A SIMULATION MODEL TO PREDICT SPILL-INDUCED BIRD MORTALITY USING BEACHED CARCASS DATA

Jeffrey R Wakefield Ph.D., Theodore Tomasi Ph.D.,
Heath Byrd, and Richard Greer Ph.D.
ENTRIX, Inc.
10 Corporate Circle, Suite 100
New Castle DE 19720

ABSTRACT: *Beached bird models have been used to estimate spill induced bird mortality as a function of carcass recovery. The basic models generate defensible estimates given the sparse data generally associated with large, infrequently searched, areas. We have extended the model to address spills of limited geographic extent and intense recovery effort. Our model simulates the number of carcasses required to re-create the vector of carcasses actually collected. Each simulation generates a single estimate of mortality consistent with carcass recovery data. Monte Carlo methods facilitate a mean mortality estimate.*

Introduction

Considerable effort has been focused on estimating the impacts of oil spills on avian species. One frequently employed method estimates total mortality as a function of carcasses collected during spill response. In this approach, the number of carcasses collected on a given search is multiplied by a search-specific constant greater than one in order to estimate the total deposition of birds since the last search. This "multiplier" corrects for the proportion of carcasses that sink before being deposited on the coast, for carcasses that are removed by scavengers, and for carcasses that, though present, are not found by searchers.

Ford (1991, 1996) and Page (1990) have used variations of this basic method (which we call beached bird models) to quantify injuries for oil spills, including the *Exxon Valdez*, the *Nestucca*, the *Apex Houston*, and the *Puerto Rican*. In their models, the time unit is a day; there is a single daily search (that may occur at a random time within the day), scavenging rates are estimated on a daily basis, and zero mortality is implied if no carcasses are recovered on a search.

The method generates defensible estimates when carcasses are deposited over a large geographic area, and/or an extended period of deposition. When this occurs, search intervals (the time between searches) are generally measured in days, the within day search pattern is stochastic, and the occurrence of "zero-searches" (searches on which no carcasses are recovered) is infrequent.

However, when spills result in short periods of carcass deposition over limited geographical areas with good access, these assumptions are often violated. A temporally and spatially intense recovery effort may yield search intervals measured in hours or minutes, within-day search patterns that are cyclic, and frequent zero searches. Under these circumstances, the basic beached bird model tends to overestimate mortality.

We have extended the basic beached bird model in a manner that is suited to intense recovery efforts with multiple searches per day (it also can be applied in less intensive daily search situations). Our model incorporates the actual temporal distribution of search effort, directly addresses the effect of multiple searches on total search efficiency, and relaxes the assumption that zero mortality is implied by a "zero search".

Discussion

In the existing beached bird model, a search-specific multiplier is estimated for each day a segment of coast is searched. This multiplier is used to estimate the total mortality represented by the carcasses collected on the search; i.e. total mortality associated with the coast segment since the last search. Key parameters include:

- Search Efficiency – proportion of carcasses present that are found by searchers
- Persistence – the fraction of beached birds not removed by scavenging
- At sea survival – the proportion of carcasses being deposited before sinking

Note that persistence is an inverse function of the interval between searches. That is, when multiple searches per day occur, persistence will be higher. Also note that each additional search will tend to increase efficiency. Failure to accurately incorporate the temporal distribution of search effort within a day will result in multipliers that are too large and therefore overestimate total mortality.

In addition, a theoretically consistent beached bird model should allow for the possibility of positive mortality associated with a "zero search". This is particularly true when low efficiency and/or low persistence increase the probability that carcasses may be deposited during intervals preceding "zero searches".

We have extended the beached bird model to incorporate temporally explicit search events and to treat "zero searches" in an appropriate manner. Rather than estimate search specific multipliers, we simulate the fate of individual carcasses and identify "carcass deposition scenarios" that are consistent with the observed collection vector.

We describe the model in two sections. The first section outlines the simulation of "non-zero searches". The second describes the simulation of "zero searches".

