CHAPTER 1

TEMPORAL, SPATIAL, AND SPECIES-SPECIFIC PATTERNS OF CHRONIC OILING AS REVEALED BY THE BEACHED BIRD SURVEY, FARALLON OILED BIRD SURVEY AND BIRD RESCUE PROGRAMS IN CENTRAL CALIFORNIA

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EXECUTIVE SUMMARY

Seabirds are potentially threatened by oil pollution from "chronic oiling," stemming from unreported small spills, bilge-dumping, etc., as well as from larger, and more conspicuous oil spills. The appearance of tarballs and a large number of oiled seabirds throughout central California, in winter and spring 1993, provided the need to evaluate the impact of the 1993 "Tarball incident," and that of chronic oiling in general, on seabirds of central California. To do so we make use of two long-term datasets: (1) Point Reyes Bird Observatory's Beached Bird Survey, for which we evaluate data from 1971/72 to 1984/85, collected at ten beaches in the Gulf of the Farallones and Monterey Bay, and (2) Point Reyes Bird Observatory's Farallon Oiled Bird Survey, which has been conducted on Southeast Farallon Island from 1977 to the present.

PRBO's Beached Bird Survey yielded sufficient data to analyze patterns of oiling in murres (Common Murre, *Uria aalge*), loons (*Gavia* spp.), and grebes (family Podicipedidae). The proportion of carcasses that were oiled (which we consider an index of oiling risk) averaged 15% in murres, 12% in loons, and 5.5% in grebes. All three species groups demonstrated significant year-to-year and beach-to-beach variation in the proportion of carcasses oiled. In addition, for murres, the effect of year on proportion oiled varied, depending on the specific beach (i.e., there was significant Year x Beach interaction). For loons and grebes there was concordance of year to year variation in proportion of carcasses oiled but not for loons and murres or for grebes and murres. For grebes and murres there was concordance of beach to beach variation in proportion of carcasses oiled but not for loons and grebes or for loons and murres. For murres, temporal and spatial patterns of variation were similar whether or not all individuals were considered or just adults.

Records from the Farallon Oiled Bird Survey and from two bird rescue and rehabilitation centers documented an increased number of oiled birds in winter and spring 1993 (December 1992 to April 1993, inclusive). Episodes involving the oiling of a moderate to large number of seabirds were observed on Southeast Farallon Island, even in the absence of known oil spills. These episodes were most common in winter and usually associated with storms.

Most oiled birds detected on SEFI (64%) were Common Murres. The number of oiled Common Murres observed per month on SEFI correlated with the number and proportion of Common Murres that were oiled and turned into bird rescue centers. However, there was only a weak correspondence between the number of oiled murres observed per year on SEFI and the proportion of murre carcasses that were oiled, as noted by PRBO's Beached Bird Survey. This result may indicate that local patterns of oiling do not necessarily coincide with regional patterns.

We estimate that, for Common Murres in central California, chronic oiling results in additional mortality of 1.7% or more for adults and 7.7% or more for juveniles (first-year birds). Additional mortality of that magnitude can lower population growth rates by 3% or more per year. We conclude that chronic oiling represents a serious threat to the viability of Common Murre populations. We still do not know the significance of chronic oiling for other seabird species. We recommend that future beached bird surveys include consistent annual effort at a relatively large number of beaches (e.g., 10 beaches). The Farallon Oiled Bird Survey appears to provide valuable information to supplement a beached bird survey program.

INTRODUCTION

Oil pollution is recognized as a major threat to the long-term viability of seabird populations on a local and regional scale (Camphuysen 1989, Burger and Fry 1993). Threats come not only from major, identified spills but also from persistent episodes of low-level oiling; indeed the latter, which has been termed "chronic oiling" may represent a greater threat to the long-term persistence of seabird populations than do major, publicized spills (Piatt et al. 1985, Camphuysen 1989, Chardine et al. 1990, Burger and Fry 1993). Sources of chronic oiling include small, unreported spills, leaking tanks and valves, and flushing of tanks and bilges (Burger and Fry 1993).

In December 1992 and January 1993, an unusual number of tarballs were observed throughout central California, in conjunction with reports of hundreds of oiled seabirds that were apparently affected by some unknown source of oil (California OSPR Bulletin February 1993 and March 1993). The tarballs continued up to and including April 1993. The primary goal of this paper is to evaluate the 1993 "Tarball incident," in particular, and the problem of chronic oiling, in general, with regard to impacts on seabirds. This evaluation includes putting the 1993 incident in perspective, compared to incidents in other years, and evaluating the likely impact of this incident and others on the long-term population dynamics of seabird species of central California. To accomplish these goals we synthesize and analyze results from two long-term data sets. The first is the Point Reyes Bird Observatory (PRBO) Beached Bird Survey, conducted throughout California, but mainly in central California, from 1971 to 1985 (Stenzel et al. 1988). Henceforth, we refer to this as the Beached Bird Survey, or BBS. The second data set is the Farallon Oiled Bird Survey, which has been carried out on Southeast Farallon Island (SEFI) since 1977. Results from this latter dataset are presented here for the first time. In this paper we utilize survey results through the end of 1994. A third dataset consists of records from two bird rescue and rehabilitation centers in central California, California Wildcare Center (San Rafael) and Native Animal Rescue (Santa Cruz), for 1993 and 1994, which we gathered specifically for this project.

An additional goal of this paper is to evaluate the two surveys themselves, retrospectively and prospectively. We examine the surveys retrospectively to determine their value in elucidating patterns and features of oiled seabirds, looking, in particular, at species specificity and commonality, magnitude and nature of temporal variation (within year and between years), and examine spatial variation in oiling patterns within central California. The goal of a prospective examination is to consider adequate, as well as optimal, design of beached bird and oiled bird surveys, and thus guide future attempts at implementing such surveys.

The BBS was carried out throughout coastal California but only in central California was an extensive time series of surveys carried out. Therefore we restrict our analyses herein to data collected in the vicinity of the Gulf of the Farallones and Monterey Bay (see Stenzel et al. 1988). By focusing attention on central California, the geographic scope of the BBS analyses coincides with data gathered from the Farallon Islands (located in the middle of the Gulf of the Farallones) and data gathered from bird rescue centers in the San Francisco Bay and Monterey Bay areas.

In these analyses we focussed attention *a priori* on four species groups that have previously been identified as being at risk from oiling (Smail et al. 1972, Point Reyes Bird Observatory, Camphysen 1989, Page et al. 1990, Piatt et al. 1990, Nur and Ainley 1992, Fry 1992, Burger and Fry 1993, Nur et al. 1994). The four groups are (with species or genera observed in central California listed in parentheses): murres (Common Murre *Uria aalge*, family Alcidae), loons (*Gavia* spp., family Gaviidae), grebes (specifically, Western Grebe *Aechmophorus occidentalis*; Horned and Eared Grebes, *Podiceps* spp; all in family Podicipedidae), and scoters (*Melanitta* spp., family Anatidae).

Specific questions we address are: (1) Is there year to year variation in patterns of oiling and oiling risk? (2) What is the nature of seasonal variation in oiling patterns? (3) Is there site to site variation in patterns of oiling within central California? (4) In what way are the patterns observed in (1) - (3) similar across species and in what way are they distinctive to each species group? (5)

Are the patterns observed in different surveys (Beached Bird Survey, Farallon Oiled Bird Survey, bird rescue center survey) concordant? and (6) What is the estimated mortality associated with chronic oiling?

METHODS

Beached Bird Survey: Data Collection

Details of data collection of the BBS are presented in Stenzel et al. (1988). In short, beaches were surveyed between June 1971 and May 1985. We follow Stenzel et al. (1988) who considered the biological year to span 1 June to 31 May. Thus the survey period represents 14 years. However, we excluded the first year of surveying due to poor coverage (only 3 beaches had good coverage that year). Thus, the following analyses are of 13 years: June 1972 to May 1985. We refer to 1972/3 as "1972", 1973/4 is referred to as "1973", etc.

As observers walked the beach, they noted carcasses or ailing beached marine birds, recording the species, degree of decomposition, evidence of cause of death (if any), presence of oil on the plumage, and, if known, age, sex and color phase. Data on sex and color phase were inadequate for analyses presented here. Carcasses were removed or distinctively marked so that would not be counted on subsequent surveys. Only murres had sufficient data to permit analysis of age-related variation in oiling. Murres were classified into "adult", "immature" and unknown. Immature included first year birds (Hatching Year, or Young of the Year) and small numbers of second year birds.

Volunteer observers made an attempt to survey each beach once a month. Whereas some beaches met this objective for most years, many more beaches did not meet this objective in most years. There were a total of 42 beaches surveyed in central California for all or part of the survey period. Details of seasonal coverage are summarized in Table 2 of Stenzel et al (1988).

