

PERSISTENCE RATES AND DETECTION PROBABILITIES OF BIRD CARCASSES ON BEACHES OF UNALASKA ISLAND, ALASKA, FOLLOWING THE WRECK OF THE M/V *SELENDANG AYU*

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SUMMARY

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Mark–recapture techniques were used to estimate persistence rates and detection probabilities of bird carcasses associated with the oil spill following the wreck of the M/V *Selendang Ayu* at Unalaska Island, Alaska. Only 14.6% of carcasses placed on beaches remained after 24 hours, and all carcasses that remained had been scavenged to some degree. Daily persistence rates for scavenged carcasses on subsequent days were substantially higher at 79.1%. Most carcasses (>98%) were removed by scavengers at night. When they made a single pass, observers searching beaches for carcasses that had washed ashore found only about 40% of carcasses known to be present. This detection probability did not vary between pairs of search teams or between beaches. Detection probability increased to about 70% when teams searched the same beach segment twice. Our data indicate that only a small fraction of beached carcasses would likely be found using standard beach survey protocols and search frequencies. These data emphasize the importance of measuring persistence and detection rates for each mortality event.

Key words: Alaska, bird carcass detection, bird carcass persistence, oil spill, scavenging rate

INTRODUCTION

Counts of bird carcasses on beaches are typically used to assess the impact of oil spills on marine birds and to characterize other mortality events (Ford *et al.* 1987, Page *et al.* 1990, Piatt *et al.* 1990, Burger 1992a, Flint *et al.* 1999, Wiese & Ryan 2003, Wiese & Robertson 2004, Ford 2006, Hampton & Zafonte 2006). The number of carcasses found by observers on a specific beach at any given time is a function of three processes:

- The rate and pattern of carcass deposition on beaches
- The persistence rates of carcasses once on beaches
- The probability of observers detecting carcasses present on beaches

All of these components are known to vary with local factors. For example, the carcass deposition rate has been shown to vary with several factors, including beach type, currents and wind (Bodkin & Jameson 1991, Ford *et al.* 1996, Flint & Fowler 1998, Ford 2006). The persistence rate has been shown to vary by beach type, time since deposition, weather, tidal activity and scavenger activity (Page *et al.* 1990; Bodkin & Jameson 1991; Burger 1992b, 1993; Van Pelt & Piatt 1995; Ford *et al.* 1996; Fowler & Flint 1997; Ford 2006). The detection probability of carcasses may vary by beach type, size of the carcass and weather conditions such as the presence or absence of snow (Fowler & Flint 1997, Osborn *et al.* 2000, Ford *et al.* 2006).

On 8 December 2004, the M/V *Selendang Ayu* ran aground and broke up in rough seas off Unalaska Island, Alaska (53°38.37'N, 167°07.67'W), spilling an estimated 354 218 gallons of oil [339 538 gallons of bunker oil (IFO 380) and 14 680 gallons of marine diesel and miscellaneous oils (see Brewer 2006)]. Numerous bird carcasses were recovered during beach searches in the months following the spill, but recovered carcasses likely represent only a fraction of the total number of carcasses deposited on beaches (Ford *et al.* 1996, Flint *et al.* 1999). At Unalaska Island, many beaches are exposed to direct wave action, which can reduce persistence rates by rewashing carcasses, and numerous resident scavengers—including Red Foxes *Vulpes vulpes*, Common Ravens *Corvus corax*, Bald Eagles *Haliaeetus leucocephalus* and Glaucous-winged Gulls *Larus glaucescens*—can remove carcasses before they are detected by observers. This combination of factors suggested very low persistence rates for carcasses on the beaches of Unalaska Island.

The persistence rates and detection probabilities of carcasses can both be estimated using mark–recapture techniques (Pollock *et al.* 1990). Applied to this situation, the usual survival rate estimate is, functionally, a persistence rate, which is defined as the probability that a carcass will remain on the study area for a given period of time. Detection probability is defined as the probability that a carcass known to be on the beach will be found by an observer. We estimate both persistence rate and detection probability for a sample of carcasses on Unalaska Island in January 2005 and discuss the results in the context of scavenger satiety.

