SINKING RATES OF DEAD BIRDS: IMPROVING ESTIMATES OF SEABIRD MORTALITY DUE TO OILING

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SUMMARY

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Seabird mortality resulting from oil spills is generally assessed based on the number of birds that arrive onshore and the proportion of birds lost at sea. Drift blocks are often employed to determine the loss at sea and because blocks do not sink, but seabird carcasses do, it is essential to determine accurate sinking rates of seabird carcasses to correctly interpret onshore drift block recoveries. To quantify sinking rates of seabird carcasses, to determine possible differences between oiled and unoiled birds, and to investigate the importance of scavenging, I conducted an experiment in St. John's, Newfoundland, Canada, with 54 intact, but previously frozen murres (*Uria* spp.), the most common victims in oil spills in the Northern Hemisphere. Birds were randomly assigned to clean, lightly oiled (25% of body oiled) or heavily oiled (50% body oiled) categories. Twelve birds of each oiling category were placed into a floating three-chambered wooden-framed pen. The remaining birds were placed in a mesh-screened pen on the wharf. After nine days, randomly assigned carcasses from the floating pen and all birds on land, were opened to simulate partial scavenging. After 19 days, all flesh and muscles were removed from remaining birds to simulate complete scavenging. Changes in the buoyancy of carcasses were determined daily by measuring the amount of added mass (in 5 g increments) necessary to sink them (Burger 1991, cited in Burger and Fry 1993). On average, carcasses remained afloat 8.2 ± 1.0 d (95% C.I. 6.2 – 10.3), with no difference between oiled and unoiled, either floating or on land. Carcasses on land retained buoyancy significantly longer and only 1 carcass sank with the 24 d period. Buoyancy loss was best described by a logistic time-dependent function. When carcasses were scavenged, buoyancy loss increased exponentially. Based on these results, it appears that backwash and subsequent sinking of stranded carcasses is likely not a significant mechanism of carcasses removal from beaches. I recommend using a 10-14 d estimate for the length of time that murres and other auks remain afloat at sea, and to use a time-dependent logistic function to estimate the proportion of birds lost at sea. It appears that most estimates of seabird mortality due to spilled oil based on drift block experiments may be too low because onshore block recoveries relevant to seabird carcasses have been over-estimated.

INTRODUCTION

Seabird mortality resulting from oil spills is usually estimated from the number of birds found on beaches (Ford *et al*. 1987, Wiese 2002). Two measurements are essential in order to extrapolate from that number accurately: the number of birds dying at sea which do not reach the shore, and the number that subsequently disappears on the beach before being recorded (Ford *et al*. 1987, Piatt *et al*. 1990, Burger & Fry 1993, Fowler & Flint 1997). Many efforts have been made to determine rates of carcass persistence on beaches in different locations where oil spills have occurred, and lately some of these studies have included assessments of both deposition and detection rates (Van Pelt & Piatt 1995, Fowler & Flint 1997, Flint *et al*. 1999, Wiese 2002). However, even when the total number of beached carcasses is known or can be well estimated, a large fraction of the total mortality remains unmeasured due to dead birds being lost at sea (Ford *et al*. 1987).

Methods used to estimate the number of birds lost at sea are carcass drift and drift block experiments. Wiese and Jones (2001) pointed out that experiments using carcasses previously washed up on shore significantly overestimated loss at sea, because buoyancy of these birds will have already decreased significantly. On the other hand, results from drift block experiments have generally been

underestimates of loss at sea, because blocks did not accurately mimic seabird drift (Wiese & Jones 2001) and did not take into account sinking rates of carcasses floating at sea. Thus, with the exception of a study by Hlady and Burger (1993), where only blocks recovered within one month after the drop were included, most studies have used all recoveries in their subsequent mortality models, even if these occurred months after blocks were deployed. To include all block recoveries without a cut-off period can greatly influence final estimates. It is thus imperative to accurately determine sinking rates of bird carcasses at sea, and to investigate whether these may differ between oiled and clean birds. Such differences could lead to subsequent biases in the proportion of birds found that are oiled, and hence in the total seabird mortality estimated due to the spilled oil.

