly. The survey is anonymous, and takes about 10 minutes. May I begin?

1 Yes) ***Repeat Q0, then Go to Q1***
2 No) ***terminate***

Terminate: Thank you for your time.
L1C: OBSERVE AND RECORD RESPONDENT'S GENDER

1 Male
2 Female
3 Don't know

Q1: This survey concerns beaches in the San Francisco Bay area. This includes any beaches or waterfront areas on San Francisco Bay or the Pacific Ocean that you might go to for a trip lasting a single day or less. During the past twelve months, since July 2007, have you taken any single-day trips to a beach or waterfront in this area for activities like swimming, fishing, boating, kayaking, wildlife viewing, sunbathing, shellfishing, or picnicking, or exercising?

1 Yes
2 No) ***Go to Q22***
3 (DO NOT READ) Don't know) ***Go to Q22***

Q2: Since May 1 of this year, have you gone to a beach or waterfront area in the San Francisco Bay area for recreational activities like swimming, fishing, boating, kayaking, wildlife viewing, sunbathing, shellfishing, or picnicking, or exercising?

1 Yes
2 No) ***Go to Q6***

Q2A: During the month of May, did you go to a beach or waterfront area in the San Francisco Bay Area for recreation?

1 Yes
2 No) ***Go to Q2B***

Q2A2. How many times? **[May trips] Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times

6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q2B: In June of this year, did you go to a beach or waterfront area in the San Francisco Bay Area for recreation?

1 Yes
2 No) ***Go to Q2C***

Q2B2. How many times? **[June trips] Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 No times
2 Once
3 Twice
4 Three
5 Four
6 Five or six times
7 About once a week
8 About twice a week
9 About three times a week
10 About four times a week
11 About five times a week
12 Almost every day
13 Every day

Q2C: Since July 1, have you gone to a beach or waterfront area in the San Francisco Bay Area for recreation?

1 Yes
2 No) ***Go to trip log***

Q2C2. How many times? **[July trips] Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 No times
2 Once
3 Twice
4 Three
5 Four
6 Five or six times
7 About once a week
8 About twice a week
9 About three times a week
10 About four times a week

11 About five times a week
12 Almost every day
13 Every day

(Begin trip log)

Log 1: If trips since May 1 < = 3 (Else go to Log 2)

Q3: What was the date of your most recent trip to a beach or waterfront area in the San Francisco Bay Area? (IF NECESSARY: "We know it can be hard to remember dates. Please do your best.") **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q3A: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. IF RESPONDENT DOES NOT KNOW THE NAME OF THE BEACH, ASK FOR NEAREST TOWN OR LANDMARK. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q3B: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other _________

Q3C: Did you travel by car?

1 Yes
2 No) ***Go to Q4***

Q3D: How many people, including yourself, rode in the car?
_______number of people

If trips since May 1 = 2 or 3: (Else go to Q6)

Q4: What was the date of your 2nd most recent trip to a beach or waterfront area in the San Francisco Bay Area? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q4A: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q4B: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising

Other _________

Q4C: Did you travel by car?

1 Yes
2 No) ***Go to Q5***

Q4D: How many people, including yourself, rode in the car?

_______number of people

If trips since May 1 = 3: (Else go to Q6)

Q5: What was the date of your 3rd most recent trip to a beach or waterfront area in the San Francisco Bay Area? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q5A: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q5B: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other __________

Q5C: Did you travel by car?

1 Yes
2 No) ***Go to Q6***

Q5D: How many people, including yourself, rode in the car?
________number of people

Go to Q6

Log 2: If May trips ≥ 1 and June trips ≥ 1 and July trips ≥ 1 (Else go to Log 3)

Q3-2: You said you took **[May trips]** trips to beaches or waterfront areas in the San Francisco Bay Area in May. What was the date of your (IF MORE THAN ONE: last) trip in May? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

__________ Date

Q3A-2: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q3B-2: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other __________

Q3C-2: Did you travel by car?

1 Yes
2 No) ***Go to Q4-2***

Q3D-2: How many people, including yourself, rode in the car?
________number of people

Q4-2: You said you took **[June trips]** trips to beaches or waterfront areas in the San Francisco Bay Area in June. What was the date of your (IF MORE THAN ONE: last) trip in June? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

__________ Date

Q4A-2: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q4B-2: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

- **1** Swimming
- **2** Fishing
- **3** Boating
- **4** Kayaking
- **5** Wildlife viewing
- **6** Sunbathing
- **7** Shellfishing
- **8** Picnicking
- **9** Exercising
- **10** Other _________

Q4C-2: Did you travel by car?

- **1** Yes
- **2** No) ***Go to Q5-2***

Q4D-2: How many people, including yourself, rode in the car?
_______number of people

Q5-2: You said you took **[July trips]** trips to beaches or waterfront areas in the San Francisco Bay Area in July. What was the date of your (IF MORE THAN ONE: last) trip in July? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q5A-2: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

- **1** Ocean Beach
- **2** Baker Beach
- **3** Etc.

Q5B-2: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

- **1** Swimming
- **2** Fishing
- **3** Boating
- **4** Kayaking
- **5** Wildlife viewing
- **6** Sunbathing
- **7** Shellfishing
- **8** Picnicking

9 Exercising
10 Other _________

Q5C-2: Did you travel by car?
1 Yes
2 No) ***Go to Q6***

Q5D-2: How many people, including yourself, rode in the car?
_______number of people

Go to Q6

Log 3: If May trips = 0 and June trips ≥ 2 and July trips ≥ 1 (Else go to Log 4)

Q3-3: You said you took **[June trips]** trips to beaches or waterfront areas in the San Francisco Bay Area in June. What was the date of your first trip in June? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**
_________ Date

Q3A-3: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**
1 Ocean Beach
2 Baker Beach
3 Etc.

Q3B-3: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**
1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other _________

Q3C-3: Did you travel by car?
1 Yes
2 No) ***Go to Q4-3***

Q3D-3: How many people, including yourself, rode in the car?
_______number of people

Q4-3: What was the date of your last trip in June? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q4A-3: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q4B-3: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other _________

Q4C-3: Did you travel by car?

1 Yes
2 No) ***Go to Q5-3***

Q4D-3: How many people, including yourself, rode in the car?
_______number of people

Q5-3: What was the date of your most recent trip in July? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q5A-3: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q5B-3: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other __________

Q5C-3: Did you travel by car?

1 Yes
2 No) ***Go to Q6***

Q5D-3: How many people, including yourself, rode in the car?
________number of people

Go to Q6

Log 4. If May trips = 0 and June trips = 1 and July trips ≥ 2 (Else go to Log 5)

Q3-4: For the trip you took in June, what was the date of your trip? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**
__________ Date

Q3A-4: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q3B-4: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other _________

Q3C-4: Did you travel by car?

1 Yes
2 No) ***Go to Q4-4***

Q3D-4: How many people, including yourself, rode in the car?
_______number of people

Q4-4: You said you took **[July trips]** trips to beaches or waterfront areas in the San Francisco Bay Area in July. What was the date of your first trip in July? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q4A-4: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q4B-4: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking

9 Exercising
10 Other **_________**

Q4C-4: Did you travel by car?
1 Yes
2 No) ***Go to Q5-4***

Q4D-4: How many people, including yourself, rode in the car?
_______number of people

Q5-4: What was the date of your most recent trip in July? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**
_________ Date

Q5A-4: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**
1 Ocean Beach
2 Baker Beach
3 Etc.

Q5B-4: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**
1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other **_________**

Q5C-4: Did you travel by car?
1 Yes
2 No) ***Go to Q6***

Q5D-4: How many people, including yourself, rode in the car?
_______number of people

Go to Q6

Log 5. Otherwise

Q3-5: What was the date of your most recent trip to a beach or waterfront area in the San Francisco Bay Area? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q3A-5: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q3B-5: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other _________

Q3C-5: Did you travel by car?

1 Yes
2 No) ***Go to Q4-5***

Q3D-5: How many people, including yourself, rode in the car?

_______number of people

Q4-5: What was the date of your 2nd most recent trip to a beach or waterfront area in the San Francisco Bay Area? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**

_________ Date

Q4A-5: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q4B-5: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking
9 Exercising
10 Other __________

Q4C-5: Did you travel by car?

1 Yes
2 No) ***Go to Q5-5***

Q4D-5: How many people, including yourself, rode in the car?
________number of people

Q5-5: What was the date of your 3rd most recent trip to a beach or waterfront area in the San Francisco Bay Area? **(NOTE TO TAI – WE CAN ACCEPT A RANGE FOR THIS)**
__________ Date

Q5A-5: What beach or waterfront area did you go to on that trip? IDENTIFY SITE FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q5B-5: What activity did you do on this trip? (IF MORE THAN ONE ACTIVITY, IDENTIFY PRIMARY ACTIVITY ONLY) **– Note to interviewer: Ask open ended but offer suggestions for clarification if needed**

1 Swimming
2 Fishing
3 Boating
4 Kayaking
5 Wildlife viewing
6 Sunbathing
7 Shellfishing
8 Picnicking

9 Exercising
10 Other _________

Q5C-5: Did you travel by car?
1 Yes
2 No) ***Go to Q6***

Q5D-5: How many people, including yourself, rode in the car?
_______number of people

(End trip log)

We are interested in how often you typically go to the beach during the course of the year. We are only interested in trips lasting one day or less, not in overnight trips. We are not interested in the details your visits, only in what you typically do.

Q6: Do you typically go to beach or waterfront areas for single-day trips in August?
1 Yes
2 No) ***Go to Q7***

Q6A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**
1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q7: Do you say you typically go to the beach or waterfront areas for single-day trips in September?
1 Yes
2 No) ***Go to Q8***

Q7A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**
1 Once
2 Twice
3 Three
4 Four

5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q8: Do you typically go to the beach or waterfront areas for single-day trips in October?

1 Yes
2 No) ***Go to Q9***

Q8A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q9: Do you typically go to the beach or waterfront areas for single-day trips in November?

1 Yes
2 No) ***Go to Q10***

Q9A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week

11 Almost every day
12 Every day

Q10: Do you typically go to the beach or waterfront areas for single-day trips in December?

1 Yes
2 No) ***Go to Q11***

Q10A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q11: Do you typically go to the beach or waterfront areas for single-day trips in January?

1 Yes
2 No) ***Go to Q12***

Q11A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q12: Do you typically go to the beach or waterfront areas for single-day trips in February?

1 Yes
2 No) ***Go to Q13***

Q12A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

Q13: Do you typically go to the beach or waterfront areas for single-day trips in March?

1 Yes
2 No) ***Go to Q14 test***

Q13A: How often? **Note to interviewer: use list to help clarify question if respondent seems to want clarification**

1 Once
2 Twice
3 Three
4 Four
5 Five or six times
6 About once a week
7 About twice a week
8 About three times a week
9 About four times a week
10 About five times a week
11 Almost every day
12 Every day

If (November trips (Q10) > 0 OR December trips (Q11) > 0) AND IF (May trips (Q2A) > 0 OR June trips (Q2B) > 0), ask Q14 (else go to Q15)

Q14: Do you typically go the same sites during November and December as you did during May and June?

1 Yes
2 No

Q15: Do recall whether anything prevented you from going to beaches or waterfront areas in the San Francisco Bay Area as much as you would have liked, or where you would have liked, during last November? Ask open ended – **DO NOT READ LIST.**

1 No, nothing
2 Weather
3 No time (including work, family obligations)
4 Cost-related reason/Too expensive
5 Oil Spill) ***Go to Q17***
6 No one to go with
7 Age/health
8 Don't know
9 Other (specify):

Q16: As you may know, there was an oil spill in San Francisco Bay that occurred November 7 of last year. Were you aware of the spill before now?

1 Yes
2 No) ***Go to Q22***
3 (DO NOT READ): Don't know) ***Go to Q22***

Q17: Did the oil spill stop you from going to certain beach or waterfront areas that you would normally have visited in the San Francisco Bay area during last November?

1 Yes
2 No) ***Go to Q18***
3 (DO NOT READ) Don't know) ***Go to Q18***

Q17A: Which beach or waterfront areas did you stop going to? IDENTIFY SITES FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. ENTER MULTIPLE SITES. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q17B: How many times would you say you normally would have gone to sites affected by the spill in November, but didn't because of the spill? **– Note to interviewer – Range okay. Encouragement such as "Give you best estimate" is okay.**

_______times **[stopped going]**

Q17C: When you stopped going to certain places because of the spill, did you sometimes go to other beaches or waterfront areas instead?

1 Yes
2 No) ***Go to Q21***

Q17D: What other beach or waterfront areas did you go to instead? IDENTIFY SITES FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. ENTER MULTIPLE SITES. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q17E: Of the **[stopped going]** times you avoided sites affected by the spill, how many times would you say you went to these other places instead?
______times ***Go to Q21***

(If answer to Q17 is no)

Q18: Did you go less often than you normally would to certain beach or waterfront areas in the San Francisco Bay area last November because of the oil spill?

1 Yes
2 No) ***Go to Q19***
3 (DO NOT READ) Don't know) ***Go to Q19***

Q18A: Which beach or waterfront areas did you go to less often because of the spill? IDENTIFY SITES FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. ENTER MULTIPLE SITES. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q18B: How many fewer times than normal would you say you went to these sites last November because of the spill?
_______fewer times **[fewer times]**

Q18C: When you went to certain places less often because of the spill, did you sometimes go to other beaches or waterfront areas instead?

1 Yes
2 No) ***Go to Q21***

Q18D: What other beach or waterfront areas did you go to instead? IDENTIFY SITES FROM LIST PROVIDED. IF NOT ON LIST, ENTER MANUALLY. ENTER MULTIPLE SITES. **– Note to interviewer, ask open-ended and clarify that nearest landmark is okay if respondent can't remember name.**

1 Ocean Beach
2 Baker Beach
3 Etc.

Q18E: Of the **[fewer times]** times you avoided sites affected by the spill, how many times would you say you went to these other places instead?
______times ***Go to Q21***

(If NO to both Q17 and Q18)

Q19: So following the spill last November you still went to the same beach and waterfront areas, as often as you normally would at that time of year?

1 Yes) ***Go to Q20***
2 No

Q19A: Did you stop going to certain sites, or just go less often?

1 Stop going to certain sites) ***Go to Q17A***
2 Go less often) ***Go to Q18A***

Q20: Did the spill affect your trips last November in any other way? **– Ask open-ended – DO NOT READ LIST.**

1 No, no effect
2 Reduced enjoyment
3 Lower catch rates
4 Other_______(specify):

Go to Q22

Q21: Have your trips to beach and waterfront areas in the San Francisco Bay Area gotten back to normal, or are the effects you just described to me still going on?

1 Back to normal
2 Still going on) ***Go to Q21B***

Q21A: In what month were your trips to beaches and waterfront areas in the San Francisco Bay Area back to normal?

1 December 2007
2 January 2008
3 February 2008
4 March 2008
5 April 2008

6 May 2008
7 June 2008

If Q17 = Yes do Q21B, else go to Q21C and check "if" statement

Q21B: ***For each month prior to the time specified in Q21A, or through July if Q21 = 2:*** How many times would you say you normally would have gone to sites affected by the spill in [**month**], but didn't because of the spill?
______ times **(*go to Q22*)**

If Q18 = Yes do Q21C, else go to Q22

Q21C: ***For each month prior to the time specified in Q21A, or through July if Q21 = 2***: How many fewer times than normal would you say you went to sites affected by the spill in [**month**]?

Q22:

If skipped from Q1: Even though you didn't take any trips to the beach in the last 12 months, it is important that we include everybody in our results. For statistical purposes, we'd like to ask you a few questions about yourself and your household.

