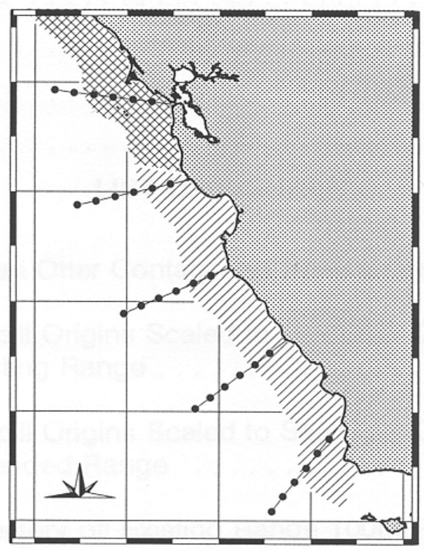
Appendix B: Potential Impacts of Oil Spills on the Southern Sea Otter Population

FINAL REPORT

Potential Impacts of Oil Spills on the Southern Sea Otter Population



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U. S. Fish and Wildlife Service

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INTRODUCTION

The purpose of this study was to assess potential impacts on the southern sea otter population from large oil spills that might occur off the California coast. This was done by running computer simulations of the movement and spread of oil from spills varying from 31,250 bbl to 1,000,000 bbl. In initial model runs, simulated spills were released from randomly selected sites within 25 nautical miles (nmi) of the existing sea otter range and a hypothetical future range along the coast of northern California. Results of model runs were analyzed to determine where oil spills present the greatest risk to populations of sea otters and the influence of spill size on number of sea otters contacted. To examine the effect of distance from shore, a second set of simulations were made in which spills were released at 10 nmi increments from land.

Initially, the model was run with 100 simulations at randomly selected sites and wind conditions to determine rank-order of results and identify the spill location and wind conditions affecting the greatest number of sea otters. These simulations were of a 250,000 bbl spill released at randomly selected sites within 25 nmi of shore. The 250,000 bbl size was approximately that of the *Exxon Valdez* spill and was used as a basis for determining "reasonable worst case" for the population of southern sea otters. The single simulation contacting the greatest number of sea otters (i.e., the 100th percentile simulation) was, by definition, the worst case in these model runs. Although such a spill is clearly possible, it may not be the best example of a reasonable worst case spill event. Reasonable worst case has no formal definition but rather depends on consensus. To encompass varying opinions, the 90th percentile was chosen as a lower bound on reasonable worst case. Both the 100th and 90th percentile simulations were modeled in detail for the existing range; only the 100th percentile spill was modeled in detail for the hypothetical northern California range. These three simulations are referred as Detailed Scenarios and discussed below.

Lastly, the model was run to determine the probability distribution of number of sea otters contacted by simulated spills, where the spill size was provided by randomly sampling from the size distribution of past spills. These probabilities were conditional on the occurrence of oil spills. To provide a best estimate of probabilities that sea otters will actually be contacted by oil spills, the expectation of number of sea otters contacted was multiplied by the expectation of oil spills. In any given year the expectation of oil spills is relatively small; therefore a reasonable time-frame must be chosen for assessing potential impacts. For this analysis, final probabilities of number of sea otters contacted by oil spills were calculated for a 30-year period.

METHODS

The computer model OSRISK was used to perform the spill trajectory analysis. Versions of this model have been developed for hindcasting real-time spills (Ford 1986), training spill-response personnel (the spill model OCCUR prepared for the Clean Bay Cooperative), conducting risk analyses (Chambers Group, Inc. and Ecological Consulting, Inc., for the California State Lands Commission; Unocal EIR), and helping define tanker transport routes that minimized the risk of oil contact with sensitive resources (Ford et al. 1990). OSRISK accepts wind and surface current information from external sources and combines them with geographic data describing animal distribution and oil spill behavior. The model simulates an oil spill occurring under a specific set of conditions, taking into account as needed the time of year, wind conditions, tidal state, spill volume, chemical composition, the extent of tidally inundated substrates, and other factors. The spill is represented as a cluster of independently moving points (Lagrangian Elements or LEs), each representing a fraction of the entire spill volume.

Hydrological data were taken from the Minerals Management Service's curvilinear surface current grid for the Pacific coast prepared by Dynalysis of Princeton. The finite element mesh forming the grid is composed of 1,200 quadrilateral elements roughly paralleling the outer coast and decreasing in size along the shoreward edge of the grid. The data used by OSRISK were seasonally averaged surface current vectors at each node. At each 2-hour time step, OSRISK located the rectangular element containing a given LE. The surface current vector at the location of the LE was estimated as the inverse distance weighted average of the current vector at each of the four adjacent nodes. OSRISK uses sequences of real-time winds to generate a time-varying wind field. At the position of each LE at each 2-hour time step, the wind vector was calculated as the inverse distance weighted mean of the wind speeds and directions recorded at each of several NOAA meteorological buoys. Crude oil was assumed to be persistent; that is, undergoing little or no decrease in volume due to evaporation. Each LE was tracked for 21 days, until beached, or until out of the model domain.

The area affected by an oil spill varies with the volume of the spill, the age of the spill, and the wind and current conditions that prevail during the course of the spill. OSRISK simulates the process of spreading by adding a random diffusive component to the advection induced by winds and currents at each model time step. The larger the random factor and larger the number of LEs used to simulate the slick, the more rapidly the slick expands and the more extensive the region impacted by the slick. The spreading rate of the model slicks was calibrated by selecting a random diffusive factor and number of LEs such that the area defined by placing a 5-km radius buffer around each LE matched the observed regression of the areal extent of real slicks of a given volume after 7 days (Ford and Casey 1985).

Baseline model runs consisted of 200 computer simulations of a 250,000 bbl oil spill for the existing sea otter range and another 200 simulations for a hypothetical northern California range. The size of the simulated spill (250,000 bbl) was chosen to approximate the *Exxon Valdez* spill. The release sites were determined using a random-number generator to select points within a polygon extending 25 nm seaward from Pt. Arena in the north to Pt. Conception in the south. Simulations consisted of the release of 100 LEs, each representing 2,500 bbl of oil, at a randomly selected time of year. The movement of each LE by winds and currents was modeled within a GIS that included a detailed digital shoreline and the position of each sea otter or group from the USFWS spring and fall 1992 censuses and from a hypothetical distribution of sea otters created by the USFWS for the northern California coast. If any LE passed within 5 km of the observed position of a sea otter or group of sea otters, the group was assumed to have been contacted by the slick. The 5 km effective radius was chosen as an approximation of the length of coastline that would be affected by 2,500 bbl of oil. (The model is relatively insensitive to this parameter: a 100% increase in the size of the effective area increased the number of contacts by only 3.6%.)

Detailed scenarios of oil movement and number of sea otters contacted over time were prepared for the 100th and 90th percentile spills affecting the existing range and the 100th percentile for the hypothetical northern California range. To provide greater spatial resolution, these were simulated using the same spill site and winds regime but releasing 2,500 LEs each representing 100 bbl of oil. Mortality of sea otters contacted in these scenarios was estimated from the relationship provided by Brody (1992). This relationship describes survival of sea otters as a function of distance from the spill origin from data collected in Alaska waters following the *Exxon Valdez* oil spill.

The relationship between spill volume and the number of sea otters contacted was examined by running the model as above, but modifying the spill volume. Two hundred spills, each consisting of 100 LEs, were simulated for each of the following spill volumes:

31,250 bbl
62,500 bbl
125,000 bbl
500,000 bbl
1,000,000 bbl

All simulations with random selection of release sites were made within 25 nmi of shore. To further examine the relationship between distance from shore and the number of sea otters contacted, the model domain was extended to 60 nmi. Simulated spills were released at 10 nmi increments along five lines orthogonal to the coastline. A total of 200 model spills, each consisting of 100 LEs, were released from each of six stations along these lines. Spill size and times of year were the same as in baseline model runs; however, release sites were predetermined rather than randomly selected so as to simplify analysis.

Final probabilities of number of sea otters in the existing range that might be contacted by oil spills over a 30-year period were calculated from the conditional probabilities resulting from the trajectory modeling described above and the expectation of oil spills. The expectation of oil spills equal to or greater than 1,000 bbl was taken from the analysis of 1974 through 1985 data by Anderson and LaBelle (1990). This occurrence rate of 0.9 spills per 1 billion bbl of oil transported is virtually unchanged from that of an earlier study (Lanfear and Amstutz 1983). It differs from the earlier study in that findings are based on a larger and more recent data base of worldwide spills. The exposure variable of volume of oil transported along the California coast was estimated for each of four routes from data assembled for the Western States Petroleum Association by DNA Associates (1993). The four routes used by tankers along the California coast are North Coast, Alaska and Overseas, South Coast, and Estero Bay. The North Coast route included all transport to or from Humboldt Bay, Oregon, Washington, and Canada past the coast from the entrance to San Francisco Bay to Point Arena. Transport of oil and products was assumed to use the northwest-southeast lanes of the San Francisco Traffic Separation Scheme (TSS). The Alaska and Overseas Route included all oil and products transported to or from San Francisco Bay and Alaska, Asia, Hawaii, Mexico, Panama, and South America. This oil was assumed to be transported exclusively along the east-west lanes of the San Francisco TSS. The South Coast Route included transport to or from San Francisco Bay, Estero Bay, and Los Angeles/Long Beach. The Estero Bay Route included only the volume of oil transported along a spur from the South Coast Route; oil from Estero Bay is transported by tanker and barge to Los Angeles/Long Beach and by tanker to Oregon and Washington.

The 1992 volumes from DNA Associates (1993) along these routes were assumed to be representative of the oil transport scenario of the next 30 years; thus the 1992 volumes were multiplied by 30 to arrive at a total projected volume transported along these routes over a 30 year period. The projected volume was then multiplied by the occurrence rate of 0.9 spills greater than 1,000 bbl per billion bbl of oil transported (from Anderson and LaBelle 1990) to arrive at an expected number of spills along each route over a 30-year period. The likelihood of spills was assumed to be uniformly distributed along each of these routes. However, because only 15.4% of the North Coast Route extends south of Point Arena, we multiplied the expected number of spills for this route by 0.154 to estimate the expectation of oil spills. Because most spills occur within 50 miles from land (Card et al. 1975), for the Alaska and Overseas Route, we assumed that one-half of spills would occur in the approaches to San Francisco Bay; the remainder was assumed to occur in the approaches to Prince William Sound, or Asian, Pacific, or other foreign ports. Thus, the expected number of spills for the Alaska and Overseas Route was multiplied by 0.5.

The steps outlined above provide an expectation of oil spills equal to or greater than 1,000 bbl along these routes. Small spills are more likely to occur than large ones, and the size of a spill directly affects the number of sea otters contacted. Therefore, a frequency distribution of spill size was constructed from the historical database used by Anderson and LaBelle (1990) and randomly sampled for each simulation. The database included spills that are larger than might reasonably be expected to occur along the California coast. Thus, the frequency distribution of spill size was truncated at 350,000 bbl. This truncation volume was determined based on the capacity of tankers using the four routes. Fully laden tankers transiting past the sea otter range along the South Coast Route carry 73,000 bbl to 350,000 bbl (from analysis of the U. S. Coast Guard 1982 Port Access Route Study). The Alaska and Overseas route into San Francisco Bay may include larger tankers; however, water depth generally limits tankers to 350,000 bbl capacity or less (Chambers Group, Inc. 1994).

RESULTS AND DISCUSSION

Baseline Model Runs

Baseline model runs consisted of 200 simulations released at randomly selected sites, and were generated for both the existing main sea otter range and the extended sea otter range. The results of these simulations are shown in Figure 1. For the existing sea otter range, the 50th, 90th, and 95th percentiles were 123, 857, and 978 sea otters contacted by oil, respectively. In other words, in 50% of the simulations, up to 123 sea otters were contacted, in 90% of the simulations, up to 857 sea otters were contacted, and so on. Comparable values for the extended sea otter range were 672, 1658, and 2,132 sea otters contacted by oil. The number of contacts in the extended range tends to be greater than in the existing range because it is assumed that the extended range will ultimately contain a larger number of sea otters than the existing range.

The origins of the spills modeled at randomly selected sites are shown in Figures 2a and 2b for the existing and extended sea otter ranges. The size of the circles representing the origin of each spill are scaled so that spills resulting in a large number of contacts are represented by larger circles, and spills resulting in few contacts are represented by smaller circles. For the existing sea otter range, spills occurring north of Point Reyes did not result in large numbers of contacts. In this northern area, simulated oil spills released farther offshore resulted in more contacts in the existing range than spills occurring closer to shore; inshore spills are beached or dissipated before drifting sufficiently far to the south to reach more densely occupied portions of the existing sea otter range. The greatest risk to the existing sea otter range results from spills originating between Point Reyes and Lopez Point. Within this area, spills originating in the region from Half Moon Bay to Monterey Bay result in the greatest number of contacts to sea otters.

