SCAVENGING OF SEABIRD CARCASSES AT OIL SPILL SITES IN CALIFORNIA AND OREGON

R. GLENN FORD[1] & MATTHEW A. ZAFONTE[2]

[1]*R.G. Ford Consulting, 2735 NE Weidler Street, Portland, Oregon, 97232, USA*
(eci@teleport.com)
[2]*California Department of Fish and Game, Office of Spill Prevention and Response,*
1700 K Street, Suite 250, Sacramento, California, 95811, USA

Received 3 January 2008, accepted 22 May 2009

SUMMARY

FORD, R.G. & ZAFONTE, M.A. 2009. Scavenging of seabird carcasses at oil spill sites in California and Oregon. *Marine Ornithology* 37: 205–211.

We studied the removal of seabird carcasses by scavengers after the M/V *Kure* oil spill in California and the M/V *New Carissa* spill in Oregon. The experimental design consisted of placing carcasses in randomized locations along the shoreline and returning at daily intervals to evaluate their condition. We placed 25 carcasses at each of four sites in Oregon near Coos Bay and Waldport and six sites in California in and around Humboldt Bay, for a total of 250 carcasses distributed along 25 km of coastline. Small birds (≤521 g) disappeared significantly faster than did large birds (>521 g) at the California sites, where the carcass removal rate over the first 24 hours ranged from 66% to 78%. Carcass removal rates varied significantly between sites in California, but not in Oregon. The daily rate of carcass removal tended to change over time, decreasing for small birds, but increasing for large birds. Domestic waterfowl (Mallard Ducks *Anas platyrhynchos*) were removed more rapidly than were seabirds, but removal of wild passerines did not appear to differ from that of seabirds in that regard. After six days, 16% of the small carcasses and 49% of the large carcasses remained at the California sites; in Oregon, 50% of the small carcasses and 56% of the large carcasses remained.

Key words: Scavenging, carcass removal, carcass persistence, Weibull distribution, *Kure, New Carissa,* beached-bird model

INTRODUCTION

Seabird carcasses are often reduced to unrecognizable fragments or are removed entirely by scavengers soon after being beached. The rapidity of the process varies widely, ranging from only a few percent removal per day to nearly complete removal over a 48-hour period (Camphuysen 1989 cited in Van Pelt & Piatt 1995, Ford *et al.* 1996). The number of carcasses present on a beach is determined by a balance between the rate of carcass deposition and the rate of carcass removal. If surveys of beached birds are used to infer the actual number of birds killed by natural die-offs (Piatt & Van Pelt 1997), oil spills (Page *et al.* 1990) or chronic pollution (Wiese & Ryan 2003), carcass removal rate is a critical parameter that determines how many carcasses are removed from the beach before searchers can find them.

Surveys of beached birds are usually based on periodic visits to the same site. Intervals between searches commonly vary from daily to monthly, with searches tending to be more frequent during oil spill responses and less frequent for long-term monitoring programs (Camphuysen & Heubeck 2001). If scavenging activity is intense or the interval between searches is large (or both), most of the beached carcasses may be removed without being found by searchers.

Several studies have estimated carcass persistence based on the monitoring of naturally deposited carcasses (Fowler & Flint 1997, Van Pelt & Piatt 1995), experimentally placed marked carcasses (Wiese & Ryan 2003) or radio-tagged carcasses (Ford *et al.* 1996). The different methodologies have different advantages, in that naturally deposited carcasses may be more "realistic" in their placement, but experimentally placed carcasses allow for more control over sample size and species composition and make it possible to separate the effects of wave action and burial from scavenging.

Carcass removal is important to estimating mortality rates in terrestrial and marine habitats alike. Wind farm developments, with the associated risks to birds and bats, have resulted in a number of studies that quantify the rate at which carcasses are removed by scavengers in various terrestrial habitats (Osborn *et al.* 2000, Barrios & Rodriguez 2004, Johnson *et al.* 2004, Smallwood 2007). Scavenging rates are often much higher on beaches than in terrestrial environments, probably because the coastline is a rich and relatively predictable food source that many scavengers rely on. Because of linearity and a relatively open nature, beaches may also be easier for scavengers to search than are vegetated two-dimensional habitats such as grasslands, croplands or marshes.

The two experiments described here, both based on the same methodologies, were carried out as part of the damage assessments for the 1997 M/V *Kure* oil spill (Ford *et al.* 2001a) in California and the 1999 M/V *New Carissa* oil spill (Ford *et al.* 2001b) in Oregon. Carcasses of a range of species were placed along beaches in various locations so that we could separate the effects of scavenging from other sources of carcass attrition. Although factors such as rewash or burial are sometimes very important to carcass persistence, the purpose of these experiments was specifically to estimate the rate at which seabird carcasses are removed by scavengers and to determine which factors (carcass size, location, age, etc.) significantly affect those rates.

