FINAL REPORT

Acute seabird mortality resulting from the *S. S. Luckenbach* and associated mystery oil spills, 1990-2003

Prepared for:

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

By:

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1.0 Introduction

On 16 November 1997, tarballs and oiled seabirds began washing ashore on beaches of Point Reyes National Seashore in Marin County, California, and continued episodically until March, 1998. While most oiled birds and tarballs were found in the vicinity of Point Reyes National Seashore, some were recovered from north of Bodega Head in Sonoma County and as far south as Point Lobos in Monterey County. No vessel reported an offshore oil spill during this period, no major accident was identified, and no responsible party was found. The spill represented one of the most extensive "mystery spills" documented in California, and is now referred to as the "Point Reyes Tarball Incidents" (PRTI) (Carter and Golightly 2003).

The majority of the oil sampled during the PRTI has since been traced to the *S.S. Jacob Luckenbach*, a vessel that sank in the Gulf of the Farallones on 14 July 1953 while en route to Korea. Loaded with 457,000 gallons of bunker fuel, the vessel sank in 55 m of water approximately 27 km west-southwest of San Francisco, and is suspected of having leaked oil since at least 1973, primarily after strong winter storms (Hampton *et al.* 2003).

The effects of this leakage on seabird populations in the Gulf of the Farallones was analyzed in Carter and Golightly (2003) which focused on the PRTI incident, from November 1997 through March 1998. Beginning again in the winter of 2001-2002 and recurring through the winter of 2002-2003, oiled seabirds continued to be recovered in large numbers in an arc extending from the Pt. Reyes Peninsula to Monterey Bay. Analysis of oil samples taken from the plumage of seabirds recovered during this period indicated that the source of the oiling continued to be the wreck of the *S.S. Jacob Luckenbach* (Hampton *et al*. 2003).

In September of 2002, the Coast Guard's Marine Safety Office San Francisco Bay, the California Department of Fish and Game's Office of Spill Prevention and Response (OSPR) and Titan Maritime LLC, completed a large-scale oil removal project in which over 100,000 gallons of fuel oil were removed from the wreck. There remains approximately 85,000 gallons that could not be reached during the lightering operation, and this oil may be released in the future as the wreck continues to deteriorate. Nonetheless, the lightering operation appears to have successfully reduced seabird mortality, and oiling incidents on the scale of the PRTI and the winter of 2001-2002 have not yet recurred.

The purpose of this report is to estimate the total injury to seabirds that has occurred between the signing of the *The Oil Pollution Act* in August, 1990, and the last significant oiling incident which occurred in the winter of 2002-2003. This report therefore includes estimates of seabird damages resulting from the PRTI as well as other related incidents. We have collected site specific data on the persistence of beached birds in the Gulf of the Farallones, and extended the time frame of our modeling efforts to include all major *Luckenbach* related incidents since August, 1990. We have also reanalyzed data from the PRTI using the new site-specific persistence data.

2.0 Sources of Beached Bird and Search Effort Data

Since these events span a period of 13 years, there has been considerable variation in data collection protocols, level of effort, and response agencies. Our analyses are therefore event specific, requiring different approaches to mortality estimation for each incident. Table 1 lists the periods during which seabird mortality related to the *S.S. Jacob Luckenbach* is believed to have occurred and the primary sources of beached bird data for each period.

Table 1. Seabird mortality incidents and data sources used in estimating mortality.

Period	Years	Season	Data Sources
1	1990-1991	Winter	Live birds found by public (Hampton et al. 2003)
2	1992-1993	Winter / Spring	Oiled bird observations on SE Farallon Is (Nur et al. 1997)
3	1993-1997	Chronic	Beach Watch database (GFNMS 2004)
4	1997-1998	Winter (PRTI)	Beach Watch database (GFNMS 2001) Incident Database Beachcombers database (MBNMS 2004)
5	1998-2001	Chronic	Beach Watch database (GFNMS 2004)
6	2001-2003	Episodic	California Department of Fish and Game -Office of Spill Prevention and Response

In order to define background deposition rates, bird recoveries and associated search effort for non-incident years were derived from GFNMS Beach Watch records from 1993 through 1999, excluding the 1997-1998 PRTI data. Only data from November through February were examined for comparison, as most oiling incidents occurred in winter. Each GFNMS Beach Watch beach segment was surveyed every 2 to 4 weeks. During each survey, surveyors recorded the locations and states of each bird carcass found within the segment, as well as presence and level of oiling. Because each survey was well documented, search effort expended along each segment was known for all birds recorded during non-incident years.

2.1 Period 1: Oil Spill Incident of Winter 1990-91

During this period, 195 live oiled seabirds were retrieved from area beaches by members of the public (Hampton *et al.* 2003). While this episode is poorly documented, these birds likely represented substantial mortality.

2.2 Period 2: Farallones Episodes, Winter 1992 and Spring 1993

Data for these episodes were derived from the Farallon Oiled Bird Survey as summarized by Nur et al. (1997). Farallon Island biologists surveyed the island daily and noted all oiled live and dead birds on shore and near shore on the water. Daily meetings among biologists to discuss observations of oiled seabirds served to minimize duplication of records.

2.3 Period 3: Chronic Oiling, October 1993 – October 1997

Data for this period were taken from the Beach Watch database (GFNMS 2004).

Beginning with October 1993 when systematic Beach Watch surveys began, but before November 1, 1997 (the beginning of the Point Reyes Tarball Incident), 3,770 beachcast birds were reported on regular Beach Watch surveys. Of these birds, 73 were scored as oiled. Oil samples taken from 15 of these birds were examined in order to determine whether the source of oiling was the *Luckenbach*. Four birds (26.7 %) were contaminated with *Luckenbach* oil. Species composition and location of oiled birds are summarized in Table 2.

Table 2. Birds recorded as oiled in the Beach Watch database, October 1993 through October 1997, in the Pt. Reyes and San Mateo sectors. No birds were collected from the Monterey Bay sector. Oil from a subset of these birds was subjected to laboratory tests to determine the origin of the oil.

Species Group	Pt. Reyes Sector	San Mateo Sector	TOTAL
Common Murre	31	14	45
Procellarids	5	1	6
Grebes	3	3	6
Cormorants	0	1	1
Loons	2	1	3
Waterfowl	0	1	1
Gulls	4	3	7
Rhinoceros Auklet	0	1	1
Other Alcids	1	0	1
Shorebirds	1	1	2
All Species Combined	**47**	**26**	**73**

2.4 Period 4: Point Reyes Tarball Incident – November 1997 – March 1998

The Point Reyes Tarballs Incident (PRTI) was comprehensively analyzed by a number of agencies and researchers, culminating in a report edited by Carter and Golightly (2003). Because oil from this incident is now known to be largely from the same source as the later incidents, these data are included as part of this damage assessment for leakage from the *S.S. Jacob Luckenbach*. Data for this period are described fully in Carter and Golightly (2003) and are summarized here.

2.4.1 Beach Segments and Search Effort

Standard beach segments established prior to the PRTI for the Central California Oil Spill Contingency Plan and GFNMS Beach Watch program were monitored before, during, and after the PRTI (Carter and Page 1989, Roletto 2000). Beach segments were grouped into regions representing generally comparable portions of coastline (Figure 1). Whenever possible, dead birds were assigned to beach segments based on collection location. Likewise, search effort was categorized based on the beach segment where dead birds were recovered. However, search effort on beach segments where only live birds were recovered was not recorded. Of 2,959 birds, only 1,362 birds could be associated an estimated 955 km of beach search effort. These data were used as inputs to the Beached Bird Model which was used to estimate how many birds were beached but not recovered during this period.

2.4.2 Live and Dead Birds Collected

A master bird database, compiled from incident-response records, was used as input to the Beached Bird Model (Carter & Golightly 2003). Several errors in the master database were noted in the original report, including counts of incorrect or missing locational data. These were corrected and included in Appendix C, but estimates of bird mortality were not revised at that time. The revised master bird database (Appendix C of the PRTI report and presented here in Table 3) was used for the present analysis.

In the original PRTI analysis, birds collected in Monterey Bay were assigned to beach segments north of the bay due to insufficient information at the time. Therefore Carter and Golightly (2003) attribute no bird damages to the Monterey Bay sector. In this analysis, those birds now known to have been collected in Monterey Bay are now included. Effort data from the original PRTI analysis ended at February 28, 1998 and were not updated. Birds collected during March 1998 were not included in model runs but were addressed separately.

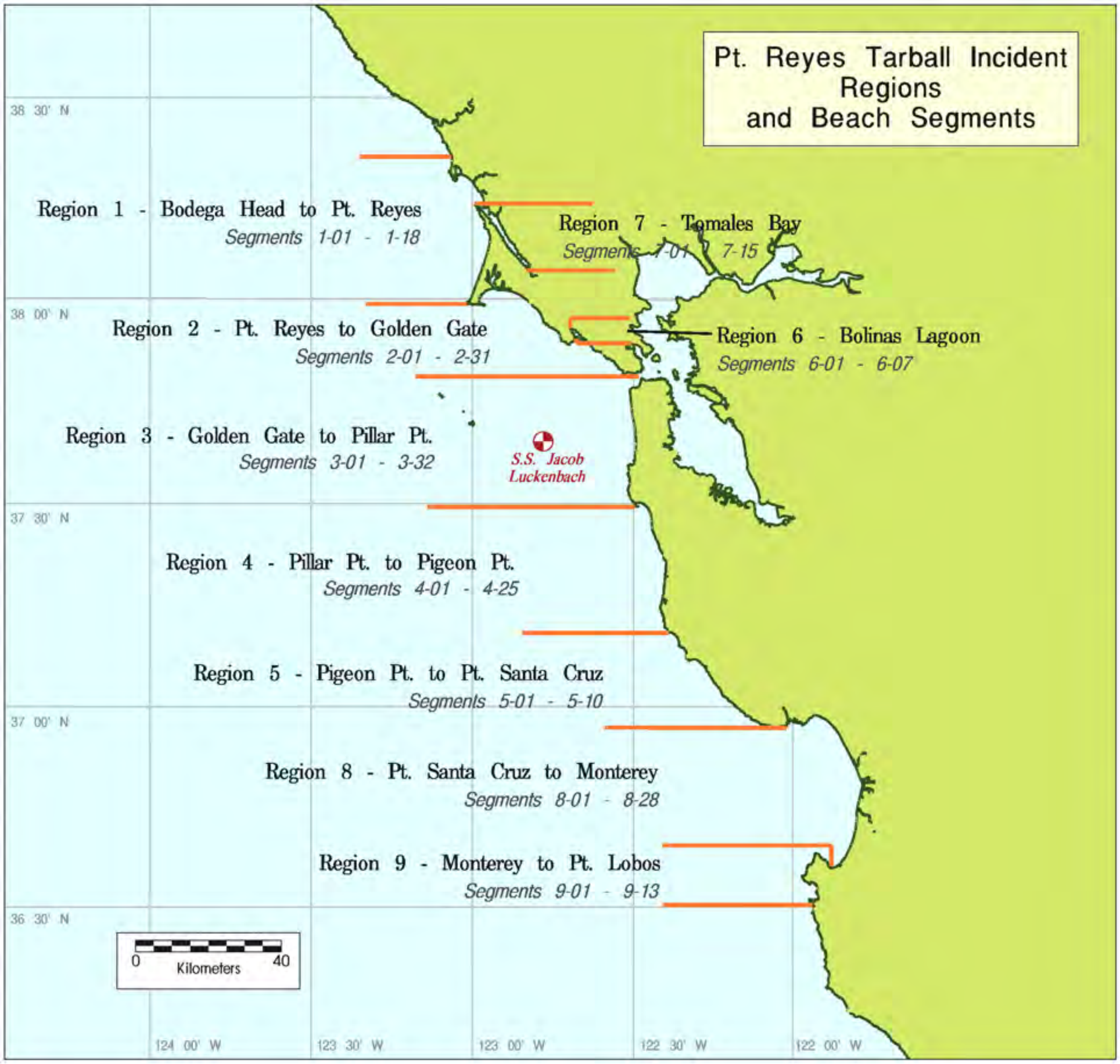
For consistency with incidents during later years, assignments of PRTI birds into species group categories were also updated. Birds were placed into the following groups for the present analysis: Common Murre, Grebes, Procellarids (Northern Fulmars, Shearwaters), Cormorants, Loons, Gulls, Phalaropes, Brown Pelicans, Cassin's Auklet, Rhinoceros Auklet, Ancient Murrelet, Marbled Murrelet, Other Alcids (Pigeon Guillemot, unidentified alcid), and unidentified seabird species.