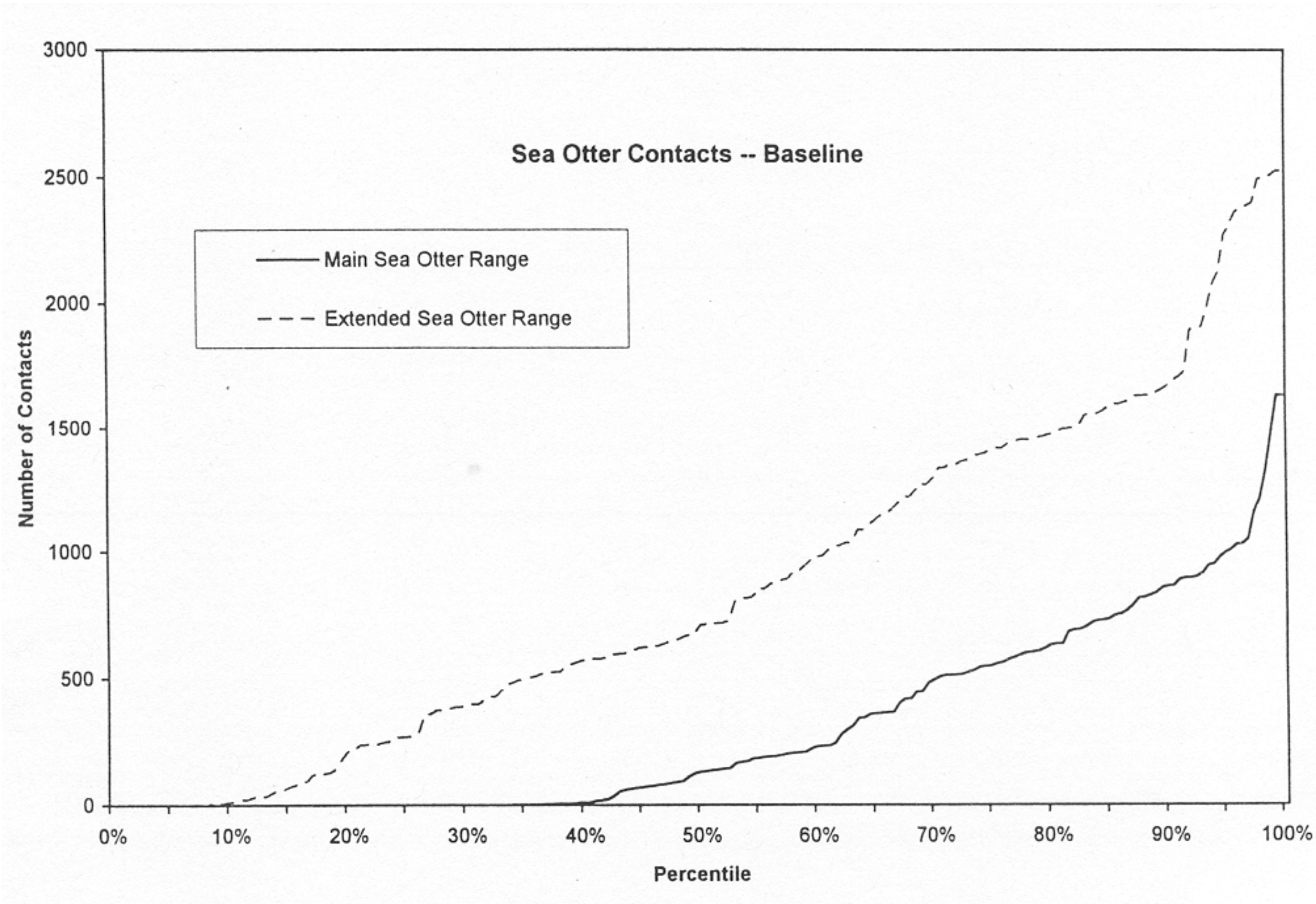

Figure 1. Sea otter contacts and rank-order percentiles from baseline model runs.

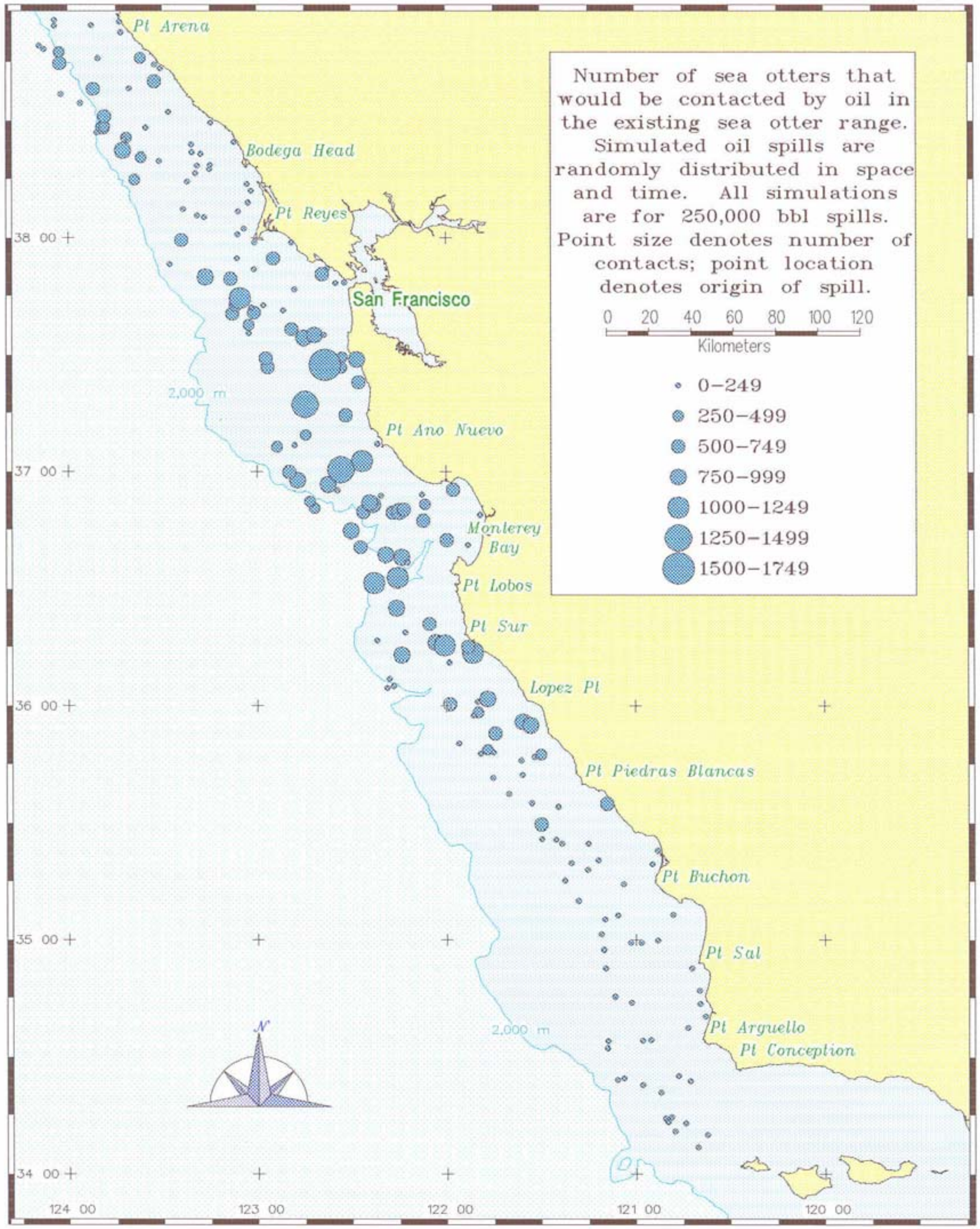

Figure 2a. Spill origins scaled to number of sea otters contacted in existing range from baseline model runs.

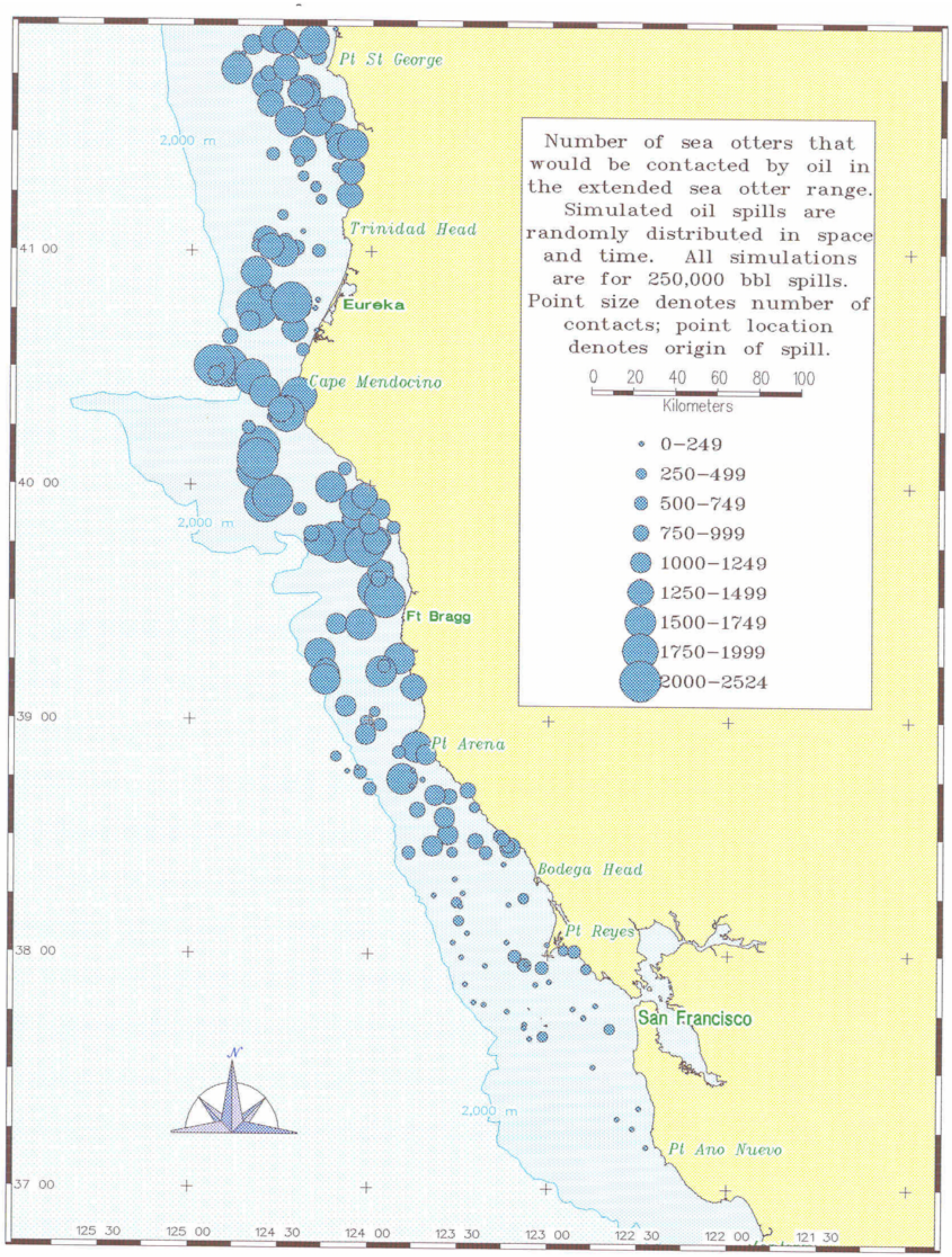

Figure 2b. Spill origins scaled to number of sea otters contacted in extended range from baseline model runs.

In the extended range, the number of sea otters likely to be contacted by a spill occurring between the California/Oregon border and Bodega Head is relatively high. (Although we did not model spills occurring north of the State boundary, spills originating off Oregon could also reach the extended sea otter range). The greatest risk would result from spills originating in the area from Eureka to Ft. Bragg. Spills south of Bodega Head do not represent a major threat to the extended sea otter range. Further, it appears unlikely that a spill could occur that would have a major impact on both the existing and the extended sea otter ranges. In general, the impact of spills occurring north of Bodega head would have little impact on the sea otters in the existing range; spills occurring south of Bodega Head would be unlikely to have a major impact on sea otters in the extended range.