Carcass persistence rates are critical to estimating the magnitude of either natural or oil-spill-related seabird die-offs, and scavenging rates are an important part of persistence. Understanding the variability in scavenging rates and the ways in which those rates are affected by covariates is important for managers when they must decide whether to apply data from various times and places, and when new studies should be undertaken.

METHODS

Data collection

Studies were carried out at two locations:

- Near the M/V *Kure* spill site in Humboldt Bay and on the adjacent coast in northern California
- In areas affected by the M/V *New Carissa* spill on the coast of Oregon near Coos Bay and Waldport

We selected sites that were typical of the coastline affected by each of the spills. Sites selected for the *New Carissa* study were all on the outer coast and generally similar in structure, consisting entirely of sandy bluff–backed beaches, which is the most common beach type in Oregon. The *Kure* study sites included two bluff-backed beach sites (South Coast Spit and North Coast Spit), two marsh sites (South Bay Spit and Indian Island) and two dune grass–backed sites (Mad River and Clam Beach) associated with the outflow of small rivers. Beaches in both California and Oregon were on the open coast and generally oriented in a north–south direction, except for South Bay Spit and Indian Island, which were in the interior of Humboldt Bay. Table 1 gives a summary of the sites and their characteristics.

We set out 25 carcasses at each of the 10 sites, for a total sample size of 250 carcasses. Each carcass was placed between 0 m and 200 m from the previous carcass, based on a uniform random distribution, so that the mean distance between carcasses was 100 m. Occasionally, we could not place a carcass in the randomly selected position because of an obstacle such as a river mouth or a rock outcropping, and in those cases, we continued to the first position where the carcass could be placed. Carcasses were placed in randomized locations between the wrack line and the top of the beach. In a few cases in which waves came all the way to the base of the low sandy bluffs that formed the beach back, we placed carcasses on the bluff face or on the bluff top so that they would be beyond the reach of the tide. To avoid providing accidental cues to the scavengers, we set out carcasses during a rising tide, walking below the wrack line whenever possible so that any tracks would be washed away by the waves. The total length of all study beaches was about 25 km. The *Kure* study took place in November 1998, and the *New Carissa* study in March and April of 2000.

Latitude, longitude, time, carcass identification number and species were recorded at the time of placement. A small block of wood, about 10×10 cm, with the carcass identification number was placed under each carcass, and a matching tag with the same number was fastened to one leg of the carcass. The wooden blocks were used to differentiate between the removal of carcasses by scavengers and removal of carcasses by waves or burial. Wooden blocks were light and easily shifted by wave action and were unlikely to remain if a carcass rewashed. Because the blocks were placed underneath the carcasses, burial of the bird would also result in burial of the block. If a carcass was missing, but the wooden block was still present, we assumed that the carcass was taken by scavengers. If both carcass and block were missing, we assumed that the carcass was either washed out or buried. Although it is possible for carcasses to wash out and to beach again later, we did not observe any such events in this study.

Carcasses were obtained from a variety of sources, but all had formerly been frozen and were unoiled at the time of placement. Some of the carcasses had originally been oiled, but they were cleaned by washing in Dawn liquid detergent using the protocols recommended for the cleaning and rehabilitation of live oiled birds (Newman *et al.* 2003), because the Oil Pollution Act of 1990 prohibits the introduction of oiled material (i.e. oiled birds) into the environment. The range of species used consisted primarily of various seabirds, but the *Kure* study in California also included some wild passerines and domestic Mallard Ducks *Anas platyrhynchos.* Table 2 lists the species used in the studies. Specimen weights were assigned using average species weights from Dunning (1984).

Carcasses were checked on a daily basis to determine if they had been removed or scavenged. All sites except Indian Island were checked

TABLE 1
Characterization of 10 sites used in scavenging studies after the *Kure* and *New Carissa* oil spills in California and Oregon

Name	Incident	Latitude (°N)	Substrate	Backing
South Spit Coast	*Kure*	40.7448	Sand	Bluff
South Spit Bay	*Kure*	40.7387	Marsh	Marsh
Indian Island	*Kure*	40.8146	Marsh	Marsh
Clam Beach	*Kure*	41.0214	Sand	Dune grass
Mad River	*Kure*	40.9173	Sand	Dune grass
North Spit Coast	*Kure*	40.7741	Sand	Bluff
Umpqua R. South (Hauser)	*New Carissa*	43.6042	Sand	Bluff
Umpqua R. North (Sparrow Pk.)	*New Carissa*	43.7858	Sand	Bluff
Waldport South (Colorado St.)	*New Carissa*	44.3583	Sand	Bluff
Waldport North (Driftwood Way)	*New Carissa*	44.4733	Sand	Bluff

for six consecutive days. Because of access difficulty (airboat required), Indian Island was checked for four consecutive days.