May I ask your age?
______years

Otherwise: We're just about through. The final few questions are for background information and help us analyze the results.

May I ask your age?
______years

Q23: How many people live in your household, including yourself?
_______number of people

Q24: How many children under the age of 16 live with you in your household?
_______number of children

Q25: How many family members, related to you by birth, marriage or adoption, live with you in your household?
______number of family members

Q26: How many different land-line telephone numbers do you have in your household?
______number of land-lines

Q27: What is your zip code?

Q28: What is the highest degree or level of school you have completed?

1 No schooling completed
2 Nursery to 4th grade
3 5th or 6th grade
4 7th or 8th grade
5 9th grade
6 10th grade
7 11th grade
8 12th grade, no diploma
9 High school diploma
10 Some college, no degree
11 Associate degree
12 Bachelor's degree
13 Masters degree
14 Professional school degree
15 Doctoral degree

Q29: Are you Spanish, Hispanic, or Latino?

1 Yes
2 No
3 Don't know
4 Refused

Q30: What race do you consider yourself to be?

1 White
2 Black or African American
3 American Indian or Alaska Native
4 Asian
5 Native Hawaiian or other Pacific Islander
6 Other_(specify):______

Q31: Do you speak a language other than English at home?

1 Yes
2 No – only English) ***Go to Q32***

Q31A: What is this language?

1 English
2 Spanish
3 Chinese
4 Tagalog
5 Japanese
6 Vietnamese
7 Other

Q32: My next question is about your family income. This includes wages, salaries, interest and other income for you and all family members living with you. During 2007, what was your total family income before taxes?

$____________ family income

IF REFUSE:

Q32A: Could I place your income in a general category? Was your family income

1 Less than $25,000
2 Between $25,000 and $50,000
3 Between $50,000 and $75,000
4 Between $75,000 and $100,000
5 Greater than $100,000

Q33: That completes the survey. Thank you very much for your time. If you have any additional comments, I can record them here. (MANUALLY ENTER ANY COMMENTS) **– note to interview, record open-ended response**

_______comments

Q34: OBSERVE AND RECORD RESPONDENT’S GENDER.

1 Male
2 Female
3 Don’t know

Attachment 2. Shoreline Recreation Sites

Table 2.1. Shoreline recreation sites

Individual site name	County	Included in onsite sampling	Aggregate site name
Bodega Bay/Point	Sonoma		Dillon Beach
Doran Beach	Sonoma		
Dillon Beach	Marin		
Tomales Beach	Marin		Tomales Beach
Kehoe Beach	Marin		
Hearts Desire Beach	Marin		
Pebble Beach	Marin		
Outer Schooner Bay	Marin		Limantour Beach
Drakes Beach	Marin		
Limantour Beach	Marin		
Santa Maria Beach	Marin		
Sculptured Beach	Marin		
Point Reyes/Arch Rock	Marin		
Palomarin Beach	Marin		Bolinas Beach
RCA Beach	Marin		
Agate Beach	Marin		
Bolinas Beach	Marin		
Stinson Beach	Marin	Yes	Stinson Beach
Bolinas Ridge	Marin		
Muir Beach	Marin	Yes	Muir Beach
Tennessee Valley	Marin	Yes	
Rodeo Beach	Marin	Yes	Rodeo Beach
Fort Cronkhite	Marin		
Marin Headlands	Marin		Marin Headlands
Point Bonita Lighthouse	Marin		
Black Sands Beach	Marin		
Headlands	Marin		
Kirby Cove	Marin		
Fort Baker	Marin		

Table 2.1. Shoreline recreation sites (cont.)

Individual site name	County	Included in onsite sampling	Aggregate site name
Angel Island State Park	Marin		Beaches near Sausalito (including Angel Island)
Beaches near Sausalito	Marin		
Mill Valley Waterfront	Marin		
Tiburon Area	Marin		
San Rafael (Canal and Bay Area)	Marin		San Rafael (Canal and Bay Area)
McNear's Beach County Park	Marin		
China Camp Beach	Marin		
Carquinez (East Bay)	Contra Costa		Carquinez
Martinez Marina	Contra Costa		
Pinole Area	Contra Costa	Yes	San Pablo
San Pablo	Contra Costa		
Point Richmond/Cliffside	Contra Costa		Keller Beach
Keller Beach	Contra Costa	Yes	
Miller/Knox Shoreline	Contra Costa	Yes	
Ferry Point	Contra Costa	Yes	
Rosie Riveter Park	Contra Costa	Yes	Point Isabel Regional Shoreline
Richmond Area/Marina	Contra Costa		
Eastshore State Park	Contra Costa	Yes	
Point Isabel Regional Shoreline	Contra Costa	Yes	
Berkeley Bulb	Alameda	Yes	
Albany Beach	Alameda	Yes	
North Basin	Alameda		Berkeley Marina
Cesar Chavez Park	Alameda		
Berkeley Marina	Alameda		
Emeryville Marina	Alameda		
Treasure Island	San Francisco		
Jack London Square	Alameda		Alameda Memorial State Beach (Robert Crown Memorial State Beach)
Crab Cove	Alameda	Yes	
Robert Crown/Alameda Memorial State Beach	Alameda	Yes	
Hayward Marsh	Alameda		

Table 2.1. Shoreline recreation sites (cont.)

Individual site name	County	Included in onsite sampling	Aggregate site name
Coyote Point	San Mateo		Coyote Point
Oyster Point	San Mateo		
Brisbane Marina	San Mateo		
Candlestick Point	San Francisco		Mission Bay
Mission Bay	San Francisco	Yes	
AT&T Park/South Beach Harbor/Marina Area	San Francisco		
Pier 38	San Francisco		
Farmer's Market/Ferry Building	San Francisco		Piers 1–45
Pier 1	San Francisco		
Pier 3	San Francisco		
Embarcadero	San Francisco		
Pier 9	San Francisco		
Pier 15	San Francisco		
Pier 23	San Francisco		
Pier 27	San Francisco		
Pier 31	San Francisco		
Pier 33	San Francisco		
Pier 39/Fisherman's Wharf	San Francisco		
Pier 41	San Francisco		
Pier 45	San Francisco		
Aquatic Park/Ghirardelli Square	San Francisco	Yes	Aquatic Park/ Municipal Pier
Alcatraz Island	San Francisco		
San Francisco Municipal Pier	San Francisco	Yes	
Fort Mason	San Francisco		
Marina Green	San Francisco		Marina Green
Beach on Scott Street in San Francisco	San Francisco		
Presidio Beach/Area	San Francisco		Crissy Field Beach
Crissy Field Beach (East Beach)	San Francisco	Yes	
Fort Point	San Francisco	Yes	

Table 2.1. Shoreline recreation sites (cont.)

Individual site name	County	Included in onsite sampling	Aggregate site name
Golden Gate Bridge (Beach)	San Francisco		Baker Beach
Baker Beach	San Francisco	Yes	
Battery Chamberlain	San Francisco	Yes	
China Beach	San Francisco	Yes	China Beach
Mile Rock Beach	San Francisco		Lands End Beach
Lands End Beach	San Francisco		
Cliff House and Sutro Baths	San Francisco		Ocean Beach
Sutro Historic District (Sutro Heights)	San Francisco		
Ocean Beach	San Francisco	Yes	
Fort Funston	San Francisco	Yes	Fort Funston
Esplanade Beach	San Mateo		Sharp Park Beach
Sharp Park Beach	San Mateo		
Mori Point	San Mateo		
Rockaway Beach	San Mateo		Pacifica Beach
Linda Mar Beach	San Mateo		
Pacifica Beach	San Mateo		
Gray Whale Cove	San Mateo		Half-Moon Bay
Montara Beach	San Mateo		
Moss Beach	San Mateo		
Half-Moon Bay	San Mateo		
San Gregorio Beach	San Mateo		San Gregorio Beach
Pescadero Beach	San Mateo		

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Appendix K

Beach Processes and the Life Histories of Benthic Invertebrates on Beach and Tidal Flat Habitats Affected by the *Cosco Busan* Oil Spill, California

Technical Memorandum
2 April 2010

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Introduction

The spill of an estimated 53,000 gallons of a heavy fuel oil (HFO 380) from the M/V *Cosco Busan* into San Francisco Bay on 7 November 2007 affected extensive areas of intertidal habitat both in San Francisco Bay and also on the outer coast. The natural resource Trustees used the Shoreline Cleanup Assessment Team (SCAT) data on visual oiling characteristics to develop categories of shoreline injury, from heavy to very light. The habitat injury subgroup for beaches, marshes, and tidal flats quantified injury using the Habitat Equivalency Analysis (HEA) approach, by which the injury is scaled in terms of the percent of ecological services present after the spill (compared to pre-spill baseline levels) and the rate at which the lost services recover over time. The Trustees relied upon a variety of literature sources, which document the effects of oil on flora and fauna, and on data collected to develop the inputs into the HEA for these shoreline habitats. Deriving HEA inputs from such sources requires a good understanding of the pathways of exposure to the oil, how the sand beach cycle affects the distribution of intertidal fauna, the life histories of affected intertidal organisms, and their seasonal distributions and behavior. This technical memorandum was prepared to summarize the current understanding of these factors, applied to the conditions during and after the *Cosco Busan* oil spill. The goal is to provide the Trustees with the scientific basis for developing appropriate HEA inputs for injury scaling.

Pathways of Exposure

Spilled oil can affect intertidal resources via multiple pathways. For a heavy fuel oil, such as the type of oil spilled from the *Cosco Busan*, one of the primary pathways of exposure and effects on intertidal habitats is by fouling and smothering from direct contact with the oil. Very few studies have even attempted to correlate fouling or smothering with effects on intertidal fauna, although often the response is obvious (e.g., avoidance, lethargy, death). A few such studies have been conducted on birds. Fry and Lowenstine (1985) reported 2 of 3 Cassin's auklets died from application of 3-5 milliliters of oil to the feathers. Tuck (1961) reported that only a small spot of oil on the belly was sufficient to kill murres. There is an obvious need for controlled experiments to determine dose-response curves from physical fouling and smothering of more birds and other intertidal taxa. Nevertheless, it is highly likely that even in the lightest oiling environments, certain proportions of inhabitants were exposed and fouled.

Seasonal Changes in Beach Processes

The distribution of intertidal invertebrates on outer coast beaches is highly variable over changing seasons and tidal stages, and can be affected by cycles of erosion and deposition. There is a common misconception that, during the winter months, all sand beaches have reduced profiles and decreased invertebrate biota because winter storm waves have eroded the beaches and transported the sand and biota to offshore bars. The concept of a flat, erosional beach profile in winter is based on the fact that erosional storm waves are more common in the winter, and depositional swell waves are more common in the summer. However, regardless of the season, the sand that is eroded from the beach during a large storm is deposited back on the beach by normal wave action during the post-storm recovery period. When storms occur at short intervals, there is insufficient time for the beach to build back fully before the next storm. However, the beach sediments do start to return to the intertidal beach shortly after the storm passes. So, there will be “summer” beaches (i.e., depositional) in winter before winter storms occur and when there is sufficient time between storms for the beaches to accrete. Many beach invertebrates are also sufficiently mobile to return quickly to their preferred feeding elevation and thus to preferred habitat on the beach (see later discussion).

There are seasonal changes in the wave climate off Central California; however, the “winter” season actually begins with the onset of large storms, which usually start late in the year. Results from detailed U.S. Geological Survey studies along Ocean Beach, San Francisco for the period 2004-2006 show typical seasonal patterns of beach erosion during the months of higher frequencies of larger storms and accretion during the non-storm periods, with beach sediment volume at a maximum in September/October and at a minimum in January (Bernard et al., 2007). Furthermore, this analysis along Ocean Beach indicates that large waves (significant wave height > 5 m) from azimuths of less than 300° caused the greatest erosion because waves from this direction escape the otherwise significant sheltering effects of the massive ebb tidal delta at the mouth of San Francisco Bay. Waves become increasingly less impeded as they approach Ocean Beach from more southerly directions. For waves from the northwest, wave height is reduced by about 50% as a result of refraction over the northern lobe of the ebb tidal delta. Therefore, the beaches north and south of the Golden Gate are less likely to erode during storms that generate waves from the northwest.

Figure 1 shows the significant wave height for the NOAA buoy Station 46026 (18 nautical miles west of San Francisco) for the period of 1 September 2007 to 30 March 2008. It shows that the wave climate prior to and for a month after the 7 November 2007 spill consisted of the normal incident swell waves, with significant wave heights generally 4 m or less. About a month after the spill, more typical “winter storms” occurred with the offshore significant wave heights greater than 5 m: on 4-7 December, 4-5 January, 26 January, and 24 February. Therefore, the outer coast beaches, particularly those south of San Francisco, would not have been highly

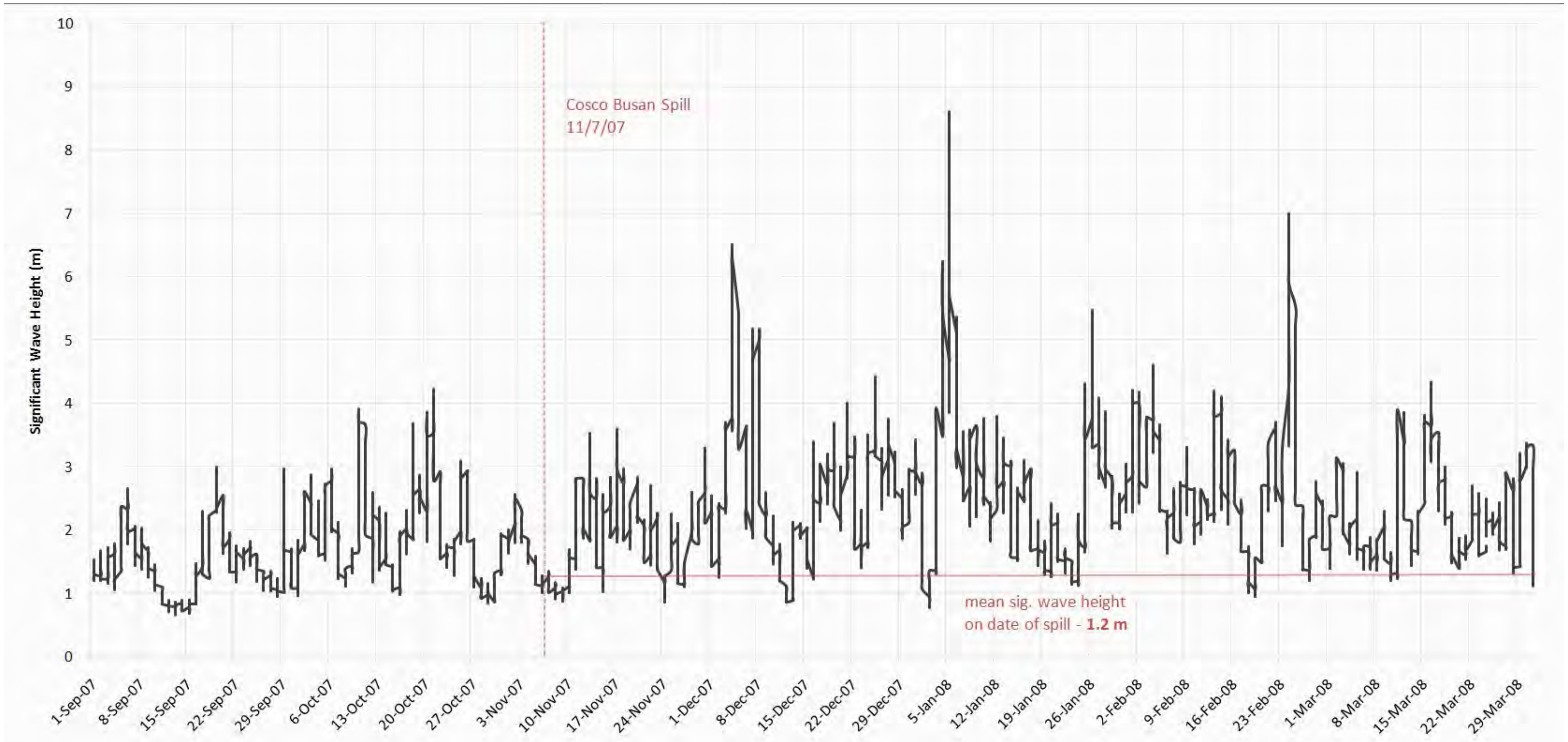

Figure 1. Significant wave height for the period 1 September 2007-30 March 2009 for Station 46026 -18NM West of San Francisco, CA, from the NBDC.

erosional prior to or shortly after the spill. In addition, there were 3-4 weeks between the late winter storms, which would allow time for sand transport back to the beach, and for re-colonization by infaunal (those buried in the sediments) invertebrates, to occur.