Murres (*Uria* spp.) are the most vulnerable species to spilled oil in the Northern Hemisphere and are generally the most common victim after large and chronic oil spills (Camphuysen & Heubeck 2001, Wiese & Ryan 2003). The purpose of this study was to test sinking rates of dead murres under experimental conditions, and to quantify possible differences in sinking rates due to different degrees of oiling. To investigate whether backwash into the sea and subsequent sinking could be a mechanism of bird removal from beaches, I also determined sinking rates for beached carcasses with

different degrees of oiling. The importance and timing of scavenging on all sinking rates was investigated. Accurate cut-off times after which recoveries from drift block experiments should no longer be considered when estimating total seabird mortality due to oil were determined, and their influence on past mortality estimates investigated.

METHODS

Experimental design

Murres were collected from hunters during the 1999/2000 hunting season or were birds confiscated by Environment Canada enforcement officers. To ensure the integrity of carcasses, murres were frozen immediately after collection, and only those with minimal damage to the plumage were used. Fifty-four carcasses were suitable for use in this experiment.

Birds were randomly assigned to clean, lightly oiled or heavily oiled categories (18 birds per category). Because all birds available for this study were clean, birds were manually oiled on the ventral side using weathered Bunker C, a type of oil commonly found on stranded seabirds in the North Atlantic (Art Cook, senior environmental chemist, Moncton, NB, Canada, pers. comm.). Birds were oiled when fully thawed. They were allowed to dry and oxidize for 2 days under ambient conditions prior to the start of the experiment to reduce excessive contamination of the water with oil. Birds in the lightly oiled category were covered with oil on approximately 25% of their bodies, while birds assigned to the heavily oiled category were covered with oil on roughly 50% of their bodies. Within each category, three further groups of 6 carcasses each were randomly assigned: intact, scavenged, and land. Each group was subject to a different treatment throughout the experiment (see below).

The study was conducted between 10 November and 3 December 2000. A floating three-chambered wooden-framed pen (3 x 1.5 x 1.5 m) was constructed and attached to a wharf in a partially-sheltered bay in Long Pond, Conception Bay, Newfoundland, Canada. The pen was lined with chicken wire to keep potential scavengers away, and to contain carcasses in the cage once they had sunk. To collect oil which might have come off the birds plumage, all inside walls, including walls separating the chambers, were lined with oil adsorbent material provided by the Canadian Coast Guard Oil Response Team in St. John's, Newfoundland. Twelve birds of each oiling category (6 for the intact, and 6 for the scavenged treatment) were placed in the different chambers. The remaining six birds per oiling category (land treatment) were placed in a mesh-screened pen on the wharf.

After nine days, carcasses from the floating pen assigned to the scavenged treatment that were still afloat, and all 18 birds on land, were opened to simulate partial scavenging (i.e. body cavity cut open and pulmonary air sacs punctured). After 19 days, all flesh and muscles were removed from remaining birds to simulate complete scavenging.

To simulate the effects of waves during testing, carcasses were manually agitated each day in the water to allow the escape of large air bubbles trapped in the plumage. Changes in the buoyancy of carcasses were determined daily by measuring the amount of added mass (in 5 g increments) necessary to sink them (Burger 1991, cited in Burger and Fry 1993). For this purpose, birds were removed from

the water or land cage, weights were attached to the center of the body and then submerged. Carcasses from the floating pen were agitated in the water for one minute prior to measuring to allow air that may have entered the plumage during this process, to escape. After 25 days the experiment was terminated because all floating birds had sunk, and all remaining beach birds had frozen solid.