Analysis

Carcass persistence as a function of time was calculated separately for each site and for each size class (large or small) of bird carcass. We chose the mean weight of a Rhinoceros Auklet *Cerorhinca monocerata* (521 g) as the upper limit of the "small" bird category because it was the median weight of the specimens used in the two studies. Additionally, Rhinoceros Auklet carcasses are small enough to be carried off by Common Ravens *Corvus corax,* one of the most common coastal scavengers in both Oregon and northern California, an event observed twice during the *Kure* study.

We used a maximum likelihood statistical model to determine how study site, carcass type and carcass size affected the rate at which scavengers removed seabird carcasses. Because carcasses were checked every 24 hours, the exact time of carcass removal was not known, a phenomenon referred to as censoring. We therefore used a Weibull parametric survival model that takes into account censored data on the dependent variable (carcass persistence time). The model

TABLE 2
Number and characteristics of carcasses used for the scavenging studies[a]

Species	Number	Weight (g)	Category
Kure study			
Dark-eyed Junco *Junco hyemalis*	1	20	Passerine
Brown-headed Cowbird *Molothrus ater*	5	44	Passerine
Varied Thrush *Ixoreus naevius*	1	78	Passerine
Common Murre *Uria aalge*			
Juvenile	13	200[a]	Seabird
Subadult	3	600[a]	Seabird
Adult	46	993	Seabird
Marbled Murrelet *Brachyramphus marmoratus*	1	220	Seabird
Pigeon Guillemot *Cepphus columba*	1	487	Seabird
Rhinoceros Auklet *Cerorhinca monocerata*	33	520	Seabird
Sooty Shearwater *Puffinus griseus*	8	787	Seabird
Western Gull *Larus occidentalis*	2	1011	Seabird
Mallard Duck *Anas platyrhynchos*	30	1082	Domestic
Common Loon *Gavia immer*	6	4134	Seabird
New Carissa study			
Cassin's Auklet *Ptychoramphus aleuticus*	4	188	Seabird
Common Murre *Uria aalge*			
Juvenile	22[a]	200	Seabird
Subadult	38[a]	336	Seabird
Adult	25	993	Seabird
Ancient Murrelet *Synthliboramphus antiquus*	1	206	Seabird
Franklin's Gull *Larus pipixcan*	1	281	Seabird
Ring-billed Gull *Leucophaeus delawarensis*	1	519	Seabird
Rhinoceros Auklet *Cerorhinca monocerata*	1	520	Seabird
Northern Fulmar *Fulmarus glacialis*	1	544	Seabird
American Coot *Fulica americana*	1	726	Seabird
Unidentified gull *Larus* sp.	3[a]	1000	Seabird
Glaucous-wing Gull *Larus glaucescens*	1	1010	Seabird
Western Gull *Larus occidentalis*	1	1011	Seabird

[a] Average based on carcass measurements; all other weights from Dunning (1984).

allows the use of left-censored removal times (i.e. removal before the first daily observation), right-censored removal times (i.e. the carcass was not removed) and interval-censored removal times (i.e. removed sometime between two daily observations). All three of these situations occurred in our dataset. The Weibull model is parametric in that it specifies a functional form of the survival distribution, but sufficiently general that it can be used to model removal rates that increase with carcass age (i.e. carcasses were *more* likely to be removed as they aged), decrease with age (i.e. carcasses were *less* likely to be removed as they aged) or remain the same with age (i.e. the likelihood of removal *did not change* as the carcasses aged, as in an exponential decay model). Estimation was performed using the *censorReg* function in S-Plus (Insightful Corporation 2006).

The parameter controlling the shape of the Weibull distribution is referred to as the dispersion parameter. When the dispersion parameter equals 1, the average rate at which carcasses are removed from the beach is constant over time as in an exponential decay model. When the dispersion parameter is less than 1, the average rate at which carcasses are removed increases over time, and when the dispersion parameter is greater than 1, the average rate at which carcasses are removed decreases over time.