Beached Bird Survey: Data Selection

Because coverage of beaches varied greatly from year to year, and from season to season, we placed a high value on selecting for analysis only beaches that had reasonably good coverage for most years of the study. If we had failed to do this then year to year variation in results could be obscured (i.e., confounded) by beach to beach or season to season variation. At the same time, we wished to maximize our sample size, both in terms of beaches included, and in terms of maximizing the total number of carcasses analyzed. We decided *a priori* to attempt to include at least ten beaches in our sample (out of a total of 42 beaches), provided coverage was adequate for each beach included in the sample. This number of beaches we felt would give a large enough sample from which to draw conclusions regarding variation and commonality among beaches.

To accomplish these two competing objectives, we adopted an initial set of criteria for beach selection as follows. Beaches were included if they met **both** criteria: (1) at least 10 years of data (out of 13) with "adequate" coverage, and (2) at least 7 years with "good" coverage. Eight beaches met this criterion: Cronkhite, Limantour, Muir, Ocean, and Seadrift in the Gulf of the Farallones, and Del Monte, Jetty, and Pajaro Dunes in Monterey Bay. "Adequate" and "good" coverage were defined by us with respect to the number of seasons per year a beach was "fully covered," the latter defined by Stenzel et al (1988). Stenzel et al. (1988) divided the 12 calendar months into three seasons: fall (June - October), winter (November - February), and spring (March - May). "Fully covered" for a season meant censuses in each month of that season. Based on that criterion, we defined "adequate" coverage as at least one season in that year fully covered; we defined "good" coverage as at least two seasons out of three fully covered. Using our initial selection criteria we identified eight beaches that met both criteria, and thus fell short of our goal of identifying 10 beaches. We therefore considered beaches that met one criterion but fell a little short on the second criterion. There were two additional beaches (both in the Gulf of the Farallones) that fell into this marginal category: Thornton, which had 10 years of adequate coverage but only 5 years of good coverage, and RCA beach, which had 7 years of good coverage, but only 9 years of adequate coverage. We decided to include both these beaches in the sample to be analyzed; we would not have been able to justify including Thornton but not RCA or including RCA but not Thornton.

In subsequent analyses we included all data in the 13 year period from each of the ten "major" beaches, ignoring whether or not a particular season was "fully covered." We classified data into four seasons of three months each: summer (June - August), fall (September - November), winter (December - February) and spring (March - May).

As noted above, we *a priori* identified four species groups likely to be impacted by oiling: murres, loons, grebes, and scoters. Below we summarize results for all four species groups; however, the number of oiled scoters (26 in total from the 10 major beaches, over 13 years) were too few to analyze statistically.

We present results in terms of total number of carcasses (dead or dying individuals), number of oiled carcasses, and proportion of carcasses that were oiled. The total number of beached carcasses in a monthly survey reflects many different factors (Stenzel et al. 1988), including: total population at risk, sources of mortality, and factors influencing carcass deposition, retention (i.e., persistence), and identification. This makes interpretation of body counts of oiled birds difficult (Piatt et al. 1990, Page et al. 1990, Burger & Fry 1993). A more robust, and less ambiguous, measure of oiling hazard is provided by the proportion of carcasses that were oiled. This proportion gives us a measure of the probability that a carcass is oiled, given that is has been deposited on a beach and been enumerated in a survey. Thus, it is a conditional probability. We present this parameter with respect to variation between species, between years, between seasons, among beaches, and among months. Our goal is to use this parameter to quantify the relative risk of oiling and determine how that varies among species, years, seasons, etc.

<u>Farallon Oiled Bird Survey</u>

To quantify the numbers of oiled birds on the Farallon Islands we conducted daily enumerations of affected wildlife starting in January 1977. Nearly every day a regular route was traversed that covered most of Southeast Farallon Island. These surveys included incidental observations of live oiled birds on the water and in colonies and dead birds washed up on shore. For each specimen we recorded the species, extent of oiling, and fate (e.g., death, behavioral changes etc.). Our coverage of the island and effort was generally consistent between 1977 and 1987, but beginning in 1988 we started censusing Common Murres that attended colonies during the non-breeding season; this censusing may have enhanced our abilities to detect oiled individuals. During this more recent period, we continued to record observations of all birds on a daily basis, just as we had in 1977-1987. Additionally, during the two major oil spills (*Puerto Rican* oil spill [Point Reyes Bird Observatory 1985, Stenzel et al. 1988], and *Apex Houston* oil spill [Page et al. 1990]), biologists on the island were generally informed of an event in progress and asked to enumerate affected specimens. Thus, effort increased at these times. Finally, although we attempted to count each individual only once, it is possible that certain individuals were counted more than once if they moved from one side of the island to another; this may have been especially important for birds noted on the water. To alleviate this problem, however, each evening, resident biologists met to discuss observations of oiled seabirds, extent of oiling and locations of oiled birds. In this way, duplicate records of individuals were minimized.

Oiling incidents or episodes were defined as a sequence of days during which oiled birds were observed, separated by at least 6 days in which no oiled birds were observed. Thus, for example, if oiled birds were detected on each of five days, no birds were detected for the next five days, and additional birds were detected for five more days, this was classified as a single incident.

<u>Collection and Analysis of Data from Bird Rescue and Rehabilitation Programs</u>

To quantify the specific effects of the 1993 Tarball incident, we collated records from avian rescue and rehabilitation centers in central California including Native Animal Rescue (NAR), Santa Cruz; California Wildlife Care (CWC), San Rafael; and International Bird Rescue and Rehabilitation Center (IBRRC), Berkeley. Unfortunately, many birds were transferred from NAR and CWC to IBRRC for final treatment, but records indicating specimen number were often lost in the process. Therefore, we were unable to use the IBRRC data because individuals would have been duplicated. Moreover, very few birds from the incident appeared to be brought to IBRRC directly, such that excluding this facility probably had a small effect on estimates of magnitude of the incident. For NAR and CWC data, we examined records from seabirds brought to each center from January 1993 to December 1994. We prepared a database from these records which included the rehabilitation center to where the bird was first brought, the year of observation, the specimen number, the date brought to the center, species identification, age, sex, location where found, date found, reason for rescue, disposition or fate of specimen, date of disposal, explanation of disposal, weight of bird, evidence of oil fouling, and location of oil on the bird's body. We compare the number and proportion of oiled birds brought to rehabilitation centers in 1993 and 1994 on a monthly and seasonal basis. Comparison of numbers and proportion of oiled birds in 1993 with 1994 provides a basis for evaluating the 1993 Tarball incident.

Statistical analysis

The probability that a beached carcass has been oiled can be analyzed using logistic regression, if one assumes that each bird carcass deposited and enumerated on a beach is oiled or not, independently of the fate of other bird carcasses. Accordingly, we analyze oiled bird carcass data to determine whether this assumption of independent carcass deposition and enumeration is supported. Under the assumption of independence, the number of carcasses detected per month per beach for a species should follow a binomial distribution; specifically, the residuals of a logistic regression should conform to a binomial distribution. Where the assumption is not supported (as was the case for murres), we analyze results using the proportion of oiled carcasses per month per beach as independent outcomes. That is, in the latter analyses, we do **not** assume that individual carcasses on a beach are independently distributed within a month, but do assume independence between months. We did not find that any single, known oil spill resulted in carcass detection over a several month period, and so view this assumption as reasonable.

To examine concordance between two datasets (e.g., concordance between loons and murres with respect to proportion of individuals oiled in each year) we use Pearson product-moment correlation coefficients (r) and the coefficient of determination (R^2). We use linear model analysis (which includes linear regression analysis, ANOVA, ANCOVA, and modifications thereof; Neter et al. 1990) in cases where data are consistent with assumptions of this analysis (e.g., normality of residuals; see Seber 1977, Chapter 6). Where assumptions are violated we make use of other methods (e.g., logistic regression), as described in the text.

RESULTS

Beached Bird Survey

The number and percentage of oiled carcasses, by species, is shown in Table 1, for the 10 major beaches (see Methods), for the 13 year-period (1972/3 to 1984/5). "Small Grebe" in Table 1 refers to Eared or Horned Grebes (*Podiceps nigricolis*, *P. auritus*) in contrast to Western Grebe (*Aechmophorus occidentalis*), a large grebe. Furthermore, Western and Clark's Grebes (*Aechmophorus clarkii*) were not considered separate species at the time of the surveys and so are not distinguished in this dataset; both species are labeled "Western Grebes." 86% of grebes were identified as Western Grebes. "Loon" in the Table refers to Arctic, Common, or Red-throated Loon (*Gavia arctica, G. immer, G. stellata*). "Scoter" in the Table refers to Surf or White-winged Scoter (*Melanitta perspicillata, M. deglandi*).