Biota on Sand Beaches

In this section, we offer our analysis of the ecological importance, distribution, habitat, and life history of the sand crab *Emerita analoga*. Populations of *E. analoga* are major components of invertebrate macrofaunal communities of exposed sandy beaches in temperate zones of the Pacific Ocean of North and South America, often making up the majority of the total intertidal abundance and biomass (Jaramillo and McLachlan, 1993; Dugan et al., 1995, 1996, 2000a, 2003). Densities of *E. analoga* can exceed 100,000 individuals per square meter on beaches on the central coast of California and elsewhere (Dugan et al., 2003). This species is important as prey for vertebrate predators, such as shorebirds, seabirds, surf fishes, and marine mammals.

Distribution of *Emerita analoga* (extracted from Dugan et al., 2005)
California beaches are among those inhabited by high abundances and biomass of the suspension-feeder, *E. analoga.* The North American range of *E. analoga* spans Point Conception, an important transition zone between coastal oceanographic regimes and the Oregonian and California marine faunal provinces (Seapy and Littler, 1980). Studies to date have found very little genetic variability in populations of this species across its North American range and recent results suggest that the populations may be essentially panmictic (Beckwitt, 1985; Barber et al. unpublished).

***Emerita analoga* habitat (extracted from Dugan et al., 2005)**
E. analoga is a highly mobile and rapidly burrowing sediment generalist (sensu Alexander et al., 1993) with excellent orientation, swimming, and digging abilities, allowing it to successfully inhabit the full range of exposed sandy beaches from fully reflective to dissipative morphodynamic states (Dugan et al., 2000b; Jaramillo et al., 2000). This sand crab is an active tidal migrant, moving with the tide level up and then down the intertidal beach so as to maintain aggregations in the active swash zone. Intertidal zonation patterns in this species vary across the tidal cycle, seasonally, and among beaches (Cubit, 1969; Fusaro, 1980; Jaramillo et al., 2000). Juveniles of *E. analoga* and other hippid crabs generally occupy a notably higher intertidal level than adult crabs (Fusaro, 1980; Haley, 1982), while adult crabs can extend their distribution into the shallow subtidal zone during higher tides, periods of beach erosion, and on some beach types (Jaramillo et al., 2000). The ability of *E. analoga* to burrow at similar speeds across a range of sediment grain sizes likely contributes to the success of this species even in the coarse sediments and harsher swash conditions typical of beaches with reflective characteristics (see Dugan and Hubbard, 1996; Dugan et al., 2000b). As such, *E. analoga* may also be able to survive temporal changes in sediment grain size, such as those occurring on many intermediate type beaches (Dugan, unpublished).

***Emerita analoga* food habits (extracted from Dugan et al., 2005)**
E. analoga is a suspension feeder that uses the plumose second antennae to sieve fine particles from the turbulent moving water in the swash zone (Efford, 1966). This species feeds primarily on phytoplankton, which is reflected in carbon and nitrogen stable isotope values (Dugan

unpublished). In addition, individual growth rates (molt increments) and life history characteristics of *E. analoga* are significantly correlated with food availability, which can be estimated from surf-zone chlorophyll concentrations (Dugan, 1990; Dugan et al., 1994). The delicacy and precision of the plumes on the second antennae of feeding *E. analoga,* which move repeatedly through the water to capture and filter out individual phytoplankters, are incompatible with encounters with heavy fuel oil in the form of rolling tarballs, floating particulate oil, or emulsions. Encounters between the feeding plumes and the heavy fuel oil will cause fouling of the plumes and inhibit the filtration process via physical smothering. In addition, oil adhering to the surfaces of any food and suspended sediment particles will lead to further fouling of feeding antennae of sand crabs such as *E. analoga*. Conova (1999) demonstrated that increasing the hydrophobic nature of particles by changing the compounds on the surface of the particles increases the rate of capture of those particles by disarticulated *Emerita* antennae (demonstrating that the change was a passive process of chemical attraction and did not involve active behavior by the crab). Particles that have surfaces covered with oil will be hydrophobic and passively accumulate on *Emerita* antennae in high proportions, resulting in impairment of feeding capacity.

Life history of *Emerita analoga* in Central California (Santa Barbara County northwards)

Proper assessment of *E. analoga* injury after an oil spill, such as heavy fuel oil, that grounds on ocean beaches in Central California includes need to properly characterize the annual life history of this species of sand (mole) crab. This species generally represents the most important infaunal invertebrate on these ocean beaches because of its seasonally high biomass and importance as prey to shorebirds, crabs, and surf fish. *E. analoga* in this biogeographic area expresses high variability in abundance from beach to beach, among seasons, and between years (e.g., Fusaro, 1980). This variability has inhibited full understanding of the life history. Particularly problematic are studies based entirely on beach sampling without also including sampling of the water column off the beach to incorporate early life stages.

The most comprehensive study of *E. analoga* life history is probably that of Barnes and Wenner (1968). This study provides a rare view of the full life history that includes the early pelagic life stages and, thereby, provides the functional linkages to the older age classes observable in the intertidal and shallow subtidal swash zones of the ocean beaches. Egg production characterized as “berrying” appears in females in late spring and intensifies and continues through summer (Boolotian et al., 1959; Dudley and Cox, 1967). Barnes and Wenner (1968) demonstrated that the zoeae in the plankton increase dramatically around the beginning of August and remain abundant until April, when the numbers drop dramatically. Wharton (1942) documented a larval development period of at least 2-2.5 months, corresponding to the high abundances of late-stage zoeae from mid August onwards through winter. Barnes and Wenner (1968) showed that the next life stage, the megalopae, arrive on the beach in abundance in fall and continue at high levels through winter into spring. Barnes and Wenner (1968) then documented the presence of larger juvenile and adult *E. analoga* on the beach during the warmer months and lasting until late fall. This study that merges pelagic life history stages with benthic stages on the beach provides the widely accepted model of its seasonal life history in Central California. Rather than presuming that the population on the beach is sustained largely or solely by breeding of adult *E. analoga* that have overwintered offshore in deeper waters, Barnes and Wenner (1968) show that the early life history stages recruit heavily to the beach in fall and winter, allowing them to complete development and spawn in the warm season to sustain the abundance of larger individuals on the beach. An alternative life history model based on the assumption that large numbers of adult females are present in the subtidal during winter and uncharacteristically mate and release larvae in that cold season, has little substantive support, only a casual winter observation of some adult *E. analoga* in deeper waters, and is inconsistent with the seasonal pattern of abundance of their pelagic zoeae larvae as demonstrated in Barnes and Wenner (1968).

Likely Exposure to and Effects of Spilled *Cosco Busan* Oil

The significance of using the correct life history of *E. analoga* for the *Cosco Busan* injury assessment is made evident in the following synthesis. The spilled oil first landed on the ocean beaches in early November and then persisted and re-oiled beaches into winter, which is when the beaches receive and hold the small megalopae of *E. analoga.* This life stage that is expected to have been present during the initial oiling and subsequent re-oiling events develops into the larger juveniles and adults that occupy the sandy beach during spring and summer. Consequently, the occurrence of oil contamination of the ocean beaches when the “seeds” of the local *E. analoga* population would have been present likely resulted in suppression of the population well into the following summer and beyond. The failure to observe large numbers of dead *E. analoga* on oiled beaches during the *Cosco Busan* spill is not surprising, as the megalopae are what are expected to be common at that time, and these would be readily overlooked during a SCAT survey and by casual observers because of their extremely small size and likelihood of being readily scavenged by birds, mammals, and beach crustaceans.

Any analysis that presumes that sand crabs like *E. analoga* are largely transported as passive particles like sand grains during storm events that temporarily erode sand off intertidal beaches is mistaken and has misleading implication about risk of injury to spilled oil. Such a presumption ignores the behavior of sand crabs and their great mobility. A recent study (Peterson et al., unpublished) of the east coast sand crab, *Emerita talpoida*, illustrates how sand crabs can and do maintain or rapidly restore their abundances on the intertidal beach after major storms. This study on Onslow Beach, North Carolina provides sampling evidence of how beach sands were eroded by two successive storms, a tropical storm (Hanna) followed by a nine-day northeaster in September 2008 and how *E. talpoida* abundance responded. Figure 2 shows the wind speeds and directions during each storm as well as the significant wave heights and water levels. Wave heights were similar during each storm, but the northeaster generated far higher storm surge for several days longer than the tropical storm. Figure 3 reveals that the consequences of these differences in water levels and storm duration on beach elevation, measured by laser scanner, were large: the tropical storm caused little beach erosion, whereas the northeaster induced substantial erosion of sands in the intertidal foreshore and in the backshore at both ends of the island. Figure 4 demonstrates that sand crab abundances on the low and mid intertidal levels of the beach did not vary from before to after the northeaster in the pattern that would be predicted by the presumption of passive transport matching the sediment loss. By five days after the end of the northeaster, *E. talpoida* had increased in abundance on the south end, where sediment erosion was high enough to reduce elevations by 40-60 cm. *E. talpoida* abundances in the intertidal zone did not change detectably at the north end, where modest sediment erosion of about 20 cm in elevation occurred during the northeaster. In the middle of the island, where sediment elevation changed the least during the northeaster, *E. talpoida* increased in abundance nearly as much as on the south end. As a consequence of behavioral adaptations, sand crabs, as a group, are able to maintain and/or rapidly restore their intertidal abundance even during dramatic erosion of intertidal beach sands during storms. A direct comparison of changes in *E. talpoida* abundance to amounts of erosion/deposition of sediments on the beach demonstrated no relationship (Fig. 5). Sediment transport in-and offshore does not predict sand crab persistence and abundance on the intertidal beach. Consequently, the assumption that sand crabs like *E. analoga* are passively transported off the intertidal beach during winter storms and then reside in deeper water is not supported by available process-oriented evidence.

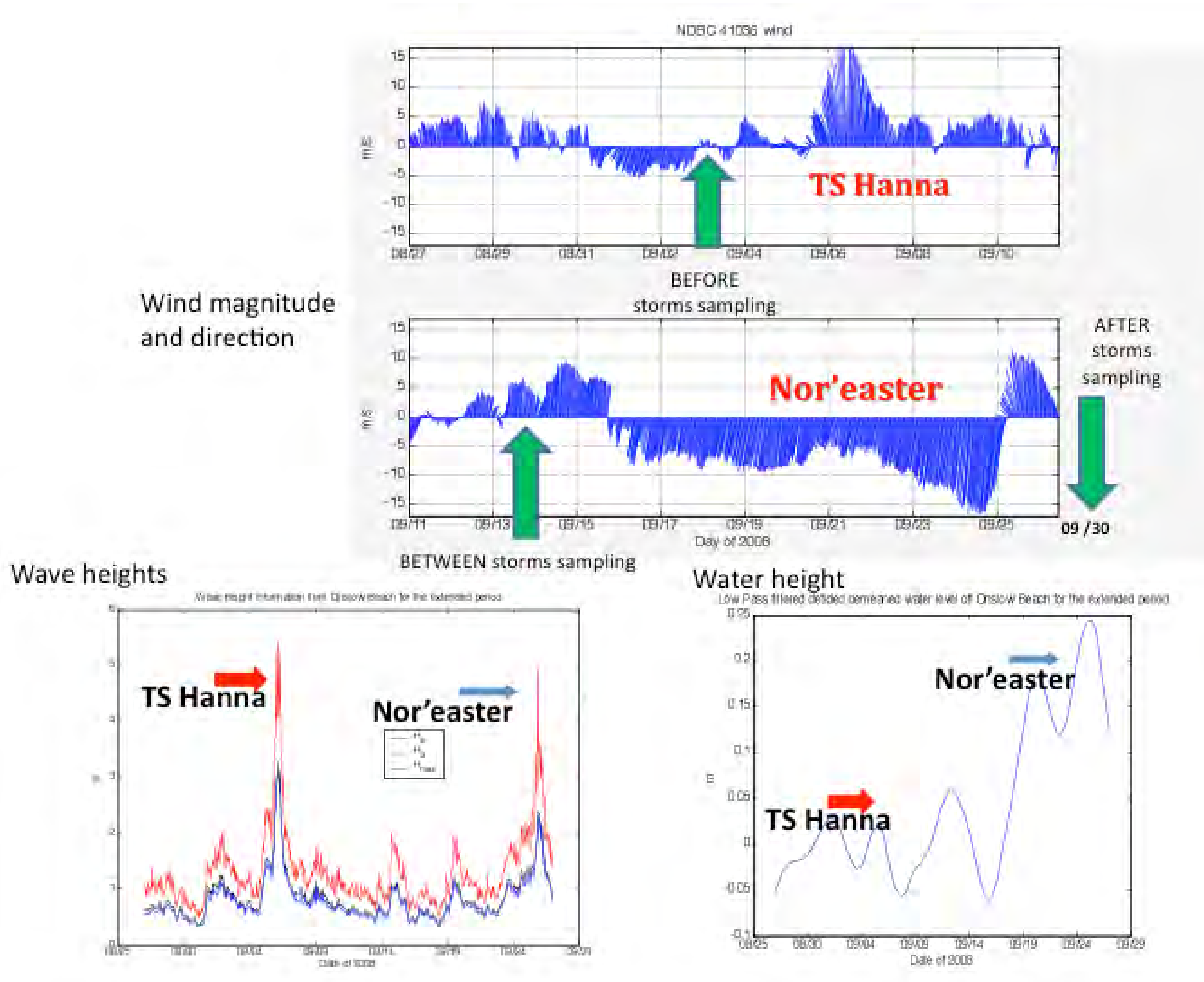

Figure 2. Wind speeds and directions during Tropical Storm Hanna and a nor'easter as well as the significant wave heights and water levels for the Onslow Beach, North Carolina study.

