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USING HISTORICAL OIL SPILL DATA TO PREDICT SEABIRD MORTALITY FROM SMALL OIL SPILLS

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ABSTRACT

The relationship between the number of seabirds killed or injured in an oil spill incident and the quantity of oil spilled is affected by numerous factors. Burger (1993) analyzed this relationship, but did not find a significant correlation. After adding twenty-nine new spill incidents to Burger's database and restricting the analysis to spills occurring in open marine waters in the northern hemisphere, we found a significant correlation between the log of spill volume and the log of number of birds recovered (n=50, R^2=0.393, P<0.001). A multiple regression of the log of spill volume, latitude, and bird density (available only for Pacific spills) was the best predictor of the number of birds recovered (n=24, R^2=0.58, P<0.001). The number of birds recovered after oil spills in the Pacific Ocean was greater than in the Atlantic Ocean for a given volume of oil. Oil type did not contribute significantly to the predictive power of the relationship.

KEY WORDS
Common Murre, latitude, oil spill, seabird mortality, spill volume, *Uria aalge*

INTRODUCTION

According to U.S. Coast Guard data compiled from 1973 to 2000, about 96% of the oil spills in U.S. waters involve less than 1,000 gallons of oil (USCG, 2000). For spills of this magnitude, injury to seabirds may appear to be small and extensive documentation of injury unwarranted. Nonetheless, small spills occur frequently and can sometimes kill surprisingly large numbers of seabirds, such as a 250-gallon fuel oil spill in Scotland (Campbell et. al, 1978), which led to the recovery of 740 dead seabirds. We examine the potential for a statistical model that can be used to estimate seabird mortality based on documented historical spills and parameters that are easily measured. A statistical model of this type could potentially be used to estimate seabird injuries in incidents, such as small spills, where few data are available for documenting effects on seabirds.

Burger (1993) examined the relationship between oil spill volume and seabird mortality using a data set consisting of 45 spills from around the world. He found a weak but significant relationship between spill volume and the number of birds recovered (n=35), accounting for 14.1% of the variation in the number of birds recovered. We approached the analysis differently, including additional spills and restricting the dataset to spills that occurred in marine waters in the northern hemisphere. We were able to extend the analysis by obtaining data relating to oil type, latitude, and bird density for the many of these spills. Our database included 50 spills, 21 of which were originally analyzed by Burger. For 24 of these spills, we were also able to obtain historical estimates of bird density. We analyzed only the number of birds recovered and did not attempt to analyze estimated mortality since these estimates were available for only a small number of spills.

METHODS

Data Sources

We conducted a literature search of historical oil spills in order to locate as many incident descriptions as possible that contain accounts of seabirds that were recovered during the spill response. Many spills that occurred before the 1970s and many international spills did not include accounts of bird injury. Literature sources included six compilations of spill incidents (Ford, 1985; NOAA, 1992; NOAA, 2003; Burger, 1993; CDFG, 2002; Carter, 2003) and numerous other sources describing specific incidents. We were able to find sufficient information on both the oil spill incident and seabird injury for 50 oil spills. For each of these spills, we recorded the number of birds recovered during spill response, the amount of oil spilled, the latitude of the spill, and the oil type. Where data were available, we also recorded estimates of bird density in the affected area based on a historical GIS database of seabird distributions published by the Minerals Management Service (Bonnell and Ford, 2001). For 24 of the spills (i.e., those which occurred on the Pacific coast), we were able to estimate historical bird densities specific to the season and location of the spill.

Rivers, bays, and estuaries differ from the open ocean in terms of the taxa and behavior of the birds inhabiting the area, and the fate and effects of the spilled oil. We excluded spills that affected primarily estuarine, tidally exposed, or wetland habitats where oil likely did not spread on water to a great extent. However, we included spills in bays and harbors where the spreading of oil on water was limited to some degree by physical barriers.

Because of differences in oceanography, oil spill response methods, seabird taxa, and seabird densities, data from southern hemisphere spills were not considered to be comparable to northern hemisphere spills. Excluding southern hemisphere spills resulted in the removal of 5 spills from the analysis: Metula (Chile), Treasure (South Africa), Venoil (South Africa), Iron Baron (Tasmania), and Castillo de Bellver (South Africa). All spills used in the analysis occurred between 18ºN and 61ºN latitude.

The north Atlantic and north Pacific also differ in ways that might affect oil spill related seabird mortality: bird densities tend to be higher, wave action more intense, and ocean temperatures colder in the Pacific than in the Atlantic. Atlantic spills included those that occurred on the east coast of North America as well as in Europe. Pacific and Atlantic spills were analyzed both separately and together. Two spills from the Baltic Sea (Antonio Gramsci 1979, Palva 1969), were not included in the analysis of Atlantic spills but were used in the analysis of all northern hemisphere spills.

Seabird Injury and Oil Spill Database

Literature sources and specific information for the incidents used in the analysis are provided in Appendix A. The nature of the variables used in the analysis is given below.

LogRecoveredBirds
We used the number of birds recovered in each incident, without correction, as an index of seabird injury. This number is a minimum estimate since the number of birds recovered during an oil spill response effort is usually less than the total number of birds killed (Piatt and Ford, 1996). Factors such as search effort, searcher efficiency, tidal height, scavenging rates, wind and current patterns, and time of year can dramatically alter the proportion of the dead and injured birds that are actually recovered. For most historical spills, however, estimates of actual mortality are not available, and data are not available to make the necessary calculations to estimate actual mortality. We applied the transform Log_{10} to the number of recovered birds for all statistical analyses.