Table 3. Total number and oiling status of birds captured or recorded as dead in each species group during the PRTI. From Carter and Golightly (2003).

Species Group / Species	Oiled	Not Visibly Oiled	Unknown Oiling	Other*	Total Number Recorded/Collected
Alcids					
Cassin's Auklet	12	8	3		23
Rhinoceros Auklet	6	1			7
Pigeon Guillemot		2	1		3
Common Murre	1,667	154	36	1	1,858
Ancient Murrelet	2	4			6
Marbled Murrelet	2	1			3
Horned Puffin		1			1
Unidentified Alcid	1				1
Total	**1,612**	**169**	**122**	**1**	**1,902**
Coots					
American Coot		4			4
Total		**4**			**4**
Fulmars, Petrels, Shearwaters					
Northern Fulmar	68	260	7		335
Leach's Storm-Petrel			1		1
Black-vented Shearwater	3				3
Pink-footed Shearwater	1				1
Sooty Shearwater	1	2			3
Short-tailed Shearwater	3	4			7
Unidentified Shearwater	3				3
Total	**79**	**266**	**8**		**353**
Gulls					
Black-legged Kittiwake	7	5			12
Bonaparte's Gull	1				1
California Gull		4	1		5
Glaucous Gull		2			2
Glaucous-winged Gull		8			8
Heermann's Gull	13	2			15
Herring Gull	1	3			4
Mew Gull	1				1
Ring-billed Gull		2			2
Unidentified Gull	1	7	3		11
Western Gull	8	24	2	4	38
Total	**32**	**57**	**6**	**4**	**99**
Land Birds					
Bushtit	2	1			3
Rock Dove		3			3
Total	**2**	**4**			**6**

Species Group / Species	Oiled	Not Visibly Oiled	Unknown Oiling	Other	Total Number Recorded/Collected
Loons & Grebes					
Common Loon	6	7	1		14
Pacific Loon	35	19			54
Red-throated Loon	7	4			11
Unidentified Loon	1	1			2
Clark's Grebe	3	6			9
Eared Grebe	8	5			13
Horned Grebe	3	12	1		16
Pied-billed Grebe	1	2			3
Red-necked Grebe	1	2			3
Unidentified Grebe	2	10			12
Unid Grebe (West. or Clark's)	12	23	5		40
Western Grebe	90	46	6		142
Total	**170**	**136**	**13**		**319**
Pelicans & Cormorants					
Brown Pelican	9	8	2	2	21
Brandt's Cormorant	3	51	6		60
Double-crested Cormorant		1	2		3
Pelagic Cormorant		11	1		12
Unidentified Cormorant	1	1			2
Total	**13**	**72**	**11**	**2**	**98**
Shorebirds					
Red Phalarope	24	10		1	35
Red-necked Phalarope		1			1
Total	**24**	**11**		**1**	**36**
Unidentified Birds					
Unidentified Water Birds	7	7	1		15
Total	**7**	**7**	**1**		**15**
Waterfowl					
Brant		1			1
Bufflehead		5			5
Ruddy Duck		1			1
Unidentified Duck	1		1		2
Greater Scaup		1			1
Black Scoter		1			1
Surf Scoter	5	77	8		90
Unidentified Scoter	1	3			4
White-winged Scoter	1	20	1		22
Total	**8**	**109**	**13**		**127**
Grand Total	**2,025**	**837**	**89**	**8**	**2,959**

Figure 1. Beach segments and regions used in data analyses for Gulf of the Farallones National Marine Sanctuary Beach Watch and Point Reyes Tarball Incident



All birds were categorized as large or small birds so that the size classes could be modeled separately. To standardize size classes with other incidents, some species were recategorized, including Rhinoceros Auklet, Horned Grebe, Eared Grebe, Bonaparte's Gull, Mew Gull, Heerman's Gull, Pigeon Guillemot, and Black-legged Kittiwake.

A total of 2,959 birds were recovered between 1 November 1997 and 6 March 1998 from Goat Rock, Sonoma County to Point Lobos, Monterey County (Table 3). Live birds accounted for 967 (33%) of the total, of which 382 birds were cleaned, rehabilitated and released, and 585 died or were euthanized in captivity. Of 2,870 birds which could be assessed for oiling, 2025 (71%) were oiled. An additional 89 birds had unknown oiling status. Eight birds showed signs of having died of an obvious physical injury other than oil, such as fishing line or a broken wing. The remaining 837 birds were not visibly oiled.

Common Murres comprised 98% of the alcids and 63% (1,858) of the total number of birds recovered. Northern Fulmars, the second most common species, were found in much lower numbers, accounting for only 335 birds. A total of 191 Western or Clark's Grebes were recovered. No other single species numbered more than 100, although three species numbered greater than 50: 90 Surf Scoters, 60 Brandt's Cormorants, and 54 Pacific Loons. Smaller numbers of two endangered or threatened species were also recovered: 21 Brown Pelicans (Carter and Golightly 2003, Appendix E) and 3 Marbled Murrelets (Carter and Golightly 2003, Appendix C).

2.5 Period 5: Chronic Oiling, March 1998 – October 2001

Subsequent to the Point Reyes Tarball Incident (see above) and before November 2001, 5,278 beachcast birds were reported between Bodega Head and Point Año Nuevo on regular Beach Watch surveys (Roletto et al. 2003). Of these birds, 94 were scored as oiled. Oil samples taken from 42 of these birds were later typed in order to determine whether the source of oiling was the *Luckenbach*. Of 38 birds for which a match was attempted, 19 (50%) were contaminated with *Luckenbach* oil. Species composition and location of oiled birds are summarized in Table 4.

Table 4. Birds recorded as oiled in the Beach Watch database (2004), March 1998 through October 2001, in two major model sectors. Oil from a subset of these birds was subjected to laboratory tests to determine the origin of the oil.

Taxa	Pt. Reyes Sector	San Mateo Sector	TOTAL
Common Murre	27	15	42
Procellarids	10	3	13
Grebes	6	0	6
Cormorants	3	4	7
Loons	4	6	10
Waterfowl	1	0	1
Gulls	3	3	6
Brown Pelican	1	0	1
Cassin's Auklet	2	1	3
Rhinoceros Auklet	2	1	3
Other Alcids	1	0	1
Other/ Un-ID Species	1	0	1
All Species Combined	**61**	**33**	**94**

2.6 Period 6: Oil Spill Incidents, November 2001 – January 2003

In late November 2001, oiled seabirds again began washing ashore along central California beaches in large numbers. An extensive agency and public response effort to this "San Mateo mystery spill" episode followed, resulting in the collection of nearly 2,000 live and dead birds. Oil samples collected at this time were matched to *S.S. Luckenbach* oil in January 2002, and (as noted above) oil analysis indicated that many previous bird oiling incidents were linked to *Luckenbach* oil (Hampton et al. 2003). During oil removal operations in the summer of 2002 , several small releases resulted in over 200 oiled birds collected on shore. After strong winter storms in 2002, a further several hundred birds were collected. Using data compiled and organized by CDFG-OSPR on search effort and collected birds, we created a composite database representing these three episodes. These data were used to model the total seabird mortality resulting from oil releases in the period from November 2001 through January 2003.

2.6.1 Beach Segments and Search Effort

All search effort and bird collection data were partitioned into 176 beach segments within an area extending from Salmon Creek in the north to Monterey in the south. The beach segmentation scheme used in this response was similar to that used by the Beach Watch program, but was extended farther to the south. Some segments considered inaccessible for this analysis may have limited access but were not searched during the response. Beach lengths were calculated by CDFR-OSPR from GPS coordinates. Locations of beach segments used in this analysis are shown in Figure 2.

Data on beach search effort were compiled by CDFG-OSPR and included searches by both trustee agencies and wildlife rehabilitation personnel. In all, 2,393 beach searches were recorded for winter 2001-2002; 505 for summer 2002, and 25 for winter 2002-2003. Search effort was expressed as miles of shoreline searched, and the maximum daily search effort was assumed to be the total segment length. Beach searches covering several segments were converted into multiple single-segment records. If more than one team searched a particular segment on a given day, search effort was combined as follows:

- If any search was of the entire segment, that value was used.
- If there were multiple searches of a segment but no search was of the entire segment, search lengths were summed to a maximum of the total segment length.
- If no search was of the entire segment, and notes indicated searches followed the same path, the longest recorded search length was used.

For analysis, beach segments were grouped into major segment groups within which deposition rates were assumed to be similar. Because beach persistence differed north and south of the Golden Gate, major segments were further grouped into Pt. Reyes, San Mateo, and Monterey Bay sectors. Table 5 summarizes beach search effort as used in the Beached Bird Model.

Figure 2. Beach segments and regions used in data analyses for *Luckenbach* oiling events, 2001-2003.

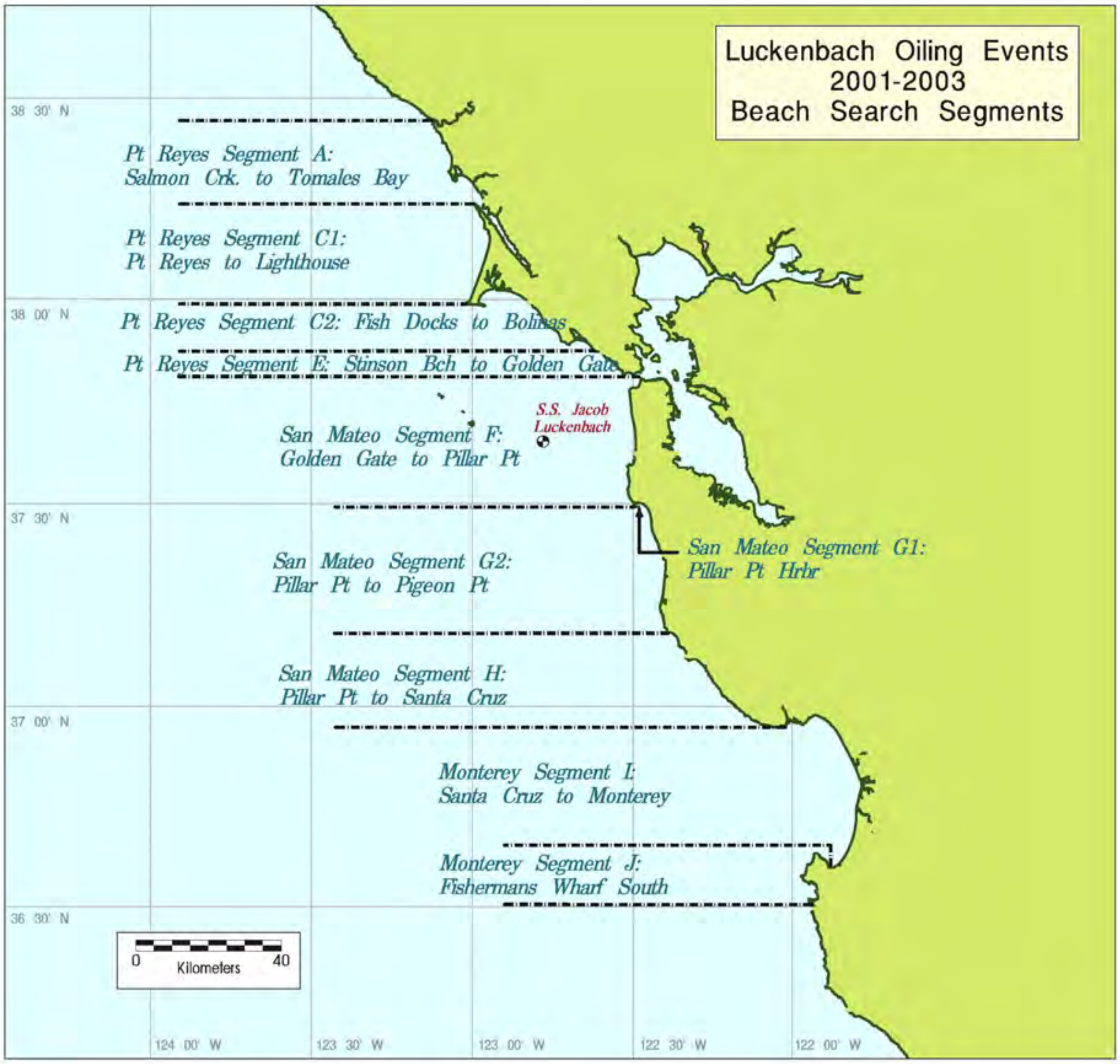


Table 5. Beach search effort in 2001-2003, as standardized for use in the beached bird model.

