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:

R. Glenn Ford, Janet L. Casey, and Wendy A. Williams

R. G. FORD CONSULTING COMPANY
2735 N.E. Weidler Street
Portland, Oregon 97232

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.

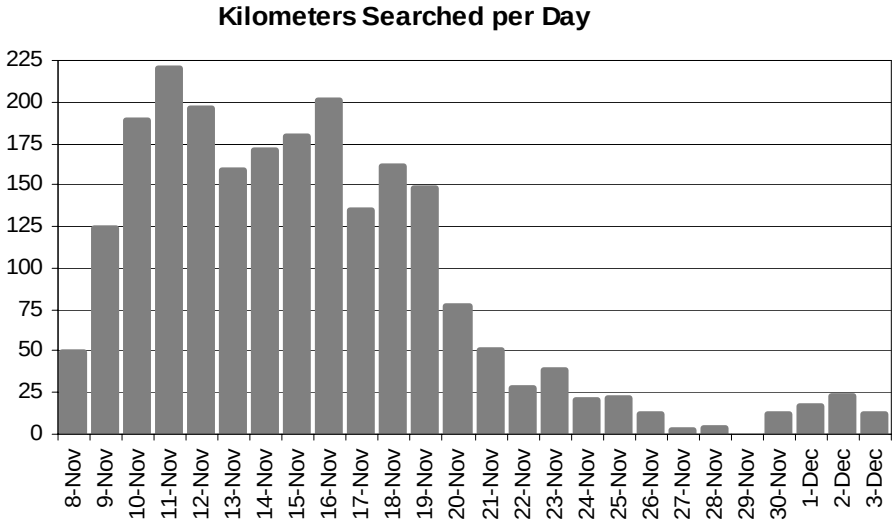

Figure 1. Coastline searched each day by Wildlife Operations search and collection teams, and by teams from Richardson Bay Audubon Society, BeachWatch, Point Reyes Bird Observatory, and Angel Island State Park.

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: Surveys 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: Surveys 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.

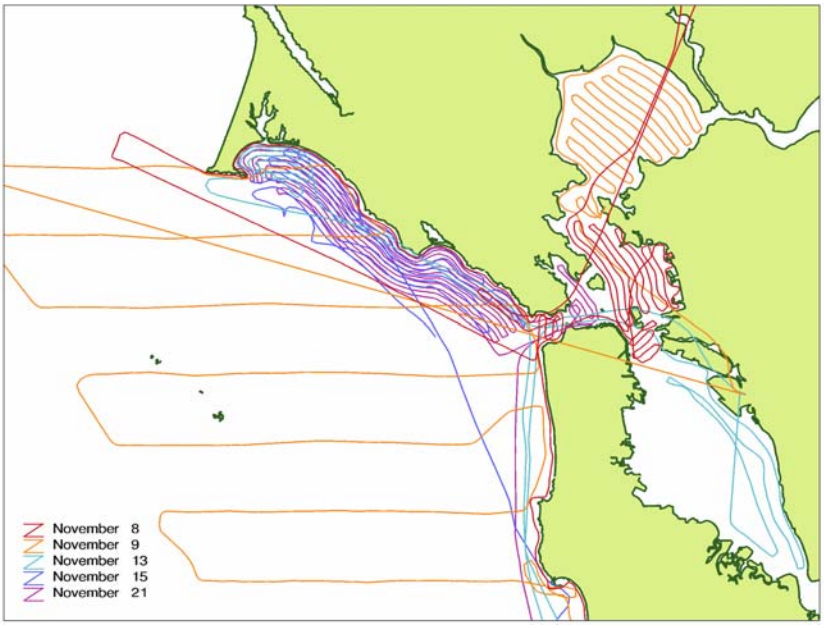

Figure 2. Aerial survey flight lines for five days in November 2007.

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).