METHODS

Study area

Unalaska Island is in the Fox Island group, eastern Aleutian Islands (Fig. 1). The study area was a stretch of coastline (>100 km) on the north side of the island where oil was found from the M/V *Selendang Ayu*. The study area encompassed several beach types:

- Exposed: Washed by direct wave action from the Bering Sea, typically do not accumulate flotsam
- Protected: Relatively protected from direct impacts of surf and thus less subject to rewash of flotsam
- “Catchment”: Typically protected from substantial rewash but, because of currents, beach aspect and local geography, tend to accumulate flotsam

Mean tidal range during the study period was approximately 1.4 m, based on National Oceanic and Atmospheric Administration (NOAA) prediction tables. Beach segment identifiers (three-

letter identifiers for specific bays, followed by a specific beach segment number) were defined by NOAA as part of the response to the spill by the Unified Command (the authority overseeing such responses).

Persistence rate

Because of the threat posed to scavengers by contamination, the Unified Command enforced a policy that precluded leaving detected oiled carcasses on beaches. To study carcass persistence, we therefore obtained (from various agencies and universities) salvaged, unoled carcasses of species commonly occurring in nearshore marine waters at Unalaska Island in winter (e.g. gulls, sea ducks and alcids). Before being placed on beaches in the spill area, these carcasses were each marked with a small numbered metal tag inserted through the gap between the radius and ulna bones of each wing.

We selected a sample of four beaches (three protected and one catchment) for study. Exposed beaches were too difficult to access