LogSpillVolume
All spill volumes were converted into U.S. gallons (gal) for this analysis. Volumes in some cases were approximate. We applied the transform Log_{10} to the oil spill volume for all statistical analyses.

Latitude
Latitudes were expressed as decimal degrees. If a spill affected an area larger than a degree of latitude, the mid-point of the southern and northern extents of the spill was used.

Oil Types
Oil types were grouped into one of four categories using codes from the National Oceanic and Atmospheric Administration (National Ocean Service, Office of Response and Restoration, 2005): Type 1 are very light oils (Jet Fuels, Gasoline); Type 2 are light oils (Diesel, No. 2 Fuel Oil, Light Crude Oil); Type 3 are intermediate oils (Most Crude Oils); and Type 4 are heavy oils (Heavy Crude Oils, No. 6 Fuel Oil, Bunker C). Four of the historical spills (Douglas Long Beach, Metrolink Long Beach, Outfall, and Loch Indaal) had no information on the type of oil spilled and were thus excluded from the oil type analysis.

BirdDensity
For a subset of 24 spills occurring along the west coast of North America, it was possible to derive historical bird densities specific to the time of year and location of the spill using a database of 1975-2000 at-sea survey data compiled for the Minerals Management Service (Bonnell and Ford, 2001). Among spill incidents, the mix of seabird species killed and injured tends to vary, and taxonomic breakdowns of injury were not available for most incidents. However, along the Pacific coast of North America, the Common Murre *Uria aalge* usually has the highest oil spill related mortality of any seabird species because it is the most numerous local breeding seabird species in most areas from southern Alaska to central California and is resident in coastal and shelf waters year round (Ford et al., 1991, Ford et al.,1996; Carter et al., 2001; Manuwal and Carter, 2001; Ainley et al., 2002; Carter and Golightly, 2003). We therefore used murre density as an index of the density of seabirds sensitive to oil spill injury, although in many estuarine areas other species predominate. Seasons were defined as Winter (Nov-Feb), Spring (Mar-June), and Summer (July-Oct). In our analysis, we used the mean density of Common Murres per km^2 in the 30-minute latitude/longitude block where the spill occurred. In cases where a spill spanned several blocks, the midpoint of the northern and southern extent of the spill was used to select the block used for the density estimate.

RESULTS

Predicting the Number of Birds Recovered
We used both simple and multiple linear regression to examine the subset of 24 incidents for which historical bird density as well as spill volume and latitude could be estimated. For this analysis, *LogBirdsRecovered* was the dependent variable, and *LogSpillVolume*, *Latitude*, and *BirdDensity* were the independent variables. *LogBirdsRecovered* is most strongly correlated with *LogSpillVolume* ($n=24$, $R^2=0.447$, $P<0.001$), followed by *BirdDensity* ($n=24$, $R^2=0.268$, $P=0.010$) and *Latitude* ($n=24$, $R^2=0.186$, $P=0.036$). For a given size of spill, the number of birds recovered increases with increasing *Latitude*, indicating that more northerly spills are associated with the recovery of larger numbers of birds. *BirdDensity* is also significantly correlated with *Latitude* ($n=24$, $R^2=0.193$, $P=0.032$), with higher densities occurring at higher latitudes.

A multiple regression model using *LogSpillVolume*, *BirdDensity*, and *Latitude* to predict *LogBirdsRecovered* accounts for 58.0% of the variation ($n=24$, $R^2=0.580$, $P<0.001$). The regression equation is:

$$[1]\ LogBirdsRecovered = -0.0769 + 0.375*LogSpillVolume + 0.0424*BirdDensity + 0.0243*Latitude$$

If *BirdDensity* is excluded from the analysis, data are available for a total of 50 spills rather than only 24. For this larger data set, *LogSpillVolume* is still the best predictor of *LogBirdsRecovered* ($n=50$, $R^2=0.393$, $P>0.001$). The form of the relationship is:

[2] *LogBirdsRecovered*=1.204+0.336**LogSpillVolume*

A scatterplot of this regression is shown in Figure 1, including the abbreviated names of the various incidents. Details for each incident are listed in Appendix A.

Slightly greater predictive power was provided by the entry of *Latitude* into the regression. The combination of *LogSpillVolume* and *Latitude* increased R^2 to 0.460 (n=50, P<0.01). The entry of Latitude into the relationship was significant (P=0.020) and resulted in the equation:

[3] *LogBirdsRecovered* =0.364+0.305**LogSpillVolume*+0.0224**Latitude*

Atlantic and Pacific Spills
Because of potential differences in oceanography, species composition, bird density, spill response methodology, and other factors, it is possible that the regression relationship is different between spills occurring in the Atlantic Ocean and in the Pacific Ocean. When we regressed *LogBirdsRecovered* on *LogSpillVolume* using Pacific spills only, the result was an increase in predictive power (R^2=0.514, P<0.001, n=27) relative to the data set that included both Atlantic and Pacific spills. When the regression was carried out for Atlantic spills only, the result was decreased predictive power (R^2=0.195, P=0.045, n=21) relative to the data set that included both Atlantic and Pacific spills. Inclusion of the two spills that occurred in the Baltic Sea with the Atlantic spills slightly improved the regression for Atlantic spills, increasing the R^2 to 0.198 and the significance level to 0.033. The predictive equation for Atlantic spills (including spills in the Baltic Sea) was:

[4] *LogBirdsRecovered*= 1.905+0.215**LogSpillVolume*

The corresponding equation for Pacific spills was:

[5] *LogBirdsRecovered* = 0.521+0.487* *LogSpillVolume*

Oil Type
It is possible that the type of product that is spilled influences the level of seabird injury. In general, lighter oils tend to be more toxic, but persist for less time than heavier oils. For the case histories where we could determine oil type (n=43), the spilled product fell into four categories:

Type 1: Very light oils (Jet Fuels, Gasoline)
Type 2: Light oils (Diesel, No. 2 Fuel Oil, Light Crude Oil)
Type 3: Intermediate oils (Most Crude Oils)
Type 4: Heavy oils (Heavy Crude Oils, No. 6 Fuel Oil, Bunker C)

We examined the residuals based on regression Equation [2] to determine if spills of a given type of oil tended to result in a larger or smaller number of birds recovered than Equation [2] predicts (Figure 2). In this context, the residuals measure the magnitude and direction of the difference between the predicted and observed numbers of birds recovered for each incident. A positive residual indicates that the observed number of birds recovered was greater than expected, a negative residual indicates that the number was less than expected, and a zero residual indicates that the number of birds recovered was equal to the expected. If the residuals for spills of a given oil type were consistently positive, for example, then we would conclude that that this oil was be more likely to kill or injure birds. Since the 95% confidence limits on the mean of the residuals overlap zero for all oil types, these data do not support the hypothesis that bird mortality is related to oil type.

Applying the Regression Model to Small Spills
Although our statistical models assume a linear relationship between the variables *LogSpillVolume* and *LogBirdsRecovered*, there is no guarantee that this relationship is actually a straight-line relationship. Systematic deviation from linearity is especially important if a statistical model based primarily on relatively large spills is to be applied to smaller spills. Figure 3 shows the residuals for Equation [2] plotted as a function of *LogSpillVolume*. There is no relationship between the residuals and spill volume, indicating that a linear model is appropriate and that the relationship of Equation [2] can be applied to spills of both large and small volumes.

Although we model the relationship between *LogSpillVolume* and *LogBirdsRecovered* as linear, the relationship between the untransformed form of the variables is not linear. Figure 4 shows the untransformed plot using the parameters of Equation [3]. The number of birds killed per unit volume of oil increases rapidly for small spills, tapering off steadily at larger spill sizes. Thus more birds are recovered per unit of oil in smaller spill incidents than in larger ones.

Based on Equation [3] some birds would be recovered during systematic beach searches even if no oil spill occurred. Thus, spill responses at 10^o, 40^o, and 70^o degrees north latitude would be expected to result , on average, in recoveries of 4, 18, and 85 birds respectively even if only one gallon of oil were spilled. This result is not unreasonable considering that low levels of carcass deposition occur naturally whether or not there has been an oil spill.

Comparison with the Results of Burger (1993)
Burger (1993) found that Log of spill volume accounted for only 14% of the variation in Log of the number of seabirds recovered, whereas we found that this relationship accounted for 43%. We analyzed several subsets of our dataset to determine what aspects of our analysis accounted for this difference. Most of the difference resulted from the addition of new spills to the database. Using Burger's original dataset and adding twenty-nine new spills increased the explained variance from 14% to 36%. Deleting inland spills, estuarine spills, and southern hemisphere spills increased the explained variance to 43% (Equation [2]). Adding the variable *Latitude* increased the explained variance to 46% (Equation [3]).

DISCUSSION

We analyzed the case histories of 50 spills that occurred in the open ocean in the northern hemisphere. For spills that occurred on the Pacific coast of the USA, we were also able to use historical data on Common Murres to estimate an index of local bird densities at sea at the time of year when the spill occurred. Case histories included information on the following factors:

- Number of birds recovered (n=50)
- Amount of oil spilled (n=50)
- Latitude of spill (n=50)
- Bird density (n=24)
- Oil type (n=43)

The relationship between spill volume and the number of birds recovered was linearized using a log transform for both variables (*LogSpillVolum*e and *LogBirdsRecovered* respectively). The best predictor of *LogBirdsRecovered* is *LogSpillVolum*e. Taken alone, this variable accounted for 39% of the variation in the number of birds recovered (n=50, R^2=0.393, P>0.001). The next best predictor was the local density of Common Murres (*BirdDensity*), a common and widespread seabird that is very sensitive to oil spill impacts and occurs along much of the north Pacific Ocean where spill data were derived. When combined with spill volume, these two variables accounted for 58% of the variation in the number of birds recovered (n=24, R^2=0.580, P<0.001).

The explanatory variable, *Latitude*, is correlated with *BirdDensity*, but accounts for less of the variation. The relationship between *Latitude* and *LogBirdsRecovered* probably results from a general pattern of increasing densities of Common Murres and other seabirds on a south to north gradient. In terms of density, the arctic is very rich in seabirds, temperate zones intermediate, and equatorial regions relatively depauperate. This gradient may result from increased upwelling and productivity at higher latitudes, as well as greater available nesting habitat for breeding species. *Latitude* information, however, has the advantage of being much easier to obtain than *BirdDensity*. Spills for which we could obtain values of *BirdDensity* all occurred in the Pacific Ocean, which appears to have a more predictable relationship between spill volume and birds recovered than does the Atlantic.