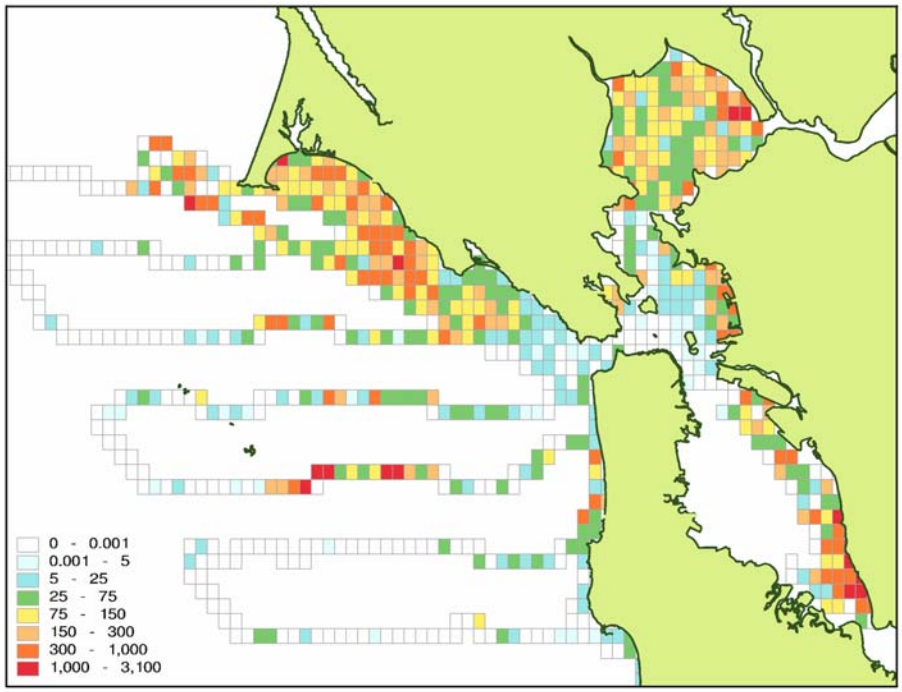

Figure 3. Density of the five most common taxa combined, based on all 5 days of aerial surveys. Birds include Common Murre, Western Grebe, cormorants, scoters and scaup. Observations and tracklines were binned into 1 minute latitude longitude blocks for display. Warmer colors (red and orange) indicate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

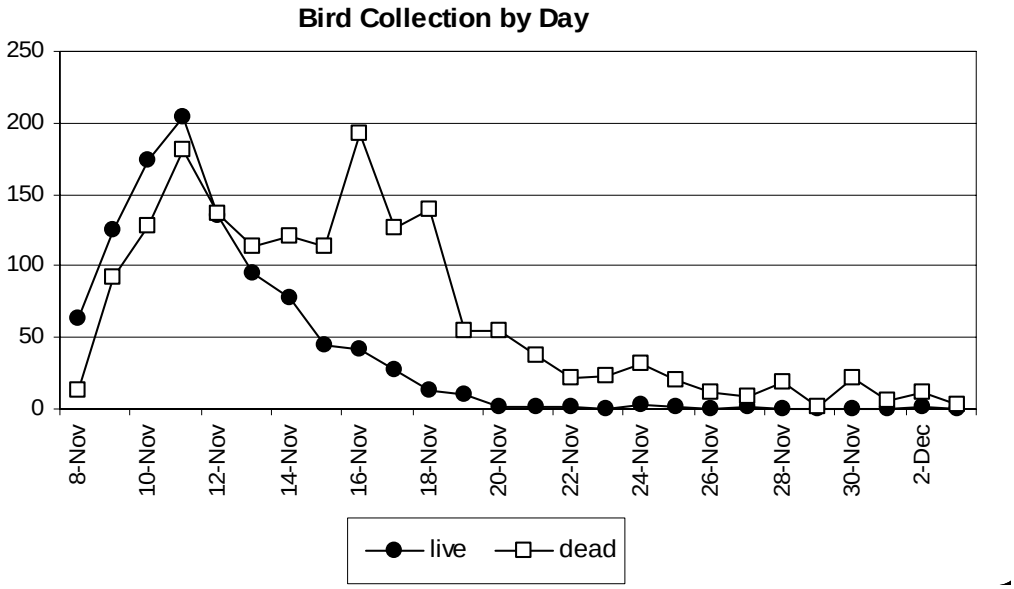

Figure 4. Number of live and dead birds collected by date during the *Cosco Busan* spill response.

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.