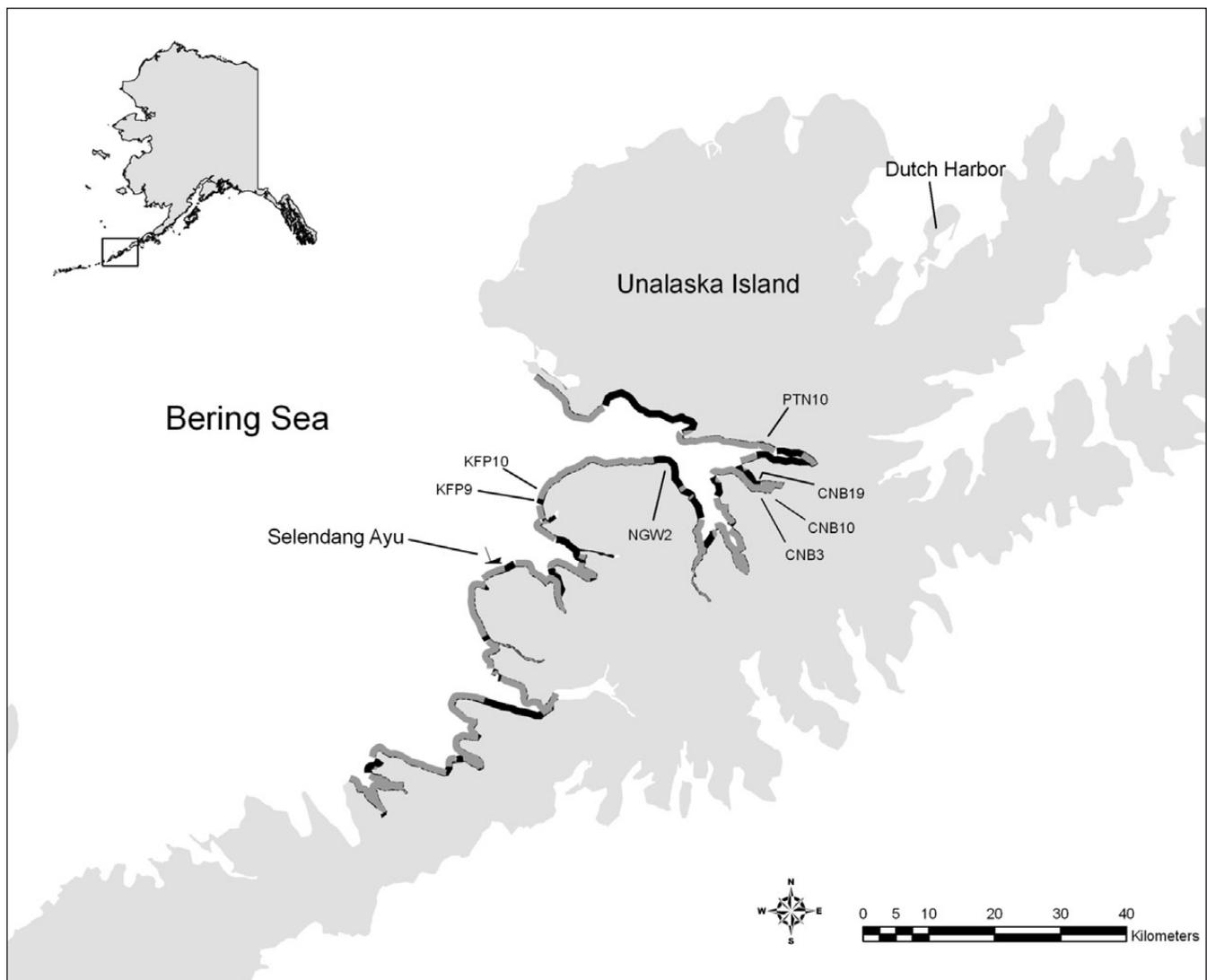


Fig. 1. Location of shipwreck and associated distribution of oil along beaches as determined by Shoreline Clean-up Assessment Team (SCAT) surveys. Black lines indicate heavily oiled beaches; grey lines indicate lightly oiled beaches. SCAT identifiers are shown for beaches selected for carcass persistence and detection studies.

regularly, and so they were not included. Carcasses were deployed on the beaches as follows:

- 9 January: 22 carcasses on beach CNB 10 (see Fig. 1 for locations)
- 17 January: 26 carcasses on NGW 2
- 25 January: 32 carcasses on CNB 10
- 26 January: 32 carcasses on PTN 10

Carcasses were distributed across each beach to match the typical distribution of carcasses found during beach searches. To assess the effect of tide on carcass persistence, the position of each carcass was recorded as above or below the mean high tide line. We classified carcasses by size:

- Large: 17 carcasses of eiders *Somateria mollissima* and *S. spectabilis*, Glaucous-winged Gulls, Pelagic Cormorants *Phalacrocorax pelagicus*
- Medium: 46 carcasses of murrets *Uria* spp., puffins *Fratercula* spp., kittiwakes *Rissa* spp.
- Small: 49 carcasses of auklets *Aethia* spp.

On three beaches, a small numbered board was placed directly under each carcass to assess tidal rewash (Ford *et al.* 2006). We assumed that if the board remained and the carcass was missing, then the carcass was not lost because of tidal rewash. If the carcass and the board were both missing, we assumed that loss was caused by tidal action.

Beaches were rechecked on a schedule that varied from 12 hours to several days (Table 1). During each revisit, observers recorded the presence of carcasses and numbered boards and the condition of the persistent carcasses in terms of scavenging. Rechecks were conducted until all carcasses on a beach were removed or until we departed the area on 31 January 2005.

Detection probability

Detection probability was estimated using a slight modification of the protocol outlined in Nichols *et al.* (2000). We selected a sample of five beaches for detection studies (two protected, two catchment

and one exposed). Two beach survey teams, each consisting of three people, conducted the study. One team made a single pass of the selected beach segment, searching for naturally occurring carcasses, leaving each detected carcass in place after recording its location and subtly marking it in a manner that would not increase subsequent detection. The second team, not having watched the first team's efforts, searched the same beach segment, again leaving each detected carcass in place after recording its location and subtly marking it. Each team then independently repeated the search, making a second pass back down the beach segment, again recording the location of each carcass and whether it was already marked by one or both teams. Thus, each team made two passes searching for carcasses independent of the other team. This process produced a set of detected carcasses, each with two detection histories, one from each team's pair of passes.