An additional factor which might increase the number of birds affected by spills in more northern latitudes is the tendency for spills of a given volume to affect a larger area of ocean at higher latitudes (Ford, 1985). Statistical analysis showed a significant relationship between latitude and both slick size and length of coastline affected. The reasons for this relationship are still unclear, but may be related to increased persistence of oil in cooler northern waters, and greater tidal and current movements at higher latitudes.

Atlantic spills differed from Pacific spills in that the regression model for Atlantic spills accounted for less variation in the number of birds recovered than the model for Pacific spills. This may have resulted from a wider range of circumstances associated with Atlantic spills since the database includes spills from both sides of the Atlantic whereas Pacific spills are primarily from the eastern Pacific. The slope of the regression lines for these regions differ, so that a unit of oil results in more recovered birds in the Pacific than in the Atlantic. This is consistent with generally higher seabird numbers in the northeastern Pacific region.

Bird density shows promise as an explanatory variable, but it is not available for most oil spills. We were able to obtain historical estimates of bird density for 24 case histories, but historical densities may not be fully representative of the situation at the time when a spill occurs. The density of birds, including Common Murres, is highly variable, and can change by orders of magnitude from year to year or month to month (e.g., Ford et al., 2004). In addition, large-scale population changes (i.e., declines and increases) have occurred over the 1975-2000 span of available historical datasets (e.g., Carter et al., 2001). Although historical densities generally reflect regional and seasonal averages, and have significant predictive power regarding oil spill effects, it is likely that the power of bird density as an explanatory variable would be greater if these data were collected at the time of the spill.

The relationship between bird density and *LogRecoveredBirds* is also influenced by the species composition and relative densities of different species present in the area affected by the spill. Because seabirds are differentially vulnerable to oiling due to many factors (King and Sanger, 1979; Speich et al., 1991), it is possible to have many birds at risk yet few are injured, or to have few birds at risk of which most are injured. By using densities of sensitive Common Murres for our index of density, we searched for general relationships related to overall bird density for birds that sit on the water surface for extended periods of time. A quantitative analysis of the relative vulnerability of different seabird species to oiling might make it possible to combine estimates of their densities to derive a more accurate predictor of *LogRecoveredBirds.*

Different types of oil have different characteristics in terms of spreading rate, toxicity, and persistence, so it is reasonable to assume that these factors affect the degree of seabird mortality observed for a specific spill. Our analysis, however, did not support this hypothesis. While oil type may have some influence on seabird injury, the magnitude of the effect seems to be small relative to other factors. Certainly, all types of oil greatly affect waterbirds.

When the relationship between *LogRecoveredBirds* and *LogSpillVolume* is plotted on linear axes (Figure 4), it can be seen that increasing amounts of spilled oil result in fewer birds being recovered per unit of oil. Small spills are therefore more deadly per unit of oil than larger spills. The residuals for regression equation [2] show no systematic trend regarding the number of birds recovered at various spill volumes, implying that the regression models are applicable to both small and large volume spills.

The reasons that small spills kill more birds per unit of oil than larger spills are unclear. Oil slick sizes tend to be asymptotic with increasing spill volume, larger spill spills resulting in less affected area per unit volume than smaller spills (Ford, 1985). In addition, bird recovery during small spills is likely to be more effective than during large spills due to coverage of a smaller area over a shorter period of time. Also, small spills often occur in ports during loading of ships, in areas that are more accessible than offshore areas. Overall, insufficient data are available to determine why small spills are more deadly. More investigation is needed to determine causes for this relationship.

The outcome of our analyses was different from that of Burger (1993), who found only a weak relationship between spill volume and bird impacts. Based on a reanalysis of Burger's data, the increase in the significance of the regression model resulted from the following methodological differences:

- Inclusion of additional spills
- Use of birds recovered rather than estimated bird mortality
- Exclusion of spills occurring in the southern hemisphere
- Exclusion of spills occurring in non-marine habitats
- Addition of bird density or latitude as explanatory variables

Many seabirds killed during oil spills are never found. Carcasses may sink at sea, be removed from beaches or the ocean surface by scavengers, beach at inaccessible locations, or simply be missed by searchers. The reasons why carcasses are not recovered are well documented (e.g., Ford et al., 1996, Ford et al., 2001). A number of investigators have conducted studies in which they released marked birds carcasses into the ocean following oil spills and subsequently recorded how many of them were recovered by searchers. Piatt and Ford (1996) summarized these results and found that recovery rates varied widely, from 0% to 48%, with a mean recovery rate of about 17%, corresponding to a recovery ratio of about 5.9 birds killed for each bird recovered. Burger (1993) also examined the recovery rate of seabirds killed by oil spills, finding an average correction factor of 4.9. As a rule of thumb, we recommend multiplying the birds recovered by 5 to obtain a very rough estimate of total mortality in a specific oil spill incident.

The most convenient and accurate method for estimating injury is to use Equation [3], the regression of *LogBirdsRecovered* on *LogSpillVolume* and *Latitude*. In order to calculate the estimated number of birds recovered using Equation [3], the equation must be untransformed to estimate the variable *BirdsRecovered*. This yields:

[6] $BirdsRecovered = \text{Exp}_{10}(0.364+0.305*LogSpillVolume+0.0224*Latitude)$

BirdsRecovered can be multiplied by 5 to obtain a very rough estimate of total mortality. While this model provides a reasonable approximation of the total number of birds killed during a "typical" oil spill incident, it should be borne in mind that it is unlikely to be very accurate in any specific incident. Actual mortality for a particular oil spill may vary by an order of magnitude or more depending on various factors affecting an individual oil spill and efforts to recover affected birds.