Murres were most likely to be oiled (15.1%), followed by loons (12.2%), grebes (5.5%) and scoters (3.4%). The proportion of loon carcasses that were oiled was significantly greater than the proportion of grebe carcasses (G test, Likelihood Ratio Statistic [LRS] = 21.47, df =1, $P < 0.0001$). The proportion of murre carcasses that were oiled was also significantly greater than the proportion of grebe carcasses (z test, $P < 0.001$; it was not possible to use a G test because of lack of independence of murre carcass oiling, see below). Proportion of oiling among murres and loons were not significantly different (z test, $P > 0.05$).

Annual variation

Year to year variation in percent oiled birds among loons (all species) and grebes (all species) is shown in Table 2 and for murres is shown in Table 3.

For loons, the percentage oiled varied from 2% (in 1982/3 and 1983/4) to 17% (in 1973/4 and 1976/7), except in 1984/5, the year of the *Puerto Rican* oil spill (Point Reyes Bird Observatory 1985), when the percentage was 50%. For grebes, the percentage oiled was 2.5% or less in 7 out of 13 years; in 1984/5 it was 18%, and in two other years it was above 10%. For murres, the percentage oiled varied from 10% (in 1976) to 45% (in 1973) except in 1982 and 1983 when the percentage was 7% in each year. The latter two years were years of high gill-net mortality (Takekawa et al. 1990), which would have inflated the denominator (the total number of carcasses that year) and thus lowered the percentage of oiled carcasses. 1984/5 was also a year of high gill-net mortality (Takekawa et al. 1990) but this was the year of the *Puerto Rican* oil spill.

The overall pattern is that all three species groups show annual variation in proportion of oiled carcasses (even after excluding aberrant years) but the variation is around levels characteristic for each species. Thus, a year with a low proportion of oiled carcasses is, for murres, about 10%, whereas for grebes it is about 1%.

With regard to these patterns we asked two questions: (Q.1) Is there parallelism between species groups in year to year variation in proportion of oiled carcasses, and (Q.2) Is the apparent annual variation statistically significant? With regard to the first question, we found evidence for concordance of patterns (in relation to annual percentages of oiled birds) comparing loons and grebes (results from linear model analysis: $P = 0.042$, $R^2=0.324$, $r=+0.569$, $N=13$ years in all analyses; Figure 1) and between loons and murres ($P = 0.011$, $R^2=0.461$, $r=+0.679$; Figure 2), but not between grebes and murres ($P = 0.31$, $R^2=0.092$; $r=+0.303$; Figure 3). Figure 2 indicates that years in which the percentage of oiled murres is high are years in which the percentage of oiled loons is also high, and vice versa, but if one looks at year to year changes (1973 to 1974, 1974 to 1975, etc.), the parallelism is not very apparent: out of 12 year to year changes, loons and murres showed the same direction of change (increase or decrease in the percentage of oiled birds from one year to the next) in only five years. We conclude that only loons and grebes show good concordance of pattern between years.

To examine the second question (Q.2), required us to examine whether the number of carcasses (oiled or not) per census per beach conformed to a binomial distribution, which would imply that individual carcasses are deposited and identified independently of one another. The number of carcasses per census was small for loons (Table 4). In other words, loons were usually encountered in ones or twos, and only rarely in larger groups. The number of oiled carcasses observed per census was also small for grebes (only three censuses with more than 2 oiled grebes observed), but the total number of grebe carcasses was sometimes large (49 censuses with more than 6 grebe carcasses noted). Nevertheless, the residuals from a logistic regression with respect to the effects of year and beach did not deviate significantly from a binomial distribution, for both loons and grebes ($P > 0.05$, Goodness of Fit test). We were therefore justified in analyzing the oiling of loons and grebes using logistic regression.

Results indicated significant variation in oiling proportion for loons ($LRS = 64.25$, $df=12$, $P < 0.0001$), but only if 1984/5 (year of the *Puerto Rican* oil spill) is included. Excluding that year from the analysis, annual variation in oiling proportion was not significant ($LRS = 18.82$, $df=11$, $P = 0.065$). For grebes, annual variation was significant, whether or not 1984/5 was included ($LRS=54.04$, $df=11$, $P < 0.0001$, with; $LRS=42.17$, $df=10$, $P < 0.0001$, without). Note that 1978 could not be included in the grebe analyses because there were zero oiled grebes in that year, which affects the maximum likelihood method used in these analyses; the same problem does not affect linear regression analyses.

For murres, the number of carcasses recorded on a single beach census did not conform to a binomial distribution: there were too many censuses with high numbers of carcasses (Table 4), even when one looked only at oiled carcasses. We therefore could not assume independence of individual carcasses. Instead we analyzed results by census. There were 703 censuses (beach-month combinations) with at least 1 murre carcass. The datum was the proportion of oiled murres on that beach that month. First, we used a linear model to assess year to year variation in percentage oiled murres. Results indicated significant year to year variation (R^2=0.040, P = 0.004). The problem with this analysis is that residuals were not normally distributed (skew-kurtosis test of normality, P < 0.01), thus violating an assumption of the linear model analysis. We therefore coded all censuses as either 0 (no oiled murres) or 1 (1 or more oiled murres), making the data amenable to logistic regression. In this way we were not violating any assumptions, but we were losing information, i.e., a census in which 5% of murres were oiled was treated the same as one in which 95% of murres were oiled. Nevertheless, the logistic regression demonstrated significant annual variation (LRS = 24.54, df = 12, P = 0.017).

There was also no significant time trend for proportion of loon, grebe or murre carcasses that were oiled (all cases, P>0.05). To summarize, grebes and murres show significant year to year variation in the proportion of oiled birds, even in the absence of major oil spills. It is not clear whether loons also show significant annual variation when major oil spills are excluded.

Age effects with respect to annual variation: For murres, we analyzed annual variation for each age class (Adult, Immature) to determine if these age classes showed the same pattern as observed for all murres (note "all murres" includes Unknown age as well). Percent oiled, by age class, is shown in Table 3. For adults and for immatures, annual variation in percent oiled was significant (results of linear model analysis: P = 0.007; P = 0.011, respectively). Percent oiled for all murres and for adults showed close parallelism (Figure 4; R^2=0.642, r=+0.801, P = 0.001, N=13 years, for association between percent oiled among all murres and among adults only). The only exception to this concordant pattern was the year 1984/5, the year of the *Puerto Rican* oil spill. Percent oiled for all murres and for juveniles showed no evidence of parallelism (R^2=0.049, r=+0.221, P = 0.47). There was weak evidence of concordance between percent of adult murres oiled each year and percent of juvenile murres oiled (R^2=0.230, r=+0.480, P = 0.098).

Beach to Beach Variation

It is important to assess beach to beach variation for at least two reasons. First, the extent of beach to beach variation in proportion of oiled birds will guide sampling design. The greater is the magnitude of such variation, the more important it is to obtain a large and representative sample of beaches in a beached bird survey. Secondly, the greater is beach to beach variation the more important it is to avoid an unbalanced design in comparing years, comparing seasons, etc.

Table 5 shows variation in proportion of carcasses oiled among beaches for loons and grebes; Table 6 shows variation among beaches for murres. There appears to be considerable variation among beaches in the percent of oiled birds, for all three species. For loons the percent oiled varied from 3% to 28%; for grebes the percent oiled varied from 0% to 30%; for murres the percent oiled varied from 8% to 32%. Logistic regression confirmed that beach-to-beach variation was significant for loons (LRS = 28.96, df=9, P = 0.0007) and for grebes (LRS = 36.63, df=8, P < 0.0001; Muir beach could not be included in the analysis due to 0 oiled grebes recorded). A linear model analysis of beach-month censuses and logistic regression analysis of the same (see Annual Variation, above) confirmed significant beach-to-beach variation among murres as well (R^2=0.0615, P < 0.0001; LRS = 64.23, df=9, P < 0.0001, respectively).

Parallelism between loons and grebes with respect to beach to beach variation was weak at best, and not significant (Figure 5; R^2=0.274, r=+0.523, P = 0.12) for regression of percent oiled loons vs. percent oiled grebes). There was even less evidence of parallelism between loons and murres (Figure 6; R^2=0.108, r=+0.268, P = 0.35). However, variation in percent oiled birds among beaches, comparing percentages among grebes and murres, revealed a significant association (Figure 7; R^2=0.639, r=+0.799, P = 0.006). Thus, parallelism between species for annual variation was demonstrated unequivocally only for loons and grebes, whereas for beach to beach variation it was demonstrated only for grebes and murres.