Non-zero searches. Simulations begin by assigning a single carcass a randomly selected hour of deposition in the interval preceding the first non-zero search. As a function of the length of time between the assigned hour of deposition and the search, the carcass may be removed by scavenging, found, or "neither scavenged nor found". If the carcass is "neither scavenged nor found", it may be scavenged in the subsequent interval, found on the subsequent search, or "neither scavenged nor found" again. The process continues until the carcass is assigned a final fate. Final fates are "Scavenged", "Found", "Scavenged in Subsequent Interval X", Found on Subsequent Search X", and "Never Found".

The process is repeated for that and subsequent searches until the number of carcasses assigned the fate "Found" on the searches, is equal to the number of carcasses actually found on those searches.

Zero searches. The algorithm that allows "zero searches" to be treated in a theoretically consistent manner is described via example using the data in Table 1. Given the data, it is possible (though unlikely) that all deposition occurred between the spill and Search 1. Similarly, deposition may have occurred between the spill and Search 1 and then again between Searches 2 and 3. In fact, there are 7 deposition combinations (Table 2).

Our simulation randomly selects a search interval combination. Carcasses are randomly assigned an hour of deposition to an interval in which deposition is assumed to be positive and their fate is simulated. Additional carcasses are simulated until the number of carcasses assigned fate "Found on Search 3" is equal to the number of carcasses actually found on Search 3.

If the subroutine has assigned zero birds to Search 1, zero birds to Search 2, and 6 birds to search 3, the outcome is accepted. If the subroutine has assigned some positive number of carcasses to either Search 1 or Search 2, the outcome is rejected and a new search interval combination is selected. The process continues until a search interval combination results in the vector 0,0,6.

Each complete simulation represents one scenario consistent with the temporal distribution of search effort, the vector of carcass collections and the occurrence of "zero searches". Monte Carlo methods are used to estimate the mean deposition scenario.

Hypothetical example

We have estimated mortality based on a hypothetical data set similar to those we have encountered in practice (Table 3). Our first estimate utilizes the basic beached bird model; our second uses the simulation.

The basic beached bird model assumes that all carcasses are collected on a daily "composite search". Each "composite search" is assigned a random time within the appropriate 24-hour period. The deposition rate in any search interval is assumed to be constant. Given these assumptions, the expected search times are hour 12 and 36. Total mortality is estimated to be 75 (Table 4).

Table 1. Schedule of search events.

	Time	Search Interval	Carcasses Collected
Spill Event	12:00 AM	NA	NA
Search 1	8:00 AM	8	0
Search 2	1:00 PM	5	0
Search 3	6:00 PM	5	6

Table 2. Search interval combinations.

Combination Number	Deposition in Search Interval 1	Deposition in Search Interval 2	Deposition in Search Interval 3
1	0	0	+
2	0	+	0
3	+	0	0
4	0	+	+
5	+	+	0
6	+	0	+
7	+	+	+

Table 3. Hypothetical data set for a 20 km coast.

Day	Hours Since Spill	Carcasses Recovered km 1-5	Carcasses Recovered km 5-10	Carcasses Recovered km 10-15	Carcasses Recovered km 15-20
1	8		3		11
1	16	0	0	5	0
2	36	0	0	1	2
2	40	0	2	1	0

Assumptions:

- Search efficiency = .4
- Persistence = $.95^h$ (h = total hours since deposition)
- At sea survival = 1

When total mortality is estimated via simulation, the actual search and carcass collection data are employed. Hence, no adjustments need to be made to the data. Total mortality based on simulation is 70.

The roughly 7% discrepancy has two sources. First, removal by scavenging is reduced when search intervals are reduced. Second, a greater proportion of carcasses will be found if an area is searched twice rather than once, all else being equal. We also note that the magnitude of the discrepancy increases as search intervals are reduced and or the duration of deposition increases.

Conclusions

The basic beached bird model constructed by Ford and Page works well when spills result in search intervals measured in days, stochastic search patterns, and infrequent "zero searches". When these conditions are violated, the basic beached bird model tends to overestimate total mortality.

We have extended the model in a manner that allows it to perform equally well when regardless of these factors. The model

Table 4. Calculations to estimate daily model.