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APPENDIX A. Summary of historical oil spill data used in analyses.

Name	Code	Month	Year	Average Bird Density*	Lat	Location	Oil Type Code**	Vol(gal)	Birds Recovered	Reference
American Trader	AT	Feb	1990	0.020	33.60	Huntington Beach, CA, USA	4	416,600	914	Carter, 2003
AMOCO Cadiz	AC	Mar	1978	-	48.58	Brittany, France	3	60,000,000	4,572	Burger, 1993
Anacortes	A	Apr	1971	1.721	48.33	Anacortes, WA, USA	2	225,000	460	Chia, 1971
Antonio Gramsci	AG	Feb	1979	-	57.40	Ventspils, Latvia	3	1,650,000	3,053	Burger, 1993
Apex Houston	AH	Feb	1986	0.800	36.00	Gulf of the Farallones, CA, USA	3	26,100	4,198	Burger, 1993
ARCO Anchorage	AA	Dec	1985	2.254	48.10	Port Angeles, WA, USA	3	240,000	1,917	Burger, 1993
Argo Merchant	AM	Dec	1977	-	43.00	Nantucket, MA, USA	4	7,686,000	181	Morson, 1978; NOAA, 2003
Arizona/Oregon	AO	Jan	1971	6.030	37.78	Golden Gate Bridge, CA, USA	3	810,000	7380	Burger, 1993
Arrow	ARR	Feb	1970	-	45.50	Cape Breton, Nova Scotia	4	3,000,000	567	Burger, 1993
Avila Beach	AB	Aug	1992	1.480	35.07	Avila Beach, CA, USA	3	24,200	84	CDFG, 2002; Carter, 2003
Berry/McGrath Beach	BMB	Dec	1993	0.160	34.15	McGrath State Beach, CA , USA	3	4,200	206	NOAA, 2003, Carter, 2003
Blue Magpie	BM	Nov	1983	4.790	44.60	Yaquina Bay, OR, USA	3	70,000	365	Bayer, 1988
Cape Mohican	CM	Nov	1996	6.030	37.83	San Francisco Bay, CA, USA	3	40,000	257	CDFG, 2002, Carter, 2003
Christos Bitas	CB	Oct	1978	-	51.00	Irish Sea, South Wales	4	923,580	1520	NOAA, 1992
Collision	C	-	1961	-	50.72	Poole, UK	Unk	90,000	487	Burger, 1993
Command	CMD	Mar	2000	7.212	37.75	San Francisco and San Mateo, CA, USA	3	3,000	171	CDFG, 2002, Carter, 2003
Douglas Long Bch	DLB	Dec	1994	0.030	33.00	Long Beach, CA, USA	Unk	13,500	20	Carter, 2003
Erika	E	Dec	1999	-	48.00	Brittany, France	4	6,000,000	63,600	Girin, 2001
Exxon Valdez	EV	Mar	1989	-	61.03	Prince William Sound, AK.	4	10,920,000	35,000	Burger, 1993; Ford et al., 1996
Firth of Forth	FF	Feb	1978	-	51.00	Between Leith & Cockenzie, Scotland	3	250	740	Campbell et al., 1978
Hamilton Trader	HT	-	1969	-	51.00	Irish Sea, UK	4	210,000	4,400	Burger, 1993
Irving Whale	IW	-	1970	-	55.00	SE Newfoundland, Canada	4	9,000	625	Burger, 1993
Kurdistan	KN	Mar	1979	-	46.00	Cabot Strait, Newfoundland, Canada	4	2,370,000	1,697	Burger, 1993
Kure	KUR	Nov	1997	1.930	40.75	Humboldt Bay, CA.	4	4,500	951	Carter, 2003
Kuroshima	KS	Nov	1997	-	54.00	Unalaska, AK, USA	4	39,000	165	NOAA, 2002
Loch Indaal	LI	-	1969	-	55.55	Loch Indaal, UK	Unk	34,500	449	Burger, 1993