Detailed Scenarios

Three oil spill scenarios were chosen to model impacts of an *Exxon Valdez*-size spill on the existing sea otter range and on a hypothetical range representing a possible future distribution of sea otters along the northern California coast. Slicks produced by simulated spills were modeled as uncontained and freely-drifting, and not acted upon by dispersants or other methods that might be used to reduce impacts. Each scenario simulated a release of 250,000 bbl of oil, but differed in the location of the release site and in the winds and currents moving oil slicks. Both 100th percentile worst case and 90th percentile scenarios were modeled in detail for the existing range, assuming that a "reasonable" worst case spill falls somewhere in between these percentiles. For the expanded range along the northern California coast, only the worst case spill was used.

Estimates of mortality of sea otters were determined from a relationship of survival of sea otters as a function of distance from the spill origin (Brody 1992). The basis for this relationship was the capture database of sea otters in Alaska following the *Exxon Valdez* oil spill. The relationship assumes that survival of captured oiled sea otters is representative of a population of oiled animals observed but not removed from their con- taminated habitat. It seems likely that many sea otters left to their fate would become additionally oiled over time until they ultimately died of exposure. In the absence of substantiation, the estimates of mortality derived from this relationship should be viewed as minimum values.

Existing Range. The 100th percentile worst case scenario simulated a spill 36 km (19.5 nmi) west of Point Ano Nuevo with oil driven by real-time winds recorded from March 4 through 25, 1991. Over this three-week period, northwest winds were interrupted repeatedly by the passage of storms. South and southwest winds associated with these low-pressure cells slowed southward movement of the slick. Contact with sea otter habitat first occurred six days following the release when oil beached near Cypress Point and Point Lobos (Figure 3). Oil continued to enter sea otter habitat over the next three days under variable west and northwest winds to about 20 kts, and resulted in heavy contamination of nearshore waters to about Pfeiffer Point. The main body of the slick resumed its southward drift on day 9 after the spill under northwest winds of 20-30 kts, sparing parts of the sea otter range between Pfeiffer Point and Point Lopez. On day 12, south, southwest, and west winds of 20 kts or more again pushed oil toward shore, initially resulting in heavy oiling of sea otter habitat from Cape San Martin to about San Simeon Point. Over the subsequent four days, variable winds kept oil close to shore, first spreading northward to Lopez Point and then southward to Point Sal. By day 17, northwest winds of 15-25 kts resumed and oil was driven southward. Oil not yet beached rounded Point Conception by about day 20, and slicks became increasingly fragmented as oil drifted into the Santa Barbara Channel.

During this 100th percentile worst case spill episode, 1,820 southern sea otters were contacted by oil. The greatest number were contacted from day 6 through day 12, when most of the sea otter range from Cypress Point to San Simeon Point was extensively oiled (Figure 4; Table 1). Applying the relationship of sea otter survival to distance from the spill origin (Brody 1992), mortality from this spill scenario was estimated to be 777 sea otters (37% of the spring 1992 population). In the heavily contaminated portions of the coast from Cypress Point to Pfeiffer Point, the local population suffered mortality of about 55%, while mortality in habitat from Cape San Martin to San Simeon Point, also subject to heavy oiling, was 36% or less.

The 90th percentile worst case scenario was a spill released 20 km (11 nmi) west of San Gregorio Beach (San Mateo County) and about 36 km (19.5 nmi) northwest of Point Ano Nuevo. The simulated spill was driven by real-time winds of August 11 through 31, 1990. Initial contact with sea otter habitat from Pescadero Point to Point Ano Nuevo occurred on the day after release (Figure 5). The oil slick moved along the shore under northwest winds of 15-20 kts, contacting sea otter habitat from Sand Hill Bluff to Point Santa Cruz two to three days after the spill; sea otter habitat near Soquel Point received only light oiling. By four to five days following the release, oil had spread across Monterey Bay resulting in heavy contamination from Moss Landing Harbor to Point Lobos. Five to six days following the spill, oil drifted south in a compact 10 km wide slick contacting sea otter habitat to about Pfeiffer Point. The slick then moved 3-5 km offshore, still remaining somewhat compact in the light winds and seas, and next contacted shore in the vicinity of Lopez Point about 13 days after the spill. Under the influence of variable winds from the south and west, oil continued to contact sea otter habitat from Lopez Point to Cape San Martin until about day 17, and thereafter drifted offshore leaving most of the range south of Point Piedras Blancas untouched.

In the 90th percentile spill scenario, oil contacted 881 sea otters. The greatest number of sea otters were contacted along the Monterey Peninsula and southward to Point Sur on days four and five following the spill (Figure 6; Table 2). Applying the relationship of sea otter survival to distance from the spill origin (Brody 1992), mortality from the 90th percentile spill scenario was estimated to be 456 sea otters (27% of the fall 1992 population). Mortality north of Point Santa Cruz was about 75% of numbers contacted, declining with distance to 56% mortality from Monterey Peninsula to Pfeiffer Point, and 39% mortality from Lopez Point to about Point Piedras Blancas.

Northern California Extended Range. The 100th percentile scenario was an oil spill released 15 km (8.2 nm) north of Cape Mendocino and 14 km (7.6 nm) off False Cape, the nearest land. Real-time winds driving the movement of oil were taken from May 11 through June 1, 1990. First contact with sea otter habitat occurred within 24 hours of the release and contaminated nearshore waters and the shoreline from Cape Mendocino to Punta Gorda (Figure 7). Over the first two days following the spill, the slick contacted shore to about Big Flat Creek and then moved 10 km offshore, well beyond sea otter habitat. By day 5, oil again moved toward shore and contaminated sea otter habitat from Cape Vizcaino to Point Arena. Thereafter, oil drifted south and did not again contact sea otter habitat until about day 9 when, under the influence of southwest winds to 20 kts, it swept along the coast of Point Reyes. From days 10 through 18, under south, southwest, and west winds to about 25 kts, oil remained predominantly within the Gulf of the Farallones. Contact with sea otter habitat was again made on days 19 through 21 when oil beached along the shore in Marin and San Francisco Counties.

The 100th percentile spill scenario off the northern California coast contacted 2,018 sea otters in the hypothetical extended range. The greatest number were contacted in the first seven days after the release when oil spread from Cape Mendocino to nearly Point Delgada and from Cape Vizcaino to Point Arena (Figure 8; Table 3). Applying the relationship of sea otter survival to distance from the spill origin (Brody 1992), mortality from this spill scenario was estimated to be 927 sea otters (20% of the northern California population). In the portion of the expanded range north of Point Arena, mortality was 50% of numbers contacted. Mortality of sea otters along the mainland shore south of Point Reyes was 28% of numbers contacted.

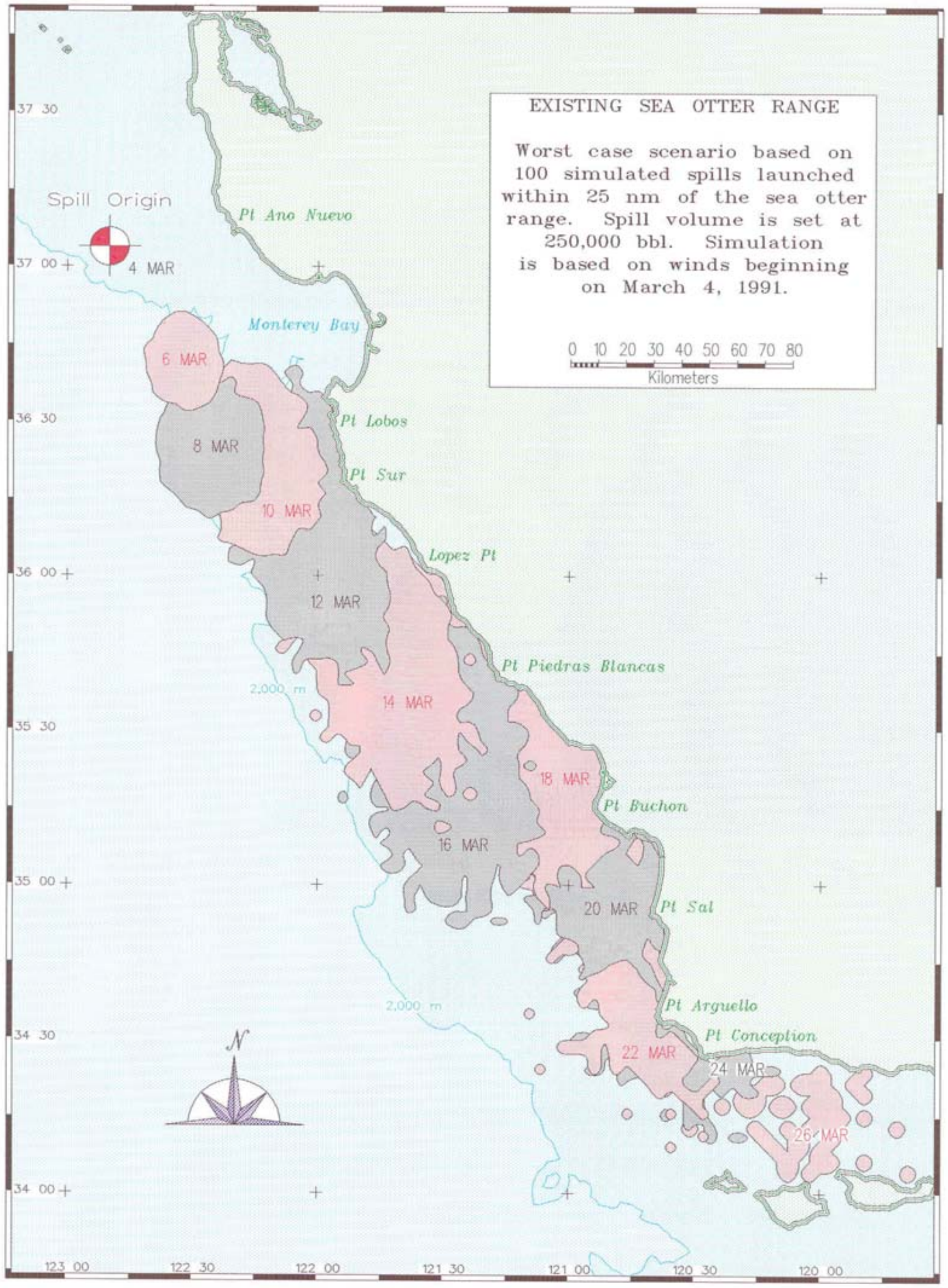

Figure 3. Trajectory of a simulated *Exxon Valdez*-size oil spill off the existing sea otter range. This simulation was the 100th ranking case out of 100 such spills launched within 25 nm of the coast. Alternating red and gray areas show the position of the slick through time.

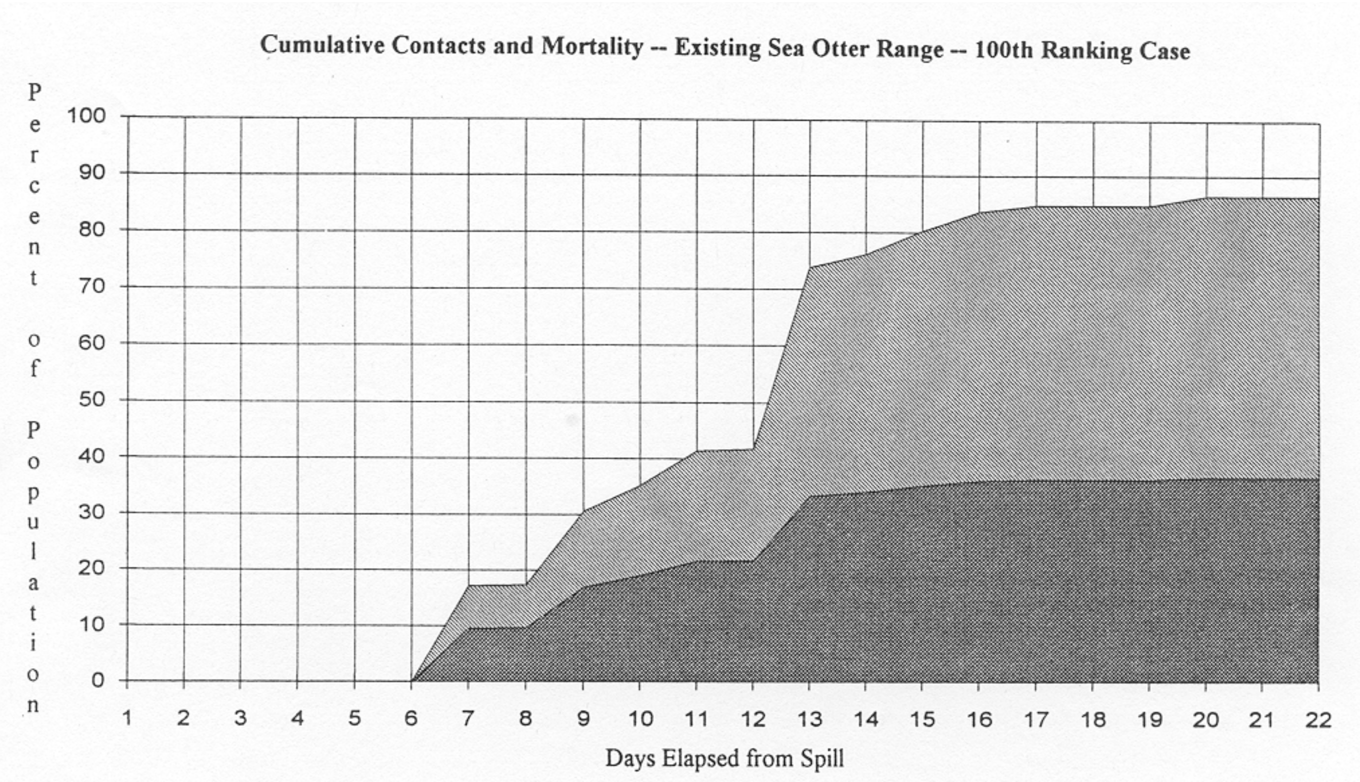

Figure 4. Cumulative percent of the total population in the existing sea otter range that would have been contacted or killed by an oil spill simulation. This simulation was the 100th ranking case out of 100 simulations of *Exxon Valdez*-size spills launched within 25 nm of the sea otter range. Light stippled area represents cumulative contacts, dark area represents estimated direct mortality.