Oregon and northern California study sites were treated as separate datasets in the statistical analysis. We built a statistical model for each site, treating carcass weight as a dichotomy, whereby all relationships between dependent and independent variables could vary depending on whether the carcass was "small" (≤521 g) or "large" (>521 g). Dummy (0/1) variables were used to identify individual sites within each study area and, in the case of the northern California *Kure* dataset, to identify whether a carcass was a seabird or a non-seabird. Table 3 lists models considered in the analysis. Alternative models were compared using the Akaike information criterion [AIC (as described by Burnham & Anderson 2002)].

RESULTS

Carcass persistence varied widely between sites for both the *New Carissa* and the *Kure* studies (Figs. 1 and 2). At the *Kure* sites around Humboldt Bay, some of the variation was clearly related to carcass size. With the exception of Indian Island, only 22%–44% of the small carcasses remained after 24 hours compared with 77%–100% of the large carcasses. On Indian Island, a marsh island in upper Humboldt Bay, carcass removal proceeded slowly for both size classes: 75% of the small and 77% of the large carcasses remained after four days on the beach. The relationship between size class and persistence was not apparent in the *New Carissa* study, in which the large and small size classes both had persistence rates comparable to the large size class in the *Kure* study.

TABLE 3
Akaike Information Criterion (AIC) values for candidate *Kure* and *New Carissa* models of carcass removal rates

Study			
Kure		*New Carissa*	
Model	**AIC value**	**Model**	**AIC value**
Size + Site + Seabird	396.0	Null	319.4
Size + Seabird	419.2	Size	320.5
Size + Site	428.5	Site	321.6
Size	442.2	Size + Site	325.4
Site + Seabird	457.7		
Site	468.1		
Seabird	471.9		
Null	479.0		

Employing the AIC (Table 3), we examined the decision to separate the dataset into large birds and small birds based on a 521 g weight breakpoint (Size), the inclusion of a factor to evaluate persistence effects by site (Site) and the effect of using non-seabirds for persistence in the *Kure* dataset (Seabird). The most parsimonious model for the *Kure* dataset was the full model that included all three dimensions (Size + Site + Seabird). In contrast, the best model for the *New Carissa* dataset was the null model (i.e. only the intercept and the dispersion parameter). The *New Carissa* model with the second lowest AIC was the model in which persistence was estimated separately for each size class (Size).

In the best model for large birds in the *Kure* study (Size + Site + Seabird), we found that large non-seabird carcasses (Mallards) showed decreased persistence time as compared with large seabird carcasses ($z = -5.89$, $P < 0.001$, n = 92). Compared with small seabird carcasses, small non-seabird carcasses showed a similar pattern, but the difference was nonsignificant ($z = -1.42$, $P > 0.10$, n = 55).

Judging from the Weibull dispersion parameter, small birds in the *Kure* study were removed at a decreasing rate over time, whereas large birds were removed at an increasing rate. However, based on a likelihood ratio test comparing the Weibull model to the exponential model, only the removal rate of the large birds in the *Kure* study was significantly different from a constant rate of removal (large birds: $\chi^2 = 5.27$, df = 1, $P < 0.05$, n = 92; small birds: $\chi^2 = 1.27$, df = 1, $P > 0.05$, n = 55). In the *New Carissa* study, carcasses were removed at a decreasing rate

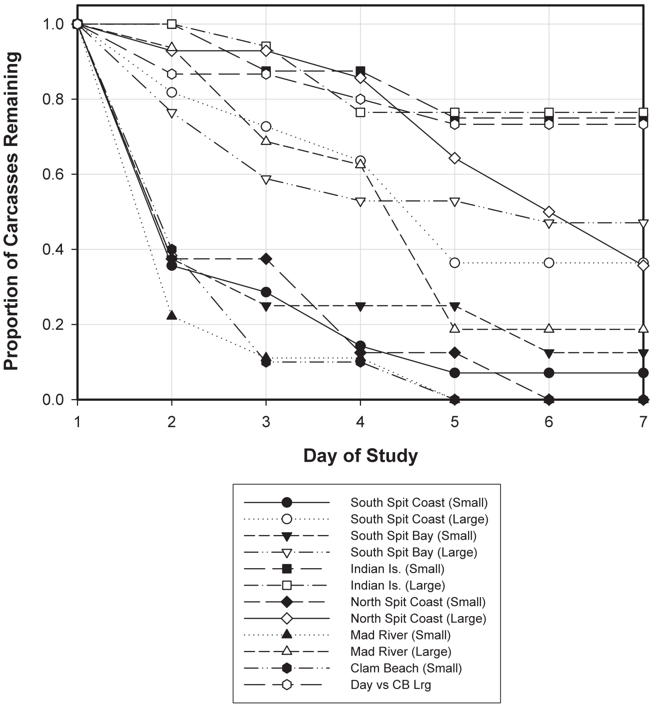

Fig. 1. Proportion of carcasses remaining on each day of the study at each site for the *Kure* study area around Humboldt Bay, California. Filled symbols indicate small birds (<521 g); open symbols denote larger birds.