Name	Code	Month	Year	Average Bird Density*	Lat	Location	Oil Type Code**	Vol(gal)	Birds Recovered	Reference
Metrolink Long Bch	MLB	Feb	1995	0.000	33.00	Long Beach, CA, USA	Unk	4,200	100	NOAA, 2003; Carter, 2003
Nakhodka	NK	Jan	1997	-	37.24	Oki Islands, Japan	3	1,701,818	1,315	Fries, 2002
Nestucca	NS	Dec	1988	22.100	46.90	Gray's Harbor, Washington, USA	4	231,000	12,535	Burger, 1993
New Carissa	NC	Feb-Mar	1999	6.290	43.50	Coos Bay to Waldport, OR, USA	3	70,000	1,140	NOAA, 2003; Ford et al., 2001
North Cape	NCP	Jan	1996	-	41.00	Moonstone Beach, RI, USA	1	828,000	405	NOAA et al., 1999
Ocean Eagle	OE	Mar	1968	-	18.48	San Juan, PR	2	3,502,800	300	NOAA, 2003
Olympic Alliance	OA	Nov	1975	-	50.98	Dover Strait, Pas de Calais, English Channel	2	600,000	199	Burger, 1993
Outfall	OUT	-	1978	-	58.35	Dounreay, UK	Unk	20,400	650	Burger, 1993
Palva	P	-	1969	-	62.50	Uto, Finland	Unk	45,000	1,000	Burger, 1993
Platform A	PA	Jan	1969	0.160	34.33	Santa Barbara, CA, USA	3	3,000,000	2,259	Carter, 2003
Platform Irene	PI	Sep	1997	0.660	34.56	Santa Barbara, CA, USA	3	1,700	140	Carter, 2003
Prestige	PT	Nov	2002	-	42.92	Galicia, Spain	3	23,100,000	23,181	SEO/Birdlife 2003
Puerto Rican	PR	Nov	1984	6.030	37.51	San Francisco, CA, USA	3	1,470,000	1,368	Burger, 1993; Dobbin, et al., 1996
Sea Empress	SE	Feb	1996	-	51.66	Milford Haven Harbor, Wales, UK	3	21,744,000	7,000	SEEEC, 1998; White & Baker, 1998
Seestern	SS	-	1966	-	51.00	Medway, UK	Unk	510,000	2,772	Burger, 1993
Shetland/Braer	SB	Jan	1993	-	60.00	Shetland Islands, Scotland, UK	2	25,860,000	1,768	ITOPF; Shetland Wildlife, 1994
Stuyvesant	SV	Sep	1999	1.110	40.75	Humboldt County, CA, USA	3	2,000	1,272	CDFG, 2002
Tanio	TAN	Mar	1980	-	49.17	Brittany, France	4	4,156,110	1,700	NOAA, 2003
Tenyo Maru	TM	Jul	1991	6.810	48.33	Cape Flattery, WA, USA	2	300,006	4,300	NOAA, 2003, Burger, 1993
Texaco Anacortes	TAN	Mar	1991	1.721	48.33	Anacortes, WA, USA	3	12,600	166	Texaco Trustees, 2003
Tidelands Long Beach	TLB	Jun	1994	0.00	33.00	Long Beach, CA, USA	4	100	15	Carter, 2003
Torrey Canyon	TC	Mar	1967	-	50.00	English Channel, UK	3	35,798,400	7,815	Burger, 1993
Tristan	T	Aug	2001	3.350	43.46	Coos Bay, OR, USA	3	12,000	250	Ford & Reed, 2002

Name	Code	Month	Year	Average Bird Density*	Lat	Location	Oil Type Code**	Vol(gal)	Birds Recovered	Reference
Whidbey Is	WI	Dec	1984	3.790	47.83	Whidbey Island, WA	3	5,100	853	Speich & Thompson, 1987; Burger, 1993

*Bird Density (individuals/km^2) was only calculated for west coast of North America.

**See text for oil type codes. (NOAA 2001)

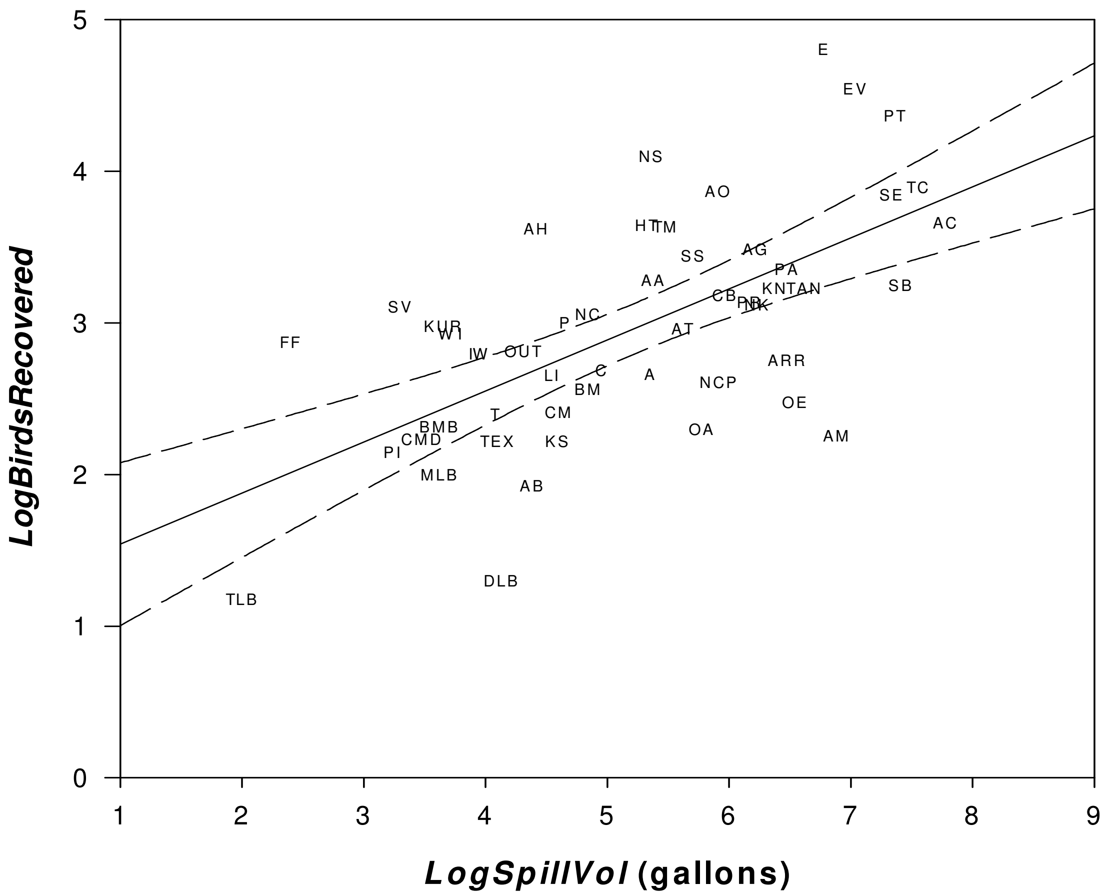

Figure 1. Simple linear regression model of recovered birds as a function of spill volume. The solid line represents regression Equation [2], the dashed lines represent 95% confidence limits on the regression line. The result is significant (n=50, R^2=0.393, P<0.001). Figure shows where each historical spill fits on the regression line. For abbreviations, see Appendix A.