Table 1. Existing Range: Number of southern sea otters contacted and estimated mortality resulting from 100th percentile worst case oil spill scenario.

Day	Number Contacted	Mortality [a]	Cumulative Contacted	Cumulative Mortality
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	362	202	362	202
7	4	2	366	204
8	277	152	643	356
9	98	45	741	401
10	129	54	870	455
11	9	3	879	458
12	673	245	1552	703
13	48	14	1600	717
14	87	25	1687	742
15	72	19	1759	761
16	25	6	1784	767
17	0	0	1784	767
18	0	0	1784	767
19	36	10	1820	777
20	0	0	1820	777
21	0	0	1820	777

[a] Mortality calculated using the relationship of sea otter survival and distance from the spill origin (Brody 1992); it is assumed that this number of sea otters will die, among those contacted, regardless of number of days of exposure. Calculations assume no mitigation of impacts by rescue and rehabilitation of sea otters.

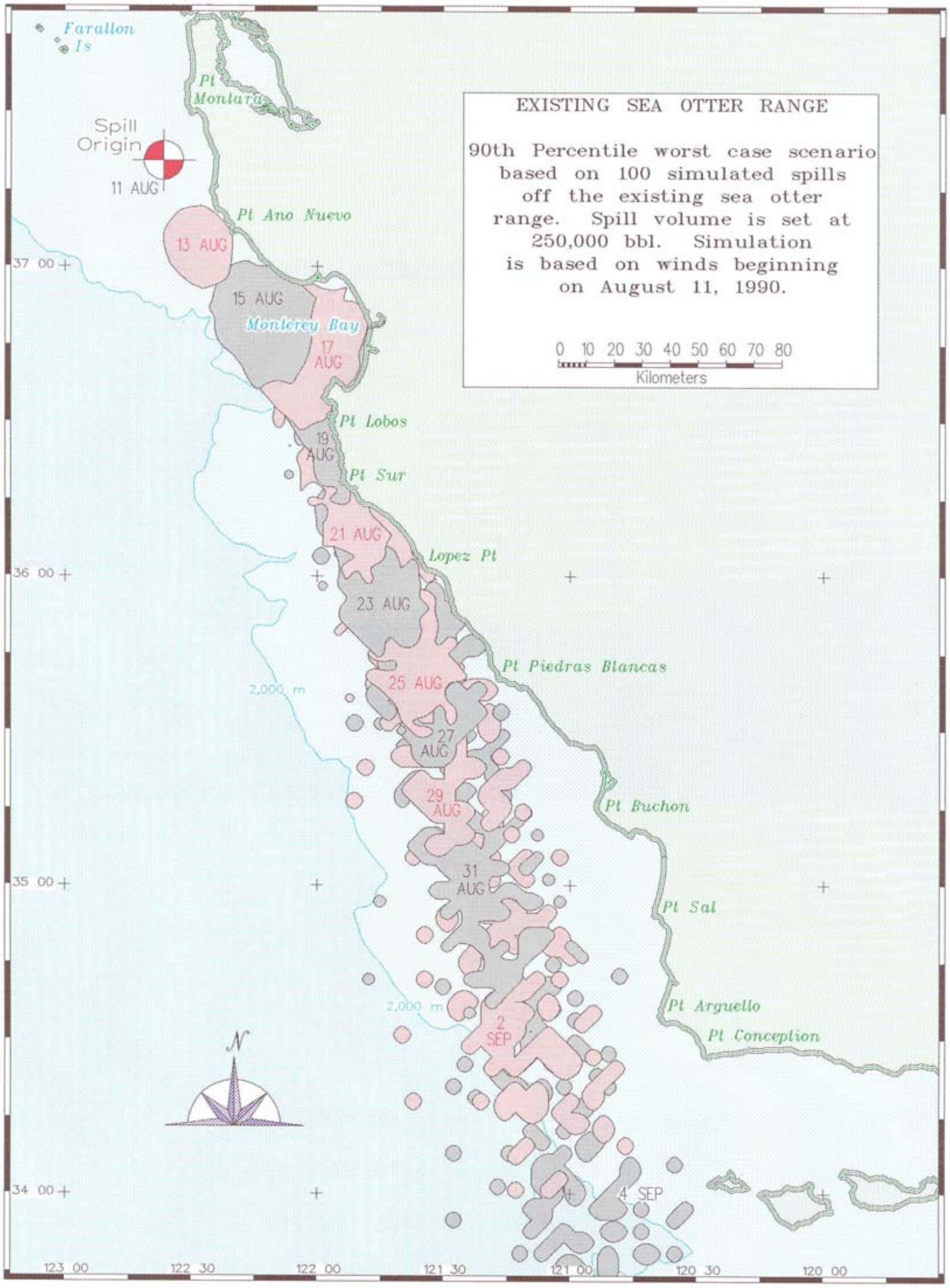

Figure 5. Trajectory of a simulated *Exxon Valdez*-size oil spill off the existing sea otter range. This simulation was the 90th ranking case out of 100 such spills launched within 25 nm of the coast. Alternating red and gray areas show the portion of the slick through time.

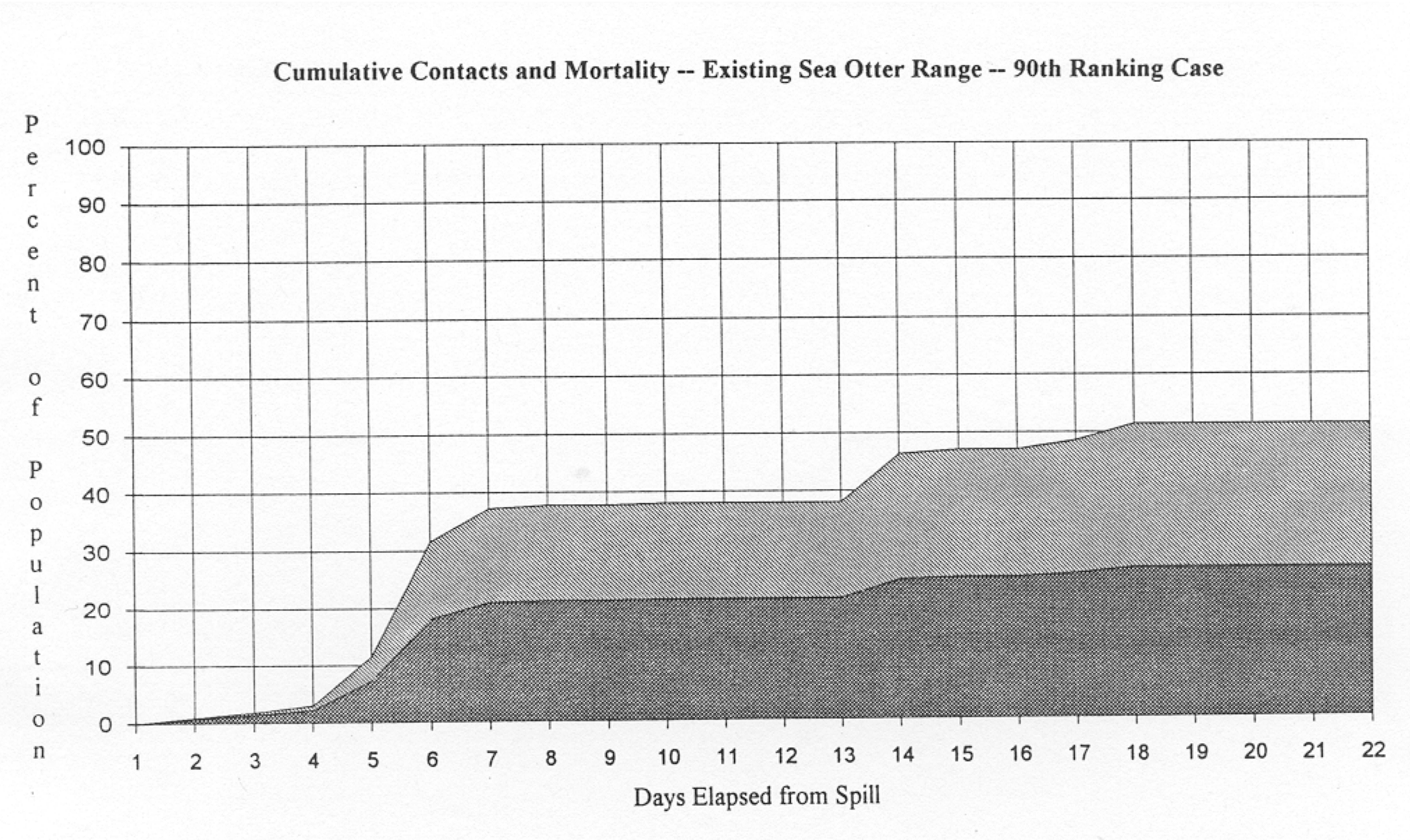

Figure 6. Cumulative percent of the total population in the existing sea otter range that would have been contacted or killed by an oil spill simulation. This simulation was the 90th ranking case out of 100 simulations of *Exxon Valdez*-size spills launched within 25 nm of the sea otter range. Light stippled area represents cumulative contacts, dark area represents estimated direct mortality.

Table 2. Existing Range: Number of southern sea otters contacted and estimated mortality resulting from 90th percentile reasonable worst case oil spill scenario.

Day	Number Contacted	Mortality[a]	Cumulative Contacted	Cumulative Mortality
0	0	0	0	0
1	17	13	17	13
2	15	11	32	24
3	20	14	52	38
4	146	87	198	125
5	344	186	542	311
6	96	49	638	360
7	9	4	647	364
8	0	0	647	364
9	6	3	653	367
10	0	0	653	367
11	0	0	653	367
12	0	0	653	367
13	141	56	794	423
14	12	6	806	429
15	0	0	806	429
16	27	10	833	439
17	48	17	881	456
18	0	0	881	456
19	0	0	881	456
20	0	0	881	456
21	0	0	881	456

[a] Mortality calculated using the relationship of sea otter survival and distance from the spill origin (Brody 1992); it is assumed that this number of sea otters will die, among those contacted, regardless of number of days of exposure. Calculations assume no mitigation of impacts by rescue and rehabilitation of sea otters.