Age effects with respect to beach to beach variation: Variation between beaches with respect to percent oiled among murres is shown by age class in Table 6. For adults and for immatures, annual variation in percent oiled was significant (results of linear model analysis: P = 0.007; P = 0.011, respectively). Percent oiled for all murres and for adults showed very close parallelism (Figure 8; R^2=0.844, r=+0.919, P = 0.0002). These results reinforce those obtained for annual variation in percent oiled for each age class, implying that percent oiled murres of all age classes is a good predictor of the percent oiled adult murres, and vice versa. Percent oiled birds among all murres and among juveniles showed only weak parallelism (R^2=0.111, r=+0.333, P = 0.35), comparing beaches. There was little evidence of concordance in pattern among percent oiled adult and juvenile murres with respect to beach to beach variation (P>0.5).

Seasonal variation

The percent of oiled birds appears to vary between seasons for loons and murres, but not necessarily for grebes (Tables 7 and 8). Table 7 also shows seasonal variation in oiled carcasses of scoters. For grebes, percent oiled birds was similar for fall, winter and spring (5 to 7%). Seasonal variation was significant for loons (LRS=21.32, df=3, P < 0.001) but not for grebes (LRS=2.84, df=3, P > 0.4). However, after controlling for beach effects and year effects, seasonal variation was not significant for either species group (LRS=2.16, df=3, P > 0.5, loons; LRS=3.03, df=3, P = 0.39, grebes). These results imply that the apparent between-season variation in percent oiled loons was due to variation among beaches and/or years, coupled with unbalanced study design.

Seasonal variation appeared significant for murres, using linear model analysis (P = 0.0013), but this was not confirmed using logistic regression of beach-month censuses (LRS = 1.97, df=3, P>0.5). Thus, results for murres are ambiguous. Both the linear model analysis and the logistic regression analysis controlled for year effects and beach effects.

Table 8 shows percent oiled murres by season, pooling across years and beaches (raw values) and percentages after controlling for year to year and beach to beach differences (see above). The latter analysis is needed because the distribution of juvenile and possibly adult murres varies between seasons (Table 8) and this can confound seasonal comparisons.

Table 8 also shows seasonal variation in percent oiled murres for each age class (Adults, Immatures). Adult values are also shown, after controlling for year and beach effects. Seasonal patterns for adults and immatures were quite similar. For example, ranking of seasons with respect to percent oiled carcasses were identical for adults and immatures (spring > winter > fall > summer). This comparison is limited by the small number of immature murre carcasses observed in winter and especially spring. Nevertheless, the seasonal pattern of oiling percentage appears consistent across age classes.

Interaction of Year, Beach, and Season

For all species groups there was evidence of year effects and beach effects; in addition, for murres there was some evidence of seasonal effects on percent oiled birds. For murres only we examined whether there were statistical interactions between year and beach effects, between year and seasonal effects, and between beach and seasonal effects. We did not attempt to statistically analyze interactions among year, beach, and season for loons and grebes because of the lack of sufficient data. For example, to estimate the beach x year interaction requires 108 degrees of freedom, which substantially exceeds the number of oiled loon or grebe carcasses in the total data set.

Year x beach interaction: For murres there was a significant interaction between year and beach (P = 0.0013, using linear model analysis). In other words, the effect of year depended on beach, and vice versa. This dependency is depicted in Table 9. For example, in 1975, the percent of carcasses that were oiled was high at Jetty and Pajaro Dunes, but very low at Cronkhite, Limantour and Muir beaches. However, in 1982, percent murres oiled were very high at Cronkhite, moderate at Pajaro Dunes, and very low at Jetty, Limantour, and Muir beaches. The year x beach interaction was confirmed for adults only (P = 0.015) and for immatures only (P = 0.042; both with linear model analysis).

Year x season interaction: For murres, there was significant interaction between year and season (P = 0.007, linear model analysis). A similar result was obtained when only adults were considered (P = 0.015, linear model analysis). Thus year, effects were not consistent across seasons, nor were seasonal effects consistent across years.

Beach x season interaction: For murres, there was no significant interaction between beach and season (P>0.3, linear model analysis). Nor was the interaction of beach and season significant when only adults were considered (P>0.3, linear model analysis). These results imply that beach effects were statistically similar across seasons and, conversely, that seasonal effects were statistically similar across beaches.

<u>Farallon Oiled Bird Survey</u>

Between January 1977 and December 1994, 2305 oiled birds and 95 oiled marine mammals were observed. A total of 26 seabird species and 3 marine mammal species were observed (Table 10). The predominant seabird species represented is the Common Murre (64%), though Western Gulls (*Larus occidentalis*) are also well represented (22%).

As described in the Methods section we identified minor and major incidents of oiling. Four major incidents were identified (199 or more oiled birds observed in a single episode) and eight moderate-sized incidents (between 34 and 71 oiled birds observed; Table 11). Month by month totals of oiled birds, for 1977-1994, are shown in Figure 9. The two largest peaks of oiled birds (November 1984 and February 1986) are clearly visible, corresponding to the *Puerto Rican* oil spill and the *Apex Houston* oil spill, respectively (Table 11). In addition there were two other major peaks of oiled birds: December 1981/January 1982 and January/February 1990. There were no known oil spills (or other identified sources of oiled birds) corresponding to the last two-mentioned incidents. These four major incidents resulted in as many as 500 oiled birds (*Apex Houston*) and as few as 199 birds (January/February 1990).

There were no single incidents with more than 71 oiled birds and fewer than 199 oiled birds. However, in winter 1990/1991 there were three apparently distinct episodes of oiling: December 1990, January 1991, and February/March 1991 (Table 11). Taken together these three episodes comprise 127 oiled birds. The total number of oiled birds observed between 18 December 1990 and 14 March 1991 was 138. Also, there were two apparently distinct episodes in winter and spring 1992/1993: December 1992 and April/May 1993. Taken together these two episodes comprise 117 birds. The total number of oiled birds observed between 11 December 1992 and 6 May 1993 was 142.

Of the twelve major and moderate-sized episodes of oiling, ten occurred during the winter (mid-December to mid-March). The only exceptions were the *Puerto Rican* oil spill (early November) and the episode in April/May 1993. Furthermore, most episodes were associated with storms (Table 11). Day by day totals of oiled birds are shown for five identified episodes: the December/January 1981/82 episode (Figure 10), the *Apex Houston* oil spill (Figure 11), the January/February 1990 episode (Figure 12), the December 1992 episode (Figure 13A) and the April/May 1993 episode (Figure 13B). We consider the entire period between 11 December 1992 and 6 May 1993 to represent the "1993 Tarball" incident; this is consistent with results from bird rescue centers (see below), which indicated a moderate level of oiled birds brought in from January to May 1993, inclusive (no data were obtained for December 1992 from bird rescue centers).

The distribution of oiled bird numbers on a daily basis indicates at least two types of patterns: sharply peaked (December 1981, *Apex Houston* incident in the first few days) vs. more broadly spread out (January 1982, *Apex Houston* later in the episode, spring 1993 episode, etc.). These different patterns may well represent different mechanisms of oiling or different mechanisms bringing oiled birds into shore.

Oiling Patterns of Common Murres and Comparison of Beached Bird and Farallon Oiled Bird Surveys

To compare results from the Farallon Oiled Bird Survey (FOBS) with Beached Bird Survey (BBS) we focus on Common Murres, a predominant species of both Surveys. The number of oiled Common Murres (all age classes) per year is shown in Figure 14. As with the BBS each "year" spans 1 June to 31 May. The first year of data for the FOBS, 1976/77, is incomplete since there was no systematic collection of data before 1 January 1977; for the same reason 1994 (=1994/1995) is also incomplete. Figure 14 indicates great year to year variation in number of oiled murres, with a trend that appears more or less stable since 1979 (recall data .

The FOBS and BBS were both conducted during the years 1977 to 1984, a period of 8 years. This provides the opportunity to determine if the two surveys demonstrate a concordant pattern during the period of overlap. Making the comparison more difficult is the fact that gill-netting was conducted in Monterey Bay in 1980-1984 and in the Gulf of the Farallones in 1982-1984, causing additional, unnatural, oil-unrelated mortality. In addition, the 1982/83 El Niño was a particular severe oceanographic anomaly, especially disruptive for seabirds (Ainley & Boekelheide 1990). We therefore have compared the number of oiled Common Murres per year observed during the FOBS with the proportion of oiled Common Murres detected in the BBS for Gulf of the Farallones beaches only (seven out of the 10 major beaches); we restricted attention to the proportion of adult murres that were oiled, because of evidence of high mortality of juveniles due to the 1982/83 El Niño (Stenzel et al. 1988). We carried out the comparison of the two data sets in two ways: in the first method, we consider only the years 1977-1981, inclusive. In both methods we compare calendar years (1 January to 31 December) in order to maximize the number of complete years of data (see above). Using only the five years, 1977-1981, the correspondence between data sets was weak: R^2=0.136, r=+0.369, P = 0.54, N=5 years).

