The Efficiency of Searchers Recovering Seabirds and Waterfowl Killed in the 1997 *M/V Kure* Oil Spill in Northern California

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ABSTRACT.-- Studies on the efficiency of searchers looking for the carcasses of beached birds were carried out in northern California following the 1997 M/V Kure oil spill in Humboldt Bay. Experimental protocols were designed to mimic as closely as possible the circumstances of the actual incident. The performance of 20 searchers or search teams was monitored during 477 encounters between searchers and carcasses in three habitats, sandy beach, rocky beach, and marsh. Searcher efficiency varied widely, from 12.5% to 55.3%, depending on carcass coloration, habitat, and carcass size. The most important factor in determining searcher efficiency was consistently body size. There was significant heterogeneity in the probability of finding the carcasses of large bodied birds, some carcasses being very easy to find and some very difficult.

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INTRODUCTION

Beached bird surveys are used throughout the world as a way of monitoring the health of seabird populations and of assessing the scale of natural or human induced die-offs (Camphuysen and Huebeck, 2001) . These surveys provide useful indices of relative mortality, but do not provide estimates of total mortality because birds are never recovered. Birds may (1) sink at sea, (2) be removed by scavengers or other processes, or (3) be missed by surveyors (Ford *et al*., 1996). Based on the results of 17 experiments in which researchers released carcasses at sea and then searched the shoreline for them, Piatt and Ford (1996) found that typically only about 1 in 5 birds that die at sea are ever found. Searcher efficiency, the success rate of beached bird surveyors in finding carcasses, is an important factor determining the proportion of carcasses that are eventually be recovered.

It is surprisingly easy for surveyors to miss beached birds. Wide or wrack filled beaches are visually difficult environments, and birds can easily be hidden in small depressions, blend in with other types of wrack, or be too far away to recognize. Monnat and Guermeur (1979) record that on a sunny day on an "unobstructed beach" 2 km long, only one carcass of nine (11%) was detected by a team of observers when "it seemed impossible to us that an oiled bird could escape detection." They also note that P. Hope Jones found that "an observer trained in the research of oiled birds" missed an average of 1 in 5 birds on an "easy-to-search beach" in the Orkneys. Fowler and Flint (1997) found detection rates varying from 44% to 94% for King Eiders following an oil spill off St.

Paul Island in 1996, though the large body size of the birds and the snow fall encountered during their study were unusual for beached bird surveys.

Searcher efficiency is also an important issue for researchers studying bird or bat mortality in a terrestrial setting. Accurate estimation of pesticide or wind-turbine induced mortality requires that carcass counts be corrected for the likelihood that searchers will find carcasses in a variety of contexts such as croplands, grassland, stubble fields, etc. (see for example Osborn *et al*., 2000; Erickson *et al*., 2000; Johnson *et al*., 2004; or Barrios and Rodríguez, 2004). Although the linear nature of shorelines would seem to make searching easier than in terrestrial habitats, the buildup and movement of wrack, wave action, and the sometimes uneven topography of beaches result in many carcasses being overlooked.

Aside from Fowler and Flint, we know of no published data that measure searcher efficiency in the kind of habitat typically encountered in beach surveys. The data presented here result from studies carried out in 1998 as part of the damage assessment for the 1997 *M/V Kure* oil spill in Humboldt Bay, California, and were designed to replicate as closely as possible the actual methodologies used by spill responders. Searcher efficiency studies were carried out in three habitats that were typical of the area affected by the spill and of the Pacific coast of the continental USA in general: sandy beach, rocky beach, and marsh. Modes of search were based on techniques actually used by survey personnel during the response to the *M/V Kure* oil spill, including walking, all-terrain vehicles (ATVs), and light trucks. The goal was to estimate the likelihood that searchers would detect beachcast seabird carcasses, and to determine some of the factors that influence the carcass detection rate.