Statistical analyses

Persistence rate

Daily persistence rate was estimated using surveys conducted as close to 24 hours apart as possible, thus ignoring data from multiple surveys conducted within days. We used the interval censored survival models presented by Johnson (1979) to estimate the daily persistence (i.e. survival) rate and associated standard error. These models assume that probability of persistence per day is constant and equal across carcasses; they make no assumptions regarding the timing of loss within observation intervals. A solution for the resulting maximum likelihood estimate of daily persistence was obtained using an iterative procedure in Excel (Microsoft Corporation, Redmond, WA, USA). Standard errors were estimated following Johnson (1979). Confidence intervals were estimated by assuming an asymptotic normal sampling distribution for the persistence estimates.

This "known fate" analysis assumed that all carcasses were detected if present on every search. However, data indicated that two carcasses missed on a search were subsequently found during a later search. The data were insufficient to directly estimate a recapture rate with a standard Cormack–Jolly–Seber model, but data from carcasses placed with numbered boards suggested that the

TABLE 1
Carcass persistence data sample sizes, by beach, number of days between visits and initial carcass state for carcasses placed on beaches of Unalaska Island, Alaska, January 2005^a

Beach ID	Type	Initial state ^b										
		Intact			Scavenged							
		Day ₀	Day ₁	Day ₂	Day ₀	Day ₁	Day ₂	Day ₃	Day ₄	Day ₅	Day ₈	Day ₁₂
CNB 19	C	22		4	4	3					0	
NGW 2	P	26	2		2	2						1
CNB 10	P	32	4		4	1		1	0			
PTN 10	P	32	1		1	1	1	1				

^a For example, 22 intact carcasses were deposited on beach CNB 19 and revisited two days later, at which time only four scavenged carcasses remained (Intact Day₂ = 4 = Scavenged Day₀). Those were revisited one day later (Scavenged Day₁), at which time three remained, then revisited after another seven days (Scavenged Day₈), at which time no carcasses remained. Of the 112 intact carcasses originally deposited, 11 remained at the first revisit, all scavenged.

^b The subscript indicates the day of exposure as used in the persistence models.
C = catchment; P = protected.

true recapture rate for these carcasses was very close to 1.0. Thus, we adjusted data for the two undetected carcasses as if they had actually been detected on all intervening searches.

In this study, carcasses were recorded in one of two distinct states: intact or scavenged. We split the analyses and modeled the persistence of intact and scavenged carcasses separately. The persistence of carcasses is reported separately by condition (intact or scavenged) based on the state of the carcass at the start of the observation interval. Data were not recorded to indicate if scavenged carcasses were further scavenged between observations, and so the analysis of scavenged carcasses assesses only whether carcasses persisted.

We used data from searches conducted at 12-hour intervals to estimate the proportions of carcasses lost during the day and at night. Data from the three beaches with numbered boards were used to estimate the proportion of carcasses that may have been lost because of tidal rewash. Both proportions were estimated following the usual binomial model (Zar 1996). Confidence intervals were calculated following Agresti & Coull (1998) using the function `binconf` from the `Hmisc` package (Harrell 2004) in the statistical freeware package R (R Development Core Team 2005).

Detection probability

Detection studies were conducted on five beach segments, but data from beaches CNB 3, 9 and 10 were pooled because of the small number of carcasses found. We considered the effect of beaches in two ways. First, each beach may have had a unique detection probability. Second, detection may have been a function of associated accumulated flotsam, and so beaches were categorized as being exposed to direct wave action or being protected or catchment (i.e. categorization by “beach type”). Conditional on the number of detected carcasses in a beach segment, the dual-detection histories follow a Cormack–Jolly–Seber design for a closed population, permitting use of standard mark–recapture models for estimating the mean detection rate (Pollock *et al.* 1990).