In the second method we attempted to correct for additional mortality due to gill-netting which would have depressed the proportion of oiled birds from what it would have been in the absence of gill-netting. Indeed the proportion of oiled murres was lowest in 1982 and 1983 compared to all other years. To make the necessary correction we made the following assumptions: (1) adult mortality due to oiling was similar in 1982 and 1983 compared to average values observed in 1975-1981. (2) Adult mortality not due to oiling or gill-netting was similar in 1982-1984 compared to 1975-1981. (3) Gill net adult mortality was greater in 1982-1984 than in previous years, but was similar among the three years. Assumptions (1)-(3) are consistent with the available evidence (Takekawa et al. 1990). Because the proportion of oiled adult Common Murres was 19.24% in 1975-1981 (on average) but only 7.02% in 1982-1983, we assumed that the drop in the proportion oiled in the latter two years was due solely to excess gill net deaths. These results imply that gill net mortality in 1982-1983 increased total non-oiling mortality by 215%. We therefore recalculated proportion of oiled carcasses in 1982-1984 after reducing non-oiling mortality to 1975-1981 levels. The result was to increase proportion of oiled carcasses in 1982-1984 from 6.9%, 7.1% and 23.1%, respectively, to 18.9%, 19.5%, and 48.6%, respectively (Figure 15).

After correcting the proportion of oiled adult Common Murre carcasses (as described above), the correlation between proportion oiled from the BBS and the number of oiled Common Murres per year (log-transformed) from the FOBS was stronger but not significant (Figure 15; R^2=0.268, r=+0.518, P = 0.19, N=8 years).

<u>Results from Bird Rescue Programs and Comparison with FOBS and BBS</u>

There were 200 birds brought into the two bird rescue centers in 1993 and 1994. Of these, 163 were Common Murres (82% of the sample). Sixty-one of the 163 murres were oiled. The distribution of oiled and unoiled murres, by month and year, is shown in Table 12. The 1993 tarball incident shows up as increased number of oiled birds during the months of January - May 1993 compared to the same months in 1994 (27 vs. 3, respectively). The proportion of rescued birds that were oiled was also greater in January - May 1993 compared to January - May 1994 (82% vs. 21%, G = 15.67, df=1, P < 0.001).

We examined whether the monthly number and percent of oiled murres from rescue centers paralleled monthly number of oiled murres as determined by the Farallon oiled bird survey, for the two years of overlap (N=24 months). There was indeed evidence of parallelism between the bird rescue data sets and the Farallon oiled bird survey data (Spearman rank correlation rs=+0.576, Kendall's tau = +0.476, P = 0.0011, N=24 months, comparing number of oiled murres from each data set; Spearman rank correlation rs = 0.546, Kendall's tau = +0.435, P = 0.0046, N=22 months, comparing percent oiled murres from rescue centers and number of oiled murres from Farallon oiled bird survey; note that percent oiled murres turned into rescue centers could not be calculated for two months without any murres).

The seasonal pattern of percent oiled murres brought to rescue centers paralleled, in a qualitative fashion, that observed from the 13 year Beached Bird Survey data set. The greatest percentages of oiled birds were in spring (70%, n=33 birds) and winter (67%, n=21 birds); the lowest percentages were in summer (21%, n=85 birds) and fall (25%, n=24 birds). Thus, the rank order of seasons with respect to percent oiled (spring > winter > fall > summer), was the same for the bird rescue data set as it was for the BBS.

Estimates of Common Murre Mortality from Chronic Oiling

We used two sources of data on oiled murres to draw inferences regarding the impact of chronic oiling on mortality of Common Murres. First, we correlated the annual pattern of oiling as indicated by the FOBS with observed survival rates of Farallon adult murres, reported in Sydeman (1993). Data on adult survival were only available for five years (1986/87 - 1990/91); none of these years included major oil spills. No comparable data are available with regard to juvenile survival. For Farallon Common Murres, annual adult survival rate decreased significantly with increased oiling of murres in each year, the latter indexed by numbers of oiled Common Murres (log-transformed) detected in the FOBS in a calendar year (results from linear regression, P = 0.016; Figure 16).

Secondly, we used the proportion of oiled murres in the BBS to provide a preliminary estimate of absolute mortality. To arrive at such an estimate required us to assume that the probability an **oiled** murre is deposited and detected on a beach survey is the same as the probability an **unoiled** murre is deposited and detected. If so, then the fraction of carcasses that are oiled gives us a measure of the fraction of the total mortality that is attributable to oiling. We also assumed that a negligible number of murres become oiled after death or while dying from an unrelated cause.

Sydeman (1993) and Nur et al. (1994) estimated that mortality of Farallon Island Common Murres is 6.7% for adults and 60% for juveniles, respectively. It is unclear what fraction of that mortality is attributable to chronic oiling. We might expect lower levels of chronic oiling on the Farallones compared to coastal populations in the Gulf of the Farallones and Monterey Bay, because of the latter's proximity to shipping lanes. We therefore consider two scenarios: (1) none of the mortality figures cited above (6.7%, 60%, respectively) includes chronic oiling, and therefore chronic oiling represents additional mortality to the stated figures, and (2) chronic oiling of the level observed here is completely included within those stated levels. Each scenario (1 or 2) generates a higher or lower estimate of mortality due to chronic oiling, respectively.

First, we calculated the percent of adult and juvenile murres that were oiled, excluding data from Monterey Bay from 1980-1984 because of gill-netting during this period and the *Puerto Rican* oil spill, and excluding data from Gulf of the Farallones from 1982-1984 because of gill-netting and the *Puerto Rican* oil spill. (Gill netting was not a major mortality source in the Gulf of the Farallones until 1982; Takekawa et al. 1990.) The overall percent of adult oiled murres was 25.3% and that of juveniles was 12.9% (Table 13). Under scenario 1, we estimate additional mortality due to chronic oiling to be 2.27% for adults and 8.9% for juveniles (Table 13). Under scenario 2, we estimate that mortality due to chronic oiling constitutes 1.70% for adults (out of the total mortality of 6.7%) and for juveniles, chronic oiling mortality constitutes 7.74% (out of the total of 60%). An excess mortality of even 1.7% on adults and/or 7.74% on juveniles can have substantial repercussions on murre populations. An additional mortality of 1.7% (on subadults and adults) lowers population growth rate by about 1.7% (Nur et al. 1994, Nur & Sydeman 1995). A population that declines at 1.7% per year will have declined to half its original size after 40 years. Additional mortality of juveniles of 7.74% will lower population growth rate by about 1.5% (Nur and Sydeman, unpublished).

DISCUSSION

Patterns of Oiling

Common Murres were the predominant species in terms of number and percent oiled birds among all 3 surveys. In beached bird surveys in the Netherlands, Common Murres also demonstrated the highest proportion of oiled individuals among all species, 89% (Camphuysen 1989). In contrast, results from beached bird surveys in British Columbia indicate the proportion of Common Murres that were oiled was low (5.4%), even lower than the overall proportion of oiled birds calculated for all species (6%; Burger 1993). In this study, eight to nine percent of juvenile (i.e., HY) murres were observed oiled in the summer and fall months, only slightly less than the percent of adults observed oiled (10 to 11 percent after statistically controlling for year and beach effects). In contrast, Bayer et al. (1991) found not a single oiled HY murre out of 3,693 HY murres recorded over a five year period (1986-1990) from two beaches in central Oregon.

Analyses of the BBS data presented here have focused on *a priori*-identified species likely to be oiled and so did not treat species such as cormorants or Western Gulls. Cormorants (Brandt's Cormorants *Phalacrocorax penicillatus*, Pelagic Cormorants *P. pelagicus*, Double-crested Cormorants *P. auritus*) do not appear often in the Farallon Oiled Bird Survey or Bird Rescue Center Survey. This finding corresponds to the conclusion reached by Ford et al. (1991; see also Nur et al. 1994) that cormorants are not likely to be oiled. The European Cormorant (*Phalacrocorax carbo*) and European Shag (*P. aristotelis*) were rarely found oiled in the Dutch Beached Bird Survey (Camphuysen 1989). In addition, Nur et al. (1994) concluded that Western Gulls are unlikely to be oiled but this does not correspond to the finding here of a substantial number of oiled birds in the FOBS (22% of all Farallon seabirds). Further investigation of risk of oiling to Western Gulls is called for.