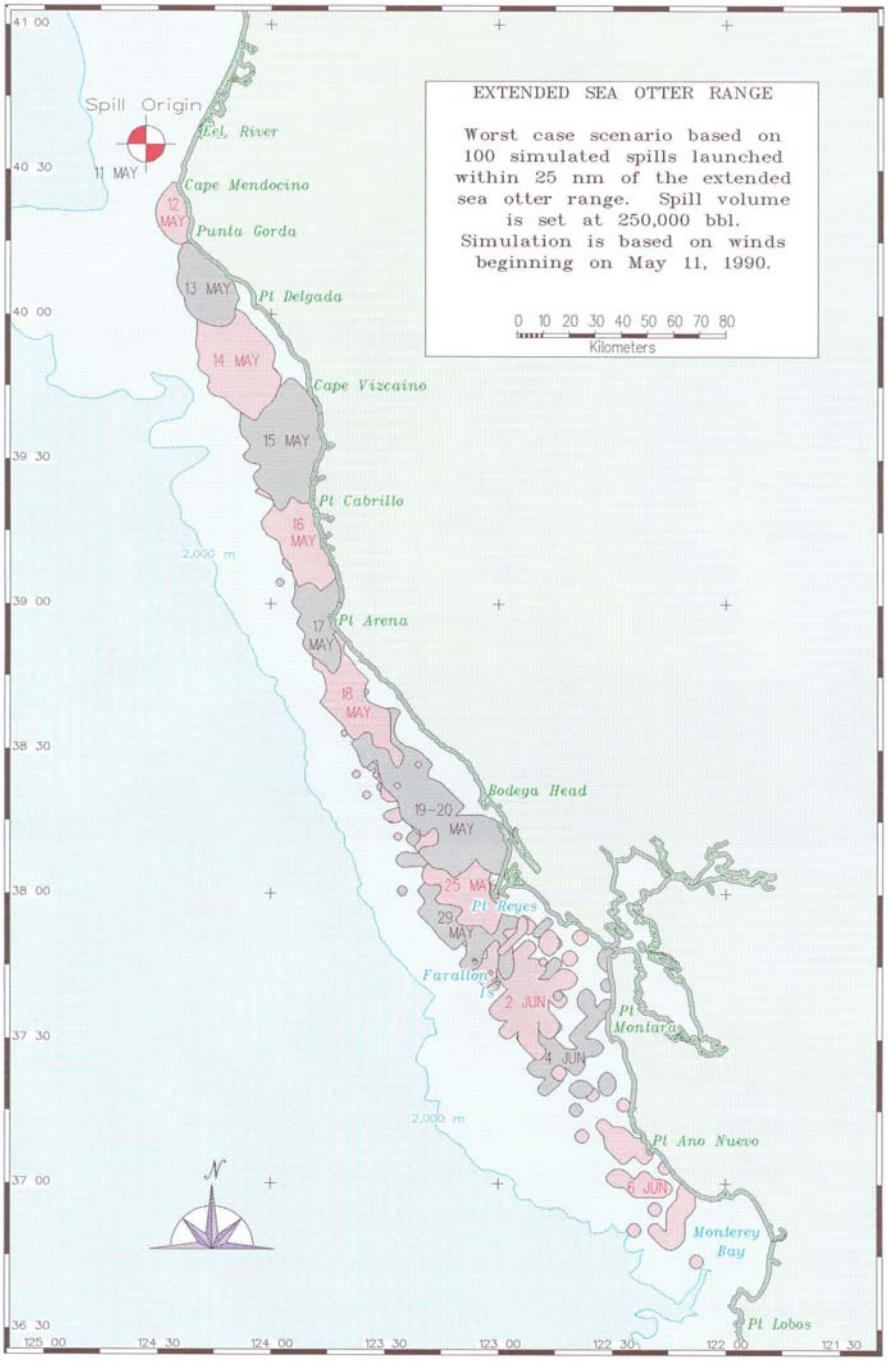

Figure 7 Trajectory of a simulated *Exxon Valdez*-size oil spill off the extended sea otter range. This simulation was the 100th ranking case out of 100 such spills launched within 25 nm of the coast. Alternating red and gray areas show the portion of the slick through time.

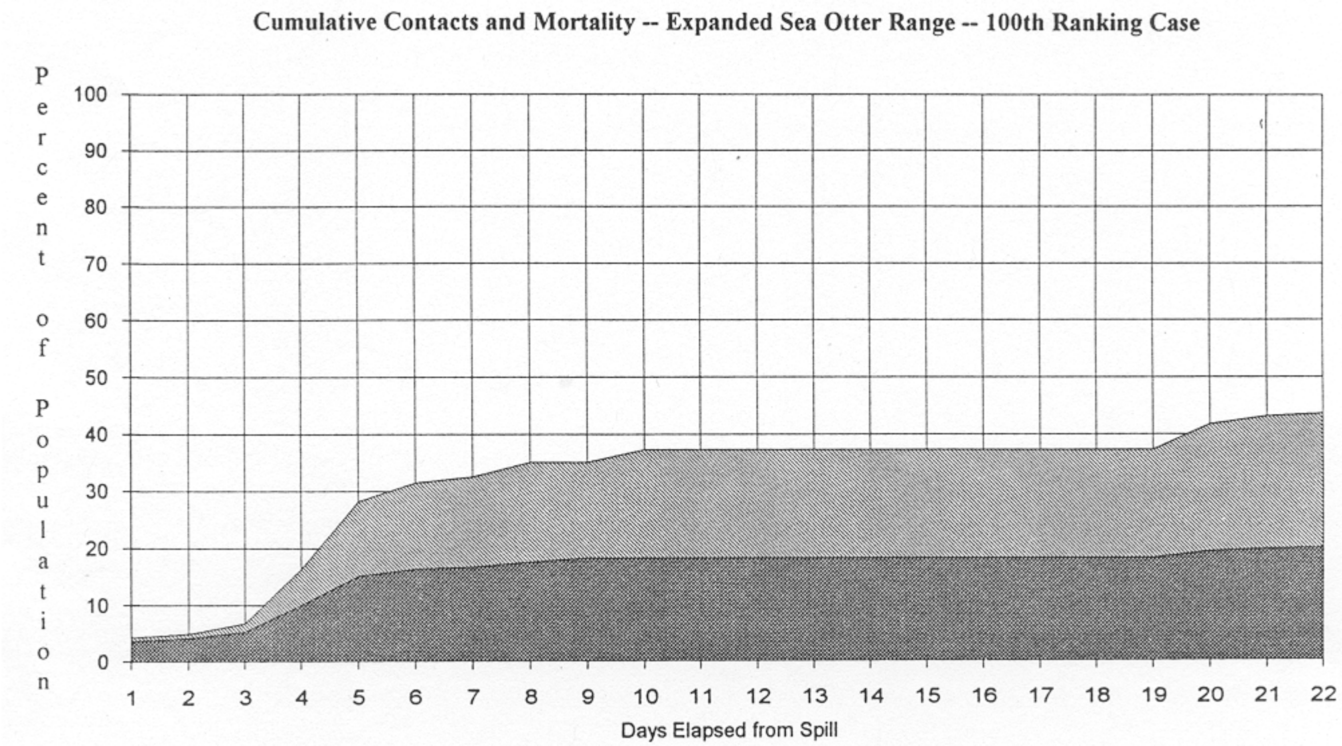

Figure 8. Cumulative percent of the total population in the extended sea otter range that would have been contacted or killed by an oil spill simulation. This simulation was the 100th ranking case out of 100 simulations of *Exxon Valdez*-size spills launched within 25 nm of the expanded sea otter range. Light stippled area represents cumulative contacts, dark area represents estimated direct mortality.

Table 3. Northern California Extended Range: Number of southern sea otters contacted and estimated mortality resulting from 100th percentile worst case oil spill scenario.

Day	Number Contacted	Mortality [a]	Cumulative Contacted	Cumulative Mortality
0	201	171	201	171
1	30	21	231	192
2	85	54	316	246
3	443	216	759	462
4	548	240	1307	702
5	151	57	1458	759
6	48	17	1506	776
7	120	41	1626	817
8	0	0	1626	817
9	101	31	1727	848
10	0	0	1727	848
11	0	0	1727	848
12	0	0	1727	848
13	0	0	1727	848
14	0	0	1727	848
15	0	0	1727	848
16	0	0	1727	848
17	0	0	1727	848
18	0	0	1727	848
19	204	55	1931	903
20	66	18	1997	921
21	21	6	2018	927

[a] Mortality calculated using the relationship of survival of a sea otter and distance from the spill origin (Brody 1992); it is assumed that this number of sea otters will die, among those contacted, regardless of number of days of exposure. Calculations assume no mitigation of impacts by rescue and rehabilitation of sea otters.

Distance From Shore

Simulated oil spills were released at each of six stations at increasing distances along five lines (Figure 9). The results of simulations for each station are shown in Figures 10a-10e and Figure 11. Offshore of Point Sal, Point Piedras Blancas, and Point Sur, the number of sea otters likely to be contacted by a spill decreases with increasing distance from shore. This occurs because spills that originate farther offshore are more likely to remain offshore, moving south-eastward with the prevailing winds into the Santa Barbara Channel. Spills occurring at the far southern end of the range off Point Sal, even those occurring close to shore, are unlikely to contact many sea otters because prevailing winds would move the slick steadily toward the southeast and because the density of sea otters is relatively low at the southern margin of the range. Spills offshore of Point Piedras Blancas occasionally result in significant numbers of contacts, especially spills originating within about 20 nmi of shore. Spills offshore of Point Sur show a pattern similar to those off Point Piedras Blancas, but with higher numbers of contacts at each distance offshore.

The number of sea otters likely to be contacted by a spill increases toward the northern end of the existing range. Spills originating in the area off Point Año Nuevo represent the greatest threat in terms of the number of sea otters that would be contacted. Spills originating in this area would typically move southeast, contacting the shoreline in the most densely occupied portions of the existing range. The relationship between the number of sea otters likely to be contacted by a spill and the distance offshore where the spill originates becomes more complex north of Point Año Nuevo. Spills originating farther seaward along the line extending west from San Francisco are actually more likely to contact large numbers of sea otters than are spills originating closer inshore. This occurs because oil from inshore spills is more likely to beach before reaching areas of high sea otter density. In contrast, spills originating further offshore drift a longer period of time before making landfall and are carried farther to the south. While older spills may undergo some weathering and decrease in toxicity, they will also have spread over a larger area and can be expected to contact a larger portion of the sea otter range.

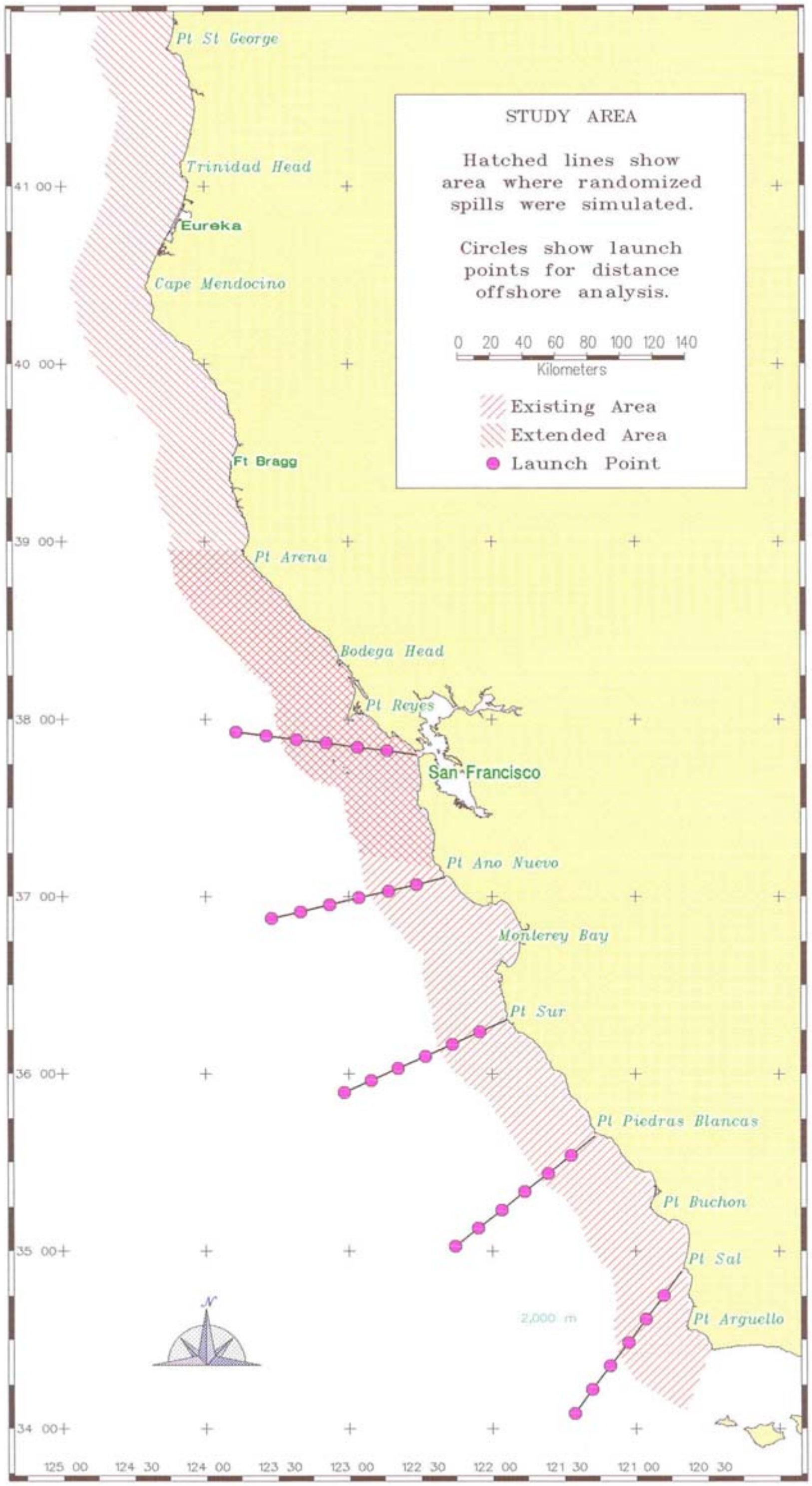

Figure 9. Location of release sites at 10 nmi increments from shore off the existing sea otter range.