over time ($\chi^2 = 8.88$, df = 1, $P < 0.01$, n = 101). When we separately estimated the Weibull function for both small and large birds (i.e. the *New Carissa* model with the second-lowest AIC), we found that the dispersion parameter for large birds was not significantly different from that in the exponential model ($\chi^2 = 0.20$, df = 1, $P > 0.10$, n = 32), whereas for small birds it was significantly different ($\chi^2 = 10.39$, df = 1, $P < 0.01$, n = 69). In other words, in the *New Carissa* study, small carcasses were removed at a decreasing rate relative to large carcasses, a pattern similar to that found in the *Kure* study.

DISCUSSION

Different sites in the two study areas varied widely with regard to carcass persistence. In general, small birds in the *Kure* study area disappeared very quickly compared with either large birds in the *Kure* study area or both size classes in the *New Carissa* study area. The low persistence of small birds at the *Kure* site resulted primarily from very rapid removal during the first 24 hours after carcass placement.

Sightings of avian scavengers were common, and such scavengers were often seen clustered around carcasses. Similarly, large numbers of bird tracks were frequently seen around scavenged or dismembered carcasses. Mammalian scavengers (aside from domestic dogs) were never observed, but their tracks were frequently associated with heavily scavenged or missing large carcasses. In the latter case, we sometimes saw drag marks in the sand that led into the vegetated back beach. In four instances at the *Kure* site, we were able to follow the drag marks to locations where carcasses had been cached inside clumps of vegetation.

Larid gulls, Common Ravens, and Turkey Vultures *Cathartes aura* were common at both sites. At the *Kure* site, we also observed two instances of Northern Harriers *Circus cyaneus* feeding on carcasses, and at the *New Carissa* site, we observed American Crows *Corvus brachyrhynchos* and Bald Eagles *Haliaeetus leucocephalus.* Large carcasses that were partially or heavily scavenged were often surrounded by hundreds of bird tracks; small carcasses often disappeared completely with no visible trace or with only a few footprints left in the immediate vicinity of the marker. We assume that many of the birds categorized as small were carried away by avian scavengers. In one instance (R. Hewitt pers. comm.), a Common Raven was videotaped flying off with a Rhinoceros Auklet in its beak. In another instance, we found part of a Rhinoceros Auklet carcass surrounded by feathers and fresh bird droppings atop a large log near the original carcass location.

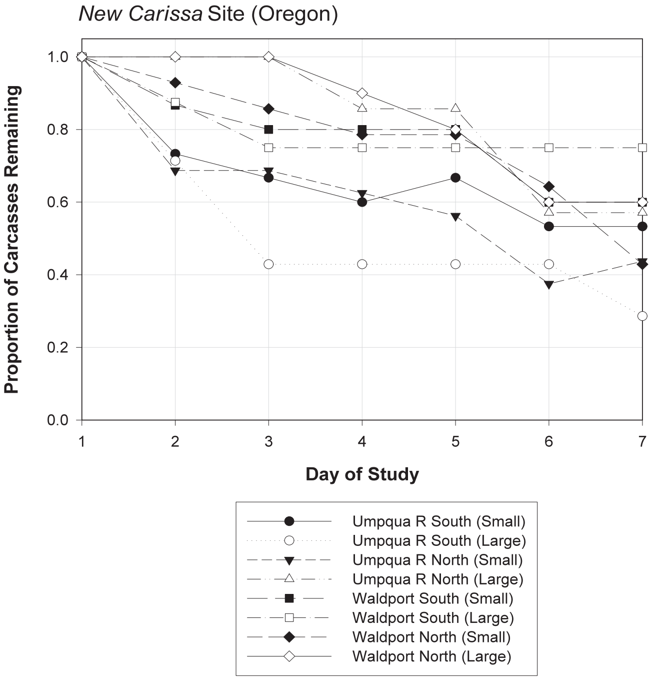

Fig. 2. Proportion of carcasses remaining on each day of the study at the *New Carissa* study area in Oregon. Filled symbols indicate small birds (<521 g); open symbols denote larger birds.