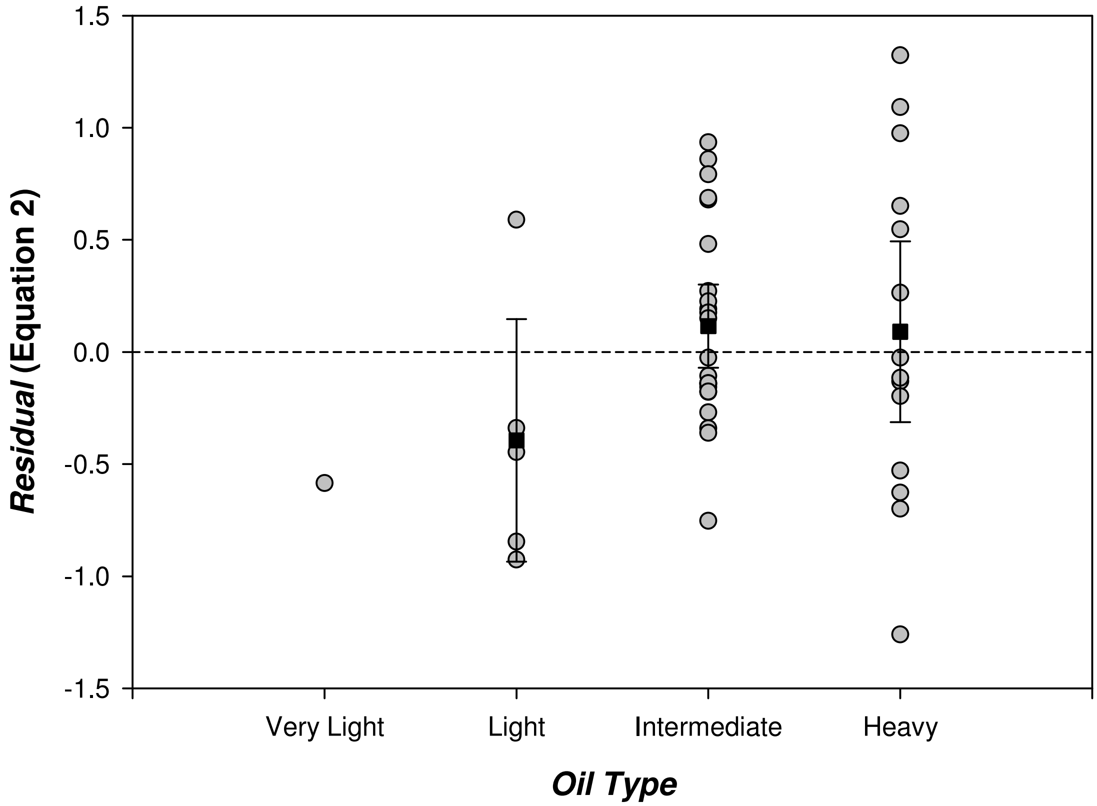

Figure 2. Residuals based on the regression Equation [2] for each oil type. Individual spills are gray filled circles. The mean of the residuals for each oil type is shown as a black square. Vertical bars show 95% confidence on the mean for each oil type. The confidence limits on the means of the residuals for each oil type overlap zero, meaning that oil type has little ability to predict the number of birds affected by an oil spill.