Nine models with different levels of variation in detection probability were considered:

- Constant
- Varies by pass, constant across beaches and teams
- Varies by beach type, constant across teams and passes
- Varies by team and pass, constant across beaches

- Varies by beach type and team, constant across passes
- Varies by beach type and pass, constant across teams
- Varies by beach and pass, constant across teams
- Varies by beach type, team and pass
- Varies by beach, team and pass

Model parameters were estimated and overall model fit assessed using program Mark (White & Burnham 1999). When there were competing plausible models [based on their small-sample AICc (Akaike Information Criteria)], AICc-weighted model averaging was used to incorporate model selection uncertainty into the parameter estimates, standard errors and confidence intervals (Burnham & Anderson 2002).

RESULTS

Persistence rate

Intact carcasses

The 112 intact carcasses placed on beaches for the persistence study were rechecked over two interval lengths (Table 1): one and two days (the two-day interval occurring only on beach CNB 19). All eleven carcasses persisting on beaches during the initial check after deployment had been scavenged. Thus, the daily persistence probability for an intact carcass remaining in an intact state was 0. That is, the state transition probability from intact to scavenged, given that a carcass persisted, was 1.0. The maximum likelihood estimate of the daily persistence rate for an intact carcass remaining as a scavenged carcass, with associated standard error, was 0.146 ± 0.034 (Table 2).

Scavenged carcasses

The 11 scavenged carcasses that remained from the previous analyses served as the initial sample for persistence of scavenged carcasses. Using the same approach described earlier, five recheck interval lengths were examined (Table 1). The maximum likelihood estimate of daily persistence probability for a scavenged carcass remaining on a beach was 0.791 ± 0.066 (Table 2). The joint persistence probability (a combination of persistence probability of intact and scavenged carcasses) suggests that 98% of all carcasses were removed within 10 days of deposition (Fig. 2).

Using data from beaches that were surveyed multiple times within a 24-hour period, we calculated the proportion of carcasses that

TABLE 2
Estimates of daily transition probabilities^a

State at time <i>i</i>	State at time <i>i</i> +1 (95% confidence limits)			
	Persisting		Disappearing	
	Intact	Scavenged	Rewashed	Removed
Intact	0.0 (0.0,0.041)	0.146 (0.079, 0.213)	0.033 (0.011, 0.093)	0.821 ^b
Scavenged		0.79 (0.662, 0.920)	0.0	0.21 ^b

^a Estimates for the transitions Intact → Intact and Intact → Rewashed are the usual binomial estimates; their confidence limits follow Agresti & Coull (1998). The estimates for the transitions Intact → Scavenged and Scavenged → Scavenged are from the survival model; their confidence limits assume asymptotic normality of the estimates.

^b Daily probability of transition Intact → Removed = $1 - 0.0 - 0.146 - 0.033$; similarly, transition Scavenged → Removed = $1 - 0.79$.

disappeared overnight. We placed 58 carcasses on beaches in the early morning, rechecked them in the late afternoon of the same day and then checked them again the following morning. Of those 58 carcasses, one was missing and five were scavenged by the afternoon search on the same day, but only three carcasses remained (all scavenged) 24 hours after placement ($3/58 = 0.0517 \pm 0.0038$). Thus, given the sample of 55 carcasses removed over the 24-hour period, only one was removed during daylight hours, suggesting that 98.18% of carcasses that are ultimately lost are removed at night. Although these results indicate that some scavenging occurred during the day ($5/58 = 0.0862 \pm 0.0048$), all such scavenged carcasses were subsequently removed by scavengers overnight.