Major Segment	Description	Number of Minor Segments	Number of Minor Segments Searched	Total Segment Search Days	Total Major Segment Length	Total Miles of Search
A	Salmon Creek to Tomales Bay	10	5	12	20.4	17.6
C1	Pt. Reyes to Lighthouse	8	5	40	19.0	58.1
C2	Fish Docks to Bolinas	13	6	46	28.1	78.2
E	Stinson Beach to Golden Gate	18	2	9	16.7	11.8
Subtotal	*Point Reyes Sector*	*49*	*18*	*107*	*84.2*	*165.7*
F	Golden Gate to Pillar Point	32	19	483	26.3	363.4
G1	Pillar Point Harbor	1	1	84	2.0	127.1
G2	Pillar Point to Pigeon Point	28	23	857	24.6	513.3
H	Pigeon Point to Santa Cruz	34	22	448	30.4	240.0
Subtotal	*San Mateo Sector*	*95*	*65*	*1872*	*83.3*	*1243.8*
I	Santa Cruz to Monterey	21	19	847	39.8	1723.5
J	Fisherman's Wharf South	11	8	97	16.1	120.4
Subtotal	*Monterey Bay Sector*	*32*	*27*	*944*	*55.9*	*1843.9*
TOTAL		**176**	**110**	**2923**	**223.4**	**3253.4**

2.6.2 Live and Dead Birds Collected

All bird collection data between 2001 and 2003, including data for birds collected by response agency personnel, Farallon Islands researchers, and members of the general public, were compiled by CDFG-OSPR. In total, 762 live and 1,169 dead birds are recorded for the winter 2001-2002, 64 live and 180 dead for summer 2002, and 278 live and 293 dead for winter 2002-2003. Birds collected by agency personnel were matched to search effort records for the appropriate date and segment. Birds collected by members of the public were matched to the next available search of the collection location. While most birds were collected from the beaches, some were picked up in the water and in locations beyond the geographic scope of the beached bird model. Table 6 summarizes the live and dead birds collected by location and source (agencies, researchers, and the public). Table 7 summarizes live and dead birds by episode and species or species group.

Table 6. Live and dead birds collected during *Luckenbach* oiling episodes, 2001-2003, by geographic location and source. Data were compiled from CDFG-OSPR records.

Major Segment	Description	Live Birds				Dead Birds				TOTAL BIRDS
		Response Agencies	Public	Researchers	Total Live	Response Agencies	Public	Researchers	Total Dead	
A	Salmon Creek to Tomales Bay	0	8	0	8	21	2	0	23	31
C1	Pt. Reyes to Lighthouse	3	4	0	7	31	4	0	35	42
C2	Fish Docks to Bolinas	23	16	0	39	83	18	0	101	140
E	Stinson Beach to Golden Gate	4	16	0	20	16	26	0	42	62
Subtotal - Pt. Reyes Sector		*30*	*44*	*0*	*74*	*151*	*50*	*0*	*201*	*275*
F	Golden Gate to Pillar Point	*55*	84	0	139	200	14	0	214	353
G1	Pillar Point Harbor	99	28	0	127	90	11	0	101	228
G2	Pillar Point to Pigeon Point	56	55	0	111	236	18	0	254	365
H	Pigeon Point to Santa Cruz	27	63	0	90	138	26	0	164	254
Subtotal - San Mateo Sector		*237*	*230*	*0*	*467*	*664*	*69*	*0*	*733*	*1200*
I	Santa Cruz to Monterey	100	152	0	252	583	34	0	617	869
J	Fisherman's Wharf South	39	75	0	114	20	12	0	32	146
Subtotal - Monterey Bay Sector		*139*	*227*	*0*	*366*	*603*	*46*	*0*	*649*	*1015*
Water	Collected by boat	138	1	0	139	*25*	*0*	0	*25*	*164*
Out of Area	Mostly San Francisco Bay	0	15	0	15	*0*	*7*	0	*7*	*22*
FI	Farallon Islands	0	0	33	33	*0*	*0*	20	*20*	*53*
Unk.	No location given	0	11	0	11	*0*	*6*	0	*6*	*17*
Total	**All Locations Combined**	**544**	**528**	**33**	**1105**	**1443**	**178**	**20**	**1641**	**2746**

Table 7. Live and dead birds collected during *Luckenbach* oiling episodes, 2001-2003, by episode and species. Data were compiled from CDFG-OSPR records.

	Winter 2001-2002			*Summer 2002*			*Winter 2002-2003*			
SPECIES	**Live**	**Dead**	**All**	**Live**	**Dead**	**All**	**Live**	**Dead**	**All**	**TOTALS**
Loons and Grebes										
Common Loon	3	2	5	0	0	0	0	1	1	6
Pacific Loon	17	27	44	0	1	1	1	10	11	56
Red-throated Loon	2	3	5	0	1	1	0	0	0	6
Loon sp.	0	1	1	0	0	0	0	0	0	10
Western Grebe	14	60	74	1	0	1	103	31	134	209
Clark's Grebe	0	3	3	0	0	0	9	1	10	13
Western or Clark's Grebe	0	13	13	0	0	0	0	8	8	21
Eared Grebe	1	1	2	0	0	0	0	0	0	2
Grebe sp.	0	2	2	0	0	0	0	0	0	2
Subtotal	*37*	*112*	*149*	*1*	*2*	*3*	*113*	*51*	*164*	*316*
Procellarids										
Ashy Storm-Petrel	0	1	1	0	1	1	0	0	0	2
Sooty Shearwater	0	2	2	0	3	3	0	0	0	5
Northern Fulmar	0	5	5	0	1	1	1	10	11	17
Subtotal	*0*	*8*	*8*	*0*	*5*	*5*	*1*	*10*	*11*	*24*
Pelicans and Cormorants										
Brown Pelican	1	8	9	5	4	9	1	1	2	20
Double-crested Cormorant	0	3	3	0	0	0	0	0	0	3
Brandt's Cormorant	0	34	34	0	5	5	0	36	36	75
Pelagic Cormorant	0	3	3	0	0	0	0	2	2	5
Cormorant sp.	0	1	1	0	0	0	0	0	0	1
Subtotal	*1*	*49*	*50*	*5*	*9*	*14*	*1*	*39*	*40*	*104*
Waterfowl										
Bufflehead	0	1	1	0	0	0	0	0	0	1
Lesser Scaup	0	1	1	0	0	0	0	0	0	1
Surf Scoter	1	5	6	0	0	0	0	0	3	3
Red-breasted Merganser	0	1	1	0	0	0	0	0	0	1
Ruddy Duck	1	1	2	0	0	0	0	0	0	2
Subtotal	*2*	*9*	*11*	*0*	*0*	*0*	*0*	*3*	*3*	*14*
Shorebirds										
Sanderling	0	1	1	0	0	0	0	0	0	1
Black Oystercatcher	0	0	0	0	0	0	0	1	1	1
Red-necked Phalarope	0	1	1	0	0	0	0	0	0	1
Red Phalarope	0	0	0	0	0	0	4	4	8	8
Shorebird sp.	0	2	2	0	0	0	0	0	0	2
Subtotal	*0*	*4*	*4*	*0*	*0*	*0*	*4*	*5*	*9*	*13*
Gulls										
Herring Gull	0	6	6	0	0	0	0	1	1	7
Western Gull	2	46	48	1	4	5	0	2	2	55
Glaucous-winged Gull	0	34	34	0	0	0	0	1	1	35
Western x Glaucous-winged Gull*	0	2	2	0	0	0	0	0	0	2
California Gull	0	33	33	0	0	0	1	1	2	35
Ring-billed Gull	0	2	2	0	0	0	0	1	1	3
Mew Gull	0	1	1	0	0	0	0	0	0	1
Heermann's Gull	4	1	5	0	0	0	0	0	0	5
Black-legged Kittiwake	0	3	3	0	0	0	0	0	0	3
Gull sp.	0	13	13	0	2	2	0	0	0	15
Subtotal	*6*	*141*	*147*	*1*	*6*	*7*	*1*	*6*	*7*	*161*

SPECIES	Winter 2001-2002			Summer 2002			Winter 2002-2003			TOTALS
	Live	Dead	All	Live	Dead	All	Live	Dead	All	
Alcids										
Common Murre	704	788	1492	57	151	208	158	172	330	2030
Pigeon Guillemot	0	1	1	0	6	6	0	0	0	7
Rhinoceros Auklet	9	21	30	0	0	0	0	2	2	32
Cassin's Auklet	1	8	9	0	0	0	0	4	4	13
Ancient Murrelet	1	14	15	0	0	0	0	1	1	16
Alcid sp.	0	0	0	0	1	1	0	0	0	1
Subtotal	*715*	*832*	*1547*	*57*	*158*	*215*	*158*	*179*	*337*	*2099*
Others										
Rock Dove	0	3	3	0	0	0	0	0	0	3
Falcon sp.	0	1	1	0	0	0	0	0	0	0
Burrowing Owl	0	1	1	0	0	0	0	0	0	1
Bird sp.	1	9	10	0	0	0	0	0	0	10
Subtotal	*1*	*14*	*15*	*0*	*0*	*0*	*0*	*0*	*0*	*15*
ALL SPECIES COMBINED	**762**	**1169**	**1931**	**64**	**180**	**244**	**278**	**293**	**571**	**2746**

All live and dead birds collected on beaches within the study area were used to develop an overall mortality estimate. Birds collected on the water were not subject to the processes affecting beachcast birds, and these birds were not used in model calculations but were added to the mortality estimate. Birds collected in outlying areas without systematic search effort were also treated in this way.

3.0 General Analytical Methods

We used two models to estimate the total seabird mortality that resulted from leakage from the wreck of the *Luckenbach*: a trajectory model, and the Beached Bird Model. The trajectory model was used to determine the likelihood of a carcass beaching in the Pt. Reyes sector, the San Mateo sector, or being washed out to sea. The Beached Bird Model was used to estimate the number of carcasses that were beached but were not recovered by searchers. We also carried out two field studies that provided site specific data on carcass retention for use in the Beached Bird Model.. These studies characterized the effect of scavenger activity and tidal action on the persistence of beached carcasses. Additional analyses address background carcass deposition and estimation of total deposition using long term monitoring data.

3.1 Trajectory Modeling

We used an oil spill trajectory model, OSRISK, to simulate oil and seabird carcass trajectories originating at the site of the wreck for the 1997-98 PRTI and recent 2001-2003 episodic events. OSRISK is a Geographic Information System (GIS) shell that can utilize output from a variety of hydrodynamic and wind models to drive an oil spill simulation and to analyze the resultant scenarios. For this study, it was configured to accept input based on the General NOAA Oil Modeling Environment (GNOME; see http://response.restoration.noaa.gov/index.php) using wind buoy data provided by the National Weather Service (NWS). OSRISK was originally developed under contract to the California State Lands Commission in 1992, and has been used to determine potential impacts resulting from renewal of the lease for the Unocal terminal in Carquinez Straits (Chambers 1993), the lease renewal of the Chevron Long Wharf facility at Point Richmond (Ford and Ward 1999), and for other sites around San Francisco Bay. It has also been set up for the California and Oregon coasts, and was used as the basis for estimating the risk of tanker transport between San Francisco Bay and Seattle (Chambers 1993), the risk of tanker spills to the southern sea otter (Ford 1994), and for hindcasting the impacts of the *M/V New Carissa* oil spill in Oregon (Ford et al. 2001).

