ECOLOGICAL
MODELLING

Modeling bird mortality associated with the M/V Citrus oil spill off St. Paul Island, Alaska

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Abstract

We developed a model to estimate the number of bird carcasses that were likely deposited on the beaches of St. Paul Island, Alaska following the M/V Citrus oil spill in February 1996. Most of the islands beaches were searched on an irregular schedule, resulting in the recovery of 876 King Eider carcasses. A sub-sample of beaches were intensively studied to estimate daily persistence rate and detection probability [Fowler, A.C., Flint, P.L., 1997. Marine Pollution Bulletin]. Using these data, our model predicted that an additional 733 ± 70 King Eider carcasses were not detected during our searches. Therefore, we estimate that at least 1609 ± 70 King Eider carcasses occurred on beaches as a result of the spill. We lacked sufficient sample size to model losses for other species, thus we applied the estimated recovery rate for King Eiders (54%) to other species and estimate a total combined loss of 1765 birds. In addition, 165 birds were captured alive making the total estimated number of birds impacted by the M/V Citrus spill 1930. Given that oiled birds occurred in places on the island which could not be systematically searched combined with the fact that it was unlikely that oiled birds that died at sea would have been recovered during our searches [Flint, P.L., Fowler, A.C., 1998. Marine Pollution Bulletin], our estimate of total mortality associated with the spill should be considered a minimum. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Bird mortality; Detection probability; Oil spill; Persistence rate

1. Introduction

On 17 February 1996 the freighter M/V Citrus collided with a crab processing vessel and subsequently spilled an unknown amount of bunker oil 6 km north of St. Paul Island, Alaska (57°16′,

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170°15′). Within several days of the spill, numerous oiled and dying birds, mostly King Eiders, began appearing on beaches of St. Paul Island. The impact of this spill was unusual in that many birds appeared to have either flew or swam to shore where they subsequently died (Fowler and Flint, 1997). An intensive study examined daily persistence rates (probability that a marked carcass will remain on a beach) and daily detection probabilities (probability that a marked carcass known to be on a beach will be detected on a given survey) of King Eider carcasses following the M/V Citrus spill (Fowler and Flint, 1997). On average, 17% of carcasses would be expected to be removed by scavengers or wave action within 1 day of deposition and only 76% of carcasses present on beaches were detected during a given search (Fowler and Flint, 1997). Furthermore, only a portion of birds killed at sea drift onto beaches following an oil spill (Flint and Fowler, 1998). Thus, it is apparent, that even if beaches were searched daily, not all carcasses related to a mortality event would be recovered.

Our goal in this study was to develop a model that estimated the total number of birds that occurred on beaches of St. Paul Island as a result of the spill from the M/V Citrus. We incorporate the concepts of persistence rate and detection probability in estimating the number of King Eider carcasses not found during beach searches. We added random variation to model parameters to examine the uncertainty of our estimate. Finally, we examine the sensitivity of our model to bias and variation in model parameters.

2. Methods

At the time of the spill, we divided the perimeter of St. Paul Island into beach segments using maps and local knowledge. Beaches were placed in three major categories based on substrate: sand, rock cobble, and cliff. Segments were selected as continuous sections of beach with uniform substrate, and each segment was assigned a unique identifier. Initially, we searched beaches where carcasses had been reported by local observers and later expanded the searches to include less accessible areas. Beaches where carcasses were found on the initial search were given priority for subsequent searches. However, all sand and rock cobble beaches on the island were examined at least twice. Sand beaches that were accessible by four-wheel ATV were searched almost every day, whereas rock beaches were searched on an irregular schedule. All carcasses found were collected and placed in bags, that were sealed and labeled with the date and location found. In conjunction with our searches, beaches were opportunistically searched by members of the public. For many of the carcasses recovered by the public, we could not determine specific beach segment of origin, but we were able to restrict the origin to within a group of several beach segments. In most cases these pooled recoveries came from a specific group of three sand beaches that were searched by four-wheel ATV. We partitioned these recoveries back to specific beach segments weighting on segment length. This approach assumes a uniform distribution of carcasses along these beach segments.

Carcasses were examined in a laboratory where each was assigned a unique number, and species, degree of oiling (to the nearest 10%), and degree of scavenging (e.g. intact, head missing, breast missing, heavily scavenged) were recorded. For most carcasses, we could determine the degree to which the bird had been oiled. However, we did not assume carcasses that had been largely destroyed by wave action or consumed by scavengers had been oiled. Instead, we estimated the number of oiled birds by applying the oiled to unoiled ratio for intact carcasses to the total number of carcasses recovered by species.