Domestic dogs were often seen investigating carcasses, but they were never observed scavenging or removing carcasses. Tracks at the *Kure* site indicated that the principal mammalian scavengers were Raccoons *Procyon lotor,* Skunks *Mephitis mephitis,* and to a lesser extent, Gray Foxes *Urocyon cinereoargenteus* (Halfpenny 1986). River Otter *Lutra canadensis* scat was commonly observed at the Indian Island site in Humboldt Bay. Tracks were sometimes difficult to identify at the *New Carissa* site because of blowing sand, but similarities in nearby habitats and species composition suggest that the mammalian scavenger fauna was probably similar at both sites. Our subjective impression is that mammal tracks or drag marks were usually associated with complete carcass removal rather than with progressive scavenging.

Although communities of avian scavengers were similar at the two sites, differences in weather conditions may have led to decreased levels of avian scavenging activity in the *New Carissa* study. Although avian scavengers were frequently seen on the beach at the *Kure* sites, they were much less common at the *New Carissa* sites, where they were regularly observed hovering a short distance inland, shielded from onshore wind by sand bluffs and rarely venturing onto the beach. The difference in removal rates of small carcasses at the two sites may have resulted from reduced avian scavenging activity in Oregon (*New Carissa*) because of the windy conditions that prevailed during the study.

Although ocean beaches are populated by both invertebrate and vertebrate scavengers, we found little evidence that carcass removal was caused by invertebrates. Invertebrate scavengers undoubtedly aided the process of decomposition, but invertebrate species in the upper beach zone were too small to disarticulate or remove even a small bird carcass. The apparently minor role of invertebrates may have resulted from placement of the carcasses above the high tide line, or because the duration of the studies was limited to one week.

The analysis demonstrated differences in the persistence of small and large birds in both the *Kure* and *New Carissa* studies, but the magnitude of the differences varied. In the *Kure* study, distinct differences were evident in the persistence of small and large birds, especially within the first few days, and those differences were highly significant. Conversely, in the *New Carissa* study, persistence varied less between size classes, and statistical support for the effect was weaker. The difference between the persistence of large and small carcasses during the *Kure* study may have resulted from higher rates of avian scavenging than occurred in the *New Carissa* study. These results emphasize the importance of conducting site-specific scavenging studies when estimating avian mortality based on the collection of beached bird carcasses.

Analysis of both the *Kure* and *New Carissa* datasets indicated that the removal of small and large bird carcasses changed over time.

In both cases, relative to large birds, small birds were removed at decreasing rates as carcasses aged. At the *Kure* site, we found that the removal rate of small birds decreased significantly as the carcasses aged, but that the removal rate of large carcasses was not significantly distinguishable from a constant rate model [Fig. 3(a)]. At the *New Carissa* site, the removal rate of small birds could not be distinguished from an exponential model, but the removal rate of large birds increased significantly in older carcasses. An increasing persistence rate, where fresh carcasses are removed rapidly by scavengers while older carcasses are ignored, is intuitive, because stripped and desiccated carcasses have little nutritional value. Decreasing persistence rates, as observed for large birds at the *New Carissa* study area, are more difficult to interpret. Examination of the records of individual carcasses suggests that many large birds were progressively dismembered near their original location on the beach. Fragmented carcasses remained in a recognizable state for several days, but ultimately many reached the point at which they could no longer be recognized as carcasses and were classified as "removed."

Obtaining seabird carcasses for persistence studies is sometimes difficult, and it is often convenient to use the carcasses of domestic fowl or wild passerines. The dataset for the *Kure* study site allowed us to determine whether passerines or domestic Mallards were scavenged in a manner comparable to that for seabirds. The persistence of small passerine carcasses was similar to that of small seabirds, and thus small passerine carcasses are potentially a useful surrogate for seabirds of comparable size. Domestic Mallards, however, persisted for significantly less time than did wild seabirds [Fig. 3(c)], a finding similar to that of Smallwood (2007), who reported that domestic chickens and game hens were removed more rapidly than were wild carcasses in terrestrial habitats. This preference should be taken into account when designing scavenging studies. Smallwood (2007) also found that previously frozen carcasses disappeared more slowly than did fresh carcasses, suggesting that our estimates of carcass persistence, which were based on carcasses that had previously been frozen, may overestimate persistence.

Estimates of seabird carcass persistence show a wide range of variation in studies carried out in different habitats (Ford 2006). Nonetheless, we found no significant differences between sites within the *New Carissa* study area; and, within the *Kure* study area, only the marsh site on Indian Island differed significantly from all other sites [Fig. 3(b)]. Persistence rates for small birds showed no significant differences between the remaining *Kure* sites, but rates for large birds did. Large carcasses were removed most rapidly at the Clam Beach and Mad River sites (both being wide sandy beaches associated with the outflow of small rivers), and both sites showed significant or marginally significant differences compared with other sites. This pattern suggests that the distribution of scavengers capable of removing large carcasses intact—probably medium-size mammals—was more variable than the distribution of scavengers capable of removing smaller carcasses.