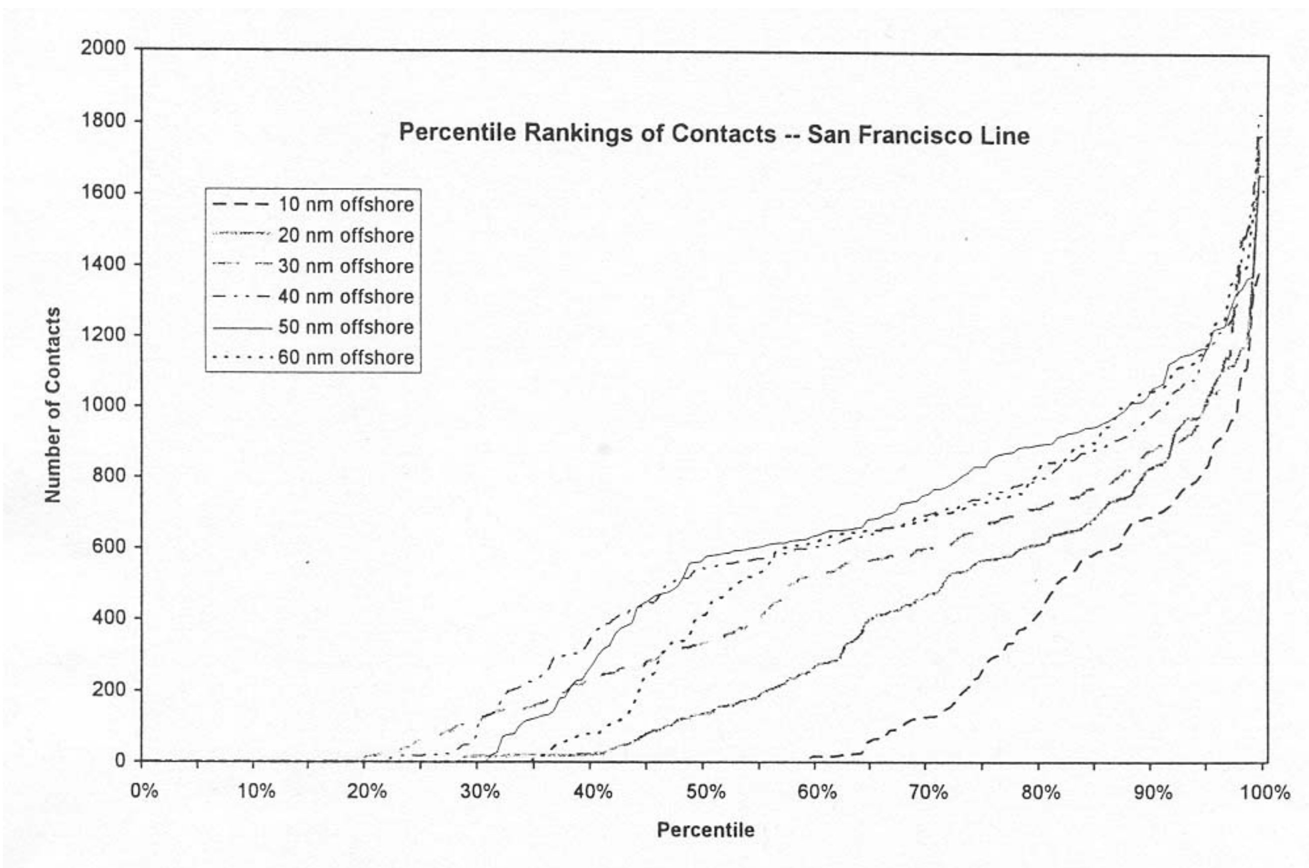

Figure 10a. Percentile ranking of number of sea otter contacts from spills at increasing distance from shore along San Francisco line.

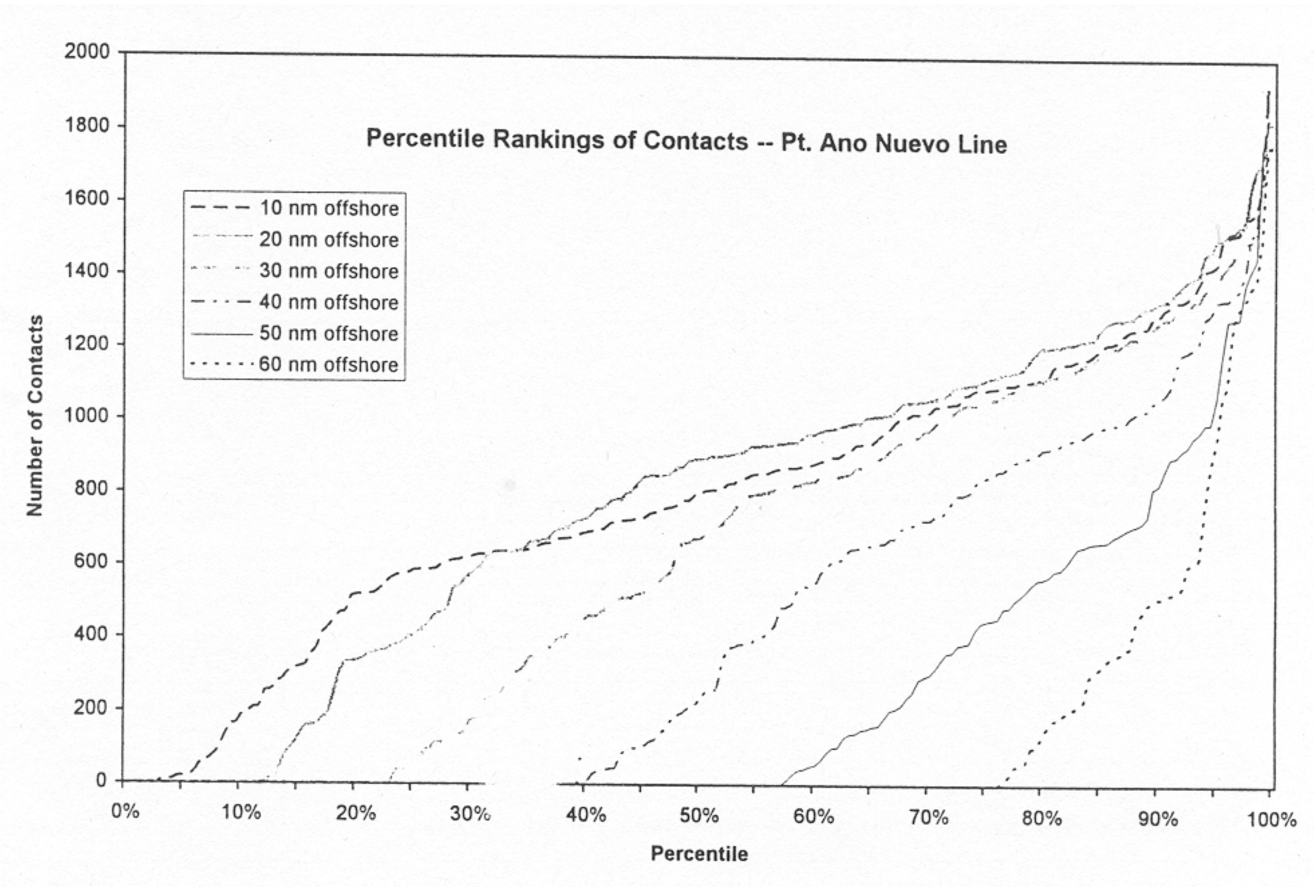

Figure 10b. Percentile ranking of number of sea otter contacts from spills at increasing distance from shore along Point Año Nuevo line.

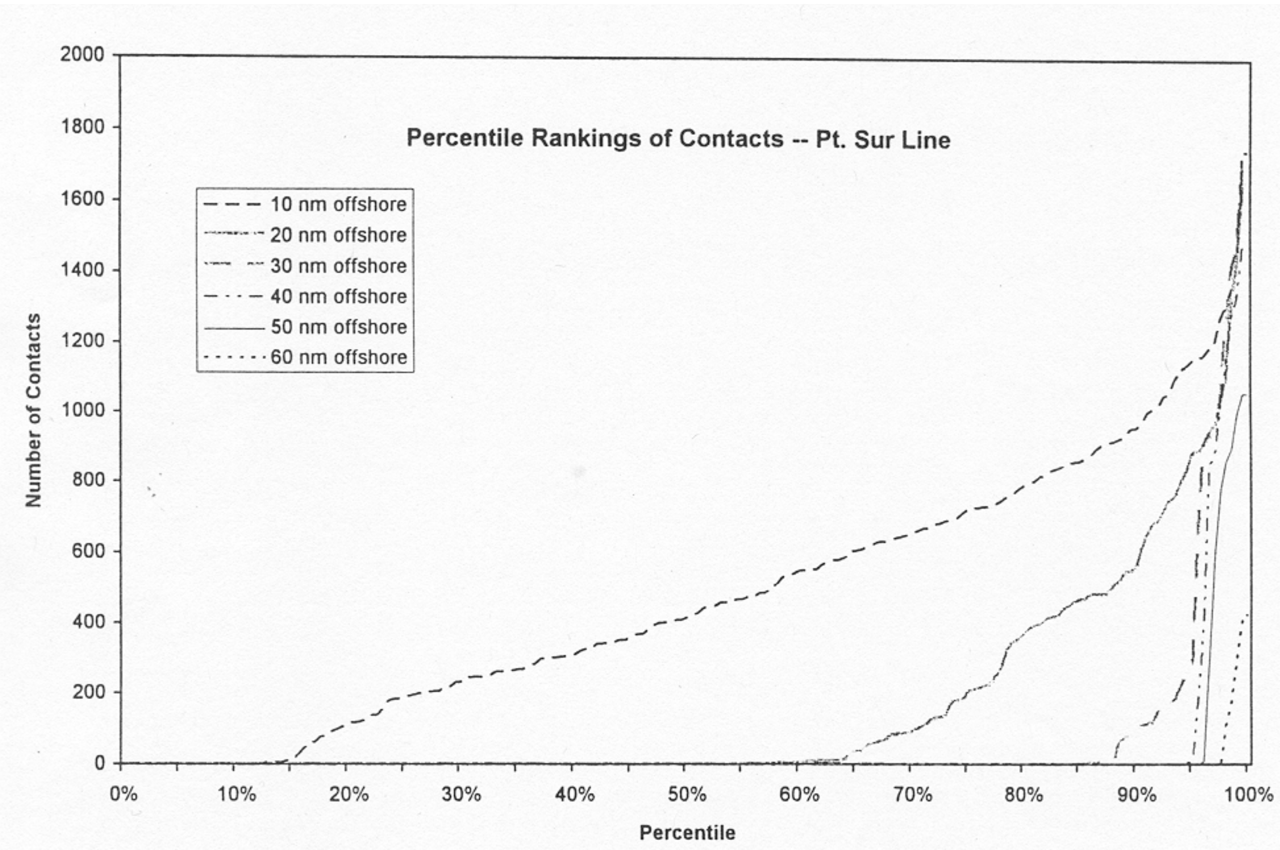

Figure 10c. Percentile ranking of number of sea otter contacts from spills at increasing distance from shore along Point Sur line.