This study has found evidence of variation between species and, at the same time, commonality of patterns among species. The overall percentage of oiled carcasses in the BBS differed among species groups (two to three times as high among loons and murres than among grebes) but this difference is hard to interpret because the behavior of oiled, living birds may differ between species (i.e., when oiled, some species may head towards or away from shore and others may not respond one way or the other). All three species groups showed significant beach to beach variation and at least two of the species groups showed significant annual variation in the proportion of carcasses oiled. The temporal and spatial patterns of oiling, however, were not strongly correlated among the three species groups. Loons and grebes showed significant concordance with respect to annual variation but not with respect to beach to beach variation. On the other hand, grebes and murres showed no significant concordance with respect to annual variation but did show concordance for beach to beach variation. It is perhaps not surprising that oiling patterns for murres differed from those of loons and grebes because the latter two groups are found near shore to a greater degree than are murres, whose distribution is more pelagic (Briggs et al. 1983). However, the distributions of loons and grebes are broadly similar which leaves unexplained why beach to beach variation in proportion of oiled birds differed between these two groups. It may be that loons and grebes utilize somewhat different areas of the coast.

Whereas previous authors have commented on differences in oiling rates comparing beached bird surveys from different regions (e.g., Burger 1993), less attention has been paid to beach to beach differences within a region. Yet this study has found considerable magnitude of beach to beach variation in the proportion of oiled carcasses for all three species groups. Furthermore, there was a significant interaction between beach and year effects among murres, i.e., the effect of year to year differences varied among beaches. The implication of these findings is that a large sample of beaches would need to be monitored consistently in each year in order to develop good estimates of oiling rates on a year to year basis.

<u>Sources of Chronic Oiling</u>

"Chronic oiling" is likely composed of two sources: moderate-sized oil spills of short duration that go unreported and other low-level sources of oil pollution (bilge-emptying, etc.), which may be of extended duration (Fry 1992, Burger and Fry 1993). With regard to the second-type of oiling, Dahlmann et al. (1994) found that illegal discharges of oil-sludge were widespread in the North Sea and Skaggerak leading to high levels of chronic oil pollution. The second-type of oiling, which is included in results from the FOBS, may involve oil escaping from the submerged tanker the *Puerto Rican*, located ~10 km SW of Southeast Farallon Island. This conjecture is supported by the correspondence observed between winter storms and the appearance of substantial numbers of oiled birds on the Farallones. The possibility of natural seepage accounting for the 1993 Tarball incident was determined to be unlikely (California OSPR Bulletin, March 1993), but the origins of other chronic oiling episodes are hard to establish. The daily pattern of oiling recorded in the FOBS supports the idea of two (or more) mechanisms of oiling; see especially Figure 10 depicting a tall, sharp peak on 29 December 1981 followed by a moderate hump in the month of January, 1982.

<u>Estimating the Impact of Oiling on Murres</u>

Using the proportion of carcasses that are oiled as a measure of oiling hazard, as we have done, is subject to several biases. In order to estimate absolute mortality due to oiling, we assumed that an oiled bird is as likely to be deposited on a beach and enumerated as is an unoiled bird. If we call the probability of deposition and enumeration a **detection probability**, then the assumption is that the detection probability is the same for oiled and unoiled birds; we have no information as to whether or not this is true. Clearly, bias in detection probability presents a potential source of error. However, for estimates of relative oiling risk (e.g., comparisons among years or among beaches), this bias is less serious. For example, comparisons of oiling risk between years are still valid even if oiled birds, dead or dying, are more likely (or less likely) to be deposited and enumerated than are unoiled birds, *as long as the ratio of detection probabilities for oiled vs unoiled birds does not change between years,* i.e., as long as the bias is constant between years.

The impact of chronic oiling for Common Murres appears substantial, as indicated by our estimates of additional mortality of 1.7% or more in adults, and 7.7% or more among juveniles. Population dynamics of any seabird species is determined by the balance between productivity and mortality. For murres (and many, but not all, other seabird species), productivity is tightly constrained: at most one murre chick is reared per year per breeding pair. Even at successful colonies, reproductive success is only on average about 0.8 chicks per year (Boekelheide et al. 1990, Harris 1991, Nur et al. 1994). The probability that a murre chick survives to breeding age is likely between 25 and 40% (Hudson 1985, Nur et al. 1994). Given the low levels of production of future recruits (breeders), any additional mortality (as represented by chronic oiling) can have serious consequences. A combination of additional mortality of 1.7% and 7.7% in adults and juveniles, respectively, will decrease population growth rate by about 3.1% per year (N. Nur and W.J. Sydeman, unpublished data). Even if our estimates of mortality are over-estimates by a factor of 2 (i.e., true additional mortality is 0.85% and 3.87%, respectively), the additional mortality represented by chronic oiling will reduce population growth rate by about 1.6% per year. This additional mortality can represent the difference between a population that is growing and one that is shrinking. Considering that recent growth of the Farallon Common Murre population is about 5% (Sydeman et al. 1997), a decrement of 1.6% growth is significant.

The correlation observed in murres between adult survival to the next year and magnitude of oiling in that year provides cause for concern and should be investigated further. The correlation observed should not be taken as conclusive evidence of a causal relationship. Some aspect of oceanographic conditions may be simultaneously influencing both variables, thereby producing a negative correlation between oiling rates and adult murre survival. Analysis of additional years of survival data (from 1991 on, updating Sydeman [1993]) is needed to confirm the pattern observed.

RECOMMENDATIONS

(1) That we were able to elucidate patterns with respect to annual, spatial and species variation with regard to proportion of oiled birds, serves to confirm the value of beached bird surveys in general (but see caveats below). In addition, the FOBS appears to make an invaluable addition to results derived from

beached bird surveys, for several reasons: (1) Temporal resolution is high (day to day variation rather than month to month variation), which can provide insights into causes and mechanisms of oiling, and (2) a different sample of oiled birds is monitored than is encountered in beached bird surveys (e.g., a large proportion of live, oiled birds are included in the FOBS). Also, different sets of biases affect the BBS and FOBS. For example, the FOBS is not subject to influences on carcass persistence. On the other hand, in the FOBS factors that cause more oiled birds to come to the island cannot be distinguished from factors that cause more birds to be oiled in the first place. This is less likely a problem for analyses of proportion of carcasses oiled based on the BBS. We do not advocate the FOBS in place of beached bird surveys but see it as a critical supplement to provide cross-calibration and high temporal resolution.

(2) The presence of beach to beach variation and a beach x year interaction puts a premium on establishing a beached bird survey monitoring program that includes a relatively large number of beaches, in order to obtain a representative sample of beaches in each year (e.g., 10 beaches per region). There is little long-term monitoring value to including beaches that have been monitored for only a few years since it would be difficult in that situation to tease apart year to year variation as distinct from beach to beach variation. Therefore we strongly recommend that consistent effort be expended year in and year out in monitoring a large set of beaches.

(3) The FOBS and the BBS proved to be good means to monitor broad temporal patterns in the oiling of murres, but other species groups were less well represented. Development of monitoring programs to target species of concern (other than Common Murres) may be necessary. For murres it has been difficult to assess mortality attributable to acute or chronic oiling on the basis of beached bird carcasses or numbers of oiled birds (as on the Farallones). With regard to other species, we are generally ignorant as to the significance of chronic oiling. Even for murres, there is much room for improvement of mortality estimates from specific incidents; such improvement can come from greater monitoring effort and advances in analytic techniques (e.g., deriving better estimates of forces influencing carcass deposition and persistence).

(4) The information collected to date (this study) indicates a substantial, deleterious effect of chronic oiling on Common Murres. Further work is needed to evaluate the effects of chronic oiling on other seabird species, some of which may be in fragile condition even in the absence of chronic oiling. More research is needed to establish sources of chronic oiling as a first step to reducing its impact. Finally, research is called for to investigate non-lethal effects of oiling (for example leading to disruption or inhibition of breeding behavior, see Sydeman and Eddy, this volume).

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TABLE 1. Number of carcasses observed and the percent oiled by species based on the PRBO Beached Bird Survey, 1972-1984.

		TOTAL CARCASSES	OILED CARCASSES	PERCENT OILED
LOONS				
Arctic Loon		261	37	14.2
Common Loon		164	14	8.5
Red-throated Loon		87	10	11.5
"Loon"		13	3	(23)
TOTAL		525	64	12.2
GREBES				
Eared Grebe		117	6	5.1
Horned Grebe		52	2	3.8
"Small Grebe"		25	1	4.0
Western Grebe		1180	66	5.6
TOTAL		1374	75	5.5
SCOTERS				
Surf Scoter		514	9	1.8
White-winged Scoter		219	5	2.2
"Scoter"		32	12	37.5
TOTAL		765	26	3.4
MURRES				
Common Murre		4402	665	15.1

TABLE 2. Year to year variation in the number of carcasses observed and percent oiled for loons (all taxa) and grebes (all taxa) based on the PRBO Beached Bird Survey, 1972-1984.