METHODS

STUDY AREA

On November 5, 1997, the cargo ship *M/V Kure* struck a loading dock in Humboldt Bay, California, rupturing a fuel tank and spilling about 4,500 gallons of fuel oil into the bay. The resultant slick moved out of the bay on successive ebb tides and drifted northward, resulting in the deposition of oil and dead or injured birds along a 50 km stretch of coastline extending from the mouth of Humboldt Bay (40° 44.27' N, 124° 15.03' W) north beyond Trinidad Head (41° 8.77' N, 124° 8.47' W). Oil spill response personnel searched beaches both within the bay and along the outer coast, ultimately recovering 951 seabirds and waterfowl. As part of the subsequent National Resource Damage Assessment (NRDA) for the spill, it was estimated that a total of 2012 birds were actually killed in the incident (Carter, 2003).

As part of the NRDA procedure, a study was undertaken in March, 1999 to estimate searcher efficiency for seabirds and waterfowl in the types of habitat affected by the spill: outer coast sandy beach, outer coast rocky beach, and bay interior marsh. The sandy beach study site extended for 4 km from Mad River to Little River north of the Humboldt Bay entrance, the rocky beach study site was located on a 350 m stretch of Luffenholtz Beach near the town of Trinidad, and the marsh study site was located on a 7 hectare plot on Indian Island in central Humboldt Bay.

BIRDS

Carcasses were obtained from the California Department of Fish and Game and the Burke Museum, University of Washington, and consisted primarily of Common Murres, gulls, grebes, ducks, and cormorants (Table 1). To determine searcher efficiency relative to smaller birds (which are rare in most collections of beach cast birds), we used Brown-headed Cowbirds which ranged in size from about 15.2-20.3 cm in length. Cowbirds have relatively dark ventral coloration matching their dorsal coloration, whereas most small seabirds and shorebirds are lighter colored on their undersides. To make these specimens more comparable to small birds affected by the spill, we sprayed the undersides of these birds with a light coat of white paint.

STUDY AREAS

In all three habitats, the general methodology was to place carcasses at randomly selected locations, simulating the process of deposition that would occur naturally. These habitats were then searched by experienced spill response personnel using the same techniques that were used during the *M/V Kure* oil spill response, recording the positions and status of each carcasses that they found. Depending on terrain, searches were carried out on foot, from ATV's, or from light pickup trucks. Because search techniques varied somewhat among the three habitats, experimental techniques also varied as described below.

Sandy Beach.-- The sandy beach study area varied in width, from about 10 m to 100m. The area behind the beach was generally either marsh grass, particularly near river outlets, or low sandy bluffs. Placement of carcasses and search trials took place on

March 1-2, 1999. Distances between adjacent carcasses were based on a uniform random variate ranging from 0 to 200 meters, with an average distance of 100 meters between carcasses. If the randomized position fell on an unusable stretch of shoreline such as a creek mouth, the carcass was placed in the first position possible. Once the position along the beach was determined, carcasses were randomly placed between the waterline and the upper wrack line. Latitude / longitude positions were recorded using a GPS, and the placement was also marked using flagging that was not visible from the beach, but could be seen from the back of the dunes behind the beach face. The entire length of beach was about 4 km (40 birds at 100 m average spacing).

A total of 19 cowbirds carcasses were placed out on March 1, 1999. During the subsequent trials, searchers found many of the other waterbird carcasses, but failed to locate any of the cowbird carcasses. On the second day of this study, the ventral side of the cowbirds, originally a dark brown color, was painted white to make them more similar in appearance to small seabirds such as Marbled Murrelets and Cassin's Auklets. All data presented in this paper are based on these modified carcasses. A flip of a coin was used to determine whether a large-bodied or small-bodied carcass was to be placed at each position.