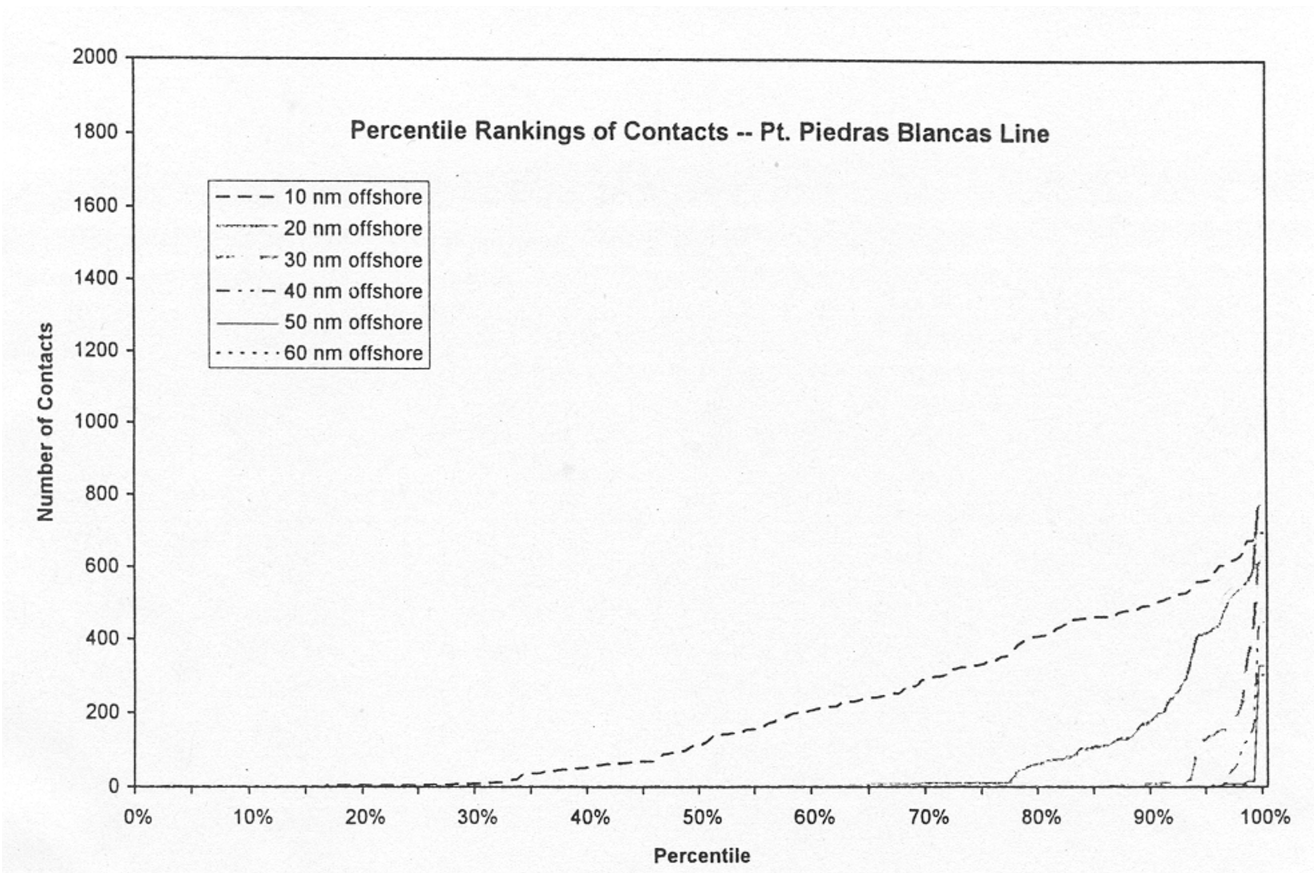

Figure 10d. Percentile ranking of number of sea otter contacts from spills at increasing distance from shore along Point Piedras Blancas line.

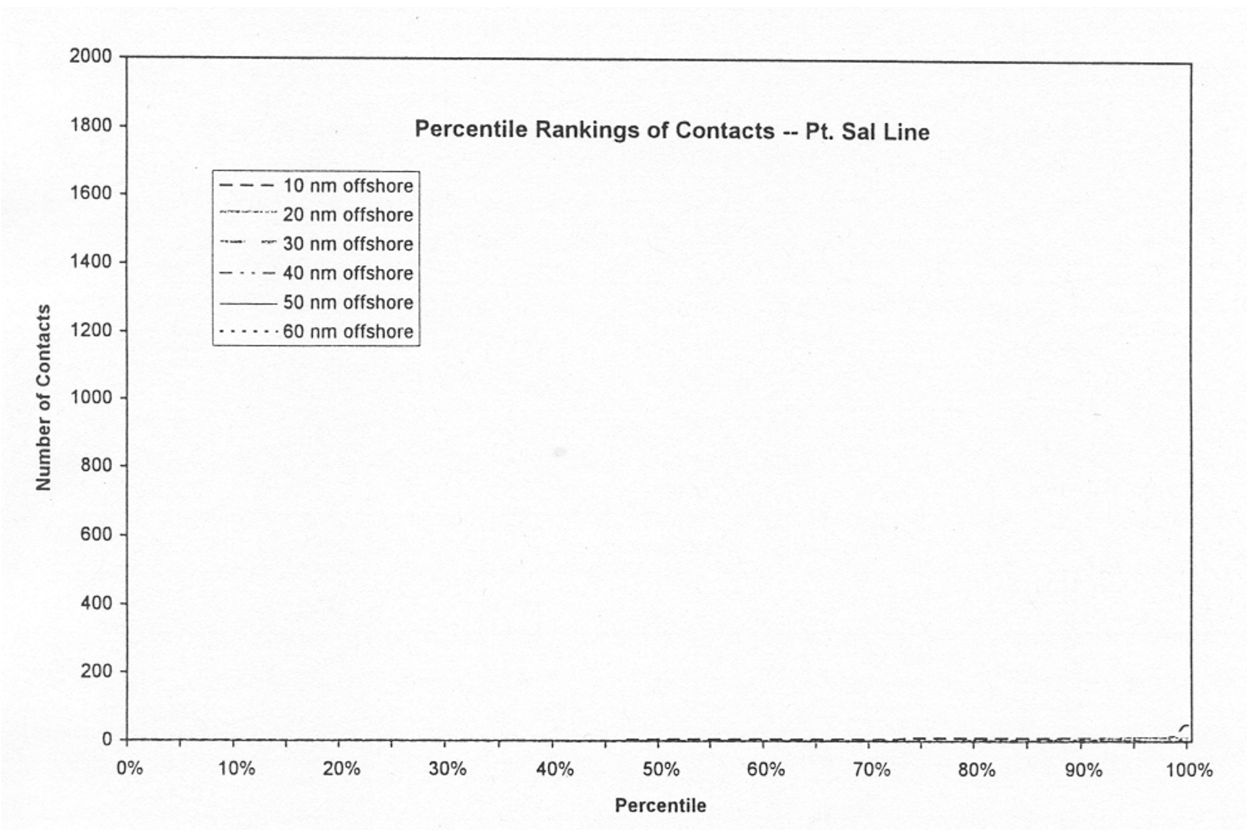

Figure 10e. Percentile ranking of number of sea otter contacts from spills at increasing distance from shore along Point Sal line.

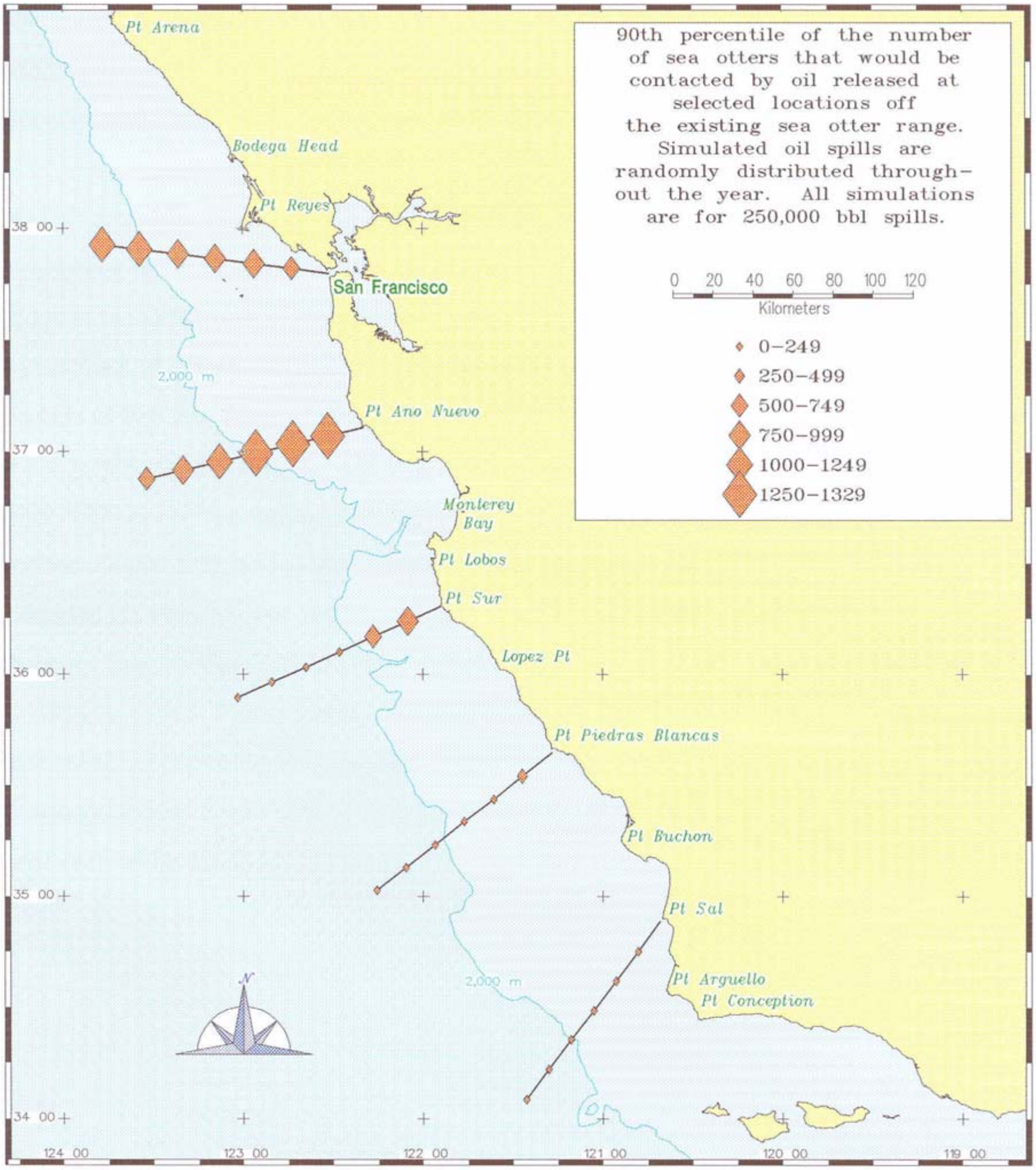

Figure 11. Sea otter contacts by release sites at increasing distance from shore for 90th percentile spill.

Analysis of simulated spills offshore of Point Año Nuevo shows some of the same pattern evident along the San Francisco line: spills originating 20 nmi offshore typically would contact more sea otters than those originating 10 nmi offshore.

The relationship between the number of sea otters contacted in model oil spill simulations as a function of distance offshore and north/south position where the spill occurred is summarized in Figures 11 and 12. Both figures show the 90th percentile of the number of otters contacted by simulated spills released at each of the six stations on each of the five lines. Clearly, the greatest risk to sea otters results from spills at the northern end of the range. Off Point Año Nuevo, the number of sea otter contacts remains high even for spills at distances of 50-60 nmi offshore. Off San Francisco, the number of contacts actually increases with increasing distance from shore. Consequently, efforts to reduce the likelihood of oil spills within 50 miles of land in waters from Monterey Bay to the Gulf of the Farallones may have little effect on reducing the risk to sea otters. For these spills, amelioration of the impacts may result from natural weathering and use of dispersants. For the range south of about Point Sur, a significant reduction in risk to sea otters may be achieved by reducing the likelihood of spills within 30-40 nmi of land.