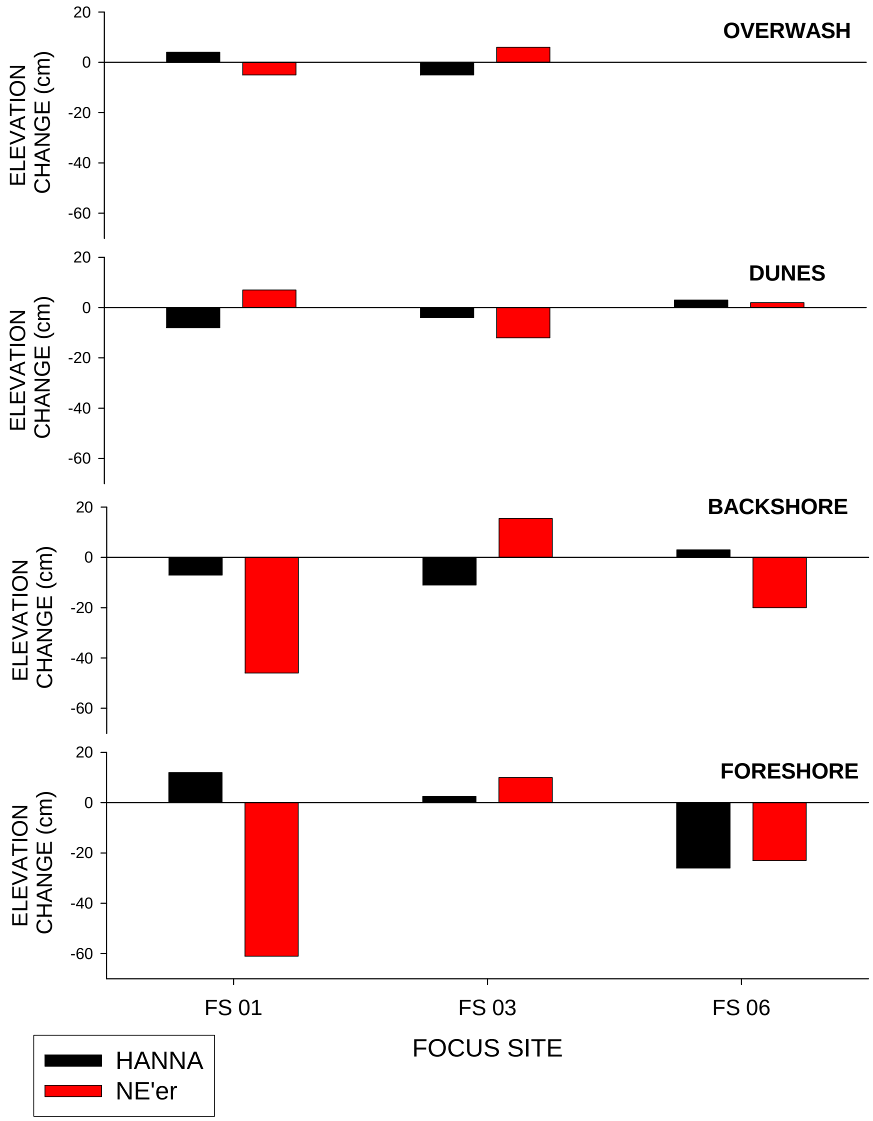

Figure 3. Mean changes in elevation by focus site and location within focus sites (locations along the beach) caused by TS Hanna and, later, by a northeaster at Onslow Beach, North Carolina.

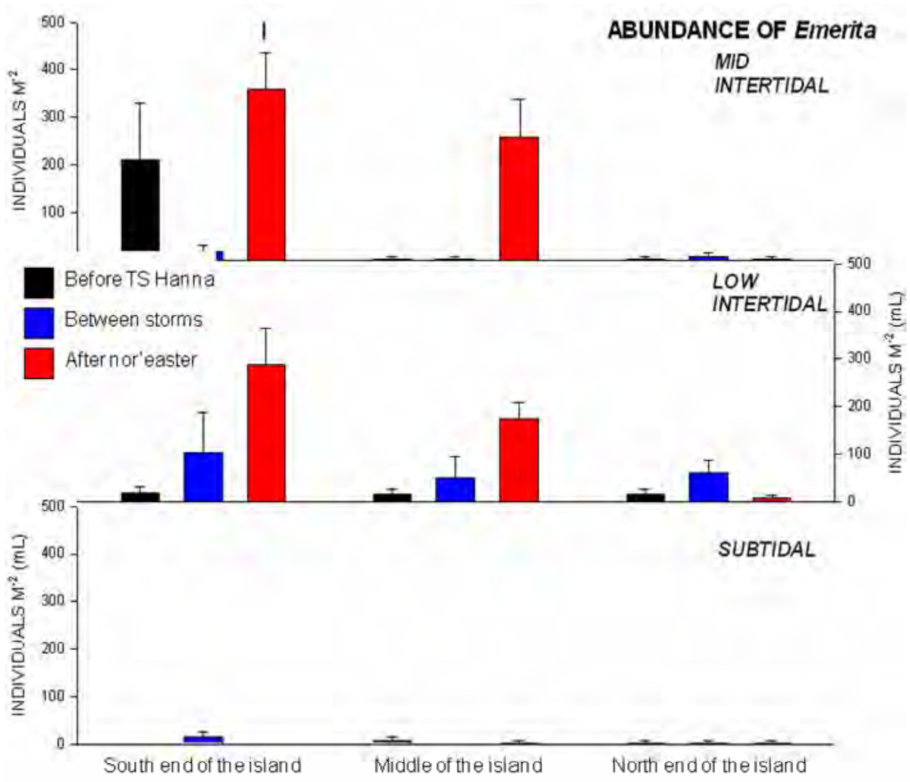

Figure 4. Abundance of *Emerita talpoida* by tidal elevation prior to tropical storm Hanna, between storms, and after a large nor'easter storm at Onslow Beach, North Carolina.

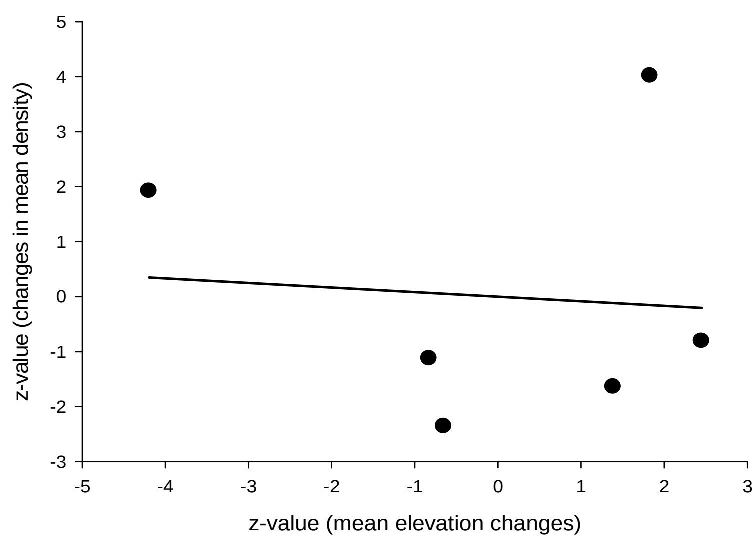

Figure 5. Mean changes in *Emerita talpoida* population density compared to mean changes in beach elevation. All values have been standardized to z-values to ease comparison. The linear regression is not significantly different from 0 indicating that changes in *E. talpoida* population density varied independently of the amount of beach erosion or sediment deposition.

Biota of Tidal Flats

The ecology of intertidal flat organisms

Intertidal sand and mud flats of marine lagoons and estuaries are characterized by highly productive benthic (bottom-dwelling) microalgae (Onuf, 1987; Pinckney and Zingmark, 1993; Sullivan and Currin, 2000), which provide food resources for deposit-feeding invertebrates. The benthic invertebrates of intertidal flats are almost exclusively infaunal (buried) in position with only a few species capable of living on the surface of the mobile sediments (Peterson and Peterson, 1979). Hence, a casual look at the tidal flat fails to reveal the abundance and high productivity of benthic invertebrates. A second important and productive feeding guild of benthic invertebrates is the detritivores. These invertebrates consume plant detritus produced by the nearby salt marsh plants (dominantly succulents like *Sarcocornia* and *Salicornia* and grasses like *Spartina* in San Francisco Bay), by submersed aquatic vegetation (like *Zostera* in San Francisco Bay), by seaweeds (dominantly *Ulva* and *Enteromorpha* in San Francisco Bay), and by death of phytoplankton and benthic microalgae. The third of the most important feeding guilds of benthic invertebrates on sand and mud flats is the suspension feeders (Peterson, 1991). These animals enjoy benefits of food supplementation by tidal current flows, which transport in their phytoplankton foods from the deeper waters of the lagoon or estuary. Benthic microalgae can also contribute to the diets of tide-flat suspension feeders because wind waves can temporarily suspend these benthic microalgae in the water column overlying the flat and thus allow them to be filtered out of the water by suspension feeders. Decomposers like bacteria and fungi play an important role in the food web of tidal flats and in the biogeochemical processing that characterize tidal flats (Kneib, 2003). Detritivorous benthic invertebrates assimilate most of their food energy in the form of bacteria and fungi that are decomposing the detritus formed by marsh plants and submersed aquatic vegetation. The detritus itself is not usually assimilated because of relatively low nutritive value.

In addition to the plants and marine invertebrates at the base of the food chain of intertidal flats, there is a variety of predators and scavengers that feed on the benthic invertebrates of tidal flats. Peterson and Peterson (1979) characterized the intertidal flats as the dining table of the estuary, where much of the entire estuary's secondary production of benthic invertebrates and tertiary production (consumption of those benthic invertebrates) occurs. These predators include most importantly shorebirds, demersal fishes, and crabs of many sorts. In Central California lagoons and estuaries, abundant shorebirds include dunlin, willets, plovers, sandpiper species, marbled godwits and others (White, 1999). Demersal fishes that consume invertebrates on tidal flats include: sculpin, halibut, and several species of ray and shark. Predatory crabs of tidal flats include *Cancer* crabs, such as the Dungeness crab, the smaller *Grapsid* crabs, and hermit crabs. Some predatory benthic invertebrates also exist and are characteristic members of the tidal flat community, such as moon snails (Naticids), blood worms (Glycerid and Nereid polychaetes), and Nemertean worms.

Taxonomic composition of tidal flat invertebrates

The benthic invertebrates of tidal flats are divided by size into two major groups, the macrofauna and the meiofauna. Macrofauna are typically defined as all those invertebrates that are retained on a 0.5-mm mesh. Meiofauna pass through 0.5 mm but are retained on a 67 *u*m mesh. This subdivision corresponds to a taxonomic distinction as well. Macrofaunal phyla that are common on tidal flats are familiar to many people: mollusks like clams and snails; polychaete worms; arthropod crustaceans like burrowing shrimp, amphipods, and crabs; and echinoderms like starfish and sand dollars. Many more phyla of meiofauna occupy tidal flats, although these microscopic animals are mostly unknown to the public: nematodes, harpacticoid copepods, turbellarians, ostracods, tardigrades, kynorhynchs, and more. The meiofauna can be found associated with vegetation (phytal), on the sediment surface (surficial), or within the interstitial spaces among sand grains (interstitial). The meiofauna occupy many different trophic positions from herbivore and detritivore to primary and even secondary predator. To varying degrees, meiofauna are consumed by larger animals such that some fraction of meiofaunal production moves up the food chain to recognizable consumer endpoints.

Physiology of feeding and respiration in benthic invertebrates – risks of suffocation

Both suspension feeders and deposit feeders, the two dominant feeding types of benthic invertebrates on intertidal flats, have high susceptibility to smothering from contact with particulate oil because of their feeding and respiratory physiology. Infaunal suspension feeders must have unobstructed access to the sediment-water interface to feed and respire. Larger oiled particulates, including tarballs, on the sediment surface would represent a physical barrier reducing or preventing access to the overlying water for feeding and respiring. Because the efficiency of particle capture by suspension feeders is affected by a number of factors including particle surface chemistry (Gerritsen and Porter, 1982) and particle concentration (Bacon et al., 1998), small oiled particulates, even at relatively low concentrations, and tidally resuspended oil droplets would interfere with feeding. Oil (and oiled) particles will adhere more readily than unoiled particles to the surfaces of filters and gills, resulting in clogging (Conova, 1999; Gerritsen and Porter, 1982). The addition of oil-derived particles to the normal seston increases the overall particle concentration of the water, which reduces particle selection efficiency and negatively affects suspension-feeder growth rates (MacDonald et al., 1998). In addition, the ability of bivalves to concentrate and move food from their gills to their mouth depends upon strings of mucus or thick slurries to relay the particles (Ward et al., 1994). It is unclear what effect incorporation of hydrocarbon-rich particles would have on these relay pathways, but alterations to the density of the mucus or slurry would disrupt the ability of cilia to move particles. For deposit feeders that select particles from the sediment surface prior to ingestion, particulate oil on the sediments will be encountered by the feeding palps and tentacles, resulting in decreased capacity to feed and internal fouling if ingested.

Meiofauna feeding and respiration are sensitive to particulate oil in both sandy and muddy habitats. With the exceptions of freezing temperatures and eroding surface sediments, meiofaunal abundances are always skewed towards the sediment surface, with generally greater than 70% of all individuals within 10 cm of the surface in sandy sediments and 90% of all individuals within 1 cm of the surface in muddy sediments (Giere, 2009). Greater availability of oxygen and higher concentrations of food (either particulate organic matter or microphytobenthos) appear to determine this surface orientation (Giere, 2009). Oil particles lying on the surface or, if finer, filling the interstices among sand grains would decrease or eliminate the exchange of oxygen-depleted pore water with oxygenated waters overlying the sediments. Oils have been found to infiltrate intertidal sand sediments to 10 cm (Chung et al., 2004). Meiofauna occurring intertidally show much larger decreases in abundances after an oil spill than the subtidal meiofauna populations (Boucher, 1980), perhaps because the direct contact between particulate oil settling on the sediment surface and meiofaunal feeding organs and respiratory surfaces has such high potential to foul those organs and induce feeding and oxygenation crises. In addition, recovery of oil-affected meiofauna populations is retarded in more protected, low-energy habitats, such as muddy shores (Giere, 2009). The shores of central San Francisco Bay are muddy.

Value of and services provided by benthic invertebrates on tidal flats of San Francisco Bay

Although San Francisco Bay has been colonized by many nonnative benthic invertebrates (Carlton, 1979), these species nonetheless contribute in important ways to ecosystem services. For example, filtration by the Asian clam *Potamocorbula amurensis* controls phytoplankton blooms in San Francisco Bay and greatly reduces turbidity, thereby allowing greater growth of seagrasses, a valuable nursery habitat for marine organisms (Alpine and Cloern, 1992). Any attempt to trivialize the role of the intertidal benthic invertebrates on the mud flats of San Francisco Bay by characterizing the benthos as invasive and by making comparisons to densities at other locations ignores the high production of invertebrates on these intertidal flats and their value as prey to shorebirds, demersal fishes, and crabs. The secondary production of benthic invertebrates is typically higher in salt marsh vegetation than on unvegetated intertidal flats (Lenihan and Micheli, 2001), yet Brusati and Grosholz (2006) show by sampling three locations (two within the central Bay and one in San Pablo Bay) that both density and biomass of macroinvertebrates are as high or higher on mudflats than in salt marshes, both for marshes formed by the native *Spartina foliosa* grass and those formed by a hybrid marsh grass. Higher density and biomass imply higher secondary production on the intertidal flats, especially when the salt marsh possesses some structural protection of infaunal invertebrates from predation, whereas the infauna of the sand flats are exposed to intense predation by shorebirds, crabs, and demersal fishes (Summerson and Peterson, 1984). San Francisco Bay is valued as a shorebird feeding location, sustaining many species during their long-distance seasonal migrations, for which energetic demands are high, and providing other shorebirds and many ducks with food during winter and other seasons of residence. Because so much of the natural wetland habitat of California has been destroyed by development, San Francisco Bay remains a region of critical conservation importance for shorebirds and waterbirds alike. The benthic infauna thus provides critical ecosystem services in the form of food provision for valued shorebirds, as well as crabs like juvenile Dungeness crabs and juvenile demersal fishes like halibut.