For purposes of oil spill trajectory modeling, it is assumed that the movement of the oil can be approximated as the vector sum of the surface current plus some fraction of the wind speed (see for example Torgrimson 1984). For this analysis an oil spill is represented as a point moving with the surface current plus 3% of wind speed in the downwind direction. The model computes position of the simulated spill at one-hour intervals for up to two weeks, or until the spill trajectory intersects the coastline. The movement of spilled oil and the movement of dead or injured birds tend to be similar (Ford et al. 1996, Wiese and Jones 2001), and we assume that the resultant trajectories represent the movement of both birds and oil. A two-week cutoff was used because dead birds seldom float for more than about two weeks before becoming waterlogged and sinking (Ford et al. 1996).

3.1.1 Wind Data

There are three meteorological buoys in the area affected by *Luckenbach* oil, one at Bodega Bay, one off San Francisco, and one at Half Moon Bay; however, only the San Francisco Buoy 46026 (37.75º N 122.82º W) was recording consistently during the period from 1993 to 1998. Fortunately, Buoy 46026 provides results that are generally representative of the entire Gulf of the Farallones region (Marc Hodges, NOAA/HAZMAT, pers. comm.). Wind records corresponding to the PRTI event, 1997 to 1998, and the most recent incidents, 2001 to 2003, were downloaded from the NOAA National Data Buoy Center website. Archived wind records report wind speed and direction averaged over one-hour intervals during the PRTI event (1997-98) and are reported every 10 minutes during the episodic events of 2001-03. For consistency, all wind records were averaged over a one hour time interval.

3.1.2 Current Data

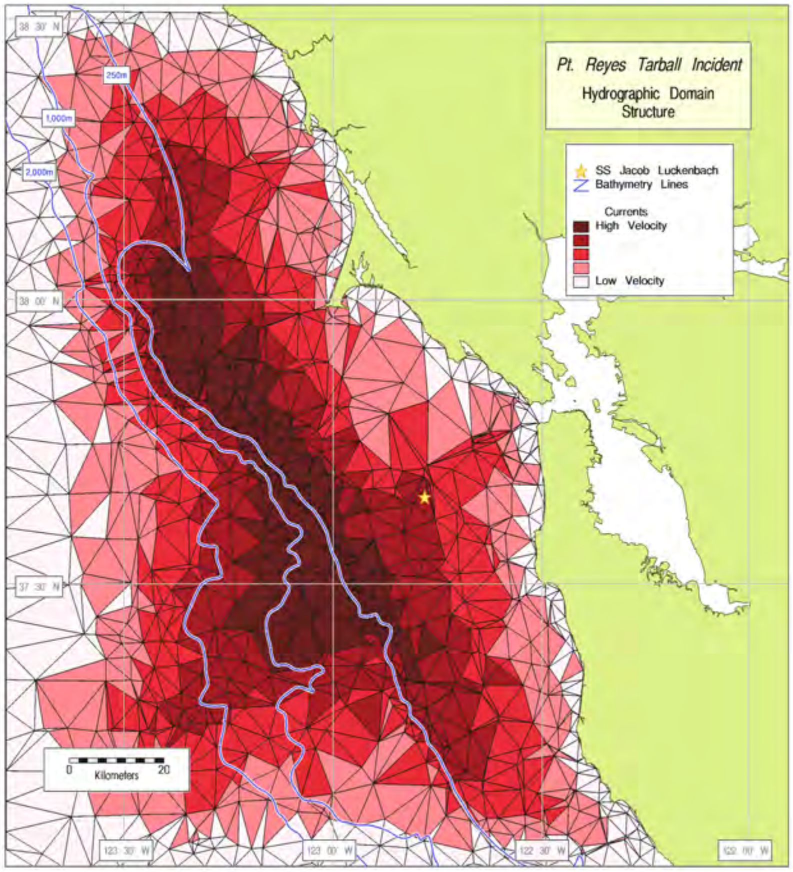
Currents in the Gulf of the Farallones are complex and can change rapidly under certain wind conditions. Although oil spill movement in this area is often wind dominated, currents are locally intense, especially in the vicinity of the continental shelf edge and the central gulf. We used a current model written by Jerry Galt (NOAA/HAZMAT retired) to simulate surface currents in the area. This model takes into account the effect of wind velocity and direction, and at each time step generates a surface current field that is consistent with the winds over the previous twelve hours. Although tidal flux through the Golden Gate is significant, for purposes of this model we assume that the net surface flux over a single tidal cycle is small.

Surface flow estimates were based on the results of two HAZMAT circulation models, Streamline Analysis of Currents (SAC) and Diagnostic Analysis of Currents (DAC). SAC was used to generate a surface current field for the shelf break and the deep portion of the study area: DAC was used to generate a surface current field over the shelf itself. Both models require bathymetric data as an input, most of which was available using GEODAS, a compendium of hydrographic survey data published by the National Geophysical Data Center. Areas where depth data were sparse or missing were filled in using hand digitized points obtained from archive files developed by HAZMAT. Bathymetric soundings were used to develop a 2,086 element triangular integrated network representing the three-dimensional structure of the study area (Figure 3).

Flow over the continental slope and deeper portions of the study area are part of the California Current regime. SAC was used to simulate the direction and relative magnitude of these flows at the ocean surface. The resulting pattern was then scaled to typical values available from historical data and past trajectory studies carried out during spill events. This component of the regional current regime is very persistent, and for the trajectory analyses in this study the flow was assumed to be constant in magnitude and pattern. The shelf circulation for the Gulf of the Farallones is more complex than that which occurs further offshore. DAC was used to simulate the direction and relative magnitude of these flows at the ocean surface. In this area, the seasonal winds play an important role and change the average direction of the flow from down-coast (north to south) during the upwelling period to up-coast (south to north) during the Davidson current period. This change in direction is related to the along-shore component of the wind stress. Wind stress causes cross-shelf transport to pile up water against the coast during Davidson current periods, and pull it away from the coast during upwelling periods. DAC solves for a dynamic balance between the surface flow and the pressure gradient across the shelf. The model is constrained by the geophysical domain represented by the 2,086 elements represented in Figure 3.

Although the concept of the upwelling current period and the Davidson current period is a useful generalization, at any time of the year the currents strengthen and weaken on a daily basis, sometimes completely reversing from the seasonal norm. While there are many reasons for these anomalies, the dominant factor is storms with persistent winds that last for the better part of a day or longer. These winds can actually modify the seasonal flows across the shelf and alter the bathystrophic balance used to set up the DAC model for the these flows. This type of variability is incorporated into the simulation by taking a running average of the long-shore component of the wind, and using that as a toggle between the flow field characteristic of the upwelling regime and the flow field characteristic of the Davidson current period.

Figure 3. Finite element mesh used in the hydrographic simulation. Color indicates relative intensity of currents (magnitude rather than direction) within each triangular element.



3.2 Beached Bird Model

3.2.1 Basic Methodology

The Beached Bird Model is used to estimate the number of birds deposited in the interval between two searches. The estimation procedure is based on the number of birds recovered, the probability of persistence over a given time interval, and the likelihood that searchers will detect a bird. The derivation of the basic equation is based on 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). Ongoing applications include damage assessments for the S.S *Jacob Luckenbach*, *Citrus*, *Bouchard 120*, and the *Selendang Ayu*. The version of the model presented here was used for the analysis of the 2001-2003 episodic event, and differs slightly from the version used for analysis of the PRTI which is described in detail in Carter and Golightly (2003). The following is the derivation of the Beached Bird Model used for the *Luckenbach* incidents of 2001-2003:

For a segment of beach searched on day j and again on day k, let:

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), let

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

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

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 must 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^*:

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

3.2.2 Estimating Bird Deposition in Unsearched Areas

A total of 218 miles of coastline in the *Luckenbach* study area was divided into 176 coastal segments averaging 1.24 miles in length. These segments were originally delineated by the GFNMS Beach Watch program and were used in organizing the spill response. These segments are referred to as *minor* segments, and were grouped into 10 larger segments referred to as *major* segments. Estimates of deposition rates using Equation 8 were carried out within each minor segment. It was assumed that the deposition rate was equal for all the minor segments within a major segment on a given day. Note that major segments were further grouped into three sectors, Pt. Reyes, San Mateo, and Monterey Bay which were used for additional analyses.

Additional extrapolation was required when searches of the same minor segment were separated by long periods of time. The Beached Bird Model is robust to the assumption that deposition is constant over the interval between searches so long as the fluctuations occur randomly throughout the inter-search interval. But long intervals between searches bias estimates of deposition rates *if* the deposition occurs mostly at the beginning or at the end of a long interval. We therefore did not use the Beached Bird Model to estimate carcass deposition for intervals greater than 7 days in length.

To derive an estimate for the entire geographic area and time span of the spill, 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 were no usable estimates of deposition rate within a major segment, the total deposition rate was assumed to be 0.

The following hypothetical example represents 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	□	■ $b_{12,12}$	■ $c_{11,12}$	$L^*(L_B b_{12,12}+L_{C\ 11,12})/(L_B+L_C)$

3.3 Estimation of Beached Bird Model Parameters

Required input parameters for the Beached Bird Model are $P_{m,n}$, the probability that a carcass will persist from day *m* to day *n*, and F, the probability that a bird will be found on a search. Estimates of searcher efficiency were derived from field studies carried out as part of the response to the *M/V Kure* spill in Humboldt Bay, California (Ford et al. in prep.). Estimates of persistence were based on studies carried out at Pt. Reyes and in San Mateo County in 2003.

3.3.1 Searcher Efficiency

Bird carcasses were randomly placed along several different types of beaches in the Humboldt Bay area and experienced searchers surveyed each stretch of beach in the manner typical of a spill-response search (Ford and Ward 2000). Searcher efficiency varied among rates differed between small (Rhinoceros Auklet or smaller) and large birds, and among the three habitats studied (marsh, rocky beach, and sandy beach). Based on Beach Watch search segment classifications, no segments similar to the marsh habitat and only one beach segment similar to the rocky habitat used in the searcher efficiency study were included in any of the searches related to *S.S. Jacob Luckenbach* spill incidents. The Beached Bird Model was therefore run separately for small and large-bodied birds usind data for sandy beaches.

During the response to the *Luckenbach* spill incidents, the number of observers searching a given beach segment varied, but often involved more than one observer at a time. Since searcher efficiency data from the *M/V Kure* spill were based on single observer searches, the single observer searcher efficiencies were adjusted to take into account the increased efficiency of multiple observers. Using the data from the *M/V Kure* study, we classified birds into 5 findability categories based on their likelihood of their being found on single observer searches. These categories were 0%, 25%, 50%, 75%, and 100% probability of being found by searchers. If $S_{m,1}$ is the probability of a bird of findability category *m* being found by 1 searcher , and $S_{m,n}$ is the probability of a bird of findability category *m* being found by *n* searchers, then

(9) $$S_{m,n} = 1 - (1 - S_{m,1})^{n}$$

The overall probability that a given number of searchers would find a bird of any findability class was calculated as the average of the $S_{m,n}$ weighted by the relative frequency of the various findability classes. The estimates of searcher efficiency used for all beached bird model runs are shown in Table 8.

Table 8. Searcher efficiencies used in beached bird model runs

Size	1 Observer	2 Observers	3+ Observers
Small	0.125	0.206	0.261
Large	0.417	0.540	0.602

3.3.2 Carcass Persistence

Beached birds are subject to a range of natural processes that remove them completely from the beach or that reduce them to unrecognizable fragments. The most important of these processes are scavenging and rewash. Scavenging is a very site specific phenomenon, and studies at a variety of locations show large variation in the rate at which carcasses are removed from the beach (Figure 5). Rewash is a difficult process to study because rewashed carcasses may potentially return to the beach but at some distance from their original location. During the spring of 2003, we carried out studies to determine the rate at which carcasses disappeared from beaches at sites throughout the area affected by the *Luckenbach* .