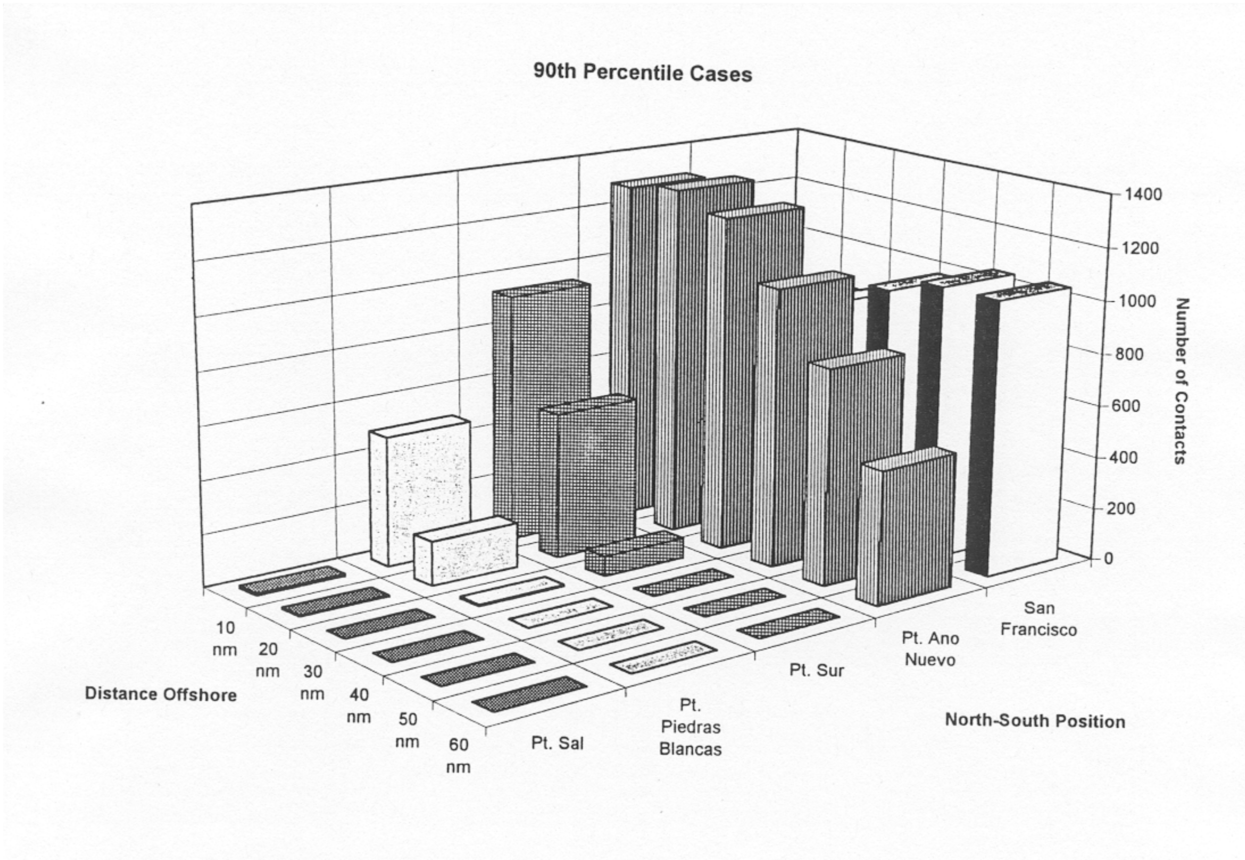

Figure 12. Sea otter contacts by distance from shore and latitude for 90th percentile spill.

Spill Size

To examine the effect of spill size on number of sea otters contacted, 200 simulated oil spills were released from randomly selected sites for each of the following volumes: 31,250 bbl, 62,500 bbl, 125,000 bbl, 500,000 bbl, and 1,000,000 bbl (Figure 13). Not surprisingly, the number of contacts at any percentile level is greater with increasing spill size, as is the likelihood that any otters at all will be contacted. However, the relationship of sea otter contacts and spill size is nonlinear. At the 90th or 95th percentile worst case level, roughly two to three times as many otters would be contacted by a 1,000,000 bbl spill as by a 31,250 bbl spill, despite a 32-fold increase in spill volume. Similarly, a 31,250 bbl spill results in a probability of no sea otter contacts of about 60.5%, while a 1,000,000 bbl spill results in a 12.5% chance of no sea otter contacts. Although relatively small spills tend to result in fewer sea otter contacts than do large spills, smaller spills do have the potential to contact many sea otters. For a 31,250 bbl spill, the 90^{th} and 95th percentile of sea otter contacts is 456 and 552 sea otters respectively, representing a substantial proportion of the total population in the existing sea otter range. The worst case scenario (i.e., the spill resulting in the greatest number of contacts among 200 simulations) resulted in 1,119 otter contacts, representing nearly one-half of the existing population.

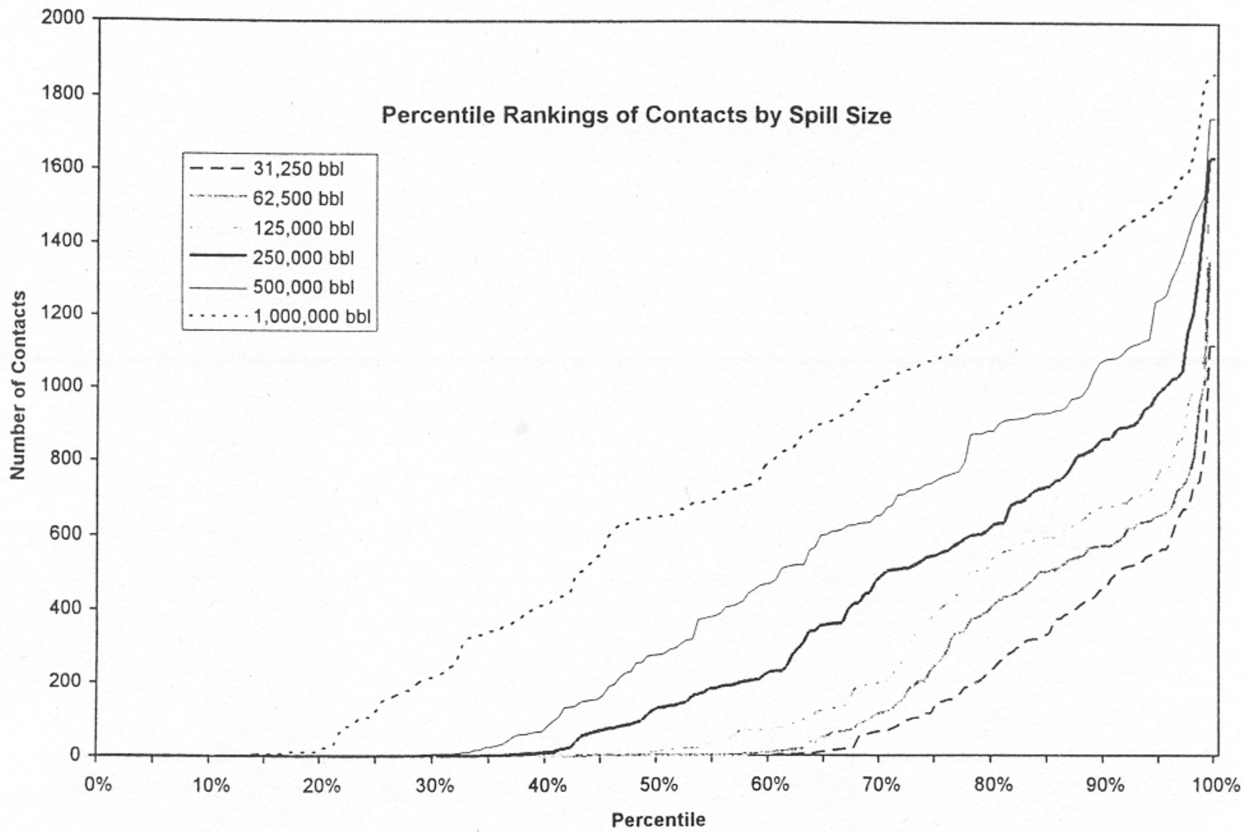

Figure 13. Percentile ranking of sea otter contacts by spill size.

Final Probabilities

The expected number of oil spills along the four tanker routes along the central and northern California coast was projected for a 30-year period (Table 4). In determining the occurrence rate, Anderson and LaBelle (1990) used a world-wide data base of crude oil spills from tankships that does not include spills from product carriers or barges and is not limited to spills in U. S. waters. However, there is no clear evidence that spills in U. S. waters are less frequent than elsewhere, nor do we have reason to suppose that the occurrence rate for spills from product carriers and barges would be substantially less than that of tankships carrying crude oil. The volume for each route included both crude oil and oil products, and transport by both tanker and barge. (Transport by barge accounted for less than 1% of all crude oil and about 8% of oil products.)

Table 4. Volumes of oil transported by tanker along the California coast and expected number of oil spills.

Route	1992 Volume (bbl)	30-yr Volume (billion bbl)	Expected Number of Spills
North Coast	38,662,107	1.160	0.161 [a]
Alaska/Overseas	219,196,895	6.576	2.959 [b]
South Coast	114,735,358	3.442	3.098
Estero Bay	3,560,489	0.107	0.096

[a]30-yr volume multiplied by 0.9 x 0.154

[b]30-yr volume multiplied by 0.9 x 0.5

The number of sea otters that may be contacted by oil spills along these routes was estimated from the trajectory model runs described above. We assumed that spills from North Coast traffic would occur with equal likelihood within 25 nmi from land along the coast between the latitudes of Point Arena and Point Año Nuevo. Spills north of Pt.

Arena were assumed to produce no impacts to the present population of southern sea otters. Spills from Alaska and Overseas tanker traffic arriving along the east-west traffic lane of the San Francisco TSS were assumed to occur within 25 nmi of land between the latitudes of Pt. Reyes and Point Año Nuevo. Spills resulting from South Coast traffic were assumed to occur within 25 nmi of land between the latitudes of Point Reyes and Point Conception. Spills south of Pt. Conception were assumed not to pose a threat to the present sea otter population. Spills originating from tanker traffic out of Estero Bay were assumed to occur within 25 nmi of the shore between the latitudes of Point Piedras Blancas and Point Conception.

The computation of final probabilities was based on the following additional assumptions:

> The occurrence of oil spills is an independent random event that can be modeled as a Poisson process. In other words, the occurrence of one oil spill in excess of 1,000 bbl does not affect the likelihood of subsequent spills.
>
> Spill size is independent of location and source and is assumed to be distributed according to data on spill events in U. S. waters from 1974-1985 (MMS 1986). We further assumed that a reasonable truncation of this frequency distribution was at 350,000 bbl, based on the size of tankers using San Francisco Bay and the South Coast Route.
>
> The sea otter distribution is static over the next 30 years, and remains unaltered from one spill incident to the next.

The upper bound of numbers of sea otters contacted by oil in the existing range during a 30-year period are provided at various levels of final probability in Table 5.

Table 5. Final probability levels and upper bound of numbers of sea otters in the existing range contacted by oil during a 30-year period.

Final Probability	Upper Bound of Sea Otters Contacted by Oil
10%	33
20%	118
30%	268
40%	455
50%	625
60%	785
70%	988
80%	1267
90%	1698
95%	2108
99%	2871

It should be emphasized that the number of otters contacted by oil would occur over a 30-year time frame, and may result from multiple spill events. Because it is assumed that the population acted upon is static and undiminished for each iteration of the model, it is probable that the analysis underestimates the impacts of multiple spills. This would be especially true if spills during the 30-year period occurred close together in time, not allowing for sufficient recovery of the population between spills.

In evaluating these estimates of number of contacts, the following points should be kept in mind:

> Spills are not equally likely to occur in all areas. The assumption that spills occur with uniform probability within a 25 nm band along the coast is an important simplification and should be evaluated. Some areas, such as the Gulf of the Farallones, may have a relatively higher risk of accidents due to the density of tanker traffic.
>
> The model samples from a frequency distribution of spill size with a cut-off at 350,000 bbl. This cut-off is provided so that the frequency distribution is truncated at the largest volume that might be released in a single accident affecting the sea otter population. It is possible that a very large crude oil tanker transiting between Alaska and Los Angeles/Long Beach could drift into waters within 25 nm of the coast; these tankers, with a capacity of 1,000,000 bbl, typically remain 50-100 nm offshore except on entry into the Santa Barbara Channel TSS. The model is sensitive to the frequency distribution of spill size and truncation volume; thus, these parameters should be further evaluated.
>
> Sea otter mortality cannot be derived in a simple manner from number of contacts. At the very least, the way an oil spill affects individual sea otters depends on the degree of exposure and properties of the oil. Thin or fragmented oil slicks, such as might result from smaller spills, may result in a lesser degree of

exposure. In the model, only very large spills were considered. However, the smaller of these may produce a lesser degree of exposure than the larger spills. The state of the oil contacting sea otters may also affect estimates of mortality. Fully weathered oil may be less toxic and less likely to adhere to a sea otter's pelage. The longer oil drifts, the more likely that weathering will occur. Therefore, spills farther offshore may have a lesser impact on the sea otter population than indicated by model results.

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