Summary

Because of various aspects of their life histories, their mobility through surface sediments especially in the case of *E. analoga*, their virtually exclusive occupation of surface sediments especially by the meiofauna, physiological susceptibility of their delicate feeding organs to particulate oil, and their need for continuous and unobstructed contact with overlying water for oxygenation, the benthic invertebrates of both sandy ocean beaches and tidal flats in San Francisco Bay and along the adjacent outer shores are very susceptible to exposure and injury through fouling and contact with particulate oil as experienced after the *Cosco Busan* oil spill.

The likely resulting reductions in productivity of the benthic invertebrates via increased mortality and reduced feeding and growth is ecologically significant in both habitats because these invertebrates represent critical prey for ecologically important consumers at higher trophic levels. These include, most importantly, shorebirds, demersal fishes, and crabs. As a consequence, the injuries induced by physical contact with tarballs, surficial oil, emulsions, and particulates of varying dimensions were likely substantial in these two habitats and imply need for restoration to compensate for lost ecosystem services of public societal importance.

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Appendix L: Summary of Public Comments and Trustee Responses

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

This appendix summarizes, by topic, the public comments received by the Trustees on the draft Damage Assessment and Restoration Plan/Environmental Assessment (DARP), and provides the responses of the Trustees to each issue. Copies of the full written public comments are available in the Administrative Record, which is at http://www.dfg.ca.gov/ospr/Science/cosco_busan_admin.aspx.

Restoration Priorities

Public comment: The amount of settlement funds allocated to bird and habitat restoration is too small relative to that allocated for recreational use projects.

Trustee Reply: The Trustees did not determine a lump sum settlement amount to be allocated among the various resource categories, i.e., there was no allocation process among the categories of injuries. Rather, the amount of compensation for each injury category (e.g. birds, habitat, recreational uses) was assessed and calculated separately, each on its own merits. The monetary compensation is derived in a scientific manner, directly linked to the degree, duration, and size of the injury.

As to the resource categories, this injury quantification information is then compared to the benefits expected from one or more restoration projects. The projects are scaled in size so that their benefits offset the injury. The cost of implementing the "scaled" projects is the amount of money needed for compensation for that particular resource injury. This method, known as Habitat or Resource Equivalency Analysis is used nationwide in most oil spill cases.

For recreational use, the calculation is simply the number of lost user-days multiplied by the value of those user-days to the public. Based on an extensive economic study, this came out to 1,079,900 lost user-days, an average value of $17.41 per user-day (which varied depending upon the activity and the number of alternative beaches open), and a resulting total lost value of $18.8 million. This value per user-day is well within the range typically found in outdoor recreational value studies.

Bird Injury

Public Comment: The bird injury was underestimated because the search and collection effort during the response was inadequate.

Trustee Reply: The estimate of bird mortality did take into account the level of search effort, estimating the number of impacted birds *not* collected because they were scavenged, missed by search teams, or came ashore at inaccessible locations or unsearched beaches. A sophisticated Beached Bird Model is used to calculate these parameters, taking into account the "life expectancy" of a bird carcass on the beach. Subsequent to the carcass search and collection effort conducted during the response, specific field studies were conducted both inside and outside the Bay, and along different shoreline types, in which bird carcasses were placed on the beach and checked over time in order to determine the predation rate(s).

This modeling exercise has been regularly used on past spills. In this case, there were detailed records of each search conducted by a Wildlife Operations search and collection team. Compared to other oil spill cases both in California and worldwide, this spill actually had the most comprehensive and well-documented bird search and collection effort ever conducted. Nearly every accessible beach in the high deposition zones was searched daily, or multiple times per day.

Rehabilitated Birds as Mitigation of Human Impacts

Public Comment: This is the first oil spill injury assessment that subtracts from the bird mortality estimate a percentage of rehabilitated birds that are likely to survive, thus giving credit for rehabilitation efforts.

Trustee Reply: Actually, subtracting a percentage (typically 25%) of the rehabbed birds has been done in many NRDA's. Most recently in California, a similar approach was used in the *Kure*, *Stuyvesant*, and *Luckenbach* NRDA's.

Other Restoration Projects for Surf Scoters

Public Comment: The Trustees should consider the following projects to benefit scoters: identification and mitigation of mortality factors affecting sea ducks in California and rehabilitation of sea ducks and other seabirds.

Trustee Reply: While these suggested projects may have merit, the Trustees indicated in the Draft DARP that they would issue a Request for Proposals (RFP) after issuance of the Final DARP to address this category of injury. Consequently, any of these suggested projects that are submitted in response to the RFP will be considered on its merits in that process.

Temporary Reduction of Hunting Pressure

Public Comment: Injuries to scoters could be compensated for by a reduction in hunting equivalent to the number of birds killed in the spill.

Trustee Reply: While intuitively appealing, such a project is not practical, and may be inconsistent with Congress's intent in funding the Wildlife and Sport Fish Restoration Program, pursuant to 16 U.S.C. 669. Hunting regulations are set through a different process which evaluates the current populations of the various game species, while supporting hunting, wetland conservation, and other wildlife associated recreation. Even assuming that the trustees had an ability to impose restrictions on hunting, the effect would be to simply shift the oil spill impacts to a subset of the public (i.e. to recreational duck hunters).

Other Restoration Projects for Birds

Public Comment: The Trustees should consider the following projects to benefit birds: Albany Bulb jetty cuts; Snowy Plover predator management in the Monterey Bay area; restoration for seabirds along West Cliff Drive, Santa Cruz; bird blind along Devil's Slide Coastal Trail.

Trustee Reply: The Trustees appreciate receiving information on these additional restoration projects. The Trustees have considered and evaluated each of these projects and added them to the Final DARP. Projects that are non-preferred in the Final DARP may be reconsidered if funds become available or if preferred projects become infeasible.

Marbled Murrelet Restoration

Public Comment: The Trustees should consider conditioned taste aversion (CTA) and should consider conducting murrelet restoration in the Santa Cruz Mountains.

Trustee Reply: The Trustees agreed that these suggested approaches should be considered and, consequently, issued a revised Marbled Murrelet section of the Draft DARP seeking public comment on them. The project in the original Draft DARP was focused exclusively on corvid management at Humboldt Redwoods and Grizzly Creek State Parks, with the option to consider habitat protection should a parcel providing suitable murrelet nesting habitat become available. The revised Marbled Murrelet section expanded the options in the selected project to include a wider variety of murrelet conservation actions (including CTA) in the Santa Cruz Mountains as well as in Zone 4. The Trustees received only one comment on the revised Marbled Murrelet section of the Draft DARP, which was supportive. This revised section is now incorporated into the Final DARP.

Berkeley Pier Enhancement Project

Public Comment: Support for the Berkeley Pier Enhancement Project and suggestions for construction.

Trustee Reply: The Trustees acknowledge the comments, and have retained the Berkeley Pier Enhancement project in the Final DARP as preferred.

Kent Island, Bolinas Lagoon Restoration

Public Comment: The Trustees should move the Kent Island project in Bolinas Lagoon from non-preferred to preferred.

Trustee Reply: The Trustees currently understand the Kent Island project to be fully funded under the Estuaries Restoration Act through the Army Corps. The comment requested long-term monitoring funds through years 6-10 of the project. Although the Trustees understand the need for long-term monitoring, other potential projects to address this injured habitat type within the spill zone are either unfunded or partially funded for on-the-ground restoration work. The Trustees place priority on active restoration activities that are in need of funding to help restore the resources impacted by the spill in a timely fashion, rather than on projects that already have funding for active restoration. The Trustees have retained the Kent Island project in the Final DARP as non-preferred and will reconsider it if funds become available or if preferred projects become infeasible.

Seadrift Lagoon Restoration

Public Comment: The Trustees should fund restoration of Seadrift Lagoon.

Trustee Reply: This is a multi-million dollar project that would still require design and permitting and may be many years from implementation. There are also issues regarding invasive species that will need to be resolved before the project is ready for implementation. The Trustees give priority to projects where implementation is likely in the short term.

Aramburu Island Habitat Restoration

Public Comment: Support for the Trustees selecting the Aramburu Island Habitat Restoration Project.

Trustee Reply: The Trustees acknowledge the comments, and have retained the Aramburu Island project in the Final DARP as preferred.

Sears Point Restoration Project

Public Comment: The Trustees should fund restoration at Sears Point, in San Pablo Bay.

Trustee Reply: The Trustee's preference is to target potential restoration sites within the Central Bay where most of the oil impacts occurred. The Trustees feel that there are a sufficient number of appropriate projects in the spill zone to compensate for injuries to these habitats.

Albany Beach Restoration Project

Public Comment: The Trustees should consider the current and future human and dog use on the beach, in consideration to any habitat improvements at Albany Beach. An alternative project in the area would be to create jetty cuts in lagoon at the west end of Albany Bulb.

Trustee Reply: The Trustees acknowledge the comments regarding human (and dog) use patterns at Albany Beach. The plan does not include any efforts to prevent continued use of the beach and trails by users. The beach dune restoration area is intended to be located behind the intertidal zone, with adequate area for continued human use on and around the beach. The dune restoration areas will include plantings of native vegetation, and fencing and appropriate control efforts will be provided in those areas, in order to prevent unintended human (and dog) encroachment. Further, the proposed improvements, including restoration and expansion of dunes, are included in the East Shore State Park General Plan that was approved in 2002.

The suggested project regarding jetty cuts at the west end of Albany Bulb has been added as a potential project for shorebirds. This project would still require complete design and permitting and may or may not be feasible. The Trustees give priority to projects ready for implementation.

Oyster Reef Restoration at Breuner March

Public Comment: The Trustees should fund oyster reef restoration at Breuner Marsh.

Trustee Reply: The Trustee's preference is to target sites within the Central Bay (such as the Emeryville/Berkeley shoreline) where most of the rocky intertidal injury occurred. However, other sites such as Breuner Marsh may be considered, especially if sites within the Central Bay are not feasible. The Final DARP has been amended to reflect this change.

Richardson Bay Eelgrass Beds and Boat Moorings

Public Comment: The Trustees should consider addressing the destruction of eelgrass caused by boat moorings and abandoned vessels in Richardson Bay.

Trustee Reply: The Trustees agree that the need to avoid impacts to eelgrass beds is a high priority for Richardson Bay. The Trustees considered the Richardson Bay mooring issue during the restoration planning process and examined the possibility of changing out mooring chains for those that were more environmentally friendly. The Trustees concluded that a permitting process had not been established for the live-aboard vessels and moorings.

However, the Trustees have included this project in the Final DARP, and may reconsider it if funding becomes available and there is resolution of the permitting issues.

Herring Monitoring

Public Comment: Herring should be monitored at the eelgrass restoration sites.

Trustee Reply: The Trustees agree that monitoring the success of herring health and spawning with the associated eelgrass restoration projects is important. All restoration projects included in the DARP will have monitoring components so that the Trustees may evaluate the success of the projects. We have clarified language in the DARP to include herring monitoring as a component of the eelgrass restoration projects.

Permitting

Public Comment: The DARP correctly states that project implementers will need to apply for required permitting, including permitting from the San Francisco Bay Conservation and Development Commission (BCDC), as appropriate. Please refer implementing agencies to BCDC's Chief of Permits or Senior Permits Analyst.

Trustee Reply: The Trustees will require project implementers to obtain required permitting and will refer implementing agencies to BCDC's Chief of Permits or Senior Permits Analyst, as appropriate.

Submittal of Recreation Project Ideas and Proposals

Public Comment: Various agencies and organizations plan to submit recreation project ideas. Several commenters have specific recreation project ideas that they would like to see implemented with settlement funds. Public and private organizations should be able to submit project ideas and implement recreation projects with settlement funds.

Trustee Reply: The Trustees encourage all those with specific project ideas or specific project proposals to collaborate with the appropriate entities to develop and/or submit recreation project proposals that enhance fishing, boating or other shore-based recreation throughout the area affected by the spill. Project proposals should carefully address the project selection criteria outlined in the DARP (see Section 4.2). Several criteria relate to project feasibility. If an organization (either private or public) submits a proposal for a project that benefits recreation users, it may be incumbent on that organization to demonstrate that they have the authority to implement the project, the ability to obtain necessary permits, and otherwise have the capacity to successfully carry out the project. The Trustees are responsible for the final selection of recreation projects to fund for implementation.

For more information on how to submit your project ideas or proposals contact the following:

For projects to primarily benefit recreational activities associated with units of the National Park Service (NPS) located in San Francisco and Marin counties contact Daphne Hatch of the National Park Service at daphne_hatch@nps.gov.

For projects to primarily benefit recreational activities in the East Bay, San Mateo County and the non-NPS portions of Marin County, information on the grant process can be found at: www.nfwf.org/coscobusanrec.

For projects to primarily benefit recreational activities associated with non-NPS lands located within the City and County of San Francisco, contact Don Margolis at don.margolis@sfgov.org or Tom Lakritz of the City of San Francisco at tom.lakritz@sfgov.org.

For projects to primarily benefit recreational activities associated with lands located within the City of Richmond, contact Bill Lindsay of the City of Richmond at bill_lindsay@ci.richmond.ca.us.

Selection of Recreation Projects

Public Comment: Non-trustee agencies and organizations would like to participate in the selection of recreation projects.

Trustee Reply: The Trustees may contact various entities to request their technical assistance in reviewing specific recreation project proposals. However, the Trustees are responsible for the final selection of recreation projects to fund for implementation.

Boating versus Shoreline Impacts

Public Comment: Boaters sustained losses that were different than “land-based” users of the shoreline and should be compensated with separate projects that benefit boaters.

Trustee Reply: As noted in the Draft DARP, boating losses were quantified separately from (a) impacts to fishing and (b) impacts to shoreline uses. It is the Trustees intent to fund projects that specifically benefit fishing, boating, and shoreline recreation. To clarify this objective, the Final DARP has been clarified to read: “It is a goal of the Trustees to select projects spanning the geographic area of the spill and to address the various types of activities *(e.g., boating, fishing, other uses)* that were impacted by the spill” [Addition in italics].

Size of Boating Impacts

Public Comment: Boating impacts are significantly underestimated because they do not include consideration of access from private facilities other than marinas and yacht clubs (e.g., mooring sites associated with private residences). It would be appropriate to note that these sites were not quantified in the assessment.

Trustee Reply: The estimate of boating impacts does not account for mooring sites associated with private residences. It is appropriate to note that these sites were not quantified in the assessment. The following text has been added to the DARP: “The estimate of lost boating trips focuses on impacts at marinas and yacht clubs, where the highest density of trips occurs. It does not include lost boat trips derived from private residences around the San Francisco Bay.” While important to consider trips originating from private residences in restoration planning, the Trustees believe that the total estimated loss originating from the 17,788 boat slips that were quantified represents the significant majority of trips affected by the spill.

NEPA Decision Document/Finding of No Significant Impact (FONSI)
For the Cosco Busan Oil Spill
Damage Assessment and Restoration Plan/ Environmental Assessment

Department of the Interior: United States Fish and Wildlife Service and National Park Service
February 10, 2012

Introduction:

On November 7, 2007, the freighter *Cosco Busan* struck the Bay Bridge as it attempted to depart San Francisco Bay. The accident created a gash in the hull of the vessel, causing it to spill approximately 53,000 gallons of oil into the Bay. Wind and currents took some of the oil outside of the Bay, where it impacted the outer coast from approximately Half Moon Bay to Point Reyes. Inside the Bay, the oil primarily impacted waters and shoreline within the central portion of the Bay, from Tiburon to San Francisco on the west side and from Richmond to Alameda on the east side.