Carcasses were set in position on foot prior to high tide. At each site where a carcass was to be placed, the beach was visually divided into four quadrants above the high tide line and the quadrant chosen by two flips of a coin. The carcass was then randomly placed within the appropriate quadrant. Whenever possible, personnel engaged in carcass placement moved between the ascending tide and the wrack line so that the rising tide would obscure footprints. Although some footprints inevitably remained along the

beach, the study area already had a high density of footprints and it is unlikely that these provided additional cues to the searchers. At half hour intervals following high tide, searchers who were unfamiliar with the placement of the carcasses proceeded along the beach. Four searchers rode on ATVs, and four rode as passengers in a light pickup truck. To avoid cues from the tracks of vehicles in the sand, pickup truck drivers and ATV operators were instructed not to drive directly up to carcasses or to leave their vehicles and walk over to carcasses, but rather to verify their identification using binoculars. Details of sample sizes and number of searchers are provided in Tables 2 and 3.

During an oil spill response, searchers have limited time to survey any stretch of coastline. During the *M/V Kure* response, the records of searchers in vehicles showed that they examined about 4 km of beach in one hour. Searchers were therefore allowed one hour to examine the area where carcasses had been placed: carcasses found after one hour were not used in the calculation of search efficiency. After the last search on a given day was completed, carcasses were retrieved by the personnel who originally placed them. Carcasses that they were unable to relocate are not used in the calculation of search efficiency, since they may have rewashed or been removed by scavengers before searchers could find them.

Rocky Beach.-- Rocky beaches along this section of coast tend to be steep, difficult to access, and relatively short in length: the length of Luffenholtz beach varied between about 250 m and 350 m depending on the state of the tide. The rocky beach study site varied from about 10m to 25 m in width, and was about 20% sand and 80% cobble and small boulders. Distances between adjacent carcasses were based on a uniform random variate ranging from 0 to 100 meters, with an average distance of 50 meters between

carcasses. Since beach length varied, the number of birds placed out in a given trial was determined by the length of beach available at the time. The size class of the carcass placed at each location was determined by the flip of a coin. Since foot searchers on rocky beaches moved at a rate of about 1 to 1.5 km/hr during the actual spill response, searchers were allowed 15 minutes to complete each trial. Details of sample sizes and number of searchers are provided in Tables 2 and 3.

Marsh.-- Access to the marsh study area on Indian Island was by airboat, but carcass placement and search trials were carried out on foot. This area was above the high tide line, but was periodically inundated and criss-crossed with tidal channels 1-2 m in width. A set of two-dimensional uniform random coordinates were used to place the carcasses within the study area. Large or small-bodied carcasses were randomly placed at each randomized coordinate located using a GPS. Carcasses were left in position over the night of March 4-5 since earlier studies on carcass removal rates indicated that carcass persistence was high in this area. (Ford *et al*., 2002). Details of sample sizes and number of searchers are provided in Tables 2 and 3.

Searchers in the marsh worked in pairs as during the response to the M/V Kure oil spill. Each team was given 2 hours to search the study area, consistent with the amount of time that searchers spent in marsh areas during the response. One pair searched before high tide and the other pair after high tide on each day of the study. Each individual searcher participated only once in these trials. After locating a carcass, searchers noted its position using GPS and whether or not it had been scavenged.

RESULTS

For this analysis, the searcher efficiency rate was defined as the probability that a searcher would locate a carcass that was present within the designated study area within the allotted time frame. Thus, if a searcher found 15 out of 20 carcasses, the estimated searcher efficiency rate would be 0.75 or 75%. Only carcasses that were still present after all trials were completed were used in the analysis.

Searcher efficiency rates for all combinations of habitat, search methods, and carcass sizes are given in Table 2. Searcher efficiencies ranged from 12.5% for small dark birds on a sandy beach to 55.3% for large birds on a rocky beach. In all cases, searcher efficiency was lower for small birds than for large birds. Searcher efficiency was highest on the rocky beach and similar in the marsh and sandy beach habitats. On sandy beaches, the type of vehicle used by searchers, pickup trucks or ATVs, had little effect on their efficiency.

Results of the Cochran's Q test are shown in Table 3. In 8 sets of replicated searches, there were no significant differences among searchers or among search teams. We therefore cannot reject the hypothesis that different individuals or search teams have the same efficiency rate. While it is likely that there minor differences between individual searchers, the lack of a significant difference in all 8 sets of trials suggests that the variation was not a major factor influencing estimates of searcher efficiency.