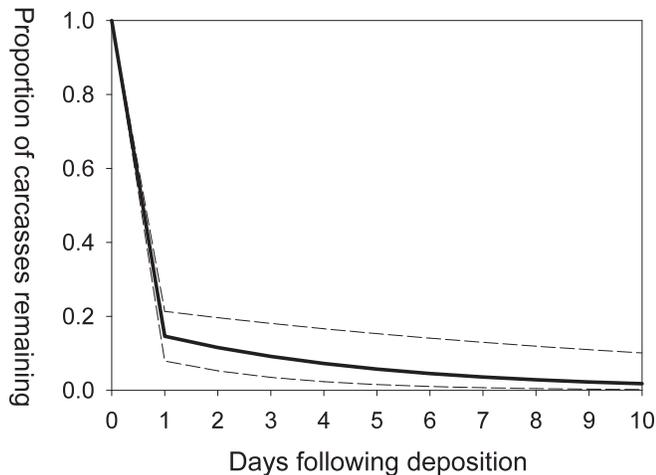


Fig. 2. Joint persistence probability for bird carcasses placed on beaches of Unalaska Island, Alaska, in January 2005. After one day of exposure, all remaining carcasses had been scavenged to some degree. Thus, probability of remaining after day 1 assumes that carcasses have been scavenged. Dashed lines represent upper and lower 95% confidence limits.

Using data from the marked boards placed under a sample of 90 carcasses, only three (0.0333 ± 0.0019) showed evidence of floatation and removal by tidal action (Table 2). Only one tagged carcass was subsequently found on a beach other than where it was marked. Although quantification of search effort off study beaches is lacking, it appeared that scavengers removed carcasses from beaches into areas not generally covered in searches.

Detection probability

The best models, according to AICc, showed support for only two levels of variation in detection probability: pass and team (Table 3). Not surprisingly, detection probability generally increased on the second pass, from around 40% to around 70% (Fig. 3). Compared with the effect of pass, the effect of team was relatively inconsequential (Fig. 3, Table 3). There was no support for variation across beach type, because the associated additional parameters resulted in a negligible change in model deviance compared with the model that included only variation across passes (models 1 and 3 in Table 3).

DISCUSSION

Persistence

Intact carcasses had very low rates of persistence on Unalaska Island during the study period. All intact carcasses were either removed or scavenged within 24 hours. Once carcasses were scavenged, estimated persistence probability increased substantially. Similarly, Van Pelt and Piatt (1995) demonstrated that carcass persistence in Resurrection Bay (south-central Alaska) followed a logarithmic decline. Although degree of scavenging was not recorded on searches, we suspect that heavily scavenged carcasses with little remaining food value had the highest persistence probabilities. This result, combined with minimal evidence of tidal rewash, strongly suggests that most carcasses were removed by scavengers. Most

TABLE 3
Comparison of models explaining variation in detection probability of natural bird carcasses on Unalaska Island, Alaska, in January 2005

Model parameters ^a	AICc ^b	Δ AICc ^c	AIC weight ^d	Parameters estimated (n)	Model deviance
Pass	297.5	0.00	0.64	2	62.60
Pass, team	300.1	2.60	0.17	4	61.02
Pass, beach type	301.6	4.09	0.08	4	62.51
Pass, beach, team	301.7	4.14	0.08	12	44.71
Pass, beach	305.5	7.99	0.01	6	62.12
Pass, beach type, team	306.6	9.09	<0.01	8	58.82
Constant	315.1	17.61	<0.01	1	82.26
Beach type	317.2	19.63	<0.01	2	82.23
Beach type, team	320.4	22.89	<0.01	4	81.31

^a Two independent teams each made two passes down five separate beach segments. "Beach type" categorizes beach segments as exposed or protected from direct surf.

^b AIC adjusted for small sample size.

^c Difference in AICc between each model and model with the lowest AICc.

^d Weight of evidence supporting model as the best model.

AIC = Akaike Information Criterion.

carcasses, both intact and scavenged during the day, were removed overnight. This finding suggests that nocturnal scavengers such as Red Foxes had the greatest effect on persistence.