Under the Oil Pollution Act of 1990 (OPA), the Natural Resource Trustee Agencies (the Trustees), including the United States Fish and Wildlife Service (USFWS), the National Park Service (NPS), the Bureau of Land Management (BLM), the National Oceanic and Atmospheric Administration (NOAA), the California Department of Fish and Game (CDFG), and the California State Lands Commission (CSLC) are Trustees for the natural resources injured by the spill. Each agency is authorized to act on behalf of the public under state and/or federal law to assess and recover natural resource damages and to plan and implement actions to restore, rehabilitate, replace, or acquire the equivalent of the affected natural resources injured as a result of a discharge of oil.

The Trustees estimate that at least 6,849 birds representing 65 different species were injured, an estimated 14-29% of the winter 2007-8 herring spawn was lost, and approximately 3,367 acres of shoreline habitat was impacted. In addition, approximately 1,079,900 human recreation user-days were lost, representing a wide variety of aquatic and shoreline activities.

The Trustees prepared the *Cosco Busan Oil Spill - Final Damage Assessment and Restoration Plan/Environmental Assessment (*DARP/EA*)* dated February, 2012 which describes the injuries resulting from the spill, and identifies restoration alternatives that would compensate for those natural resource injuries. This Decision Document/FONSI completes the evaluation conducted under the National Environmental Policy Act (NEPA) for the DARP/EA.

The DARP/EA is both a "programmatic" plan and implementation level plan. As such, it does not make an irreversible or irretrievable commitment of resources as to the programmatic projects. Subsequent NEPA compliance will be required prior to implementation of some of the selected restoration actions that are conceptual once development of sufficient project-level detail is available. Specifically, additional environmental review may be needed for Tule Lake Grebe Nesting Habitat, Berkeley Pier Enhancement, and Eelgrass/Rockweed/Native Oyster restorations as implementers proceed with project development and/or project locations are identified. Additional NEPA compliance will be conducted for scoter and recreational use projects, which have yet to be selected.

Restoration Alternatives:
The DARP/EA evaluated several categories of restoration alternatives (e.g., Birds, Fish, Habitats, Human Recreation) in a public process, including a "no action" alternative. The Trustees developed criteria to evaluate projects that were under consideration. These criteria included the project's ability to restore those resources directly impacted by the release of oil and/or response actions, and compliance with the relevant federal and state law provisions governing use of recoveries for natural resources. A complete list of the evaluation criteria can be found in the DARP/EA. The Trustees considered and rejected the no-action alternative, which relied on natural processes for recovery of the injured natural resources. Natural recovery does not compensate for interim losses suffered by the public's resources, and the OPA clearly establishes trustee authority to seek and obtain compensation for interim losses pending recovery of natural resources. Furthermore, technically feasible project alternatives for restoration exist to compensate for these losses. Thus, the Trustees reject the "no action" alternative and instead have selected the appropriately scaled restoration projects and approaches listed below as the preferred alternative:

- *Request for Proposals for Project(s) Benefiting Surf Scoters;*
- *Tule Lake Grebe Habitat;*
- *Winter Diving Duck Habitat at the South Bay Salt Ponds;*
- *Farallon Island Nest Site Improvements;*
- *Berkeley Pier Enhancements;*
- *Marbled Murrelet Restoration;*
- *Eelgrass Restoration;*
- *Muir Beach Dunes Restoration;*
- *Albany Beach Restoration;*
- *Aramburu Island Restoration;*
- *Native Oyster Restoration;*

- *Rockweed Restoration; and*
- *Recreational Use Projects.*

This decision document concludes that a FONSI is appropriate for all of the restoration actions selected for implementation by the Trustees and evaluated in the DARP/EA for the *Cosco Busan* Oil Spill as summarized here, except for Project(s) to Benefit Surf Scoters, Tule Lake Grebe Nesting Habitat, Berkeley Pier Enhancement, Eelgrass/Rockweed/Native Oyster restorations and Human Recreational Use Projects which will be subject to further environmental review and compliance.

Alternatives Considered:
Following are the project alternatives that the Trustees considered for each injury category presented in the DARP/EA. Selected projects appear in italics with a brief project description. Non-preferred projects are also listed and may be reconsidered if funds become available or if selected projects prove to be infeasible. For a complete description of all of the restoration alternatives, see the DARP/EA.

BIRDS

<u>Benefits to scoters and other large diving ducks</u>

- *Request for Proposals for Project(s) Benefiting Surf Scoters*

This project will seek proposals and award funding for one or more projects that will provide an appropriate level of benefits to Surf Scoters, the bird species most impacted by the spill. Additional NEPA compliance will be conducted prior to implementation of the selected restoration project(s).

The following projects are non-preferred at this time:

- Wetlands or salt pond enhancement around San Francisco Bay;
- Wintering foraging habitat enhancement;
- Removal of derelict fishing nets in Puget Sound;
- Removal of derelict fishing nets in SF Bay or elsewhere in California;
- Disturbance reduction in San Francisco Bay;
- Rehabilitation of Sick and Injured Scoters; and
- Research of Scoter Mortality.

<u>Benefits to Western/Clark's Grebes</u>

- *Tule Lake Grebe Habitat*

This project seeks to create more suitable nesting habitat for Western and Clark's Grebes at Tule Lake National Wildlife Refuge (NWR). These species spend the winter in the Bay and along the outer coast. The project primarily involves managing water levels in

Tule Lake's Upper Sump to create over 500 acres of new freshwater marsh, in which the birds would nest. Additional NEPA compliance may be required prior to implementation, pending development of sufficient project-level detail.

The following projects are non-preferred at this time:

- Grebe colony protection at northern California lakes and
- Grebe colony protection at southern California lakes.

<u>Benefits to small diving ducks and small grebes</u>

- *Winter Diving Duck Habitat at the South Bay Salt Ponds*

This project complements on-going efforts to restore the South Bay Salt Ponds by maintaining and managing habitat for wintering Lesser Scaup and Eared Grebes, among other species. The same ponds would be managed for Snowy Plover nesting during the summer. This project will be a component of the larger South Bay Salt Pond Restoration Project (SBSPRP). A full discussion of the environmental consequences can be found in the EIR/EIS for the SBSPRP. The Trustees have considered the information contained in the SBSPRP EIR/EIS and incorporate by reference the analysis of environmental consequences presented there.

The following project is non-preferred at this time:

- Creation of grebe nesting habitat at Tule Lake NWR.

<u>Benefits to Alcids and Procellarids</u>

- *Farallon Island Nest Site Improvements*

This project seeks to increase suitable nest sites for seabirds at Southeast Farallon Island. Specifically, it will replace up to 60 Rhinoceros Auklet and 200 Cassin's Auklet nest boxes, and create nest sites for up to 60 pairs of Ashy Storm-Petrels. The project includes redesigning the existing boxes, building new ones with better insulation and more durable materials, and placing them on the island in more protected locations with more soil cover. The second component of the project entails breaking up old concrete slabs and arranging them into rock piles for crevice nesting seabirds.

The following projects are non-preferred at this time:

- Removal of derelict crab pots in the Gulf of the Farallones;
- Seabird Protection Network to protect Murre colonies;
- Fortification of the Murre Ledge;
- Bird Island habitat enhancement;
- Mouse eradication on Southeast Farallon Island; and
- Bird Blind to reduce disturbance at Devil's Slide Rock Interpretive Trail.

Benefits to pelicans, cormorants, gulls and shorebirds

- *Berkeley Pier Enhancements*

This project will enhance the dilapidated tip of the Berkeley Pier for cormorant and gull nesting and pelican roosting. It will also enhance another section nearer the base of the Pier as a high tide roost site for shorebirds. Additional NEPA compliance may be required prior to implementation, pending development of sufficient project-level detail.

The following projects are non-preferred at this time:

- Alcatraz Island human disturbance reduction project;
- Reduce impacts to pelicans and gulls from fishing waste;
- Reduce entanglement and hooking of pelicans and gulls in recreational fishing gear;
- Seabird habitat restoration on Southeast Farallon Island; and
- Habitat enhancement for nesting Brandt's Cormorants.

Benefits to Marbled Murrelets

- *Marbled Murrelet Restoration*

This project seeks to restore Marbled Murrelets through a variety of measures. Actions that would be implemented include expanding current corvid management efforts to additional areas as well as including additional corvid management measures. Current corvid management efforts include public education and "soft" enforcement of food storage regulations to reduce human food waste, improvements to garbage receptacles and food storage lockers, and removal of ravens and/or their nests. New measures include conditioned taste aversion (CTA), removal of jays and/or their nests; and installation of food waste receptacles at water spigots (grates). CTA involves training jays to avoid Marbled Murrelet eggs by exposing them to painted chicken eggs (colored to mimic murrelet eggs) that contain carbachol. Carbachol is a drug that mimics the action of the neurotransmitter acetylcholine. When ingested, it causes jays and many other species to experience temporary discomfort, nausea, and possibly vomiting. Jays that ingest carbachol-treated eggs are expected to associate the unpleasant experience with murrelet eggs such that they modify their behavior and avoid ingesting actual murrelet eggs they encounter in the future.

The following projects are non-preferred at this time:

- Corvid management at Humboldt Redwoods and Grizzly Creek State Parks and
- Breeding habitat protection via acquisition or easement.

FISH AND OTHER AQUATIC ORGANISMS

Benefits to eelgrass habitat, invertebrates, herring, and other bay fishes

- *Eelgrass Restoration*

This project will create or expand eelgrass beds at multiple locations inside the Bay. Eelgrass beds are a vital part of the Bay ecosystem, providing benefits to a variety of eelgrass-dependent organisms, as well as herring, which use eelgrass beds for spawning. There will be several project sites within and around the Central Bay. Additional NEPA compliance will be conducted prior to implementation of the selected restoration project once specific locations are identified.

The following projects are non-preferred at this time:

- Abandoned vessel removal in Richardson Bay;.
- Mooring chain replacement in Richardson Bay;
- Herring hatchery; and
- Pier piling replacement.

HABITATS

Benefits to sandy beach habitat

- *Lower Redwood Creek and Big Lagoon; Muir Beach Dunes Restoration*

This project will enhance dune vegetation and habitat within Golden Gate National Recreation Area at Muir Beach by removing non-native vegetation, planting native vegetation, and re-routing pedestrian traffic. It is part of a larger effort to restore Redwood Creek, including the creek, wetlands, lagoon and sand dunes in the Muir Beach area that were all evaluated in the Lower Redwood Creek and Big Lagoon - Environmental Impact Statement (EIS).

- *Albany Beach Restoration*

This project will enhance and expand Albany Beach in the East Bay by removing non-native vegetation, planting native vegetation, and importing more sand, among other activities. In addition to the information in the EA, additional information provided by the project implementer has been reviewed and considered for this determination. It is expected that the U.S. Army Corps of Engineers will provide additional NEPA compliance for Section 404 permitting.

The following projects are non-preferred at this time:

- Radio Beach expansion and
- Limantour Beach dune enhancement.

Benefits to salt marsh and tidal flat habitat

- *Aramburu Island Restoration*

This project seeks to restore 17 acres of tidal marsh and shoreline habitat on Aramburu Island in Richardson Bay. The project will include expansion and rehabilitation of tidal marsh and flats; improvements to upland grassland areas; creation of roost habitat for herons and egrets; and expansion of existing sand and gravel areas for shorebird roosting and to reduce wave erosion. This will result in reduced erosion along the eastern shoreline of the Island, enhanced resilience of the Island to sea-level rise, enhanced shorebird, waterfowl, and wading bird habitat, and enhanced suitability of haul-out habitat for harbor seals.

The following projects are non-preferred at this time:

- Schoolhouse Creek day-lighting project;
- Invasive *Spartina* control project;
- Strawberry Creek enhancement;
- Quartermaster Reach wetland restoration; and
- Bolinas Lagoon restoration.

Benefits to rocky intertidal habitat

- *Native Oyster Restoration*

This project will create rocky intertidal habitat by installing hard substrates augmented with oyster shells in low intertidal areas. These provide a substrate for the attachment and development of native oyster communities. The hard surfaces will permit the establishment of algae and will create nooks and crevices to harbor small fish and crabs, creating a diverse rocky intertidal community. There will be several project sites within the Central Bay. Additional NEPA compliance will be conducted prior to implementation of the selected restoration project once specific locations are identified.

- *Rockweed Restoration*

Rockweed habitat in the Central Bay will be created at mid-intertidal elevations using two techniques: seed bags and direct transplant. Some of the proposed sites for rockweed restoration include rocky intertidal habitats heavily damaged by hot water pressure washing used to remove oil from the Cosco Busan spill. Once established, the rockweed habitat provides shelter for many invertebrates, particularly from desiccation during very low tides. There will be several project sites within the Central Bay. Additional NEPA compliance will be conducted prior to implementation of the selected restoration project once specific locations are identified.

The following project is non-preferred at this time:

- Albany Bulb Rocky Shoreline Restoration.

HUMAN RECREATIONAL USES

Benefits to human recreation

- *Recreational Use Projects*

There will be a suite of local projects to enhance recreational uses of the Bay and outer coast, and their adjoining shorelines. The projects will be located in the East Bay, San Francisco Peninsula, and Marin County, proportional to the levels of lost uses in each region. A major portion of the recreational use projects will be located on affected National Park Service lands in San Francisco within Golden Gate National Recreation Area (GGNRA) and San Francisco Maritime National Historical Park, and in Marin County within GGNRA and Point Reyes National Seashore. While this plan does not specify particular projects, it selects a process, which includes working with local governments and affected users, to select projects. Upon selection, restoration projects for lost recreational uses will be subject to further environmental analysis, including a cumulative effects analysis, and public review as appropriate.

Environmental Consequences:

The Trustees analyzed the effects of each restoration project on the quality of the human environment. As documented in the DARP/EA, the Trustees expect the proposed actions to substantially benefit the species and habitats targeted, and to be implemented without significant adverse effects to soil, air quality, water resources, floodplains, wetlands, vegetation, fisheries, wildlife, visual quality, aesthetics/recreation, wilderness, subsistence, cultural resources, park management, or the local economy. The proposed actions are designed to make the environment and the public whole for injuries to, or lost use of, natural resources and services from the Spill.

Restoration projects to be selected later to compensate for lost recreational uses and to benefit surf scoters and other large diving ducks, will be subject to further environmental analysis, and public review, as appropriate, once sufficient information is developed to provide for that analysis. Also, additional environmental review will be conducted as appropriate for the Tule Lake NWR Grebe Nesting Habitat and Berkeley Pier Enhancement Restoration projects as more site-specific information is developed.

Overall, the Trustees' selected restoration projects for the *Cosco Busan* NRDA will result in long-term net improvement in fish and wildlife habitat, restoration of ecological balance in areas where disturbances have led to adverse impacts on sensitive native species, and improvement in the natural resource services provided by fish and wildlife in the region. The cumulative impacts for the restoration projects selected are summarized below from the analysis presented in the DARP/EA.

All of the selected projects to restore ecological services to compensate for injuries from the oil spill to birds, fish, and habitats are consistent with and in some cases a part of ongoing regional environmental restoration efforts described in plans for projects such as the San Francisco Baylands Ecosystem Goals Project and the San Francisco Bay Subtidal Goals project.

In the long-term, the overall water quality effects of the selected habitat improvement projects and other past and reasonably foreseeable restoration projects is expected to be beneficial, since they are generally acknowledged to provide favorable water quality improvement and enhanced biological activity. Construction for some of the projects, including the Aramburu Island project and Albany Beach Restoration project, could cause temporary water quality impacts; however, these impacts would be limited in scope and duration, would be mitigated by use of best management practices, and are unlikely to contribute to cumulative water quality impacts in San Francisco Bay.