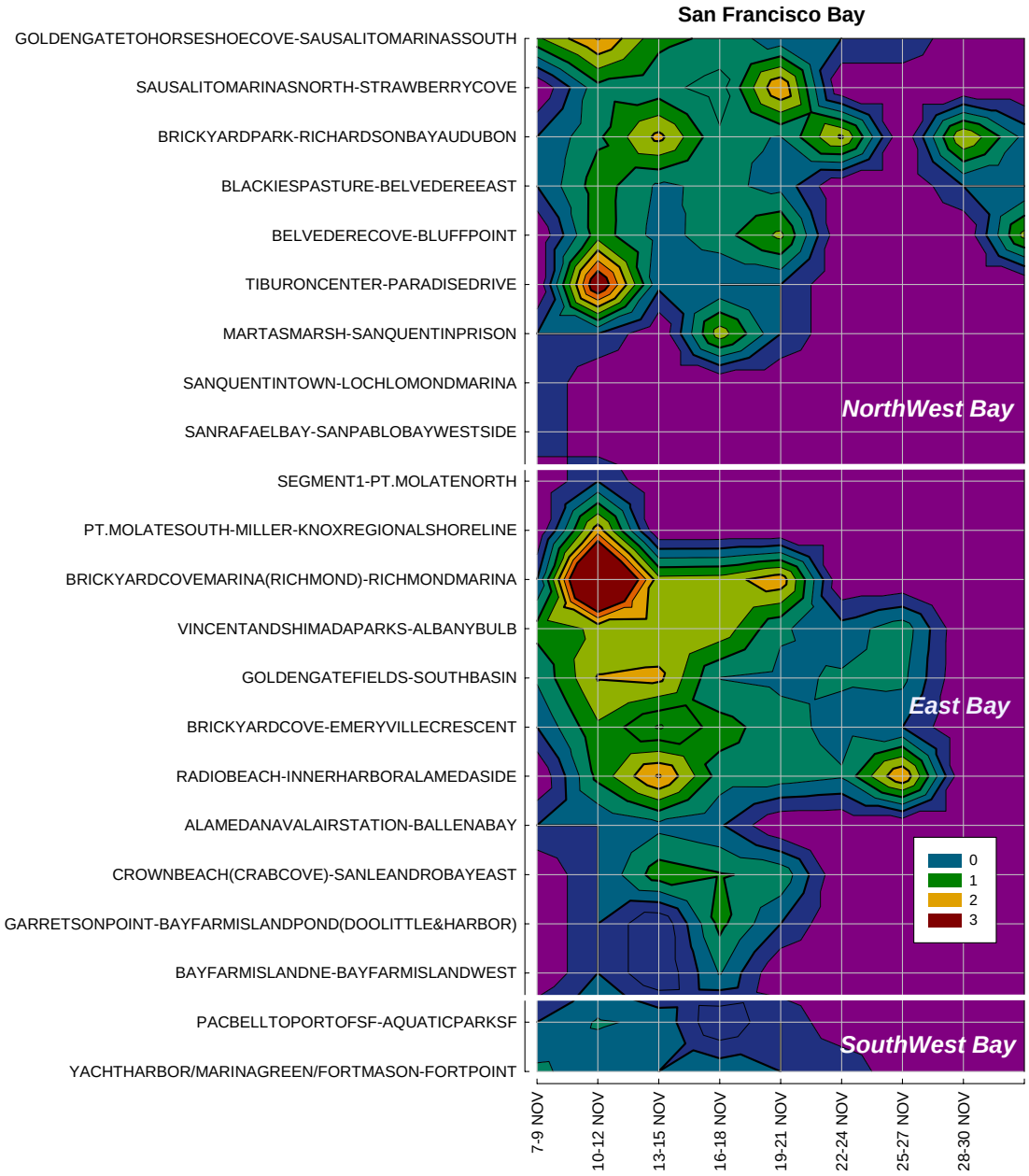

Figure 5. Number of birds recovered per km of search inside San Francisco Bay following the *M/V Cosco Busan* oil spill. The horizontal axis is date, the vertical axis is location. Segments are ordered in a clockwise fashion around the Bay, starting at the Golden Gate and ending at Fort Point. Contours 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.