The observed rates of persistence are considerably lower than those obtained during most previous studies of carcasses on beaches (Berger & Fry 1993, Van Pelt & Piatt 1995, Fowler & Flint 1997, Ford 2006). Additionally, our estimates are considerably lower than the estimates of bird carcass persistence in terrestrial habitats (Tobin & Dolbeer 1990, Linz *et al.* 1991, Kostecke *et al.* 2001, Rivera-Milán *et al.* 2004, Smallwood 2007). This result implies that scavengers at Unalaska did not become satiated, as suggested by some studies (Fowler & Flint 1997, Smallwood 2007).

Linz *et al.* (1991) concluded that carcass persistence rates vary with carcass density, with carcasses at the highest density persisting at the lowest rates. They hypothesized that high carcass density caused scavengers to focus on specific areas, resulting in removal of a high proportion of the carcasses. Our study was conducted 48 days after the initial spill. Thus, the initial mortality event and deposition of carcasses may have caused scavengers to focus activity on beaches, but deposition of carcasses at the time of our study was apparently well below that required to satiate or overwhelm scavengers. Alternatively, it is possible that degree of oiling affects the probability of scavenging, and hence persistence, such that oiled carcasses may persist at higher rates than we report. All of the carcasses used to study persistence were completely unoled. However, Wiese (2002) found no difference in persistence time for oiled and unoled carcasses. Future studies could avoid this potential bias by using a random sample of carcasses associated with the mortality event being studied.

Even though relevant data were collected, the very low persistence rates of intact carcasses prevent assessment of variation across beaches, by carcass size (i.e. species) or relative to tide level on the beach. That is, too few carcasses remained to assess variation in persistence across those covariates. Previous studies suggest that

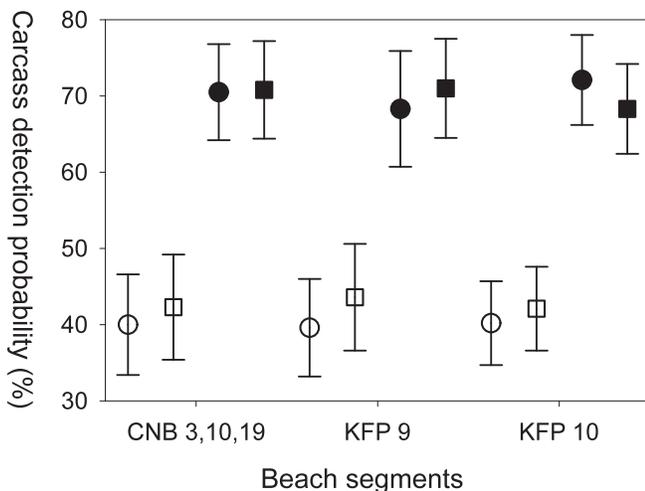


Fig. 3. Model-averaged detection probabilities for naturally occurring bird carcasses on beaches of Unalaska Island, Alaska, in January 2005. Open symbols indicate the first pass by a team down a beach segment; filled symbols indicate the second pass. Circles and squares represent the two search teams. Bars indicate the standard error. The effects of team and beach are minor compared with the effect of pass.

persistence rates vary across habitat types (Kostecke *et al.* 2001), beach types (Fowler & Flint 1997), carcass age (Van Pelt & Piatt 1995) and carcass condition (Fowler & Flint 1997). Kostecke *et al.* (2001) concluded that carcass persistence rates did not differ by species, implying that scavengers were not satiated or selective. We conclude that scavenger density on Unalaska Island is uniformly high, resulting in consistently low and hence relatively invariant persistence rates.