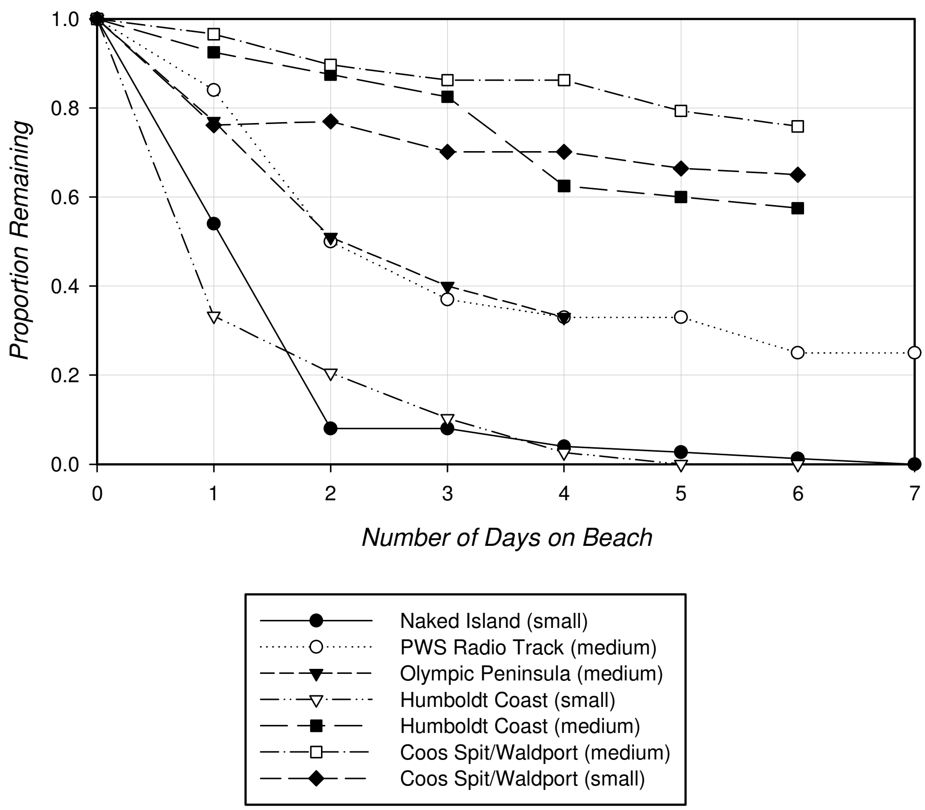


Figure 5. Persistence of seabird carcasses subjected to scavenging based on studies at four different sites on the Pacific coast.

3.3.2.1 Scavenging

The rate at which scavengers remove carcasses from the beach was measured by placing 76 carcasses at five representative sites around the Gulf of the Farallones (Limantour Beach, Pillar Point, Tunitas Creek, San Gregorio Beach, and Bean Hollow Beach) and monitoring their condition on a daily basis during April and May of 2003 (Figure 6). A total of 25 large carcasses (>500g) and 17 small carcasses (<500g) were set out at three sites south of the Golden Gate: Tunitas Creek, San Gregorio Beach, and Bean Hollow Beach. Similarly, 20 large and 14 small carcasses were set out at Limantour Beach in the Pt. Reyes area north of the Golden Gate.

Figure 6. Scavenging and rewash study sites: (a) Locator map, (b) Pt. Reyes Great Beach, (c) Limantour Beach , (d) Pillar Point, (e) Tunitas Creek, (f) San Gregorio Beach, (g) Bean Hollow Beach. Photos Copyright © 2002-2005 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org

Carcasses were placed above the high tide line at approximately 100m intervals. To avoid confusing the processes of scavenging and rewash, small numbered wooden blocks were placed under each carcass. If a bird was missing and the block remained, it was assumed that the carcass was removed by scavengers, whereas if the both the block *and* the carcass were missing, it was assumed that the carcass had been rewashed. Carcasses were checked each day and scored as scavenged, heavily scavenged, or missing (Figure 7a). For use in the beached bird model analysis, we partitioned the data into four categories based on north or south of the Golden Gate, and large or small carcasses.

Figure 7b shows the proportion of carcasses remaining as a function of the length of time that a carcass was on the beach. Most carcasses disappeared more slowly than at other sites where similar studies have been carried out (see Figure 5). A notable exception was the initial disappearance rate of small birds at Pt. Reyes , where 29% of the carcasses disappeared within the first 24 hours.

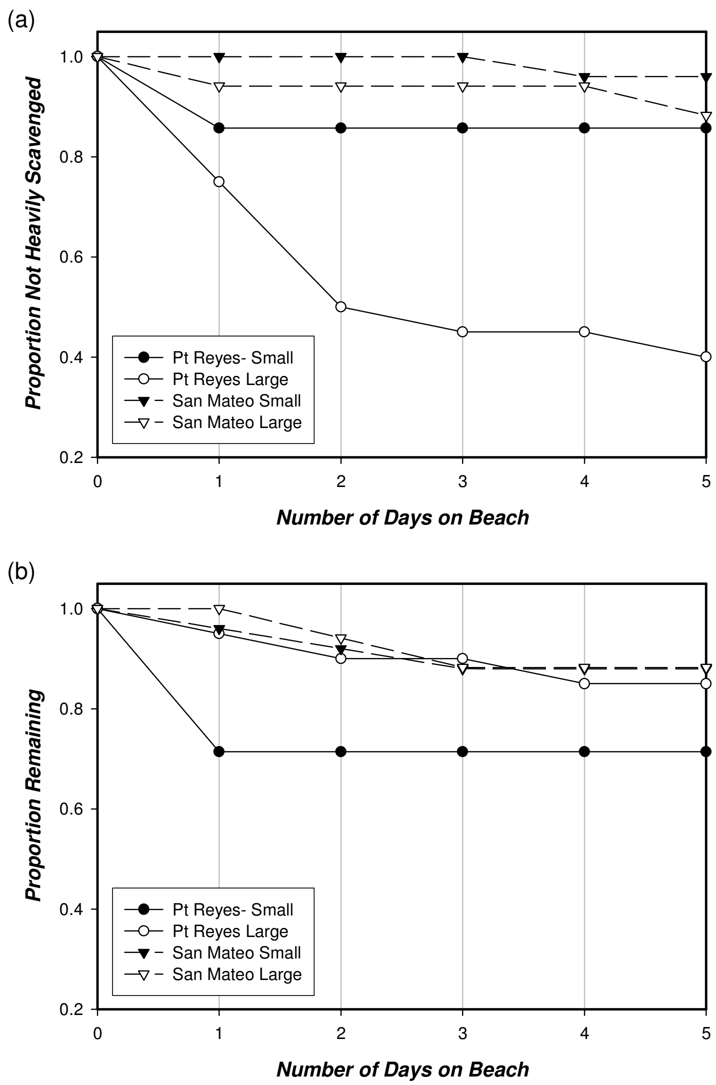


Figure 7. Condition (a) and disappearance (b) of carcasses subjected to scavenging at locations in the area affected by leakage from *S.S. Jacob Luckenbach.*

Heavily scavenged carcasses were defined as those that were still present on the beach, but had been stripped of pectoral muscles and heart, lungs, or intestines. Heavy scavenging is important to carcass retention because it makes the carcass less attractive to scavengers, but also increases its buoyancy which makes it more likely to rewash. For both large and small birds, heavy scavenging was more frequent at Pt.Reyes than at San Mateo sites. At Pt. Reyes most heavy scavenging tended to occur within the first 1 to 2 days. Large carcasses in particular were subject to intense scavenging at this site, and after 6 days only 40% had not been heavily scavenged.

3.3.2.2 Rewash

As with all flotsam, seabird carcasses are initially deposited in the intertidal, at or below the high tide line. During subsequent tidal cycles, those carcasses may be cast higher on the beach, rewash and beach again in a different location, or rewash and be lost at sea. We studied these alternative fates by placing carcasses fitted with radio-transmitters on Common Murre carcasses and placing them in the intertidal during April and May of 2003.

Transmitters were epoxied into foam floats and attached to the feet of the carcasses so as not to interfere with their flotation and drift charcteristics. Transmitter floats were spherical and counterweighted so as to add minimal additional buoyancy to the carcass and so that transmitters would tend to float or come to rest on the beach with their antenna pointing skyward. The method of attachment and the construction of the transmitter floats was based on similar studies in Prince William Sound and in the Gulf of Alaska (Ford et al. 1996) in which this type of attachment proved highly effective.

Three different types of “carcasses” were used (Figure 8):

- Intact Common Murre carcasses. These carcasses were previously frozen while fresh and in good condition. All had been recovered during previous oil spill responses. Any oil found on the plumage of these birds was removed by repeated washing in Dawn dishwashing detergent before they were placed on the beach.

- Eviscerated Common Murre carcasses. These were equivalent to the intact carcasses described above, but the pectoral muscles, heart, lungs, and intestines had been removed

- Dummies. These were 500ml Evian plastic waterbottles sealed in red wet-suit neoprene casings. They were designed to have flotation charcteristics similar to intact Common Murres, but were not subject to scavenging

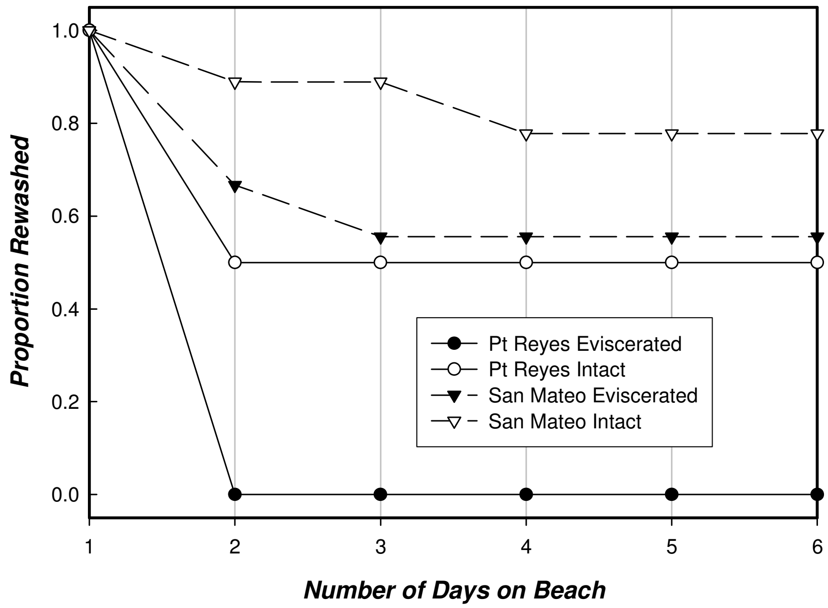
Sets of transmittered carcasses and dummies were deployed at the six sites shown in Figure 6. .

Figure 8. Different types of “carcasses” deployed in the rewash study. From top to bottom, carcass types are “eviscerated”, “dummy”, and “intact”. Transmitters are epoxied into foam floats connected by stiff metal rods. The laminated notices request that these units not be removed from the beach if found, and provide contact information.

At each site, 3 groups of “carcasses” were set out. Each group consisted of an intact carcass, an eviscerated carcass, and a dummy, so that a total of 54 telemetered units were deployed. Once deployed, transmitters were tracked using handheld directional antennas or from a Cessna 152 equipped with directional antennae. Aircraft services and aerial tracking were provided by Bob VanWagenen of EcoScan. Most carcasses were located every one to two days.

The ultimate fate of carcasses was usually determined within one to two days of being placed in the intertidal (Figure 9). Typically, carcasses were either pushed higher on the beach above the wrack line, or washed back down into the surf zone. Carcasses that were pushed high enough on the beach remained in the same position indefinitely , even on an ascending tidal cycle. In some cases, we removed these carcasses because they were clearly beyond the reach of wave action.

Figure 9. Proportion of carcasses that were rewashed as a function of time spent on the beach. Results are partitioned by site and by carcass condition.



The greater buoyancy of eviscerated carcasses increased the likelihood that they would wash back out. At both the Pt. Reyes and San Mateo sites, eviscerated carcasses disappeared at nearly twice the rate of intact carcasses, indicating a strong interaction between scavenging and rewash. Study sites in the Pt. Reyes area had consistently higher rates of rewash than did the San Mateo sites.

Carcasses that washed back out rarely beached again. In all but two cases, carcasses that rewashed ceased transmitting and were never relocated. Transmitters were designed to float with their whip antenna above water, and could be located offshore or even in the surf zone. Similarly constructed transmitters used by Ford et al. (1996) functioned for over three weeks at sea and there was no evidence of failure. Signal cessation was therefore assumed to result from waterlogged carcasses sinking and dragging their transmitter down with them. In the instances in which carcasses rewashed and later were recast on the beach, they returned as partial skeletons with only bits of skin and feathers adhering to the bones (Figure 10). Under normal circumstances or during oil spill response, beached birds in this condition are very rarely found, and we believe that these fragments refloated because of the slight buoyancy of the transmitter floats.