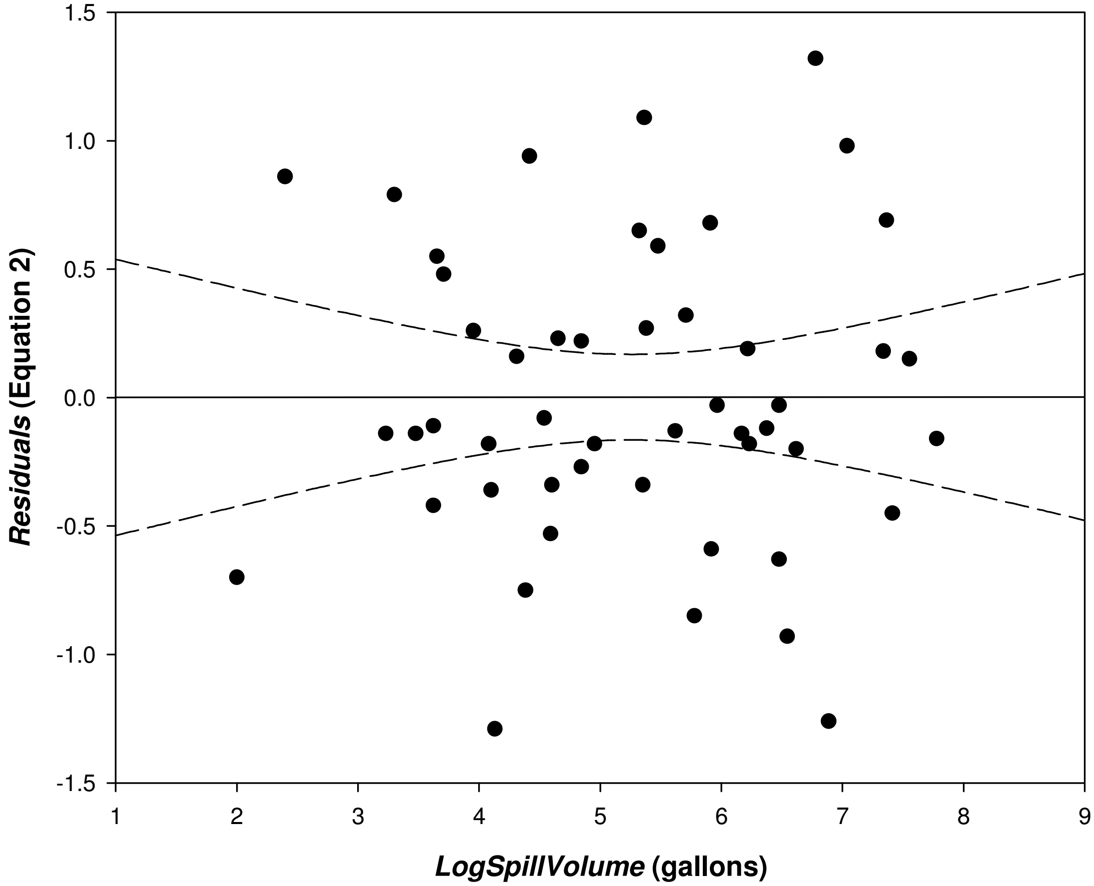

Figure 3. Residuals based on the regression of equation [2] plotted as a function of *LogSpillVolume*. Each data point represents the difference between the observed number of birds actually recovered during a spill incident and the number predicted by equation [2]. The solid line is the regression of the residuals on *LogSpillVolume,* the dashed lines are 95% confidence intervals. The residuals are unrelated to *LogSpillVolume*, indicating that the regression fits for the entire range of spill sizes.

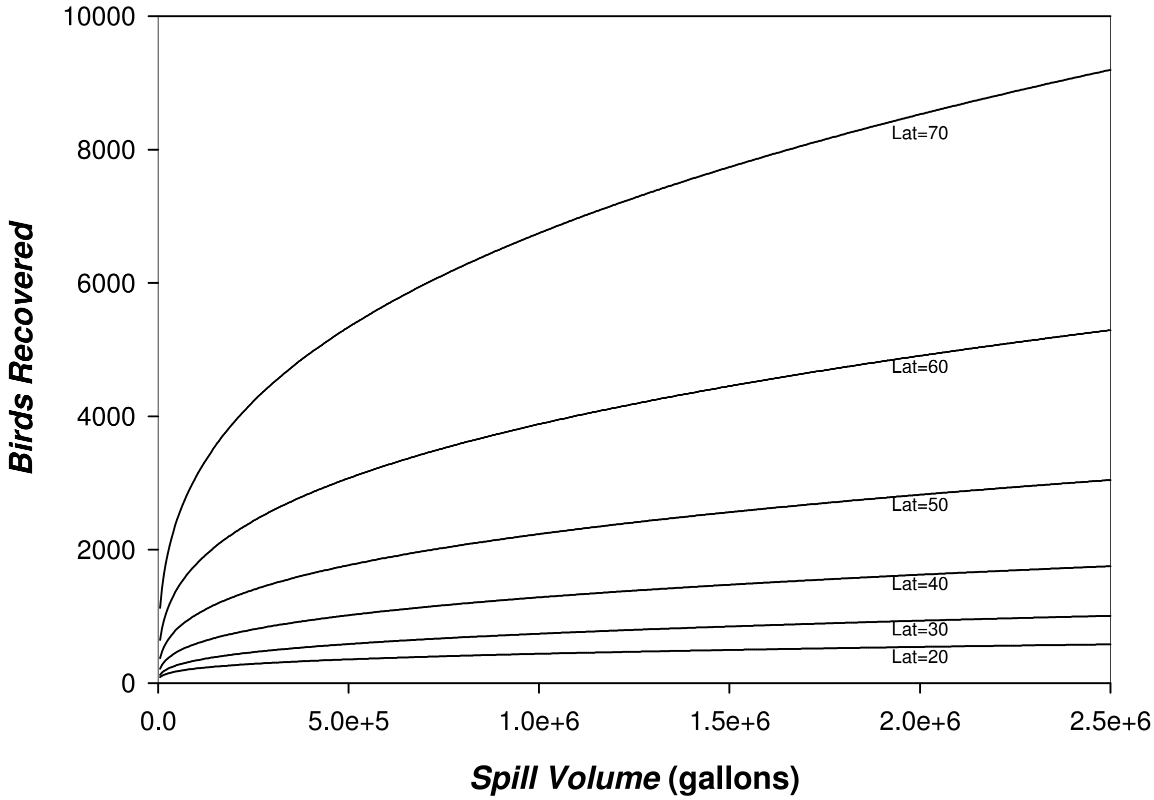

Figure 4. Untransformed plot of birds recovered versus spill volume and latitude, equations [3,6]. Birds recovered per unit of oil spilled is greater at smaller spill volumes.