2.1. Model development

Using the logic outlined by Page et al. (1990), we developed a general set of equations that describe the likelihood of the number of carcasses present on a beach on a given day:

Table 1
Detection probabilities and persistence rates of King Eider carcasses on beaches following the M/V Citrus spill off St. Paul, Alaska in Feb. 1996

| Date | Detection probability | | Persistence rates | | | |
| | | | Sand beaches | | Rock beaches | |
	Sand	Rock	Males	Females	Males	Females
20 Feb.–22 Feb.[a]	0.880	0.640	0.910	0.820	0.860	0.860
23 Feb.	0.830	0.480	0.790	0.720	0.940	0.910
24 Feb.	0.890	0.440	0.940	0.970	0.880	0.800
25 Feb.	0.890	0.870	0.990	0.960	0.960	0.990
26 Feb.	0.860	0.540	0.880	0.600	0.990	0.770
27 Feb.	0.940	0.850	0.940	0.870	0.520	0.840
28 Feb.–11 Mar.[a]	0.880	0.640	0.910	0.820	0.860	0.860

[a] Average values for persistence rates and detection probabilities were used for days not intensively studied (Fowler and Flint, 1997).

Day	Expected # of carcasses on beaches
1	D_1
2	$D_1^* P_1 + D_2$
3	$D_1^* P_1^* P_2 + D_2^* P_2 + D_3$
4	$D_1^* P_1^* P_2^* P_3 + D_2^* P_2^* P_3 + D_3^* P_3 + D_4$

where D_t is the number of new carcasses deposited on the beach on day t and P_t is the probability that a carcass deposited on day t will still be there on day $t + 1$. This series of equations can be reduced to a single equation describing the number of carcasses on a beach (defined as θ) on day t as follows:

$$\theta_t = \sum_{i=1}^{t-1}\left(D_i \prod_{j=i}^{t-1} P_j \right) + D_t \qquad (1)$$

Given θ_t, the number of carcasses expected to be found on beaches searched at time t is described as:

$$E(F_t) = \theta_t \times \phi_t \qquad (2)$$

where ϕ_t is the detection probability of carcasses on beaches at the time of the search. If carcasses are not removed during searches, but only counted, then this relationship holds true for each search.

If all carcasses found are removed during each search then the above equations are only valid for the first search. The number expected to be found on each subsequent search at any time b when the preceding search occurred at time a is described as:

$$E(F_b) = \left((1 - \phi_a)(\theta_a \times \phi_a)\left(\prod_{i=a}^{b-1} P_i \right) \right.$$
$$\left. + \left(\sum_{i=a+1}^{b-1}\left(D_i \prod_{j=i}^{b-1} P_j \right) + D_b \right) \right)\phi_b \qquad (3)$$

Eqs. (2) and (3) were rearranged and solved for D after substituting estimates of daily persistence rate and detection probability determined in a previous study (Fowler and Flint, 1997) and using the actual number of carcasses found on a particular search. We assumed that D was constant within intervals between searches. The number not detected on a given search was then estimated as:

Not Detected =

$$\{D \times (\# \text{ days between times } a \text{ and } b)\} - F_b. \qquad (4)$$

We modeled King Eiders carcass recoveries separately by sex and beach segment. Individual estimates for daily persistence rate and detection probability were only available for 5 days during

the peak of carcass recoveries. Therefore, we used average values of persistence rate (by beach type and sex) and detection probability (by beach type) for other days (Table 1). We added random normal variation to estimated parameters (persistence rate and detection probability) but constrained estimates between 1.0 and 0.1. We used the concepts described by Annan (1997) and applied different levels of random variation to each day for which average values of persistence rate and detection probability were used. We ran 500 simulations at each of six levels of variation in persistence rate and detection probability ($\sigma^2 = 0.0–0.25$ in increments of 0.05). We calculated the mean and standard deviation of the estimates of total King Eider carcasses not found during searches for each level of variability.

2.2. Model testing

We examined the sensitivity of our model to bias in estimates of detection probability and persistence rate. We ran simulations of 1000 trials where random variation was added to parameter estimates, then parameter estimates were adjusted by a fixed amount (i.e. bias). We used seven levels of potential bias from -0.15 to 0.15 in increments of 0.05. Bias adjustments were made for persistence rate and detection probability separately.

3. Results

The spill occurred on 17 Feb. 1996 and oiled birds on beaches were first observed on 19 Feb. Our searches began on 23 Feb.; however, for our modeling effort, we assumed that carcasses began accruing on beaches on 20 Feb. Average interval between searches was 2.5 ± 1.4 days. We recovered 961 oiled bird carcasses during our searches, of which 876 were King Eiders (Table 2). With the exception of Murre and Red-faced Cormorants, most carcasses recovered were oiled. Assuming no variation in model parameters for carcass detection probability and persistence rate, our model predicts that an additional 661 King Eider carcasses would have been missed during our beach surveys (Fig. 1). Adding variation to model parameter estimates ($\sigma^2 = 0.1$), we predict that 733 ± 70 carcasses were not detected during our searches. Therefore, we predict that at least 1609 ± 70 King Eider carcasses likely occurred on beaches as a result of the spill.