Figure 10. Eviscerated carcass that was recast after being missing at sea for several days. Only a partial skeleton and skin fragments are still connected to the transmitter float.

The processes of scavenging and rewash are interconnected because heavily scavenged carcasses are much more likely to rewash than are intact carcasses. Both processes occur within days of the arrival of a carcass on the beach face, and heavy scavenging decreases the likelihood that a carcass will persist to be found by searchers, even if that carcass is not entirely removed by the scavengers. Because our experimental treatment separated the processes of scavenging and rewash, we used a computer model to combine them in order to generate an overall persistence function that could be used as an input to the beached bird model. The model first transforms the daily rates of heavy scavenging and rewash into hourly rates. Let

D The daily rate of either heavy scavenging or rewash

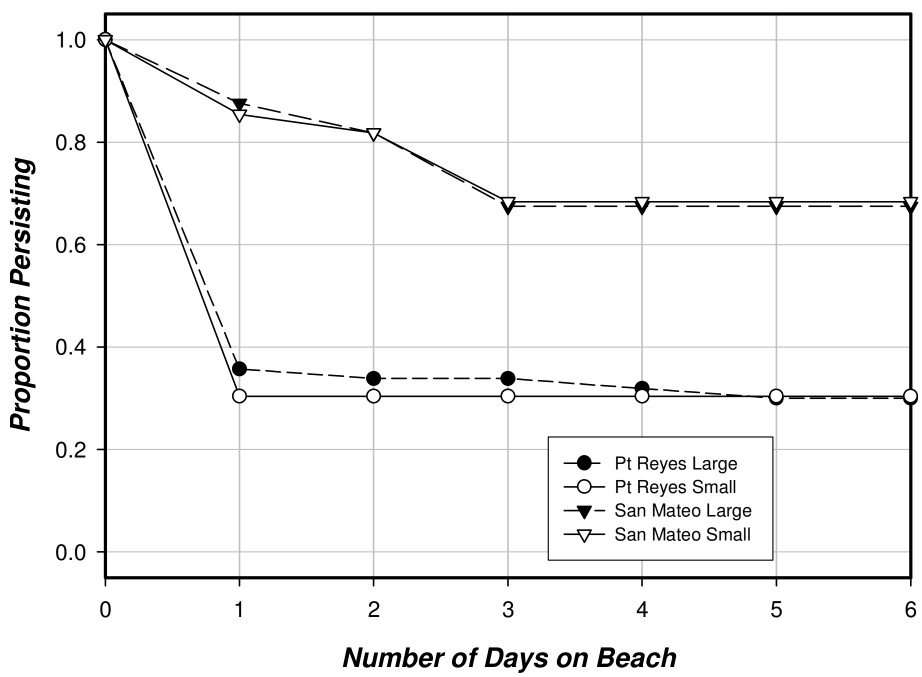
H The hourly rate assuming that the rate is constant over the course of a day

Then

(9) $H = 1 - e \bullet \mathrm{Exp}(\ \mathrm{Ln}\ (1 - D) / 24)$

Using the data shown in Figure 7 adjusted to hourly persistence rates using Equation (9), the model randomly simulated the fates of 100,000 carcasses, randomly classifying the carcass as disappeared or heavily scavenged on an hourly basis. At the end of each day, the carcass is designated as present or absent, and this classification is used to generate a persistence function that is used as an input to the beached bird model. The joint persistence functions, taking into account both scavenging and rewash, for small and large birds for the Pt Reyes and San Mateo sectors are shown in Figure 11. Both large and small carcasses at both sites rapidly approached stable levels of persistence, asymptoting within 1 to 3 days after being placed on the beach.

Figure 11. Model estimate of the proportion of carcasses persisting, taking into account the interaction between scavenging and rewash



3.4 Background Deposition Rate

Although oil spills can be a major cause of seabird mortality, seabirds die for many other reasons. During an oil spill incident, it is inevitable that birds dying of spill related injuries are mixed in with birds dying of unrelated causes. We refer to these birds as ‘background’ mortality, implying that they would have died and been beached even in the absense of *Luckenbach* oiling. Accurate determination of the number of birds killed by *Luckenbach* oil therefore requires that background carcass deposition be separated from spill related carcass deposition. This process can be difficult because seabirds killed by oil often show neither visibly detectable oiling or recognizable systemic damage (Ford 2006).

In order to estimate background deposition, we used data from beach monitoring surveys carried out during periods when the *Luckenbach* was not releasing oil. Beach Watch data for winter months of non-incident years (November through February of 1993-1997 and 1998-99) were used to estimate background mortality rates for each species group. Estimated background deposition rates were then subtracted from estimates of the overall deposition rate during oiling episodes in order to determine how many dead and injured birds could be attributed specifically to the effects of *Luckenbach* oiling.

Comparing deposition rates between incident and non-incident years is complicated by the fact that the frequency of searches was higher during periods when the *Luckenbach* was leaking than periods when it was not. Infrequent searches tend to result in a higher rate of carcass recovery per search because old carcasses, mostly skin, bone, and feathers, buildup on beaches during the long interval between searches. Longer search intervals would result in more buildup, shorter intervals in less buildup. The relationship between the expected number of birds found on searches spaced at different intervals can be approximated using the following procedure. Let:

m Search frequency (the number of days between searches)

N_m Number of birds recovered on a search m days after the last search

D Daily deposition rate of carcasses

P_i Likelihood that a carcass would persist to be found for i days

S Probability of finding a carcass on a search

Then:

$$(10) \quad N_m = \sum_{i=1}^{m} D \bullet S \bullet P_i = D \bullet S \bullet \sum_{i=1}^{m} P_i$$

In other words the number of birds recovered on a given search will be a function of searcher efficiency, daily persistence, the daily carcass deposition rate, and the number of days between searches. If we assume that there are two widely spaced sets of searches, A and B, similar in all ways except for differing search frequencies *a* and *b,* we can estimate the ratio of the numbers of carcasses recovered on A searches to B searches as follows. Let:

a The number of days between searches for search set A

b The number of days between searches for search set B

C_{ab} The ratio of the bird recovery rate for search set A to the recovery rate for search set B

Then:

$$(11) \quad C_{ab} = N_a / N_b = \left(D \bullet S \bullet \sum_{i=1}^{a} P_i\right) / \left(D \bullet S \bullet \sum_{i=1}^{b} P_i\right) = \sum_{i=1}^{a} P_i \Big/ \sum_{i=1}^{b} P_i$$

Figure 11 shows that the probability of a carcass persisting decreases rapidly after its arrival on the beach, then remains constant for a seemingly indefinite period of time. This means that except for the first couple of days (1 day for small birds and 3 days for large birds), P_i is approximately constant. Equation 11 can therefore be simplified by letting P_i be constant value. Let:

P* The asymptotic value of the persistence function for search sets A and B

Then, from equation (11):

(12) $C_{ab} \approx aP^* / bP^* = a / b$

So that the ratio of the bird recovery rate for search set A to search set B is simply the ratio of the search intervals, *a* and *b*. If the search interval for survey set A is 30 days, and the interval for survey set b is 15 days, we expect that twice as many birds will be recovered per search during survey set A. This approximation holds as long as *a* and *b* are large compared to the number of days required for the persistence function to reach its asymptotic limit. We used this relationship to normalize Beach Watch survey data, typically collected at one month intervals, so that the deposition rates recorded during these surveys were comparable to the rates recorded during spill response surveys which were carried out on a much more frequent basis.

3.5 Estimating Total Deposition Using Long-term Monitoring Data

Because many beached birds disappear soon after they arrive, the number of carcasses found on Beach Watch or on other monitoring surveys represents an underestimate of the total number of birds actually deposited. The form of the persistence function (Figure 11), declining rapidly to an asymptotic value, allows a simple way to approximate the number of birds removed by scavenging and rewash between searches. If (1) P* is the asymptotic limit of the persistence function, (2) the asymptotic persistence value is reached within days of a carcass being beached, and (3) the interval between searches is on the order of a month, then most of the birds found on each search will have had probability P* of persisting until they were found. Therefore, if N birds were found on a search, then approximately N / P* birds were originally deposited.

Consider an example where 25% of the carcasses remain after two days, and that percentage then remains constant. Now suppose that the beach is searched after a 30 day hiatus and 10 birds were found. These 10 birds would represent a net deposition of 10 / 0.25 = 40 birds. This formulation is only an approximation because birds that were deposited within the last day would actually have a slightly greater chance of persistence than 25%. For searches separated by 30 days and persistence functions that asymptote in 1 to 3 days, this inaccuracy is minimal.

The asymptotic values of the persistence function were estimated to be 0.647 and 0.293 for the San Mateo and the Pt. Reyes areas respectively (Figure 11).

4.0 Event-Specific Analyses and Results

Oil was released from the *Luckenbach* on a sporadic basis over a period of at least 13 years. During this time, agency and public response to seabird injury from oil spills changed dramatically. In the early 1990s and in previous years, the documentation of episodes of seabird oiling was casual compared with later response efforts. These later efforts involved large scale mobilization of personnel to rehabilitate injured birds and to document damages. Agency efforts were supplemented by extensive volunteer networks organized by the Gulf of the Farallones NMS and Monterey Bay NMS who monitor beaches on a regular basis and record the presence of beached birds and oil.

The long time frame over which the *Luckenbach* oiling episodes occurred and the evolution of the spill response process during that time resulted in a patchwork of data collection methodologies. The following section describes differing methods of analysis used to estimate seabird mortality based on varying data collection protocols and levels of effort over a 13 year period.

4.1 *Luckenbach* Oil Spill Incidents - November 2001 through January 2003

4.1.1 Beached Bird Model

The Beached Bird Model was run separately for the Pt. Reyes and San Mateo/Monterey Bay sectors and for small and large birds because carcass persistence was determined to be different in these areas. Size classes were further broken down into species groups, providing species specific estimates of deposition. Additional calculations were needed to estimate total mortality for each species or species group:

- A correction was applied to estimate the deposition represented by beached birds for which the beaching location was not recorded.
- For offshore species, a correction was applied to estimate the number of carcasses that were lost at sea.
- Birds recovered from the interior of San Francisco Bay or on the Farallon Islands were added to the total, as were birds recovered from the water. These birds were not used in Beached Bird Model extrapolations because search effort in these areas was not quantified.
- For each species, the estimated background deposition was subtracted from the mortality estimate.
- For each species, a proportion of birds released from rehabilitation centers were subtracted from the mortality estimate.

4.1.2 Trajectory Analysis

Depending on wind and oceanographic conditions, some proportion of birds killed by oil sink before being beached. In order to estimate this proportion, we conducted trajectory simulations using the wind speeds and wind direction during the three oiling episodes that occurred between November 2001 and January 2003. Episodes were defined by the recovery of unusually large numbers of dead birds and included the winter of 2001-2002, the summer of 2002, and the winter of 2002-2003.

One oil spill simulation was run for each day of the incident starting at 1300 (PSD), and originating at the site of the *Luckenbach* wreck. It was assumed that any birds killed or injured along the trajectory of each potential spill would continue to move along the same trajectory as the oil. Simulations were run for 14 days, a reasonable estimate of the length of time required for a carcass to sink at sea (Ford et al. 1996). Figure 12 depicts the trajectory simulations for each incident.

Annual and seasonal variation in winds and oceanographic conditions among these three episodes resulted in variation in the number of trajectories that went out to sea. Loss at sea was greatest during winter 2002-03 when 37% of all the trajectory simulations never reached the shore. By comparison, none of the trajectory simulations for the summer of 2002, and only 5% of the trajectory simulations for winter 2002-2003 failed to reach the shore.

Estimates of total mortality derived from the beached bird model were subsequently corrected to take into account loss at sea. For example, if the Beached Bird Model estimated that there were 100 birds deposited during some time frame, and during that time frame only 75% of the trajectory simulations were beached, we would estimate that 100 / 0.75 = 133 birds actually died, of which 75% (100) were beached, and 25% (33) were carried out to sea. Estimated bird mortality for Period 6 (November 2001 – January 2003) is summarized in Table 9.