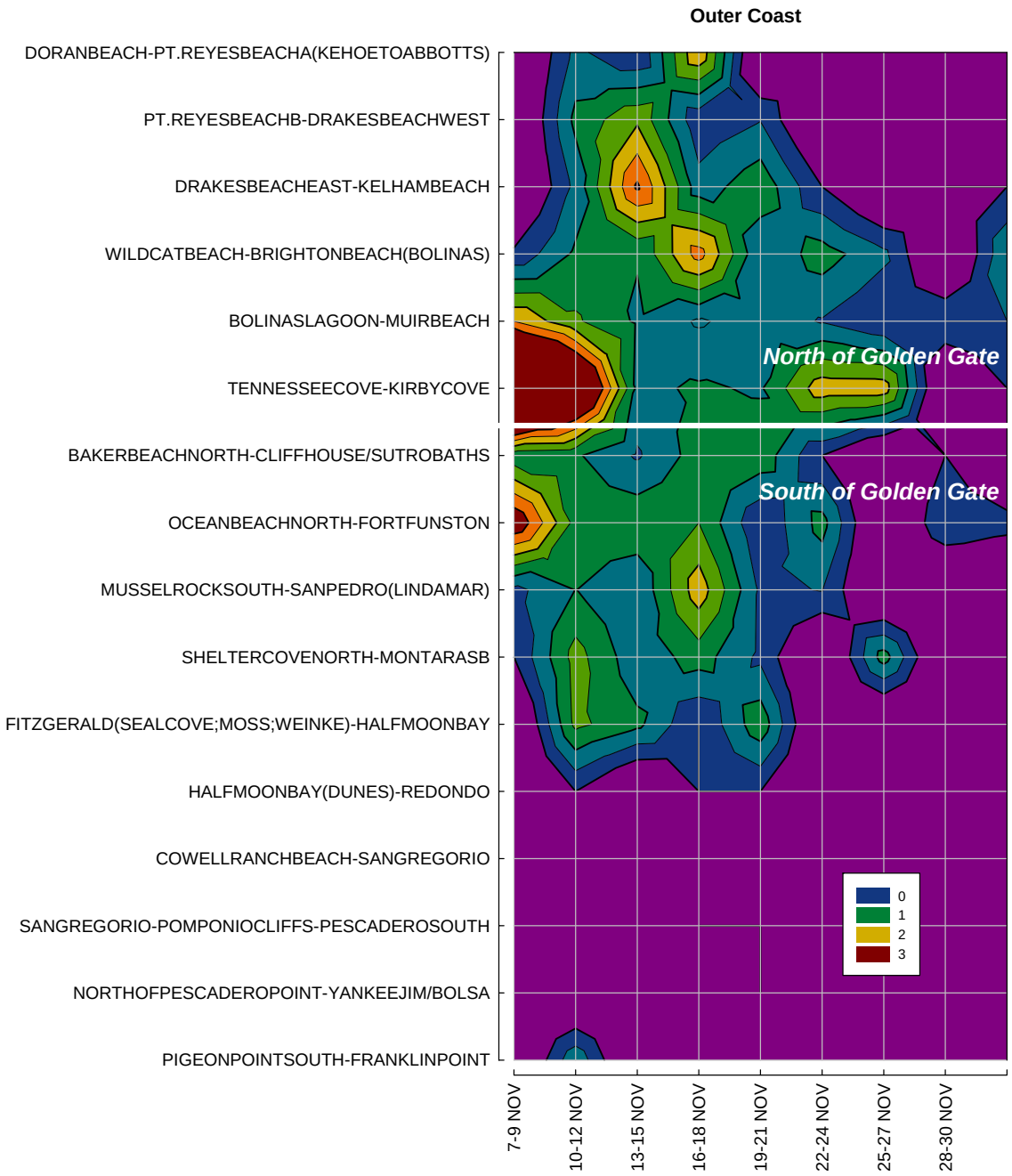

Figure 6 Number of birds recovered per km of search on the outer coast following the *Cosco Busan* oil spill. The horizontal axis is date, the vertical axis is location. Segments are ordered in a north to south sequence, with the mouth of San Francisco Bay indicated by the dashed white line. Contours 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**