All of the past and proposed wetlands and subtidal habitat enhancement efforts for this region are part of a long-term strategy to recreate a complex mosaic of wetlands and subtidal habitats in the greater San Francisco Bay area. The selected restoration projects, considered along with other restoration projects, will result in cumulatively beneficial impacts to plants and wildlife, including special-status species, will provide additional habitat to support recovery of these sensitive communities and will result in greater habitat complexity, diversity, and productivity. The project implementers for the Aramburu Island project have consulted with both NOAA and the USFWS, both of whom concurred that the project is not likely to adversely impact species listed under the Endangered Species Act. These projects will cumulatively increase the availability and quality of marsh and shallow water aquatic habitats throughout the region. The wetlands restoration project on Aramburu Island involves enhancement of existing degraded site conditions rather than conversion of uplands or diked bay lands to tidal marsh or mudflat. The eelgrass restoration project entails the gradual conversion of un-vegetated shallow subtidal habitat to vegetated habitat resulting in a shift in biological communities from those that occupy un-vegetated shallows to those that utilize vegetated shallows. Similarly, native oyster restoration entails gradual introduction and expansion of oyster beds beyond areas where they are currently located. Impacts from eelgrass restoration, even when considered along with changes anticipated as other similar projects are implemented throughout San Francisco Bay, will be minimal to soft bottom habitats of the bay and will only enhance habitat complexity at sites where eelgrass restoration will be located. Similarly, the acreage of subtidal habitat affected by the selected native oyster restoration projects, when considered along with other reasonably foreseeable oyster restoration efforts, is *de-minimis* compared to the available subtidal habitat.

Another potential cumulative impact from multiple tidal habitat restoration projects is the potential for invasion of aggressive non-native plant species, such as certain cordgrass species (*Spartina alterniflora and Spartina densiflora*). The number of restoration projects planned in the region increases the availability of suitable habitat for colonization by these species, and in the past, several restoration projects along the shores of San Francisco and San Pablo bays have been degraded because of non-native

cordgrass. Applicable restoration projects, including the Aramburu Island project require monitoring and control of exotic pest plant species within restored marsh areas, and coordination with the Invasive Spartina Project (a regional program to control non-native *Spartina* in the San Francisco estuary).

Projects to enhance public recreation in areas affected by the spill (i.e., improvements to public piers, parks, bike paths, boat ramps, fishing areas, or other infrastructure that increase the value of recreational experiences involving beach use, boating, and fishing) will have minor short-term impacts on air quality, water quality, and traffic that will be mitigated during the construction phase of such projects. The cumulative long term beneficial effects and public use trade-offs of the recreational projects to be implemented under this restoration plan, combined with similar foreseeable development projects throughout the San Francisco Bay region, which are much larger in scale than the types of recreational projects which will be subsequently selected by the Trustees, are potentially significant. However, it is anticipated that the incremental impacts from such recreational projects are less than significant.

Summary:
The Trustees believe that, overall, the alternatives selected in this restoration plan, when considered along with past and reasonably foreseeable future projects, will have long term, local and regional beneficial impacts to natural resources; and beneficial impacts to human recreation activities such as waterfowl hunting, fishing and bird watching.

Environmentally Preferred Alternative:
The environmentally preferred alternative is the alternative that will promote the policies of NEPA, as expressed in Section 101 of NEPA. The environmentally preferred alternative is the one that best meets the following:

- Fulfills the responsibility of each generation as trustee of the environment for succeeding generations;
- Ensures for all Americans a safe, healthful, productive, and aesthetically and culturally pleasing surrounding;

• Attains the widest range of beneficial uses of the environment without degradation, risk of health or safety, or other undesirable and unintended consequences;
• Preserves important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice;
• Achieves a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and
• Enhances the quality of renewable resources and approaches the maximum attainable recycling of depletable resources.

Based upon analyses of the proposed action when compared to the alternative projects (non-preferred) and the no action alternative, the proposed action meets the criteria above and is, therefore, also the environmentally preferred alternative.

Basis for Decision:
Implementation of the proposed actions will have local and regional long term beneficial impacts on natural, cultural, and social resources, with minimal short-term unfavorable impacts during project implementation activities. No highly uncertain or controversial impacts, unique or unknown risks, significant cumulative negative effects, or elements of precedence have been identified, and implementing the proposed and preferred alternative will not violate Federal, State, or local environmental protection laws.

Public Involvement:
The Trustees sought the public's input on a draft version of the DARP/EA. Public review of the Draft DARP/EA occurred between September 19 and October 31, 2011 and included two public meetings, a press release, an announcement in the Federal Register, an email announcement to over 900 individuals, a two-page newsletter and a 3 ½ minute YouTube video that summarized the Draft DARP/EA. Written and oral comments received on the Draft DARP/EA and Trustee responses are included as Appendices in the Final DARP/EA. After considering the public comments, the Trustees modified the DARP/EA in a number of ways (detailed in Appendix L), including the section regarding restoration for Marbled Murrelets. The Trustees then sought additional public comment on the section of the draft DARP/EA concerning Marbled Murrelet restoration, with public review occurring between December 28, 2011 and January 27, 2012. One additional supportive comment on this modified section was received.

Conclusion:
Based upon an environmental review and evaluation of the DARP/EA for the *Cosco Busan* Oil Spill as summarized above, it is determined that implementation of the

restoration plan does not constitute a major Federal action significantly affecting the quality of the human environment under the meaning of Section 102(2)(c) of the National Environmental Policy Act of 1969 (as amended). Accordingly, an environmental impact statement is not required for this action. In addition, those project(s) identified as: Benefiting Surf Scoters, Tule Lake Grebe Nesting Habitat, Berkeley Pier Enhancement, Eelgrass/Rockweed/Native Oyster restorations and Human Recreational Use Projects will be subject to further environmental review and compliance as appropriate, as the projects and/or their locations are identified.

Regional Director, Pacific Southwest Region U.S. Fish and Wildlife Service	Date
Regional Director, Pacific West Region National Park Service	Date

restoration plan does not constitute a major Federal action significantly affecting the quality of the human environment under the meaning of Section 102(2)(c) of the National Environmental Policy Act of 1969 (as amended). Accordingly, an environmental impact statement is not required for this action. In addition, those project(s) identified as: Benefiting Surf Scoters, Tule Lake Grebe Nesting Habitat, Berkeley Pier Enhancement, Eelgrass/Rockweed/Native Oyster restorations and Human Recreational Use Projects will be subject to further environmental review and compliance as appropriate, as the projects and/or their locations are identified.

Alexandra Pitts

Acting Regional Director, Pacific Southwest Region
U.S. Fish and Wildlife Service

2.10.2012
Date

Patricia L. Neubacher

acting Regional Director, Pacific West Region
National Park Service

2/10/12
Date

FINDING OF NO SIGNIFICANT IMPACT

Cosco Busan Oil Spill Final Damage Assessment and Restoration Plan/Environmental Assessment

Background:

Under the Oil Pollution Act of 1990 (OPA) the Natural Resource Trustee Agencies (Trustees), including the National Oceanic and Atmospheric Administration (NOAA) on behalf of the U.S. Department of Commerce, the United States Fish and Wildlife Service (USFWS), National Park Service (NPS), and Bureau of Land Management (BLM) on behalf of the U.S. Department of the Interior, and the California Department of Fish and Game (CDFG) and California State Lands Commission (CSLC) on behalf of the State of California, prepared the Final Damage Assessment and Restoration Plan and Environmental Assessment (DARP/EA) for the November 7, 2007, M/V Cosco Busan oil spill in San Francisco Bay. The DARP/EA evaluates restoration alternatives for natural resource injuries incurred as a result of this oil spill.

On November 7, 2007, the freighter Cosco Busan struck the San Francisco-Oakland Bay Bridge as it attempted to depart San Francisco Bay. The accident created a gash in the hull of the vessel, causing it to spill more than an estimated 53,000 gallons of Intermediate Fuel Oil (IFO-380) into the Bay (the "Spill"). Wind and currents quickly took some of the oil outside of the Bay, where it impacted the outer coast from approximately Half Moon Bay to Limantour Beach at Point Reyes. Inside the Bay, the oil primarily impacted waters and shoreline within the central portion of the Bay, from Tiburon to San Francisco on the west side and from Richmond to Bay Farm Island and Alameda on the east side. Following the incident, representatives of the Trustees and the vessel owners jointly conducted a Natural Resource Damage Assessment (NRDA) to determine the nature and extent of injuries resulting from the spill to natural resources.

The injuries from the oil spill can be divided into the following categories:

- **Birds**: 6,849 birds were estimated killed, representing 65 different species.
- **Mammals**: No significant injuries.
- **Fish**: An estimated 14% to 29% of the winter 2007-8 herring spawn was lost due to widespread egg mortality in some areas of the Bay.
- **Shoreline Habitats**: 3,367 acres of shoreline habitat were impacted, and recovery is expected to vary from a few months to several years, depending upon the habitat type and degree of oiling.
- **Human Uses**: Approximately 1,079,900 user-days were lost, representing a wide variety of activities (recreational fishing, general beach use, surfing, etc.).

In addition to other costs and damages, the parties responsible for the spill are liable for natural resource damages, which are used to fund environmental restoration projects to compensate the public for the diminished ecological value of injured resources, including those previously mentioned, caused by the spill and related response activities.

Restoration Alternatives:

The Trustees cooperatively developed the Final DARP/EA. It examines and evaluates potential projects to restore natural resources in compensation for injuries resulting from the spill.

The Trustees published a draft DARP/EA in 2011 and invited the public to comment on it. It included discussion of a “no action” alternative and several alternative actions to address the injured resources. The Trustees rejected the “no action” alternative because it does not compensate the public for losses suffered by the resources. OPA clearly establishes Trustee authority to seek compensation for injuries and interim losses pending recovery of natural resources. Furthermore, technically feasible alternatives for restoration are available. For the remaining active restoration alternatives, the Trustees considered criteria to evaluate the entire suite of projects that were under consideration. These criteria included each project’s ability to restore resources of the type impacted by the incident and relevant federal and state laws governing use of damages for natural resources. Based on an evaluation under these criteria, the Trustees selected several alternatives that would compensate for injuries to natural resources affected by the spill. Several non-preferred projects were also considered in the DARP/EA. These projects may be reconsidered if funds become available or if selected projects prove to be infeasible. For a complete description of all of the restoration alternatives, see the DARP/EA.

This decision document concludes that a Finding of No Significant Impact (FONSI) is appropriate for restoration actions evaluated in the DARP/EA as summarized here. For the following projects that are developed to a sufficient level of detail, and for which the DARP/EA contains a full environmental impacts analysis, the Final DARP/EA serves to satisfy NOAA’s requirements under the National Environmental Policy Act (NEPA).

1. PROJECT: Winter Diving Duck Habitat at the South Bay Salt Ponds
   BENEFITS: small diving ducks and small grebes
   This project complements on-going efforts to restore the South Bay Salt Ponds in southern San Francisco Bay by maintaining and managing habitat for wintering lesser scaup and eared grebes, among other species. The same ponds would be managed for snowy plover nesting during the summer. This project will be a component of the larger South Bay Salt Pond Restoration Project (SBSPRP). A full discussion of the environmental consequences can be found in the EIR/EIS for the SBSPRP (South Bay Salt Pond Restoration Project 2007). The Trustees have considered the information contained in the SBSPRP EIR/EIS and incorporate by reference the analysis of environmental consequences contained in the SBSPRP EIS/EIR. In addition, NOAA adopted the SBSPRP EIR/EIS in 2009. Therefore, no additional NEPA review will be necessary.

2. PROJECT: Farallon Island Nest Site Improvements
   BENEFITS: Alcids and Procellarids

This project seeks to increase suitable nest sites for seabirds at Southeast Farallon Island of the coast of San Francisco. Specifically, it will replace up to 60 rhinoceros auklet and 200 Cassin's auklet nest boxes and create nest sites for up to 60 pairs of Ashy storm-petrels. This project is described in the Farallon NWR Comprehensive Conservation Plan and Environmental Assessment (2009) and is further evaluated in the DARP/EA. Therefore, no additional NEPA review will be necessary.

3. PROJECT: Marbled Murrelet Restoration
   BENEFITS: Marbled Murrelets
   This project seeks to restore marbled murrelets through a variety of measures, including corvid (predatory birds of the crow family) management. Measures may include public education and "soft" enforcement of food storage regulations to reduce human food waste, improvements to garbage receptacles and food storage lockers, removal of ravens and/or their nests, conditioned taste aversion (CTA), removal of jays and/or their nests, and installation of food waste receptacles at water spigots (grates). This project, undertaken by the USFWS and the State of California, may be implemented anywhere in California where there are opportunities that benefit marbled murrelets. This project has been evaluated in the DARP/EA; therefore, no additional NEPA review will be necessary. In addition all necessary permits under the Migratory Bird Treaty Act are in place for this project.

4. PROJECT: Muir Beach Dunes Restoration
   BENEFITS: sandy beach habitat
   This project will enhance dune vegetation and habitat at Muir Beach in Marin County by removing non-native vegetation, planting native vegetation, and re-routing pedestrian traffic. This project is part of a larger effort to restore Redwood Creek, including the creek, wetlands, lagoon and sand dunes in the Muir Beach area that were evaluated in the Lower Redwood Creek and Big Lagoon Environmental Impact Statement. It is also further evaluated in the DARP/EA. Therefore, no additional NEPA review will be necessary.

5. PROJECT: Aramburu Island Restoration
   BENEFITS: salt marsh and mud/sand flats
   This project seeks to restore tidal marsh and shoreline habitat on Aramburu Island in Richardson Bay. Project elements include rehabilitation of tidal marsh and flats, improvements to upland grassland areas, creation of roost habitat for herons and egrets, and expansion of existing sand and gravel areas for shorebird roosting and to reduce wave erosion. NEPA compliance was completed earlier by NOAA for engineering and design as documented under the National Association of Counties 2009, Explanation of Inclusion of Projects under the Community-based Restoration Program Programmatic Environmental Assessment and Supplement (PEA/SPEA) and Findings of No Significant Impact. Other aspects of the project have been evaluated in the DARP EA. Therefore, no additional NEPA review will be necessary.

6. PROJECT: Albany Beach
   BENEFITS: sandy beach habitat

This project will enhance and expand Albany Beach in the East Bay by removing non-native vegetation, planting native vegetation, and importing more sand, among other activities. This project has been evaluated in the DARP/EA. The Trustees also considered further environmental analysis conducted in compliance with the California Environmental Quality Act and have added this information to their administrative record. Therefore, no additional NEPA review will be necessary.

For the following selected actions that are at various stages of conceptual planning and for which it is not possible to conduct a full environmental analysis, NOAA (or the lead implementation Trustee agency) will either conduct further environmental analysis as the necessary detailed information becomes available or require the project implementer(s) to conduct such an analysis These actions are:

7. PROJECT: Request for Proposals for project benefiting Surf Scoters
   BENEFITS: scoters and other large diving ducks
   This project will seek proposals and award a grant to one or more projects that will provide benefits to surf scoters, the bird species most impacted by the spill. Additional NEPA compliance will be required as appropriate prior to implementation.

8. PROJECT: Tule Lake Grebe Habitat
   BENEFITS: Western/Clark's grebes
   This project seeks to create more suitable nesting habitat for Western and Clark's grebes at Tule Lake National Wildlife Refuge in northern California. These species spend the winter in the Bay and along the outer coast. The project primarily involves the management of water levels in Tule Lake's Upper Sump to create over 500 acres of new freshwater marsh, in which the birds would nest. Additional NEPA compliance will be required prior to implementation, pending development of sufficient project-level detail.