We lacked sufficient sample size to fully model losses for other species, therefore, we assumed that the overall recovery rate for King Eider carcasses applied to other species. We estimate that 54.4% of King Eider carcasses were recovered. Applying this rate to recovered carcasses of other species, we estimate that a total of 1765 oiled carcasses were deposited on beaches as a result of this spill. Adding the 165 oiled birds that were captured alive and sent to rehabilitation, we estimate that total number of birds impacted by the M/V Citrus spill that occurred on St. Paul Island was 1930.

Adding variation to the model parameters increased the estimated number of birds not detected during beach searches and decreased the precision of the estimates (Fig. 1). The response of the model to bias adjustments of model parameters was asymmetrical; decreases in parameter estimates had a greater effect than comparable increases (Fig. 2).

4. Discussion

4.1. Comparison with other models

Overall, our model is similar to the one developed by Van Pelt and Piatt (1995); however our model is unique in that it incorporates the concept of detection probability of carcasses. Additionally, Van Pelt and Piatt's (1995) model assumes an underlying logarithmic function to both the persistence and deposition rates. As applied in this study, our model makes no assumptions regarding a functional relationship for persistence rate and we assumed that daily deposition rate was constant for a given search interval. Functional relationships for persistence and deposition rates could easily be included in our model; likewise, the concept of detection probability be could included in the model of Van Pelt and Piatt

Table 2
Recoveries of birds following the M/V Citrus spill off St. Paul, Alaska in February 1996

Species	Degree of oiling			Est. oiled[b]	Rehab. birds[c]	Total oiled birds[d]	Est. total impact[e]
	Oiled	Unoiled	Unk.[a]				
King Eider (*Somateria spectabilis*)	683	2	194	876	144	1020	1753
Common Murre (*Uria aalge*)	26	204	5	27	4	31	54
Unknown Murre (*Uria* spp.)	10	11	11	16	0	16	29
Crested Auklet (*Aethia cristatella*)	6	1	12	16	2	18	31
Oldsquaw (*Clangula hyemalis*)	4	0	1	5	12	17	21
Pigeon Guillemot (*Cepphus columba*)	3	1	3	5	1	6	10
Parakeet Auklet (*Cyclorrhynchus psittacula*)	1	0	3	4	0	4	7
Unknown Auklet (*Cyclorrhynchus* or *Aethia* spp.)	1	0	7	8	0	8	15
Red-faced Cormorant (*Phalacrocorax urile*)	2	7	1	2	1	3	5
Pelagic Cormorant (*Phalacrocorax pelagicus*)	0	1	0	0	1	1	1
Unknown Cormorant (*Phalacrocorax* spp.)	1	0	1	2	0	2	4

[a] Unknown oiling is birds that were heavily scavenged or destroyed by wave action. Commonly, all that was recovered was a pair of wings attached to the breast bone. We could not determine the degree of oiling for these birds.

[b] We used the percentage of complete carcasses recovered that were oiled to estimate the proportion of unknown oiled carcasses that were likely oiled. Thus estimated oiled, for each species, was calculated as follows:

$$\text{estimated oiled} = \text{oiled} + \left(\frac{\text{oiled}}{(\text{oiled} + \text{unoiled})} * \text{unk.} \right).$$

[c] Birds that were recovered alive and sent to a rehabilitation facility. These birds were not considered in the overall model.

[d] Total oiled birds is the product of estimated oiled carcasses plus oiled birds captured and sent to a rehabilitation facility. This column represents birds known to have been impacted by the Citrus spill.

[e] Estimated number of oiled carcasses corrected for carcasses not detected during beach searches plus oiled birds captured and sent to a rehabilitation facility. Correction factor for King Eiders is a direct result of our modeling effort. Correction factor for other species used the overall recovery rate for King Eider carcasses (i.e. 54%).

(1995). As presented, Van Pelt and Piatt's (1995) model is appropriate for long-term studies where repeated surveys throughout the effected area are impossible, carcasses are not removed, and only general patterns of persistence rate are known. Whereas our model is most appropriate for short-term events when detailed information is available on persistence rates and detection probabilities, and when carcasses must be removed from beaches as is often the case following oil spills.