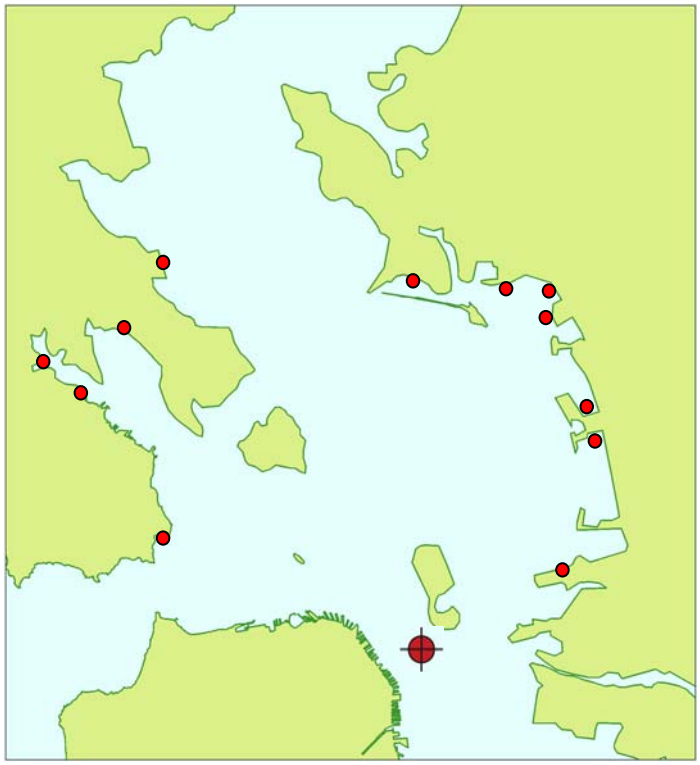

Figure 7. Approximate location of shoreline segments used for searcher efficiency study. Quartered circle is spill site.

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

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

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

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

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

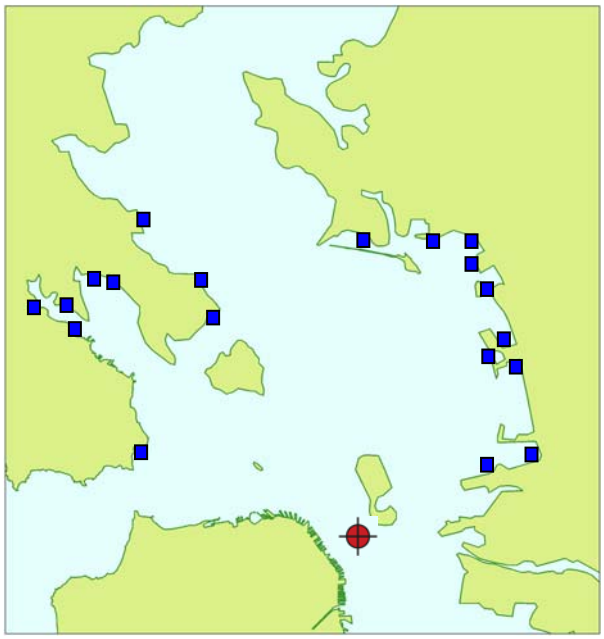

Figure 8. Approximate location of shoreline segments used for San Francisco Bay persistence study. Quartered circle is spill site.

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

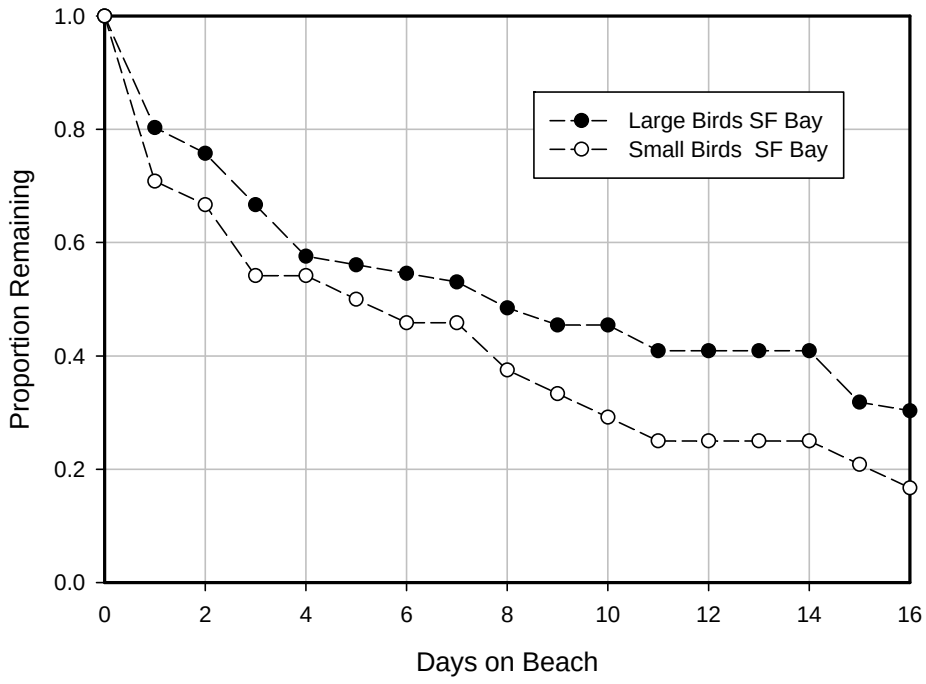

Figure 9. The proportion of carcasses that searchers during the spill response would have recovered as a function of the number of days since the carcasses were placed. Open circles indicate results for small carcasses (≤500 g), and solid circles indicate results for large carcasses (>500 g). Data are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