Searchers riding on ATVs were somewhat more effective than searchers riding in pickup trucks, respectively locating 33 of 98 carcasses compared to 27 of 98 carcasses. Based on the two-tailed binomial probability test, the likelihood of this degree of difference occurring randomly if the two rates are in fact equal is not significant

(P=0.167), and the hypothesis that the two search modes are equally efficient cannot be rejected.

We tested the hypothesis that all carcasses have the same probability of being found (as compared to some carcasses being very easy to find and others being very difficult) by simulating the situation where each searcher/carcass interaction was an independent random event in which all carcasses had equal likelihood of being found. We compared the observed number of carcasses that were found or missed by all searchers to the probability that this would have happened if all the carcasses were equally likely to be found each time a searcher passed them (Table 4). For large birds in all three habitats, it was much more likely that a bird would be found by all searchers or by no searchers than would have been the case if all birds were equally difficult to find, indicating that the carcasses of large birds varied in regard to the likelihood that they would be found. This was not true for small birds which did not show a significantly higher incidence of birds that were found by all searchers or that were missed by all searchers.

Habitat and body size are factors that potentially affect searcher efficiency, and these two factors may interact in ways that cannot be accounted for by either factor alone. We used a multivariate approach for examining whether carcass size and habitat affect the likelihood that a carcass will be found. Classical multiple regression models are not appropriate in this case since the frequency with which the carcasses were found is strictly bounded between 0 and 4, and the residuals therefore do not have an expectation of zero and constant variance. The ordered logit regression model for ordered categorical dependent variables is designed for such instances (Davidson and MacKinnon, 1993).

Table 5 presents the results of an ordered logit analysis using carcass size as a "dummy" variable which takes on the value of 1 for large birds and 0 for small birds. To examine differences between habitat types, we estimated the model three times, each time including two habitat dummy variables and suppressing the third. Coefficients on the habitat variables are interpreted as the difference in effect between the "included" habitat type and the suppressed habitat type. The coefficient of the carcass size variable is exactly the same for all three models, as is the overall model fit. The model fit is good, producing a 42% reduction in the sum of square prediction errors when compared to the naïve model in which all observations are placed in the modal category of zero birds found.

The results of the ordered logit regression (Table 5) indicate a highly significant positive relationship between carcass size and searcher efficiency ($P < 0.001$), with the larger birds being found more often. The habitat variables were less successful at explaining variation in the number of times that a carcass was found. Of the three contrasts, Sandy Beach x Rocky Beach, Sandy Beach x Marsh, and Rocky Beach x Marsh, only the comparison between Sandy Beach and Marsh was statistically significant. The level of significance of this comparison was marginal ($P < 0.10$), with a positive sign indicating that birds are more likely to be found in the Marsh habitat compared to the Sandy Beach habitat.

DISCUSSION

Factors potentially influencing searcher efficiency include variation among observers, method of transport, habitat type, bird coloration, and bird size. Our results suggest that

differences among searchers was not a major source of variation, nor was the mode of motorized transport (ATV or pickup), at least on sandy beaches. Hampton and Zafonte (2005), however, found that foot searchers recovered more birds per mile than did motorized searchers, and our estimates of searcher efficiency should not necessarily be considered representative of foot searches on sandy beaches.

The structure of the three study habitats, sandy beach, rocky beach, and marsh, differed in ways other than the substrate. Sandy beaches tended to be wider, lighter in color, and contain larger quantities of wrack than rocky beaches. The marsh study area, by comparison, was covered by ankle or knee high vegetation, and the muddy substrate made walking difficult. Given these differences, we found it surprising that searcher efficiencies in the different habitats were as similar as we found. For large birds, searcher efficiency ranged from 40.9% on sandy beaches (pickup truck) to 55.3% on a rocky beach, and for small birds from 12.5% to 27.9% in the same habitats. Based on our pair-wise comparisons, differences between habitats were not significant except for sandy beach and marsh which were marginally significant ($P = 0.10$, two tailed).