	LOONS			GREBES		
	Total Carcasses	Oiled Carcasses	Percent Oiled	Total Carcasses	Oiled Carcasses	Percent Oiled
YEAR						
1972/73	23	1	4.3	167	4	2.4
1973/74	41	7	17.1	72	7	9.7
1974/75	4	1	(25)	48	7	14.6
1975/76	35	3	8.6	160	2	1.3
1976/77	41	7	17.1	196	21	10.7
1977/78	45	4	8.9	66	3	4.5
1978/79	22	3	13.6	32	0	0.0
1979/80	76	8	10.5	155	12	7.7
1980/81	47	3	6.4	103	2	1.9
1981/82	30	2	6.7	79	2	2.5
1982/83	52	1	1.9	159	2	1.3
1983/84	62	1	1.6	68	2	1.2
1984/85	46	23	50.0	63	11	17.5
TOTAL	524	64	12.2	1368	75	5.5

TABLE 3. Year to year variation in the number of carcasses observed and percent oiled stratified by age class for Common Murres based on the PRBO Beach Bird Survey, 1972-1984.

YEAR	TOTAL			ADULTS			JUVENILES		
	Number of Carcasses	Oiled Carcasses	Percent Oiled	Number of Carcasses	Oiled Carcasses	Percent Oiled	Number of Carcasses	Oiled Carcasses	Percent Oiled
1972/73	141	19	13.5	85	15	17.6	33	0	0.0
1973/74	443	100	45.1	186	62	33.3	181	8	4.4
1974/75	97	13	13.4	50	5	10.0	33	1	3.0
1975/76	360	118	32.8	125	56	44.8	124	25	20.0
1976/77	370	38	10.3	150	18	12.0	154	12	7.8
1977/78	157	26	16.6	75	16	21.3	61	10	16.4
1978/79	267	43	16.1	110	32	29.1	129	11	8.5
1979/80	196	38	19.4	85	18	21.2	57	10	17.5
1980/81	847	93	11.0	374	40	10.7	422	45	10.7
1981/82	302	34	11.3	161	19	11.8	122	11	9.0
1982/83	669	44	6.6	334	19	5.7	240	11	4.6
1983/84	318	22	6.9	190	14	7.4	32	0	0
1984/85	235	77	32.8	70	9	12.9	34	0	0
TOTAL	4402	665	15.1	1995	323	16.2	1622	142	8.8

TABLE 4. Frequency distribution of censuses with respect to the number of oiled and total carcasses per census for loons, grebes, and murres based on the PRBo Beached Bird Surcey, 1972-1984.

LOONS			GREBES			MURRES		
Number enumerated in census	Total[1]	Oiled [1]	Number enumerated in census	Total[1]	Oiled [1]	Number enumerated in census	Total[1]	Oiled [1]
0	- - [2]	210	0	- - [2]	411	0	496	- -
1	144	27	1	188	41	1	107	205
2	48	8	2	102	5	2	38	127
3	14	0	3	56	0	3	17	70
4	19	1	4	40	0	4	10	39
5	8	1	5	16	1	5	5	38
6	5	0	6	10	1	6	7	27
7	4	0	7	8	1	7	1	25
8	0	0	8	6	0	8	4	19
9	2	0	9	8	0	9	5	17
10+	4	1	10-12	12	0	10	0	15
			13-20	12	0	11-15	8	44
			21+	13	0	16-30	3	49
						31+	2	18

[1] - Shown is number of censuses.
[2] - Censuses with no birds of that species group are omitted.

TABLE 5. Beach to beach variation in the number of carcasses observed and percent oiled for loons (all taxa) and grebes (all taxa) based on the PRBO Beached Bird Survey, 1972-1984.

	LOONS			GREBES		
	Total Carcasses	Oiled Carcasses	Percent Oiled	Total Carcasses	Oiled Carcasses	Percent Oiled
Cronkhite	6	1	(17)	20	6	30.0
Del Monte	213	14	6.6	440	11	2.5
Jetty	68	2	2.9	193	5	2.6
Limantour	44	8	18.2	99	5	5.1
Muir	10	1	10.0	46	0	0.0
Ocean	30	8	26.7	107	12	11.2
Pajaro Dunes	31	6	19.4	89	9	10.1
RCA	25	7	28.0	74	4	5.4
Seadrift	80	14	17.5	273	19	7.0
Thornton	18	3	16.7	33	4	12.1

TABLE 6. Beach to beach variation in the number of carcasses observed and percent oiled stratified by age class for Common Murres based on the PRBO Beached Bird Survey, 1972-1984.

BEACH	TOTAL			ADULTS			JUVENILES		
	Number of Carcasses	Oiled Carcasses	Percent Oiled	Number of Carcasses	Oiled Carcasses	Percent Oiled	Number of Carcasses	Oiled Carcasses	Percent Oiled
Cronkhite	409	131	32.0	162	55	34.0	201	65	32.3
Del Monte	404	46	11.4	131	11	8.4	56	6	10.7
Jetty	427	45	10.5	294	28	9.5	117	13	11.1
Limantour	349	98	28.1	114	32	28.1	90	0	0.0
Muir	378	13	3.4	180	9	5.0	188	4	2.1
Ocean	391	62	15.9	224	38	17.0	151	17	11.3
Pajaro Dunes	392	97	24.7	178	41	23.0	789	120	15.2
RCA	493	53	10.8	171	30	17.5	227	6	2.6
Seadrift	764	61	8.0	374	41	11.0	318	7	2.2
Thornton	395	59	14.9	167	38	22.8	195	14	7.2

TABLE 7. Seasonal variation in the number of carcasses observed and percent oiled for loons grebes, and scoters (all taxa) based on the PRBO Beached Bird Survey, 1972-1984.

	LOONS		
	Total Carcasses	Oiled Carcasses	Percent Oiled
SUMMER	68	10	14.7
FALL	101	26	25.7
WINTER	163	14	8.6
SPRING	193	14	7.3
	GREBES		
	Total Carcasses	Oiled Carcasses	Percent Oiled
SUMMER	56	1	1.8
FALL	253	17	6.7
WINTER	611	34	5.6
SPRING	454	23	5.1
	SCOTERS		
	Total Carcasses	Oiled Carcasses	Percent Oiled
SUMMER	35	0	0
FALL	134	15	11.2
WINTER	310	10	3.2
SPRING	286	1	0.3

TABLE 8. Seasonal variation in the number of carcasses observed and percent oiled by age class for Common Murres based on the PRBO Beached Bird Survey, 1972-1984. Values adjusted for beach and year effects are also shown.

SEASON	**ALL AGE CLASSES**			
	Number of Carcasses	Number of Oiled Carcasses	Percent Oiled	Percent Oiled Statistically Controlled
Summer	1827	171	9.4	9.7
Fall	1837	299	16.3	10.1
Winter	294	69	23.5	20.2
Spring	444	126	28.4	20.4

SEASON	**ADULTS**			
	Number of Carcasses	Number of Oiled Carcasses	Percent Oiled	Percent Oiled Statistically Controlled
Summer	884	91	10.3	10.5
Fall	692	115	16.6	10.6
Winter	111	29	26.1	22.6
Spring	308	88	28.6	21.0

SEASON	**JUVENILES**		
	Number of Carcasses	Number of Oiled Carcasses	Percent Oiled
Summer	866	65	7.5
Fall	718	68	9.5
Winter	30	7	23.3
Spring	8	2	50.0

TABLE 9. Percent oiled Common Murres (all age classes) classified by beach and year, based on the PRBO Beached Bird Survey, 1972-1984.

YEAR BEACH[1]

		CRO	DEL	JET	LIM	MUI	OCE	PAJ	RCA	SEA	THO
1972		0.0	--[2]	--	25.0	--	8.0	0.0	0.0	19.5	--
1973		4.2	0.8	--	10.5	3.6	4.5	7.5	7.1	10.6	--
1974		21.4	--	--	51.4	0.0	--	14.8	36.0	47.4	93.9
1975		0.0	15.2	67.3	3.8	0.0	38.5	75.8	7.0	10.5	31.9
1976		25.0	7.1	5.0	7.7	0.0	38.1	24.1	9.4	0.0	1.8
1977		--	25.6	14.3	--	0.0	35.7	10.0	--	0.0	9.5
1978		33.8	12.9	6.5	27.3	0.0	20.0	5.3	28.0	4.5	10.0
1979		--	--	--	10.0	0.0	33.3	41.7	0.0	0.0	4.3
1980		57.4	15.5	1.2	15.6	4.3	33.3	12.9	3.7	5.2	7.1
1981		45.5	8.8	0.0	--	0.0	4.5	17.5	--	4.7	0.0
1982		68.6	0.0	0.0	0.0	1.3	3.6	11.8	8.5	4.6	0.0
1983		16.4	0.0	0.0	10.0	0.0	4.7	18.9	2.6	0.0	0.0
1984		15.4	--	--	68.1	50.0	5.0	--	28.9	20.0	8.3
ALL YEARS		32.1	11.4	10.5	28.1	3.4	15.9	24.6	10.7	8.0	14.9

[1] BEACHES: CRO=Cronkhite, DEL=Del Monte, JET=Jetty, LIM=Limantour, MUI=Muir, OCE = Ocean, PAJ = Pajaro Dunes, RCA=RCA, SEA=Seadrift, THO=Thornton

[2] -- means no census or < 10 bodies that year.