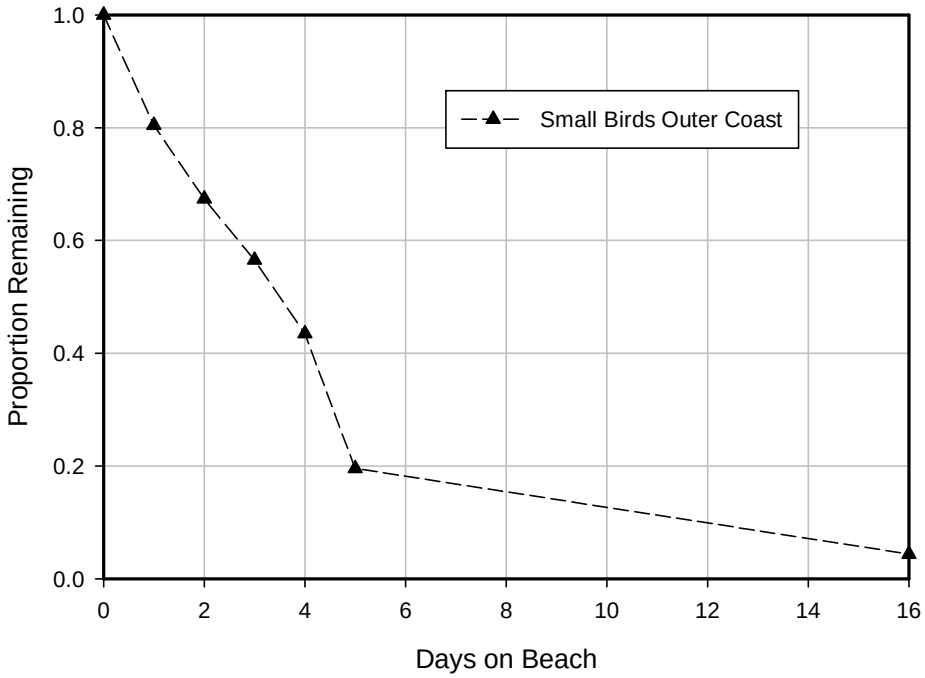

Figure 13. The proportion of carcasses that searchers during the spill response would have recovered as a function of the number of days since the carcasses were placed on beaches on the outer coast. Solid triangles indicate results for small carcasses (≤500 g).

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	Distance (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 $1-F_k$ 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

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

and (4) becomes:

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

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*:

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

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^*:

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

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**

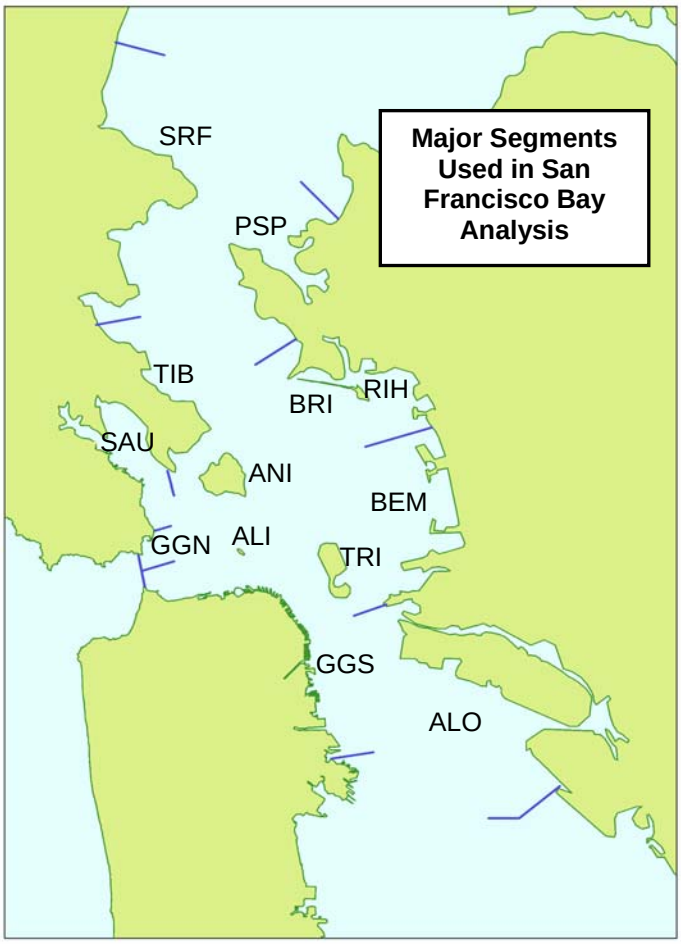

Figure 11. Locations of the 13 major segments in San Francisco Bay where the BBM was used to estimate carcass deposition rate.

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 Segments	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
TOTAL		**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.

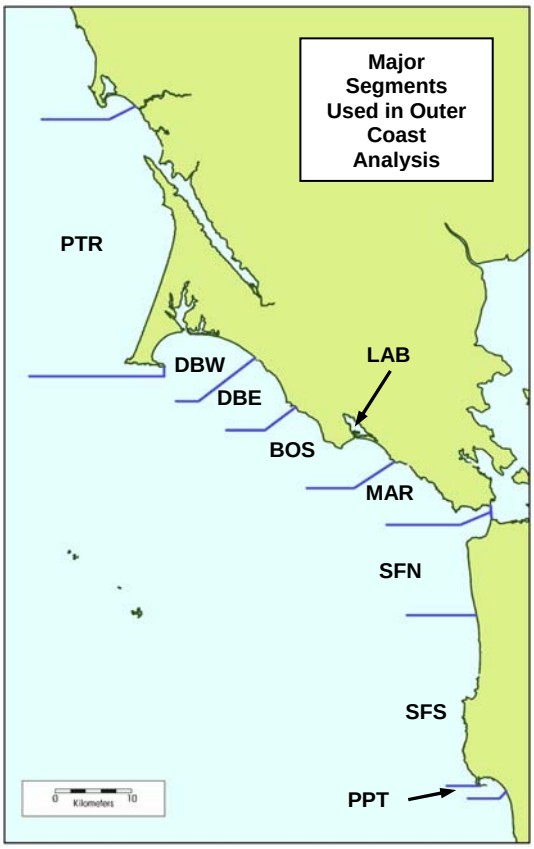

Figure 12. Locations of the 9 major segments on the outer coast where the BBM was used to estimate carcass deposition rate.

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:

$$e_n = 1 - p_1 ** n$$

Where 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 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**

References Cited:

BeachWatch. 2006. Annual Report . Gulf of the Farallones National Marine Sanctuary.

Briggs, K.T., W.B. Tyler, and D.B. Lewis.. 1985. Aerial surveys for seabirds: methodological experiments. *Journal of Wildlife Management* 49: 412–417.

Carter, H.W. and G.W. Page. 1989. Central California Oilspill Contingency Plan: Assessment of Numbers and Species Composition of Dead Beached Birds. NOAA Technical Memorandum 25. Prepared for Gulf of the Farallones National Marine Sanctuary.

Carter, H.R. and R.T. Golightly, editors. 2003. Seabird injuries from the 1997-1998 Point Reyes Tarball Incidents. Unpublished report., Humboldt State University, Department of Wildlife, Arcata, California. 215 pp.

Campbell, L.H., K.T. Standring and C.J. Cadbury. 1978. Firth of Forth Oil Pollution Incident, February 1978. Marine Pollution Bulletin 9: 335-339.

CDFG 2004. Spills and Events Natural Resource Damage Assessment and Restoration (NRDA) Estimating Bird Mortality Available at: http://www.dfg.ca.gov/ospr/spill/nrda/beachbirds3.html

Dobbin, J.A., H.E. Robertson, R.G. Ford, K.T. Briggs and E.H. Clark, II. 1986. Resource damage assessment of the *T/V Puerto Rican* oil spill incident. Unpublished report, James Dobbin Associates, Inc., Alexandria, Virginia.