Our analysis indicates that study area (*New Carissa* or *Kure*), specific beach-site, carcass size, carcass type and carcass age are all potentially important factors determining scavenging rates. However, the differences between the best-supported (AIC) models for the *New Carissa* and the *Kure* events show that the importance of the various factors may vary from incident to incident, even when the circumstances are superficially similar. This finding suggests that a carcass persistence function developed for one event is not necessarily applicable to other events.

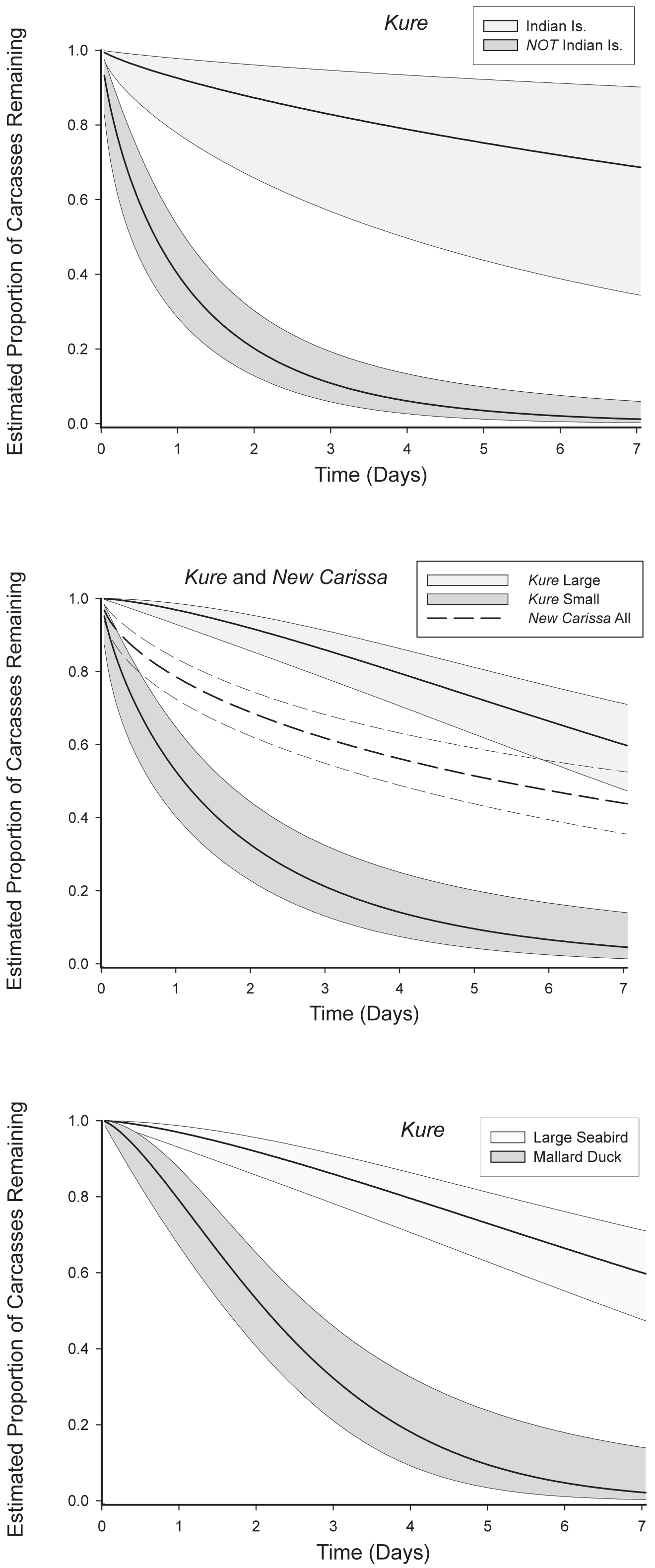

Fig. 3. Estimated daily proportion of carcasses remaining based on the Weibull parametric model with the best Akaike information criterion (AIC) score for both the *Kure* and the *New Carissa* spills (*cf.* Table 3). Envelopes indicate upper and lower 95% confidence limits. (a) Persistence for *Kure* large and small birds compared with all *New Carissa* birds. (b) Indian Island site in the *Kure* study compared with all other *Kure* sites. (c) Large seabirds compared with Mallard Ducks *Anas platyrhynchos* at all *Kure* sites.