Table 10. Summary of oiled bird and mammal species recorded on Southeast Farallon Island, California, 1977-1994.

Species	Total Number Seabirds Oiled	Percent of Seabirds Oiled
Common Murre	1481	64.3
Western Gull	512	22.2
Cassin's Auklet	154	7.7
Northern Elephant Seal	87	--
Eared Grebe	34	1.5
Rhinoceros Auklet	22	1.0
Pelagic Cormorant	16	0.7
Pigeon Guillemot	15	0.7
Brandt's Cormorant	14	0.6
Black-legged Kittiwake	11	0.5
California Gull	10	0.4
California Sea Lion	7	--
Harbor Seal	1	--
Other Seabirds (16 spp.)	36	1.6

Table 11. Summary of oiling "episodes" at Southeast Farallon Island, California, 1977-1994. Under “Notes,” a storm is defined as >0.50 inches of rain and/or south winds of >20 knots and a large storm is defined as >0.80 inches of rain and/or south winds of >30 knots. Large swells are defined as those >10 feet.

Dates	Total Seabirds Oiled	Notes
7-11 January 1978	34	Large storm 4-5 Jan.
15-20 January 1980	55	Large storm 11-14 Jan.
25 December 1981-31 January 1982	218	No storms 15-30 Dec.
6-8 November 1984	363	*Puerto Rican*
1-22 February 1986	500	*Apex Houston*
4 January - 1 March 1990	44	Storm 3 Jan.
25 January - 1 March 1990	199	Large swells 21-23 Jan.
18-25 December 1990	38	Large storms 15-20 Dec.
15-23 January 1991	36	Large swells 14 Jan.
7 February - 14 March 1991	53	Large swells 4-6 Feb.
11-23 December 1992	46	Large storm 7-10 Dec.
18 April - 6 May 1993	71	Storm 15-17 Apr.

TABLE 12. Number of Common Murres, number oiled, and percent oiled from bird rescue centers in central California, by month from 1993 and 1994.

	1993			1994		
MONTH	NUMBER OF BIRDS	NUMBER OILED	PERCENT OILED	NUMBER OF BIRDS	NUMBER OILED	PERCENT OILED
JANUARY	3	3	100	0	0	--
FEBRUARY	8	3	38	3	1	33
MARCH	8	7	88	4	1	25
APRIL	5	5	100	2	1	50
MAY	9	9	100	5	0	0
JUNE	4	2	50	14	1	7
JULY	6	4	67	22	1	5
AUGUST	21	8	38	18	2	11
SEPTEMBER	9	1	11	6	0	0
OCTOBER	1	0	0	0	0	--
NOVEMBER	2	0	0	6	5	83
DECEMBER	6	6	100	1	1	100

TABLE 13. Derivation for estimating mortality due to chronic oiling (i.e. all oiling excluding major opills) for Common Murres in central California.

Adults[1]	Percent oiled	25.3
Juveniles[1]	Percent oiled	12.9

If natural adult mortality is 6.7% then additional mortality due to oiling = .253 x (.067/.747) = .0227
i.e. additional 2.27% mortality

If natural juvenile mortality is 60% then additional mortality due to oiling = 0.129 x (.60/.871) = .089
i.e. additional 8.9% mortality

However, if total adult mortality is 6.7% then mortality due to oiling is 1.70%

Similarly, if total juvenile mortality is 60% then mortality due to oiling is 7.74%

[1] Based on Beached Bird Survey data excluding 1982-1984 for Gulf of the Farallones and excluding
1980-1984 for Monterey Bay, due to gill netting.

Figure Legends

Figure 1. Annual variation in proportion of carcasses that are oiled in Loons (circles, thin line) and in Grebes (triangles, thick line). Note that 1972 refers to 1972/73, etc. (see text). Note log-scale on y-axis.

Figure 2. Annual variation in proportion of carcasses that are oiled in Loons (circles, thin line) and in Murres (triangles, thick line). Note that 1972 refers to 1972/73, etc. (see text). Note log-scale on y-axis.

Figure 3. Annual variation in proportion of carcasses that are oiled in Grebes (circles, thin line) and in Murres (triangles, thick line). Note that 1972 refers to 1972/73, etc. (see text). Note log-scale on y-axis.

Figure 4. Annual variation in proportion of Common Murre carcasses that are oiled in relation to age class. All individuals (of all age classes) shown (circles, thin line) and in just adults (triangles, thick line). Note that 1972 refers to 1972/73, etc. (see text).

Figure 5. Beach to beach variation in proportion of carcasses that are oiled in Loons compared to variation among Grebes. Coding of beaches: CRO = Cronkhite; DEL = Del Monte; LIM = Limantour; JET = Jetty; MUI = Muir; OCE = Ocean; PAJ = Pajaro Dunes; RCA = RCA; SEA = Seadrift; THO = Thornton. Regression statistics shown in Figure. Note log scales for x- and y-axes.

Figure 6. Beach to beach variation in proportion of carcasses that are oiled in Loons compared to variation among Murres. Coding of beaches: CRO = Cronkhite; DEL = Del Monte; LIM = Limantour; JET = Jetty; MUI = Muir; OCE = Ocean; PAJ = Pajaro Dunes; RCA = RCA; SEA = Seadrift; THO = Thornton. Regression statistics shown in Figure. Note log scales for x- and y-axes.

Figure 7. Beach to beach variation in proportion of carcasses that are oiled in Grebes compared to variation among Murres. Coding of beaches: CRO = Cronkhite; DEL = Del Monte; LIM = Limantour; JET = Jetty; MUI = Muir; OCE = Ocean; PAJ = Pajaro Dunes; RCA = RCA; SEA = Seadrift; THO = Thornton. Regression statistics shown in Figure; least squares line of best fit is shown. Note log scales for x- and y-axes.

Figure 8. Beach to beach variation in proportion of Common Murre carcasses that are oiled, comparing adults only and all individuals. Coding of beaches: CRO = Cronkhite; DEL = Del Monte; LIM = Limantour; JET = Jetty; MUI = Muir; OCE = Ocean; PAJ = Pajaro Dunes; RCA = RCA; SEA = Seadrift; THO = Thornton. Regression statistics shown in Figure; least-squares line of best fit is shown. Note log scales for x- and y-axes.

Figure 9. Month to month variation in the number of oiled seabirds detected in the Farallon Oiled Bird Survey. Months in which 1 or more birds were observed oiled are shown with a circle symbol. Symbols and tick marks for each year are lined up with the January record of that year.

Figure 10. Number of oiled birds per day detected in the Farallon Oiled Bird Survey, for the December/January 1981/1982 episode (see text).

Figure 11. Number of oiled birds per day detected in the Farallon Oiled Bird Survey, for the *Apex Houston* oil spill, February 1986 (see text).

Figure 12. Number of oiled birds per day detected in the Farallon Oiled Bird Survey, for the January/February 1990 episode (see text).

Figure 13. Number of oiled birds per day detected in the Farallon Oiled Bird Survey, for the December 1992 episode (A) and for the April/May 1993 episode (B).

Figure 14. Annual variation in number of oiled Common Murres detected in the Farallon Oiled Bird Survey detected in each year. Note that 1976 refers to 1976/77, etc., and that 1976/77 and 1994/95 are incomplete (see text). Thus the *Apex Houston* spill is included in the "85" year; also, the 1993 Tarball incident is included in the 1992 year. Note log-scale on y-axis.

Figure 15. Year to year variation in oiling patterns of Common Murres for Beached Bird Survey (circles, thin line) and Farallon Oiled Bird Survey (triangles, thick line). Left axis shows proportion of murres that were oiled, averaged over all Gulf of the Farallones beaches, but corrected for presumed effects of gill netting in 1982-1984 (see text). Right axis shows number of oiled Common Murres detected each year in

the Farallon Oiled Bird Survey. In
this figure, year refers to calendar year for both data sets (see text).

Figure 16. Annual survival of Farallon Common Murres in relation to magnitude of oiling on SE Farallon Island that year. Survival of adults (from Sydeman 1993) is measured from the stated year ("87", etc.) to the following year. Logarithm of number of oiled Common Murres detected in the Farallon Oiled Bird Survey is shown for each calendar year. Least-squares line of best fit is shown as are associated regression statistics.