Hour	Carcasses Deposited in Given Hour	Probability of Scavenging Before Hour 12 Search	Carcasses Present at Hour 12 Search	Number Found on Hour 12 Search	Present Following Hour 12 Search	Probability of Scavenging Between Searches	Carcasses Present at Hour 36 Search	Number Found on Hour 36 Search
0	4.88	0.46	2.64	1.05	1.58	0.71	0.46	0.18
1	4.88	0.43	2.78	1.11	1.67	0.71	0.49	0.19
2	4.88	0.40	2.92	1.17	1.75	0.71	0.51	0.20
3	4.88	0.37	3.08	1.23	1.85	0.71	0.54	0.22
4	4.88	0.34	3.24	1.29	1.94	0.71	0.57	0.23
5	4.88	0.30	3.41	1.36	2.04	0.71	0.60	0.24
6	4.88	0.26	3.59	1.43	2.15	0.71	0.63	0.25
7	4.88	0.23	3.78	1.51	2.27	0.71	0.66	0.26
8	4.88	0.19	3.97	1.59	2.38	0.71	0.70	0.28
9	4.88	0.14	4.18	1.67	2.51	0.71	0.73	0.29
10	4.88	0.10	4.40	1.76	2.64	0.71	0.77	0.31
11	4.88	0.05	4.64	1.85	2.78	0.71	0.81	0.32
12	4.88	0.00	4.88	1.95	2.93	0.71	0.85	0.34
13	0.48	0.00	0.00	0.00	0.00	0.69	0.15	0.06
14	0.48	0.00	0.00	0.00	0.00	0.68	0.16	0.06
15	0.48	0.00	0.00	0.00	0.00	0.66	0.16	0.07
16	0.48	0.00	0.00	0.00	0.00	0.64	0.17	0.07
17	0.48	0.00	0.00	0.00	0.00	0.62	0.18	0.07
18	0.48	0.00	0.00	0.00	0.00	0.60	0.19	0.08
19	0.48	0.00	0.00	0.00	0.00	0.58	0.20	0.08
20	0.48	0.00	0.00	0.00	0.00	0.56	0.21	0.08
21	0.48	0.00	0.00	0.00	0.00	0.54	0.22	0.09
22	0.48	0.00	0.00	0.00	0.00	0.51	0.23	0.09
23	0.48	0.00	0.00	0.00	0.00	0.49	0.25	0.10
24	0.48	0.00	0.00	0.00	0.00	0.46	0.26	0.10
25	0.48	0.00	0.00	0.00	0.00	0.43	0.27	0.11
26	0.48	0.00	0.00	0.00	0.00	0.40	0.29	0.11
27	0.48	0.00	0.00	0.00	0.00	0.37	0.30	0.12
28	0.48	0.00	0.00	0.00	0.00	0.34	0.32	0.13
29	0.48	0.00	0.00	0.00	0.00	0.30	0.34	0.13
30	0.48	0.00	0.00	0.00	0.00	0.26	0.35	0.14
31	0.48	0.00	0.00	0.00	0.00	0.23	0.37	0.15
32	0.48	0.00	0.00	0.00	0.00	0.19	0.39	0.16
33	0.48	0.00	0.00	0.00	0.00	0.14	0.41	0.16
34	0.48	0.00	0.00	0.00	0.00	0.10	0.43	0.17
35	0.48	0.00	0.00	0.00	0.00	0.05	0.46	0.18
36	0.48	0.00	0.00	0.00	0.00	0.00	0.48	0.19
Total	**75**			**19**				**6**

requires a temporally explicit schedule of search events, a description of each searches geographic coverage, and a schedule that details the location and time and search event associated with each carcass recovery.

Our current modeling is based on an actual recovery effort in which beaches were generally searched once in the morning, once in the evening and occasionally at mid-day. Moving from a daily model to a temporally explicit model resulted in a 10% to 15% decrease in total mortality estimates.

References

1. Ford, R. G. 1996. Total Direct Mortality of Seabirds from the *Exxon Valdez* Oil Spill. American Fisheries Society Symposium 18:684-711.
2. Ford, R. G., and six coauthers. 1991. Seabird mortality resulting from the *Nestucca* oil spill incident, winter 1988-1999. Final report for the Washington Department of Wildlife, Olympia.
3. Page, G. W., H. R. Carter, and R. G. Ford. 1990. Numbers of Seabirds Killed or Debilitated in the 1986 *Apex Houston* Oil Spill in Central California. Studies in Avian Biology 14:164-174.