9. PROJECT: Berkeley Pier Enhancements
   BENEFITS: pelicans, cormorants, gulls, shorebirds
   This project will enhance the dilapidated tip of the Berkeley Pier for cormorant and gull nesting and pelican roosting. It will also enhance another section nearer the base as a high tide roost site for shorebirds. Additional NEPA compliance will be required prior to implementation, pending development of sufficient project-level detail.

10. PROJECT: Eelgrass Restoration
    BENEFITS: eelgrass habitat, invertebrates, herring, and other bay fishes
    This project will create or expand shallow subtidal eelgrass beds at multiple locations within the footprint of the spill. Eelgrass beds are a vital part of the Bay ecosystem, providing benefits to a variety of eelgrass-dependent organisms, as well as herring, which use eelgrass beds for spawning. Additional NEPA compliance will be required prior to implementation, pending development of sufficient project-level detail.

11. PROJECT: Native Oyster Restoration
    BENEFITS: rocky intertidal habitat

This project will create rocky intertidal habitat by installing hard substrates augmented with oyster shells in low intertidal areas. These provide a substrate for the attachment and development of native oyster communities. The hard surfaces will also permit the establishment of algae, and any nooks and crevices would harbor small fish and crabs, creating a diverse rocky intertidal community. There will be several project sites within the Central Bay. Additional NEPA compliance will be required as appropriate prior to implementation.

12. PROJECT: Rockweed Restoration
BENEFITS: rocky intertidal habitat
Rockweed habitat in the Central Bay will be created at mid-intertidal elevations using two techniques: seed bags and direct transplant. Some of the proposed sites for rockweed restoration include rocky intertidal habitats heavily damaged by hot water pressure washing during the oil spill response. Once established, the rockweed habitat provides shelter for many invertebrates, particularly from desiccation during very low tides. Additional NEPA compliance will be required as appropriate prior to implementation.

13. PROJECT: Recreational Use Projects
BENEFITS: human recreational users
There will be a suite of local projects to enhance recreational uses. The projects will be located in the East Bay, San Francisco Peninsula, and Marin County, proportional to the levels of lost uses in each region. While this plan does not specify any particular project, it proposes a process, working with local governments and affected users, to select projects. Additional NEPA compliance will be required as appropriate prior to implementation, pending selection of specific projects and locations.

Public Involvement:

Throughout the NRDA process, the Trustees have made information available to the public. The Trustees held public meetings in Oakland and Mill Valley shortly after the oil spill in January 2007 and published a series of fact sheets to keep the public up to date on the progress of the NRDA.

The Trustees also sought the public's input on a draft version of the DARP/EA. Public review of the Draft DARP/EA occurred between September 19 and October 31, 2011 and included two public meetings, a press release, an email announcement to over 900 individuals, and a two-page newsletter and a 3½ minute YouTube video that summarized the Draft DARP/EA. Public comments were received and are available in the Administrative Record. The Trustees' responses to the comments are in Appendix L of the Final DARP/EA.

After considering the public comments, the Trustees modified the DARP/EA in a number of ways (detailed in Appendix L), most significantly the section regarding restoration for marbled murrelets. The Trustees sought additional public comment on the changes for the marbled murrelet subsection, with public review occurring between December 28, 2011 and January 27, 2012.

In addition, the Trustees published a Notice of Intent (NOI) to Conduct Restoration Planning, pursuant to the Oil Pollution Act regulations at 15 CFR § 990.44, and concurrently opened an Administrative Record in compliance with 15 CFR § 990.45. The Record includes documents relied upon or considered by the Trustees during the assessment and restoration planning process.

Alternatives Considered:

The DARP/EA evaluates an array of project alternatives for restoration of the various injured resources. The evaluation criteria used by the Trustees considered the following, taken from the NRDA regulations promulgated under the Oil Pollution Act: the cost to carry out the alternative action, the extent to which each alternative is expected to meet the Trustees' goals and objectives in returning the injured natural resources and services to baseline and/or compensating for interim losses, the likelihood of success of each alternative, the extent to which each alternative will prevent future injury as a result of the oil spill and avoid collateral injury as a result of implementing the alternative, the extent to which each alternative benefits more than one natural resource and/or service, and the effect of each alternative on public health and safety. In addition, the Trustee considered proximity to the geographic location of the injury, the relative costs of potential projects, how quickly a project would provide benefits, the duration of benefits, benefits to multiple resources, the extent to which a project would contribute to the overall restoration plan, the potential for maintenance and oversight of projects, opportunities to collaborate with other entities involved in restoration projects, the ability to document project benefits to the public, education and research value of projects, the degree to which project benefits would duplicate each other, and compliance with applicable federal and state laws and policies. The Trustees selected the most meritorious projects based on this evaluation.

Dozens of projects underwent evaluation. The specific projects which the Trustees considered are discussed in greater detail in Section 4 of the Final DARP/EA.

Environmental Consequences:

The NEPA requires an analysis of the effects of government actions on the quality of the human environment. In addition, Council on Environmental Quality (CEQ) regulations and NOAA's implementing procedures for NEPA recommend the avoidance of repetitive discussions when more than one environmental document addresses the same action(s).

The selected restoration projects or action types were identified through various multi-party regional restoration planning efforts such as the San Francisco Bay Baylands Ecosystem Habitat Goals Project, the San Francisco Subtidal Habitat Goals Project, the San Francisco Bay South Bay Salt Pond Adaptive Management Plan, National Park Service Management Plans, and the East Bay Regional Park District Master Plan. In addition, the Trustees consulted with multiple state and federal agencies in the San Francisco Bay region and with multiple nonprofit groups dedicated to the restoration and conservation of coastal resources in the Bay and the outer coast.

NOAA's Administrative Order (NAO) 216-6 (May 20, 1999) contains criteria for determining the significance of the impacts of a proposed action. In addition, the Council on Environmental

Quality (CEQ) regulations at 40 C.F.R. §1508.27 state that the significance of an action should be analyzed both in terms of "context" and "intensity." The significance of this action is analyzed based on the NAO 216-6 criteria and CEQ's context and intensity criteria. The criteria listed below are relevant to making a Finding of No Significant Impact, and have been considered individually, as well as in combination with the others, and include:

(1) Can the proposed actions reasonably be expected to cause substantial damage to the ocean and coastal habitats and/or essential fish habitat as defined under the Magnuson Stevens Act and identified in Federal Management Plans (FMPs)?

> Response: No. As documented in the Final DARP/EA, the Trustees do not expect the selected projects to cause substantial damage to the ocean and coastal habitats and/or essential fish habitat as defined under the Magnuson-Stevens Act. Any short-term and temporary localized impacts from the restoration activities, such as those associated with wetland construction, the placement of oyster shell or the planting of eelgrass seeds and Fucus algae, will be minimized by the use of Best Management Practices. As documented in the Final DARP/EA (in section 4.3.3, and Appendix D), the Trustees expect the selected projects to substantially benefit the habitat targeted for restoration and the species associated. The planned restoration actions will have beneficial impacts by increasing and or enhancing habitats for anadromous fish, and special status fish species, migratory shorebirds, and diving ducks and salt marsh-dependent special status species such as the salt marsh harvest mouse and clapper rail. Overall, impacts to the ocean, coastal habitats, and/or essential fish habitat are expected to be beneficial.

(2) Can the proposed actions be expected to have a substantial impact on biodiversity and/or ecosystem function within the affected area (e.g., benthic productivity, predator prey relationships, etc.)?

> Response: No. The selected projects are not expected to have substantial adverse impacts; however, they are expected to have beneficial impacts on ecosystem function and species biodiversity. As documented in the Final DARP/EA (in sections 4.3.4 and 4.5), all of the proposed wetlands, intertidal and subtidal habitat enhancement efforts for this region are part of a long-term strategy through various Federal, State and environmental restoration groups to recreate a complex mosaic of wetlands and subtidal habitats in the greater San Francisco Bay and coastal areas. The projects described in the DARP/EA will result in beneficial impacts to plants and wildlife, including special-status species, providing additional habitat to support recovery of these sensitive communities and resulting in greater habitat complexity, diversity, and productivity. These projects will cumulatively increase the availability and quality of marsh and shallow water aquatic habitats throughout the region. As such there would be an expected increase in ecosystem function and species biodiversity. Any potential adverse impacts (such as those discussed in (1) above) are expected to be minimal, short term, localized, and are not expected to decrease function or species biodiversity.

(3) Can the proposed actions reasonably be expected to have a substantial adverse impact on public health and safety?

Response: No. The selected projects are not expected to have any impacts on public health and safety. The implementation of the proposed restoration projects would not present any unique physical hazards to humans. Any human use projects that are selected later under the framework outlined in the Final DARP/EA may provide benefits to public health and safety; however, any such projects would have to undergo additional review beyond this Final DARP/EA.

(4) Can the proposed actions reasonably be expected to adversely affect endangered or threatened species, their critical habitat, marine mammals, or other non-target species?

Response: No. The selected projects are not expected to adversely affect endangered or threatened species, their critical habitat, marine mammals, or other non-target species for the listed project numbers 1-6. Overall, the selected projects are expected to benefit special status species and their habitat. In addition, for each project selected in the Final DARP/EA that requires additional environmental review and has not already undergone consultation with the USFWS and/or NOAA under Section 7 of the Endangered Species Act, the Federal Trustees will complete consultation prior to and as a condition of future project implementation.

(5) Are significant social or economic impacts interrelated with natural or physical environmental effects?

Response: No. The Trustees do not expect there to be significant adverse social or economic impacts interrelated with natural or physical environmental effects of the selected projects. On the contrary, these projects will only promote positive economic returns to San Francisco Bay and associated areas impacted by the spill. It is anticipated that any selected recreational projects will provide positive social interactions with the natural environment.

(6) Are the effects on the quality of the human environment likely to be highly controversial?

Response: No. The selected restoration projects are not controversial. The public's response during the DARP/EA public comment period was positive. Furthermore, due to the environmentally beneficial nature of the selected projects, the Trustees anticipate that the public will remain supportive.

(7) Can the proposed actions reasonably be expected to result in substantial impacts to unique areas, such as historic or cultural resources, park land, prime farmlands, wetlands, wild and scenic rivers, essential fish habitat, or ecologically critical areas?

Response: No. The physical characteristics of the area in which the proposed restoration projects would be implemented do not increase the risk of significant impacts. The affected environment encompasses portions of San Francisco Bay which includes the near shore tidal flats, wetlands, rocky intertidal areas, sandy beaches, eelgrass beds and subtidal habitats. In addition, the physical environment includes the Gulf of the

Farallones National Marine Sanctuary, managed by NOAA; the Farallon Islands, Tule Lake, and Don Edwards National Wildlife Refuges, managed by the USFWS; and the Point Reyes National Seashore and Golden Gate National Recreation Area, managed by the NPS. While these and other areas do contain unique characteristics, the proposed projects are, overall, expected to be beneficial to these areas. Furthermore, no unique or rare habitat would be destroyed due to restoration of wetlands to those areas that previously supported wetlands.

(8) Are the effects on the human environment likely to be highly uncertain or involve unique or unknown risks?

Response: No. The areas in which the projects will be implemented are well known to the project implementers, and none of the project methods that are expected to be used are unique, controversial, or untried.

(9) Are the proposed actions related to other actions with individually insignificant, but cumulatively significant impacts?

Response: No. The Trustees evaluated the restoration projects selected in the Final DARP/EA in conjunction with other known past, proposed or foreseeable closely related projects that could potentially add to or interact with the these projects within the affected area to determine whether significant cumulative impacts may occur. All of the selected projects to restore ecological services to compensate for injuries from the oil spill to birds, fish, and habitats are consistent with and in some cases a part of ongoing regional environmental restoration efforts described in plans such as the San Francisco Baylands Ecosystem Goals Project and the San Francisco Bay Subtidal Goals project.

(10) Are the proposed actions likely to adversely affect districts, sites, highways, structures, or objects listed in or eligible for listing in the National Register of Historic Places or may cause loss or destruction of significant scientific, cultural or historical resources?

Response: No. As noted in the Final DARP/EA, the Trustees have evaluated the selected projects and determined that they are not expected to impact any cultural, scientific, or historic resources. However, if potential impacts become known during project implementation, the Trustees will either conduct or require the project implementer to conduct any appropriate compliance under the National Historic Preservation Act.

(11) Can the proposed actions reasonably be expected to result in the introduction or spread of a non-indigenous species?

Response: No. While, tidal habitat restoration projects may increase the availability of suitable habitat for colonization by aggressive, non-native plant species (such as Spartina alterniflora and Spartina densiflora), the selected projects will include extensive measures to prevent such colonization. In the past, several restoration projects along the shores of San Francisco and San Pablo bays have been degraded because of non-native cordgrass out-competing native California cordgrass. Accordingly, projects selected in the Final DARP/EA that have the potential to support non-native wetland plant species (e.g., the Aramburu Island project), will undergo continuous monitoring and control of exotic pest plant species within restored marsh areas, as described in the restoration plan. The proponents will also coordinate with the Invasive Spartina Project (a regional program to control non-native *Spartina* in the San Francisco estuary). Other projects that increase hard substrate within the tidal zone may also provide available space for the colonization of aquatic non-natives. However, the number and footprint of these types of projects, related to the size of the bay are minimal and therefore would not constitute a significant threat for the spread of invasives.

(12) Are the proposed actions likely to establish a precedent for future actions with significant effects or represent a decision in principle about a future consideration?

Response: No. All of the project types selected have been implemented before or have been attempted in San Francisco Bay, along the outer coast, and in other West Coast estuaries. The selected restoration projects are not expected to set precedents for future actions that would significantly affect the human environment or represent a decision in principle about a future consideration.

(13) Can the proposed actions reasonably be expected to threaten a violation of Federal, State, or local law or requirements imposed for the protection of the environment?

Response: No. Implementation of the selected projects (numbers 1-6) would not require any violation of federal, state or local laws designed to protect the environment. All projects prior to implementation will undergo required Federal and State review and permits if needed.

(14) Can the proposed actions reasonably be expected to result in cumulative adverse effects that could have a substantial effect on the target species or non-target species?

Response: No. The proposed action will not result in a substantial cumulative adverse effect on target species and non-target species. The proposed restoration projects are not expected to contribute to potentially significant cumulative impacts. The reasons for this conclusion are detailed in the Final DARP/EA “Cumulative Impacts” section. Furthermore, since the proposed restoration projects are designed to achieve recovery of injured natural resources, any cumulative environmental consequences will be largely beneficial.

DETERMINATION

Based upon an environmental review and evaluation of the DARP/EA for the Cosco Busan Oil Spill as summarized above, it is determined that implementation of the restoration plan does not constitute a major Federal action significantly affecting the quality of the human environment under the meaning of Section 102(2)(c) of the National Environmental Policy Act of 1969 (as amended). Accordingly, an environmental impact statement is not required for this action. In addition, those project(s) identified as: Benefiting Surf Scoters, Tule Lake Grebe Nesting Habitat, Berkeley Pier Enhancement, Eelgrass/Rockweed/Native Oyster restorations and Human Recreational Use Projects will be subject to further environmental review and compliance as appropriate, as the projects and/or their locations are identified.

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Brian T. Pawlak
Acting Director, Office of Habitat Conservation
National Marine Fisheries Service Date

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Brian T. Pawlak
Acting Director, Office of Habitat Conservation
National Marine Fisheries Service

2/27/12
Date