Ford, R.G., J.L. Casey, D.B. Hewitt, D.H. Varoujean, D.R. Warrick, and W.A. Williams. 1991. Seabird mortality resulting from the *Nestucca* oil spill incident, winter 1988-89. Report for Washington Department of Wildlife. Ecological Consulting Inc., Portland, OR.

Ford, R.G., M.L. Bonnell, D.H. Varoujean, G.W. Page, H.R. Carter, B.E. Sharp, D. Heinemann, and J.L. Casey. 1996. Total direct mortality of seabirds from the *Exxon Valdez* oil spill. Pages 684–711 *in* S.D. Rice, R.B. Spies, D.A. Wolfe, and B.A. Wright, editors. Proceedings of the Exxon Valdez Oil Spill Symposium. American Fisheries Society Symposium 18.

Ford, R.G. and M.L. Bonnell. 1998. Preliminary bird injury assessment for the Torch/Platform Irene Pipeline Oil Spill, September 1997. Unpublished report for California Department of Fish and Game Office of Spill Prevention and Response. 21 pp. plus Appendices.

Ford, R.G., G.K. Himes Boor, and J.C. Ward. 2001. Seabird mortality resulting from the *New Carissa* oil spill incident of February and March 1999. Unpublished report, R.G. Ford Consulting Company, Portland, Oregon.

Ford, R.G., G.K. Himes Boor, B.E. Sharp, and J.L. Casey. 2002. Estimates of bird impacts resulting from the *M/V Kure*/Humboldt Bay Oil Spill of November 5, 1997. Unpublished report prepared for California Department of Fish and Game Office of Spill Prevention and Response. 71pp.

Ford, R.G. 2004. dLOG2: data entry and real-time mapping program. Software and documentation for integration of GPS location and observer data. Portland, OR: RG Ford Consulting Company.

Ford, R.G., N.A. Strom, and J.L. Casey. 2006. Acute seabird mortality resulting from the *S. S. Luckenbach* and associated mystery oil spills, 1990-2003. Final Report to CDFG. 46 pp.

Ford, R.G. and N.A. Strom. 2006. Assessment of bird impacts resulting from the *M/V Tristan* Oil Spill of August 8, 2001. Unpublished report for U.S. Fish and Wildlife Service. 18 pp.

Ford, R.G.and M.A. Zafonte. In press. Scavenging of seabird carcasses at two oil spill sites in California and Oregon. Marine Ornithology.

Henkel, L.A., R.G. Ford, W.B. Tyler, and J.N. Davis. 2007. Comparison of aerial at at-sea survey methods for Marbled Murrelets and other marine birds. Marine Ornithology 35(2): 145-151.

Kure Trustee Council. 2008. Kure/*Humboldt Bay Oil Spill Final Damage Assessment and Restoration Plan/Environmental Assessment.* Prepared by California Department of Fish and Game and United States Fish and Wildlife Service.

Luckenbach Trustee Council. 2006. S.S. Jacob Luckenbach *and Associated Mystery Oil Spills Final Damage Assessment and Restoration Plan/Environmental Assessment.* Prepared by California Department of Fish and Game, National Oceanic and Atmospheric Administration, United States Fish and Wildlife Service, National Park Service.

Page, G.W., H.R. Carter, and R.G. Ford. 1990. Numbers of seabirds killed or debilitated in the1986 *Apex Houston* oil spill in central California. Pages 164–174 *in* S.G. Sealy, editor.Auks at Sea. Studies in Avian Biology 14.

Petersen, J., J. Michel, S. Zengel, M. White, C. Lord, and C Plank. 2002. Environmental Sensitivity Index Guidelines., Version 3.0. NOAA Tehcnical Memorandum NOS OR&R 11. 89 pp. plus Appendices.

SS Cape Mohican Trustee Council. 2002. Final SS Cape Mohican Oil Spill Restoration Plan and Environmental Assessment. Prepared by the National Park Service, United States Fish and Wildlife Service, National Oceanic and Atmospheric Administration,

California Department of Fish and Game, and the California Department of Parks and Recreation. Available at http://www.darrp.noaa.gov/southwest/cape/pdf/moh-frp1.pdf.

Stuyvesant Trustee Council. 2007. Stuyvesant/*Humboldt Coast Oil Spill Final Damage Assessment and Restoration Plan/Environmental Assessment.* Prepared by California Department of Fish, California State Lands Commission, and Game and United States Fish and Wildlife Service.