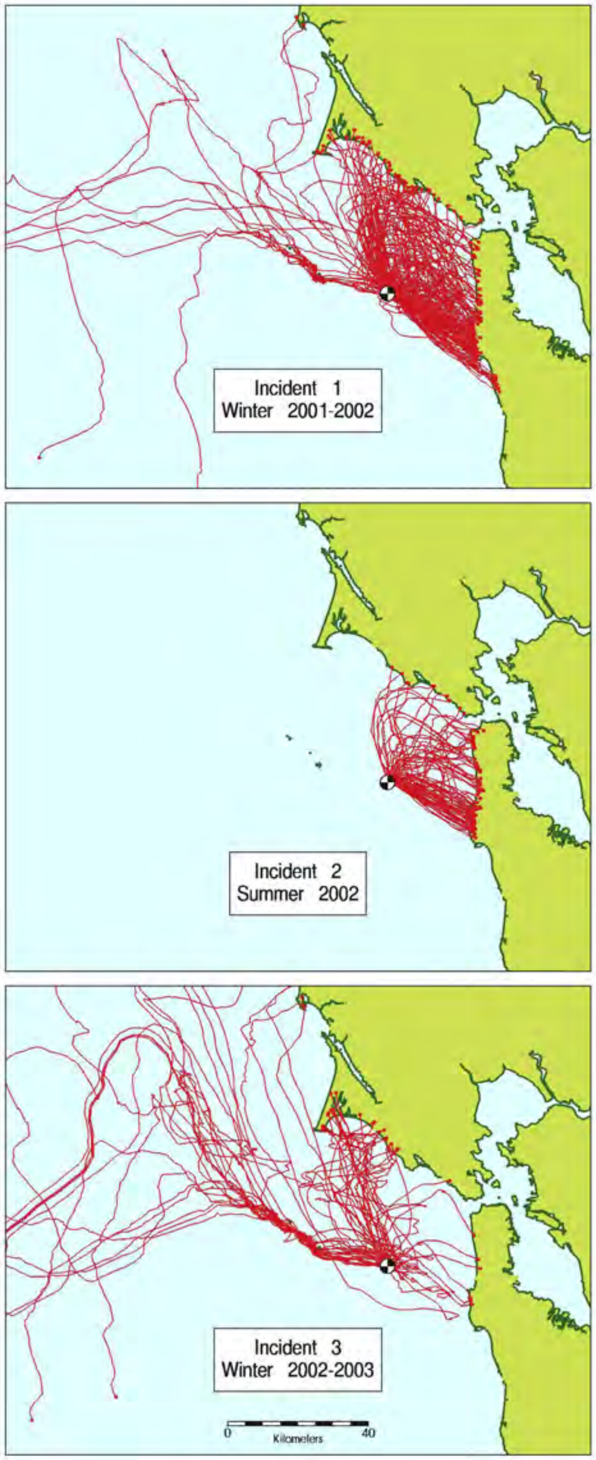


Figure 12. Trajectory simulations launched from the site of the *Luckenbach* each day during the separate *Luckenbach* incidents. Each trajectory was run for 14 days or until it encountered land.

Table 9. Estimated bird mortality for Period 6 (2001-2003) by taxon. Results from the beached bird model are corrected for additional factors which increase or decrease the total mortality estimate. Survival of rehabilitated and released birds is assumed to be 25% for Common Murres and Western Grebes and 100% for other species.

Species/Groups	Beached Bird Model	Lost at Sea	Unknown Locations	Bay / FI / Water	Estimated Back-ground Deposition	Survived Rehab and Release (Estimate)	TOTAL Estimated Dead
Common Murre	5600	515	44	204	130	74	6159
Procellarids							15
Grebes	1001	0	4	18	142	14	867
Cormorants	628	0	0	0	99	0	529
Loons	348	20	0	3	41	4	326
Waterfowl	33	0	0	0	14	2	17
Phalaropes	65	6	0	0	25	0	46
Other Shorebirds	43	0	0	0	12	0	31
Gulls	1144	105	0	2	444	6	801
Brown Pelican	82	0	0	1	24	3	56
Marbled Murrelet							9
Ancient Murrelet	94	9	0	2	0	0	105
Cassin's Auklet	81	7	0	1	11	0	78
Rhinoceros Auklet	148	14	0	10	23	0	149
Other Alcids	30	3	0	0	20	0	13
Other/Unid. Spp.							3
Land Birds							5
ALL SPECIES	**9,297**	**679**	**48**	**241**	**985**	**103**	**9,209**

4.2 Point Reyes Tarball Incident – November 1997 through March 1998

The large numbers of oiled birds deposited recovered between November, 1997 and March, 1998 was initially thought to have been caused by a vessel spill of unknown origin, but oil fingerprinting later established that it was largely the result of leakage from the *S.S. Luckenbach* (Hampton et al. 2003). The original analysis of this event is reported in detail by Carter and Golightly (2003). The re-analysis here is the result of new model runs based on an updated and expanded database of bird recoveries and updated persistence parameters. Beached bird recovery data from the 2001-2003 *Luckenbach* oil spill incident analyses are also used to extrapolate PRTI results to include the Monterey Bay beaches that were excluded from the original analysis.

4.2.1 Beached Bird Model

The final morgue database presented in Appendix C of Carter and Golightly (2003) was used for the present analysis. This new database involved several changes from the original, and these changes are fully discussed in that document.

Results from the persistence studies show birds deposited in the Point Reyes region (north of the Golden Gate) disappear much more quickly than do birds deposited in the San Mateo region (south of the Golden Gate), and that large and small birds also have distinctly different persistence rates. The four combinations of these factors were therefore modeled separately. The original analysis presented in Carter and Golightly (2003) also modeled large and small birds separately, but using a slightly different categorization scheme (see Section 2.4.2), so that the analyses differ primarily regarding the use of the updated persistence values in the different regions.

4.2.2 Unsearched Areas

Because the updated model separates the analysis of the Pt. Reyes and San Mateo sectors, the amount of area that was unsearched in each of these two regions was calculated separately. About 55.9% of beaches in the Point Reyes sector were searched and about 47.4% of beaches in the San Mateo sector were searched. We therefore estimate that actual mortality in the Point Reyes sector was 2.109 times greater than the Beached Bird Model estimates, and 1.788 times greater in the San Mateo sector. Based on this calculation, 13,272 birds were beached in unsearched areas during this incident (Table 10).

4.2.3 Loss at Sea: Trajectory Analyses

Trajectory simulations described in Carter and Golightly (2003) indicate that only 73.3% of the birds killed or injured by oil originating from the *Luckenbach* would have beached during the PRTI. Correction for at sea loss was only applied to birds that spend the majority of their time offshore waters, and not to nearshore taxa such as Brown Pelicans, waterfowl, loons (other than Pacific Loons), grebes and cormorants. We estimate that 8,834 affected birds would have been lost at sea in addition to those estimated to have been beached (see Table 10).

4.2.4 Extrapolation to Monterey Bay

Search effort records were not available for searches that occurred in Monterey Bay during the PRTI event, even though 241 birds were recovered in that area during that time. However, better record keeping during the later *Luckenbach* events make it possible to define the relationship between bird deposition along the San Mateo sector and the Monterey Bay sector. Deposition rates in these two areas during the 2001-2003 *Luckenbach* events were strongly related, and model estimates of bird deposition per week in the San Mateo sector were significantly correlated with the equivalent estimates for the Monterey Bay sector (R^2=0.429, P=0.003)

We therefore use estimates of the bird deposition rate in the San Mateo sector as a basis for estimating the bird deposition rate in the Monterey Bay sector during comparable time periods. During the 2001-2003 *Luckenbach* events, when both the San Mateo and Monterey Bay sectors were simultaneously surveyed, we estimated that 3,951 and 1,973 birds were deposited in these two areas respectively. The ratio of the estimated deposition rates is 1,973 / 3,951 = 0.499, and this number is used to estimate deposition in the Monterey Bay sector based on deposition the

San Mateo sector. Since the estimated number of birds deposited in the San Mateo area during the PRTI was 4,485, the estimated number of birds deposited in Monterey Bay during PRTI would be 0.499 x 4,485 = 2,240. Estimated Monterey Bay birds are included in Beached Bird Model numbers in Table 10.

Table 10. Estimated bird mortality for Period 4 (PRTI) by taxon. Results from the beached bird model are corrected for additional factors which increase or decrease the total mortality estimate. Survival of rehabilitated and released birds is assumed to be 25% for Common Murres and Western Grebes and 50% for other species.

Species/Groups	Beached Bird Model	Un-searched Areas	Lost at Sea	March 1998	Estimated Background Deposition	Survived Rehab and Release (Est.)	TOTAL Estimated Dead
Common Murre	10456	7116	5710	130	184	76	23152
Procellarids	2010	1612	1316	19	208	1	4749
Grebes	1750	1392	0	9	249	5	2897
Cormorants	408	324	0	0	20	0	711
Loons	431	316	166	5	72	3	843
Waterfowl	489	384	0	0	38	1	835
Phalaropes	703	533	427	0	170	2	1490
Gulls	812	644	506	0	700	6	1256
Brown Pelican	144	64	0	0	6	4	198
Marbled Murrelet							32
Ancient Murrelet	158	128	104	0	108	0	281
Cassin's Auklet	561	461	372	0	0	0	1395
Rhinoceros Auklet	169	140	112	0	41	0	379
Other Alcids	128	105	85	0	106	0	212
Other/Unid. Spp.	66	54	36	0	49	0	107
Land Birds							2
ALL SPECIES	**18,285**	**13,272**	**8,834**	**163**	**1,951**	**98**	**38,539**

4.2.5 Extension to March 1998 in the San Mateo and Monterey Bay Sectors

Official documented searches for birds ended in February 1998, but oiled birds continued to arrive during the following month. In March 1998, 35 oiled birds were documented by Beachcomber vounteers on Monterey Bay area beaches. To estimate the total number of oiled birds beached in Monterey Bay, we used equation (12) with the asymptotic value of the persistence function for the San Mateo sector (0.647). This results in an estimated deposition of 35 / 0.647 = 54 birds. Based on the relationship between deposition in the San Mateo sector and the Monterey Bay sector, about twice as many birds wouild have been beached in the San Mateo sector, so that altogether roughly 54 + 2 x 54 = 162 would have been beached during this period in the San Mateo and Monterey Bay sectors combined.

4.3 Chronic Mortality from *Luckenbach* Oil, 1993-1997 and 1998-2001

Since 1990, there were two distinct periods when birds fouled with *Luckenbach* oil were beached in large numbers: 1997-1998, and 2001-2003. But even at other times, oiled seabirds were regularly beached and were recorded by Beach Watch volunteers during their monthly monitoring surveys. Based on these data, two separate periods of chronic oiling are identified: Period 3 from the inception of the Beach Watch program to the beginning of the Point Reyes Tarball Incidents (October 1993 – October 1997) and Period 5 after the Point Reyes Tarball Incident and before the *Luckenbach* Oil Spill Incident (April 1998 – October 2001) (see Table 1 for definition of periods). A subset of these oiled birds were subjected to fingerprinting in order to determine whether the *Luckenbach* was the source of the oil, and it was found that 26.7% (4 / 15) of the oiled birds recovered during Period 3 and that 50.0% (19 / 38) of the birds recovered during Period 5 showed evidence of *Luckenbach* oil.

We estimated the total number of birds killed and injured by *Luckenbach* oil during these two periods by correcting the number of oiled birds for the frequency of *Luckenbach* oiling and for the persistence rate. For example, 26 oiled birds were recorded by Beach Watch volunteers in the San Mateo sector between 1993 and 1997. Based on equation 12 (see Section 3.5), the total number of birds beached would be 1.546 x 26 = 40.20. Correcting for the proportion of oiled birds with *Luckenbach* oil, the relevant number of beached birds would be 40.20 x 0.267 = 10.73. Since these events occurred before the Monterey Bay sector was regularly monitored by the Beachcomber program, we also estimate the number of birds deposited in the Monterey Bay sector. In Section 4.2.4, we estimate that, on average, half as many birds are beached in Monterey Bay as in San Mateo. Deposition of birds injured or killed by *Luckenbach* oil in the Monterey Bay sector would therefore be 10.73 x 0.5 = 5.36 birds. These calculations for both periods and for all three sectors are shown in Table 11.