4.2. Behavior of the model

Reducing average parameter values for persistence rate and detection probability has the effect of increasing the estimated number of carcasses not detected during beach searches. Thus, as persistence rate declines, more carcasses would be removed by natural processes between searches and therefore go undetected. The response of our model to increases and decreases in parameter
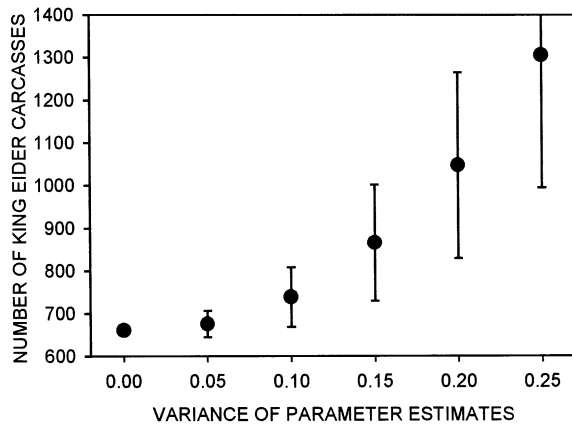
Fig. 1. Estimates of the number of King Eider carcasses not detected during beach searches under different levels of variability in parameter estimates of daily carcass persistence rate and detection probability. Bars represent S.E.

estimates was non-linear with the model being more sensitive to decreases in parameter estimates. Further, our model was slightly more sensitive to changes in detection probability than persistence rate. The addition of random variation to model parameters increased the uncertainty in model output; however, this result was expected for this type of model (Wallach and Genard, 1998). More importantly, the addition of random variation to model parameters increased the estimated number of carcasses not detected during beach searches.
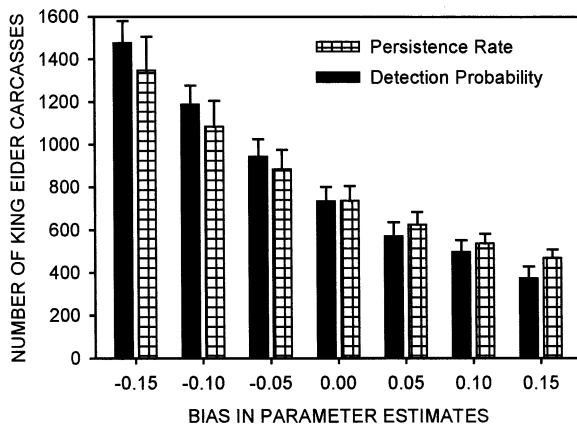

Fig. 2. Estimates of the number of King Eider carcasses not detected during beach searches for different levels of potential bias in parameter estimates of daily carcass persistence rate and detection probability. Bars represent S.E.

This occurred because parameter estimates were close to 1.0 in most cases (average values for persistence rate all > 0.82) and parameters were constrained to be ≥ 0.1 and ≤ 1.0 after the addition of random variation. That is, parameter values > 1.0 after the addition of random variation were truncated and input as 1.0. Thus under high levels of variation, 1.0 becomes an absorbing upper boundary which has the effect of functionally reducing average input values of persistence rate and detection probability. Accurate estimation of model parameters for persistence rate and detection probability are essential for unbiased estimation of total loss using a modeling approach (Wallach and Genard, 1998).

4.3. Model assumptions and associated bias

Our model assumes a uniform rate of deposition of carcasses between searches. In other words, we assumed that equal numbers of carcasses were deposited on a particular beach each day between searches. Failure of this assumption will influence estimates of total loss. If more carcasses were deposited early in the period between searches, our estimate will be biased low. Conversely, if most carcasses were deposited just prior to our searches then our estimate will be biased high. For our specific situation, however, it is unlikely that this potential bias strongly influenced our estimates because the intervals between our searches were short (i.e. 2.5 days).

4.4. Estimates of total loss

We lacked sufficient sample size to fully model losses for species other than King Eiders, therefore we assumed that the overall recovery rate for King Eiders applied to other species. The smaller body size of Murre, Guillemots, Oldsquaw, and Auklet found during beach searches suggests that their detection probability was likely lower than was measured for King Eider carcasses. Over-estimation of the detection rate would tend to result in under-estimation of total loss. Thus, we suggest that our estimate for total loss for species other than King Eiders should be considered a minimum.

It appeared that most of the King Eiders found on St. Paul Island flew or swam to shore after being oiled (Fowler and Flint, 1997). Several hundred oiled birds were observed roosting in places on St. Paul Island that could not be systematically searched (e.g. inland freshwater lakes and surrounding meadows). Given that our recoveries and model only apply to St. Paul Island beaches, our estimate should be considered a minimum for the total number of oiled birds that occurred on the island. Further, additional birds may have become oiled and died at sea. Given the results from the drift study of Flint and Fowler (1998), it is unlikely that oiled birds that died at sea would have been recovered during our searches. We have no data that will allow estimation of the number of birds that may have died at sea. However, 96 oiled bird carcasses, mostly King Eiders, were recovered on St. George Island (80 km SSE of the spill site), suggesting that the birds recovered on St. Paul Island were only a fraction of the total loss associated with the M/V Citrus spill.

Acknowledgements

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