The weak statistical relationship between habitat and searcher efficiency that we found differs from the results of Fowler and Flint (1997) who found a highly significant difference between rocky and sandy beaches. In their study, King Eider carcasses deposited on rocky beaches were less likely to be found than carcasses deposited on sandy beaches. This may have resulted in part from snow fall that occurred on three days of their study, making it much more difficult for searchers to locate snow covered carcasses among snow covered rocks than along relatively flat sandy beaches. Researchers working on the effects of wind turbines on birds in inland settings have also

found evidence for variation in searcher efficiency among different habitats. Erickson *et al*. (2000) found a difference between searcher efficiency in grassland (57%) and wheat stubble (76%), and Osborn *et al*. (2000) found differences between searcher efficiency in cropland (82%) and grassland (63%), though neither of these differences were statistically significant. Johnson *et al*. (2004) studied searcher efficiency for bat carcasses on gravel pads and vegetated fields and estimated efficiencies of 20% and 77% respectively, a highly significant difference.

We found that bird size had a highly significant relationship with searcher efficiency, and that this effect that was apparent in all habitats. The importance of body size has previously been noted by Osborn *et al*. (2000) who found searcher efficiency rates for small and large size classes of birds of 67% and 92% respectively ($p=0.025$), and by Erickson *et al*. (2000) who found values of 50% and 88% respectively ($p<0.001$). In our study, body size may have interacted with coloration in determining searcher efficiency. Large bird carcasses were predominately dark-backed species with white undersides such as the Common Murre, but included nearly as many light colored species (mostly gulls), and some all dark species (cormorants). Our cowbird sample was colored in a manner comparable to bi-colored species such as Common Murres, Marbled Murrelets, Cassin's Auklets, and Dunlin. Among large birds in the sandy beach habitat, bi-colored alcid species were found less often (22 / 64 = 34.4%) than light colored gull species (33 / 64 = 51.6%), indicating a marginally significant difference between the two color patterns ($\chi^2 = 3.708$, $P=0.054$). The presence of dark colored birds in the large bird category would tend to increase the estimate of searcher efficiency for this grouping

296 indicating since the difference in search efficiency between large and small birds is
297 related to coloration as well as to size.
298 Searcher efficiency for small birds on sandy beaches was lower than any published
299 value that we have encountered. Small seabirds and shorebirds are numerous in the
300 northern Pacific and other regions, including very common species such Cassin's Auklet,
301 Rhinoceros Auklets, sandpipers, and phalaropes, as well as endangered species such as
302 the Marbled Murrelet. Since sandy beaches are a very common shoreline, counts of
303 small beached birds may often be biased by a factor of 8:1. Such undercounting would
304 affect both beached bird monitoring surveys and oil spill response efforts.
305 For large birds, there was a significant tendency for carcasses to be found on every
306 search or to be missed on every search, indicating that the likelihood that a carcass would
307 be found varied among carcasses: some carcasses were very easy to find, and some were
308 very difficult. This variation probably resulted from differences in the color and
309 orientation of the carcasses as well as variation in beach structure, beach color, and
310 wrack volume in the vicinity. Overall, a large proportion of both large and small birds
311 (33.3%) were never found by any searcher even in four trials. Individual variation in the
312 probability that a carcass will be found (i.e. "recaptured") means that mark recapture
313 models such as the Cormack-Jolly-Seber estimator (Pollock *et al*., 1990) may yield
314 biased results when applied to the recovery of beached birds. These models assume that
315 all individuals are equally likely to be enumerated and that the population does not
316 include a substantial number of individuals that are impossible to find. Mark recapture
317 models are a promising technique for estimating the total number of carcasses present in
318 a given area after an oil spill (Fowler and Flint, 1997), but the effect of the violation of