Table 11. Oiled beachcast birds attributable to *Luckenbach* oil for two periods of chronic oiling. Data from the Beach Watch database (2004).

	Period 3: 1993-1997			Period 5: 1998-2001		
	Pt Reyes	San Mateo	Monterey Bay	Pt Reyes	San Mateo	Monterey Bay
Oiled birds recorded	47	26	0	61	33	0
Correction for persistence	3.413	1.546	na	3.413	1.546	na
Oiled birds on beaches	160.41	40.20	20.01	208.19	51.02	25.51
Proportion with *Luckenbach* oil	0.267			0.500		
Estimated *Luckenbach* birds	42.83	10.73	5.36	104.10	25.51	12.76

Most oiled birds on the beaches were Common Murres, with lesser numbers of various other species. Estimates of oiled beachcast birds attributable to the *Luckenbach* were assigned to species based on the proportion of each species found oiled on the beaches during each chronic oiling period. (Tables 12 and 13).

Table 12. Estimated *Luckenbach* mortality for Period 3 (1993-1997), by taxon. Totals are rounded to the nearest whole bird.

	Percentage of Birds Recorded Oiled on Pt. Reyes Sector Beaches	Estimated *Luckenbach* Mortality, Pt Reyes Sector Beaches	Percentage of Birds Recorded Oiled on San Mateo Beaches	Estimated *Luckenbach* Mortality, San Mateo / Monterey Bay Beaches	Estimated Period 3 *Luckenbach* Total Mortality
Common Murre	66.0%	28.27	53.8%	8.66	37
Procellarids	10.6%	4.54	3.8%	0.61	5
Grebes	6.4%	2.74	11.5%	1.85	5
Cormorants	0	0	3.8%	0.61	1
Loons	4.3%	1.84	3.8%	0.61	2
Waterfowl	0	0	3.8%	0.61	1
Gulls	8.5%	3.64	11.5%	1.85	5
Rhinoceros Auklet	0	0	3.8%	0.61	1
Other Alcids	2.1%	0.90	0	0	1
Shorebirds	2.1%	0.90	3.8%	0.61	2
				TOTAL	**60**

Table 13. Estimated *Luckenbach* mortality for Period 5 (1998-2001), by taxon. Totals are rounded to the nearest whole bird.

	Percentage of Birds Recorded Oiled on Pt. Reyes Sector Beaches	Estimated *Luckenbach* Mortality, Pt Reyes Sector Beaches	Percentage of Birds Recorded Oiled on San Mateo Beaches	Estimated *Luckenbach* Mortality, San Mateo / Monterey Bay Beaches	Estimated Period 5 *Luckenbach* Total Mortality
Common Murre	44.3%	46.12	45.5%	17.41	63
Procellarids	16.4%	17.07	9.1%	3.48	21
Grebes	9.8%	10.20	0	0	10
Cormorants	4.9%	5.10	12.1%	4.63	10
Loons	6.6%	6.87	18.2%	6.97	14
Waterfowl	1.6%	1.67	0	0	2
Gulls	4.9%	5.10	9.1%	3.48	9
Brown Pelican	1.6%	1.67	0	0	2
Cassin's Auklet	3.3%	3.44	3.0%	1.15	5
Rhinoceros Auklet	3.3%	3.44	3.0%	1.15	5
Other Alcids	1.6%	1.67	0	0	2
Other/Unid. Spp.	1.6%	1.67	0	0	2
				TOTAL	**145**

4.4 Early Oiling Events, 1990-1993

Oiling events during the years 1990-1993 are less well documented than later events, but oiled seabirds were reported by scientists on the Farallon Islands and on the mainland by private citizens in winter and spring. We used these records to estimate mortality from these events.

During the winter of 1990-1991, a substantial number of live oiled seabirds (195) were collected from area beaches by members of the public (Hampton et al. 2003). Similarly, during the most thoroughly documented events (2001-2003), 493 live oiled seabirds were collected from these beaches by private citizens (OSPR database). If we treat these two events as directly comparable, we can estimate the total mortality represented by the 195 live oiled birds collected in 1990-1991 (Table 14) by assuming that the ratio between recoveries in 1990-1991 and 2001-2003 is 195 / 493 = 0.3955. Species composition is assumed to be proportional to the 2001-2003 events.

Table 14. Estimated seabird mortality during the winter of 1990-1991, based on comparability with the events of 2001-2003**.** Modeled mortality for murres and grebes does not include rehabilitated and released birds.

	Modeled Mortality, 2001-2003	**Estimated Mortality, 1990-1991**
Common Murre	5935	2348
Procellarids	15	6
Grebes	827	327
Cormorants	529	209
Loons	326	129
Waterfowl	17	7
Phalaropes	46	18
Other Shorebirds	31	12
Gulls	801	317
Brown Pelican	56	22
Marbled Murrelet	9	4
Ancient Murrelet	105	42
Cassin's Auklet	78	31
Rhinoceros Auklet	149	59
Other Alcids	13	5
Other/Unid. Spp.	3	1
Land Birds	5	2
ALL SPECIES	**8,945**	**3,539**

During winter and spring of 1992-1993, two separate oiling episodes were noted by Farallon Island biologists, the first from 11-23 December 1992 and the second from 18 April to 6 May 1993 (Nur et al. 1997). Oiled birds were enumerated daily, and in each case the number of oiled birds observed rose to a peak and then declined. The maximum count from each episode was used as a conservative estimate of birds oiled, for a total of 47 birds. All birds observed were Common Murres.

4.5 Estimation of Marbled Murrelet Mortality

In this report, we analyze seabird mortality resulting from leakage from the *S.S. Jacob Luckenbach* that took place over a 13 year period. During this time, bird kills occurred sporadically, and shorelines often were not systematically searched or were searched only at widely spaced intervals. Our estimates of total mortality suggest that, for all species and mortality events, only about 10% of the birds dying from exposure to *Luckenbach* oil were ever documented. Since small birds in central California disappear from beaches much more rapidly than larger birds, it is likely that only a few percent of the total injury to small species such as Marbled Murrelets was ever documented.

Compared to other seabird species, murrelets occur in relatively small numbers in the Gulf of the Farallones. Given that they are rare, small, and unlikely to be recovered after being oiled, the numbers of murrelets documented by searchers in any given *Luckenbach* event was likely to be zero, providing no basis for mortality estimation. We therefore used an estimation technique developed for the *Kure* (Ford et al. 2002) and *Command* (Ford 2002) spills, which involves utilizing other more common seabird species as proxies for murrelets. In this case, we assume that Western Grebes died at the same rate as Marbled Murrelets as a result of spillage from the *Luckenbach*. Grebes are distributed nearshore as are Marbled Murrelets, and their areas of concentration are generally very similar in the Gulf of the Farallones. Both grebes and murrelets spend most of their lives on the water, and both forage for fish by diving from the surface, factors that contribute to vulnerability relative to spilled oil (King and Sanger 1979, Camphuysen 1989, Williams et al. 1994). Since Western Grebes are significantly larger than Marbled Murrelets, about 1,477g compared to 222g (Dunning 1993), it is likely that the smaller bodied murrelets are more vulnerable to the effects of hypothermia than are the grebes. Additionally, the small body size and dark coloration of the murrelets makes them difficult to detect, so the number of Marbled Murrelets observed on surveys probably represents a smaller fraction of the birds actually present than for Western Grebes. These factors would tend to make the use of Western Grebes as Marbled Murrelet proxies conservative, biasing estimates of Marbled Murrelet mortality downward.

A historical database of seabird surveys for California covering the period from 1980 to 2001 includes a total of 15,495 sightings of Western Grebes within the study area. This database, compiled for the Gulf of the Farallones National Marine Sanctuary, is the most comprehensive and current database of seabird surveys in the area and is described in detail in Ford et al. (2004). On the same surveys, observers also counted 170 Marbled Murrelets. Over all of the spill episodes, we estimate that a total of 4,106 Western Grebes died, corresponding to 26.5% of the total grebe sightings. If murrelets are equally vulnerable to oiling except that they occur less frequently in the area, then 0.265 x 170 = 45 Marbled Murrelets died as a result of *Luckenbach* oiling.

5.0 Summary and Conclusions

Leakage from the wreck of the *S.S. Jacob Luckenbach* resulted in episodic kills of seabirds in and around the Gulf of the Farallones for at least 13 years, and it is likely that similar events occurred prior to that time. We identified 6 events of varying duration that occurred between 1990 and 2003, killing an estimated 51,539 seabirds. The most significant events took place in the winter of 1997 to 1998 (Pt. Reyes Tarball Incident), during the years 2001 to 2003, and during the winter of 1990-1991. We estimate that these events killed 38,539, 9,209, and 3,539 seabirds respectively (Table 15). As is typical for spills in this region, Common Murres were the most severely affected species, accounting for 62% of the overall mortality. Procellarids were the next most severely affected, accounting for 9% of the total mortality, followed by grebes which accounted for 8%.

Table 15. Overall projected mortality from the *S.S. Luckenbach* and related mystery spills during the period 1990-2003, by event and taxon. Oiled land birds are included here without extrapolation.

Species/Groups	Winter 1990-91	Winter 1992-93	Chronic 1993-1997	Winter 1997-98	Chronic 1998-2001	2001-2003	TOTAL
Common Murre	2,348	47	37	23,152	63	6,159	31,806
Procellarids	6		5	4,749	21	15	4,796
Grebes	327		5	2,897	10	867	4,106
Cormorants	209		1	711	10	529	1,460
Loons	129		2	843	14	326	1,314
Waterfowl	7		1	835	2	17	862
Phalaropes	18		0	1,490	0	46	1,554
Other Shorebirds	12		2	0	0	31	45
Gulls	317		5	1,256	9	801	2,388
Brown Pelican	22		0	198	2	56	278
Marbled Murrelet	4		0	32	0	9	45
Ancient Murrelet	42		0	281	0	105	428
Cassin's Auklet	31		0	1,395	5	78	1,509
Rhinoceros Auklet	59		1	379	5	149	593
Other Alcids	5		1	212	2	13	233
Other / Un-ID Spp.	1		0	107	2	3	113
Land Birds	2		0	2	0	5	9
TOTALS	**3,539**	**47**	**60**	**38,539**	**145**	**9,209**	**51,539**

The difference in the estimated mortality resulting from the Winter 1997-1998 event (PRTI) and the 2001-2003 event demonstrates the importance of annual variation in weather patterns and geographic variation in persistence rates. Although the number of birds recovered during the two events were roughly comparable, 2,959 and 2,746 respectively, our modeling efforts indicate that the PRTI killed about four times as many birds. The difference in estimated mortality results from differing weather patterns during the two periods, and the relatively low persistence of carcasses in the Pt. Reyes area. During the PRTI, a larger proportion of birds were directed northward toward the Pt. Reyes peninsula and Drakes Bay or were carried out to sea. Birds beaching in the Pt. Reyes area were subjected to much higher rates of scavenging and rewash than in the area south of the Golden Gate.

Because oiling incidents occurred regularly over a period lasting more than a decade, the cumulative mortality caused by leakage from the wreck of the *Luckenbach* was considerable. Only six documented spills occurring in US waters have resulted in the recovery of more injured seabirds (Ford et al. in review): the *Apex Houston, Nestucca, Hamilton Trader, Tenu Maru, Arizona/Oregon, and the Exxon Valdez* incidents. Two of these spills, the *Arizona/Oregon* and the *Apex Houston* also occurred in the Gulf of the Farallones. In retrospect, the scale of the estimated mortality is not surprising since the wreck of the *Luchenbach* lay nearby and upwind of the largest murre concentration in continental US waters (Ford et al. 2004). Murre densities in this area are even higher in winter when spillage tended to occur than than they are during the breeding season, since the local murre population actually increases due to the influx of wintering birds.

In 2002, an extensive salvage operation was carried out in order to remove as much oil as possible from the wreck. About 22% of the oil was successfully lightered, and most of the remaining holes and vents were blocked. Subsequent beach monitoring indicates that mortality has declined greatly, especially during periods without major storm events, but additional incidents may occur at some time in the future (Hampton et al. 2003).

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