ACKNOWLEDGEMENTS

We thank Jennifer Ward, Pablo Herrera, Rob Hewitt and Adrian del Nevo for assistance with field work. Jennifer Ward helped with data preparation and analyses. Adrian del Nevo provided useful commentary on some of the early analyses. Funding for manuscript preparation was provided by the California Department of Fish and Game, Office of Spill Prevention and Response.

REFERENCES

BARRIOS, L. & RODRIGUEZ, A. 2004. Behavioral and environmental correlates of soaring-bird mortality at on-shore wind turbines. *Journal of Applied Ecology* 41: 72–81.

BURNHAM, K.P. & ANDERSON, D.R. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. New York: Springer Science and Business Media.

CAMPHUYSEN, C.J. 1989. Beached bird surveys in the Netherlands 1915–1988: seabird mortality in the southern North Sea since the early days of oil pollution. Amsterdam, Netherlands: Werkgroep Noordzee.

CAMPHUYSEN, C.J. & HEUBECK, M. 2001. Marine oil pollution and beached bird surveys: the development of a sensitive monitoring instrument. *Environmental Pollution* 112: 443–461.

DUNNING, J.B. 1984. Body weights of 686 species of North American birds. Monograph 1. Cave Creek, AZ: Western Bird Banding Association.

FORD, R.G. 2006. Using beached bird monitoring data for seabird damage assessment: the importance of search interval. *Marine Ornithology* 34: 91–98.

FORD, R.G., BONNELL, M.L., VAROUJEAN, D.H., PAGE, G.W., CARTER, H.R., SHARP, B.E., HEINEMANN, D. & CASEY, J.L. 1996. Total direct mortality of seabirds from the *Exxon Valdez* oil spill. In: Rice, S.D., Spies, R.B., Wolfe, D.A. & Wright, B.A. (Eds). Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium 18. Bethesda, MD: American Fisheries Society. pp. 684–711.

FORD, R.G., SHARP, B.E., CASEY, J.L. & HIMES BOOR, G.K. 2001a. Estimates of the numbers of birds oiled by the M/V *Kure*/Humboldt Bay oil spill of November 5, 1997 [unpublished report]. Sacramento, CA: California Department of Fish and Game, Office of Spill Prevention and Response.

FORD, R.G., HIMES BOOR, G.K. & WARD, J.C. 2001b. Seabird mortality resulting from the M/V *New Carissa* oil spill incident February and March 1999 [unpublished report]. Portland, OR: US Fish and Wildlife Service.

FOWLER, A.C. & FLINT, P.L. 1997. Persistence rates and detection probabilities of oiled King Eider carcasses on St. Paul Island, Alaska. *Marine Pollution Bulletin* 34: 522–526.

HALFPENNY, J. 1986. A field guide to mammal tracking in North America. Boulder, CO: Johnson Printing Company.

INSIGHTFUL CORPORATION. 2006. S-Plus (version 7.0.4). Seattle, WA: Tibco Software. [Available online at: www.insightful.com; accessed 22 May 2009]

JOHNSON, G.D., PERLIK, M.K., ERICKSON, W.P. & STRICKLAND, M.D. 2004. Bat activity, composition, and collision mortality at a large wind plant in Minnesota. *Wildlife Society Bulletin* 32: 1278–1288.

NEWMAN, S.H., ZICCARDI, M.H., BERKNER, A.B., HOLCOMB, J., CLUMPNER, C. & MAZET, J.A.K. 2003. A historical account of oiled wildlife care in California. *Marine Ornithology* 31: 59–64.

OSBORN, R.G., HIGGINS, K.F., USGAARD, R.E., DIETER, C.D. & NEIGER, R.D. 2000. Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota. *American Midland Naturalist* 143: 41–52.

PAGE, G.W., CARTER, H.R. & FORD, R.G. 1990. Numbers of seabirds killed or debilitated in the 1986 *Apex Houston* oil spill in central California. *Studies in Avian Biology* 14: 164–174.

PIATT, J.F. & VAN PELT, T.I. 1997. Mass-mortality of Guillemots (*Uria aalge*) in the Gulf of Alaska in 1993. *Marine Pollution Bulletin* 34: 656–662.

SMALLWOOD, K.S. 2007. Estimating wind turbine–caused bird mortality. *Journal of Wildlife Management* 71: 2781–2791.

VAN PELT, T.I. & PIATT, J.F. 1995. Deposition and persistence of beachcast seabird carcasses. *Marine Pollution Bulletin* 30: 794–802.

WIESE, F.K. & RYAN, P.C. 2003. The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached-bird surveys 1984–1999. *Marine Pollution Bulletin* 46: 1090–1101.