319 the assumption that all carcasses are equally likely to be found should be checked when
320 these models are used.
321 Variation in the probability of locating a carcass also makes it more difficult to
322 extrapolate searcher efficiency rates measured for individual searchers to teams
323 composed of multiple searchers, or to take into account multiple searches of the same
324 beach. Suppose, for example, that there were two birds on the beach, each with a 50%
325 chance of being found by a single searcher. Then the probability that one of the carcasses
326 will be found by at least one of the two searchers is $1 - 0.5^2 = 0.75$. If, on the other
327 hand, one carcass had a 100.0% chance of being found, and the other had a 0.0% chance
328 of being found, the average probability of locating a carcass would still be 50%. But
329 only one of the two carcasses would ever be enumerated no matter how many search
330 trials took place, and a mark recapture analysis would yield an estimate of 100% searcher
331 efficiency.
332 Searcher efficiency is a significant factor determining the number of birds killed at sea
333 by an oil spill or by natural causes. The most important correlates of the searcher
334 efficiency rate are carcass size and coloration. When comparing the recovery rates of
335 species that vary in size or coloration, efforts should be made to compensate for this
336 variability. Searcher efficiency is also a critical factor if researchers attempt to estimate
337 total mortality based on the recoveries of beached birds.
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400 Table 1. Species used in the bird carcass detection study.

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Species	Number
Common Murre	**24**
Herring Gull	**3**
Heermann's Gull	**2**
California Gull	**2**
Glaucous-winged Gull	**1**
Gull spp.	**16**
Double-crested Cormorant	**1**
Cormorant spp.	**3**
Pied-billed Grebe	**1**
Grebe spp.	**8**
Ruddy Duck	**1**
Mallard	**2**
Duck spp.	**2**
Goose spp.	**1**
Green Heron	**1**
Great Egret	**1**
Least Sandpiper	**1**
Brown-headed Cowbird	**56**
Total carcasses:	**126**

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403 Table 2. Search efficiency rates (expressed as percentage of total carcasses found) for
404 different habitats, search methods, and carcass sizes.

		Small	**Large**
Sandy Beach (ATV)		12.5%	43.9%
	n	(32)	(66)
Sandy Beach (Pickup Truck)		3.1%	40.9%
	n	(32)	(66)
Rocky Beach (On Foot)		27.9%	55.3%
	n	(43)	(38)
Marsh (On Foot)		24.0%	42.3%
	n	(96)	(104)

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412 Table 3. Comparison of searcher teams.

Date	Number of Trials	Transport	Habitat	# of Birds	Chi-square adjusted	df	P^{ns}
Mar. 1	2	ATV	Sandy	20	0.50	1	ns
Mar. 2	2	ATV	Sandy	29	0.00	1	ns
Mar. 1	2	Pickup	Sandy	20	0.00	1	ns
Mar. 2	2	Pickup	Sandy	29	0.25	1	ns
Mar. 3	5	Foot	Rocky	9	2.80	4	ns
Mar. 5	3	Foot	Rocky	12	4.33	2	ns
Mar. 4	2 teams	Foot	Marsh	50	2.40	1	ns
Mar. 5	2 teams	Foot	Marsh	50	3.56	1	ns

413 ns = not significant

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Table 4. Test of heterogeneity of detection probabilities among carcasses

Bird Size	Habitat	Number of Birds in Trial	Probability of Finding a Bird If All Birds Are Equally Likely to be Found	Observed Number of Birds Found or Missed by All Searchers	Probability of Observed If All Birds Are Equally Likely to be Found
Large	Sandy	33	0.417	13	0.0004 **
Small	Sandy	16	0.078	12	0.5330 ns
Large	Rocky	8	0.469	4	0.0123 *
Small	Rocky	8	0.250	5	0.0752 ns
Large	Marsh	26	0.423	8	0.0193 *
Small	Marsh	24	0.240	7	0.7506 ns

Table 5. Results of ordered logit analysis for the effect of carcass size and habitat.

COMPARISON	ESTIMATE
Large versus Small Carcasses	1.484***
Rocky Beach versus Sandy Beach	0.550
Marsh versus Rocky Beach	0.077
Marsh versus Sandy Beach	0.627*
Percent Reduction of SSE	42%
Sample Size (N)	115

Note: *** denotes = 0.001; * denotes α = 0.10 (two-tailed)