Detection

Similar to previous studies that directly estimated carcass detection probabilities on beaches (Fowler & Flint 1997, Ford 2006), we did not find all carcasses known to be present on any given search. On a single search, both search teams in each pair found fewer than half the carcasses known to be present (Fig. 3). Other studies of detection probability of carcasses in natural habitats report detection probabilities from 45% to 93% (Tobin & Dolbeer 1990, Linz *et al.* 1991, Philibert *et al.* 1993, Fowler & Flint 1997, Ford 2006). Overall, it appears that detection rates of bird carcasses on beaches are lower than in terrestrial habitats (Tobin & Dolbeer 1990, Linz *et al.* 1991, Philibert *et al.* 1993, Smallwood 2007). Comparing detection rates on beaches, we suspect that the lower detection probabilities in the present study were related to carcass size (i.e. many of the scavenged “carcasses” were just wings or parts of wings) and cryptic coloration (i.e. many of the carcasses were dark-plumaged remains on dark rocky beaches), because most of the study carcasses were smaller than the eider carcasses studied by Fowler & Flint (1997).

We found little evidence for variation in detection probability across beaches or search teams, but other studies report considerable variation between observers (Tobin & Dolbeer 1990, Linz *et al.* 1991, Philibert *et al.* 1993). Our studies were conducted after crews had been searching beaches for days, and thus we suspect that consistency was related to experience and training. However, detection rates increased substantially when crews re-searched the same beach a second time. Searchers likely recalled the location of carcasses discovered on the first search, allowing them to expand their effective coverage on the second pass. Thus, it is clear that detection rates in our particular study could have been increased substantially by double-searching beaches or by otherwise increasing search intensity. In fact, it may be more efficient to reduce the total sample of beaches searched and to focus more on double-sampling a smaller number of beaches. The trade-off between single- and multiple-pass searches will depend on increases in detection probability between passes and on the logistics associated with accessing beaches for sampling.

Model assumptions

Many of the assumptions of mark–recapture studies are irrelevant in applying the same models to carcass persistence, but several assumptions do apply. First, the models used assume no tag loss. Three untagged scavenged carcasses found during revisits to the study beaches were of the same species that had been placed on those beaches. These were likely tagged carcasses from which scavengers had removed the tags, because the wings of the carcasses were damaged or missing. Failure to include these carcasses as recaptures would result in underestimation of persistence rates. Thus, we assumed that all of those carcasses had been tagged ones, and we adjusted the recapture histories for three carcasses accordingly.

The specific persistence model used is considered a “known fates” model, with the assumption that carcass detection probabilities on recheck are 1.0. However, two carcasses were missed on one or more searches and were subsequently re-located, suggesting violation of that assumption. We adjusted the recapture histories for the two carcasses missed to indicate their presence on all intervening searches. Our data were insufficient to estimate a detection probability for the persistence carcasses, and thus we assumed that all detection probabilities were 100%. Violating this assumption would lead to underestimation of the persistence rate. However, we suspect that violations of this assumption were minimal because

- this was an experimental study, and carcasses were purposely placed on the beach. Hence, the initial number and location of carcasses were known by the searchers.
- crews were instructed to search at each visit until they were confident that all carcasses present were located.
- all numbered boards placed under carcasses were re-located.

Accordingly, we believe that any effect of imperfect carcass detection on parameter estimates was minor.

Our analyses of carcass detection rates were based on the sample of naturally occurring carcasses discovered by the search teams. Our results are therefore conditional on the sample of carcasses discovered. There may have been additional carcasses present on the study beaches that remained undiscovered. That is, some carcasses may have been deposited in locations that were functionally impossible to discover. If such heterogeneity in carcass detection probability exists, we would have overestimated the true carcass detection probability.

CONCLUSIONS

The combination of relatively low detection probabilities and extremely low persistence rates suggests that a very small proportion of total carcasses that washed ashore were found during beach searches on Unalaska Island. These results emphasize the importance of measuring these parameters for each occurrence or specific location, because these data are essential for modeling the total mortality associated with specific events (Flint *et al.* 1999). Our data indicate that double-searching beach segments may increase the efficiency of carcass recovery, particularly in situations such as Unalaska, where most carcasses were heavily scavenged and only partial carcasses remained.

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