Fig. 1. Change in buoyancy of clean, lightly oiled and heavily oiled carcasses floating in seawater. Each line represents a single carcass. Dotted lines (solid diamonds) indicate carcasses subject to partial simulated scavenging at day 9, solid lines (open triangles) indicate carcasses left intact or which sank before the simulated scavenging on day 9.
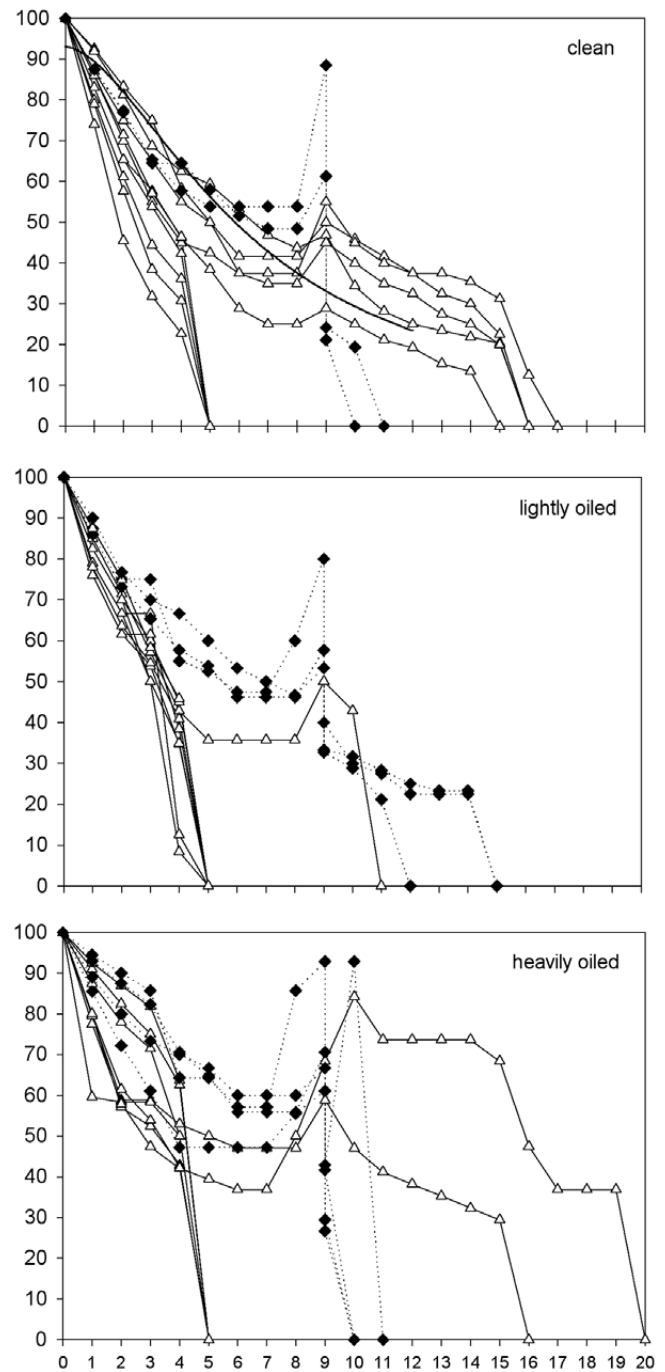
Data analysis

Days afloat

Differences in the number of days carcasses remained afloat among carcasses subjected to different degrees of oiling, simulated scavenging, and interactions between the two, were analyzed using ANOVA/ANCOVA designs. Chi-square values are presented instead of the usual F as a General Linear Model framework was used for all analysis.

Sinking rates

Sinking rates were observed, and buoyancy was calculated daily for each carcass. Curve-fitting test were performed to best describe changes in sinking rates over time. Means are presented ± 1 SE, and all tests are 2-tailed. Differences among groups and categories were considered significant where P < 0.05.

RESULTS

Birds floating

Birds varied in buoyancy at the beginning of the experiment, but there was no relationship between the initial body mass and initial buoyancy (slope = -0.106 ± 0.076, P > 0.1). Birds in the floating pen quickly lost buoyancy during the first few days (Fig. 1). Nine of the 18 carcasses assigned for scavenging sank prior to day 9. For analysis purposes, this increased the number of unscavenged carcasses from 6 to 10, 9, and 8 in the clean, lightly oiled and heavily oiled category, respectively, and reduced the sample sizes for scavenged carcasses accordingly.

Days afloat

All oiling categories lost buoyancy quickly during the first five days: 70% sank within 5 d, and all sank within 20 d (Fig. 2). Fourteen carcasses that had sunk previously (all at day 5) resurfaced between days 7 and 9, but quickly lost their buoyancy again, especially if scavenged at day 9. The first time of sinking for all re-surfaced birds was taken as the actual sinking day because under natural conditions, carcasses would sink to a depth from
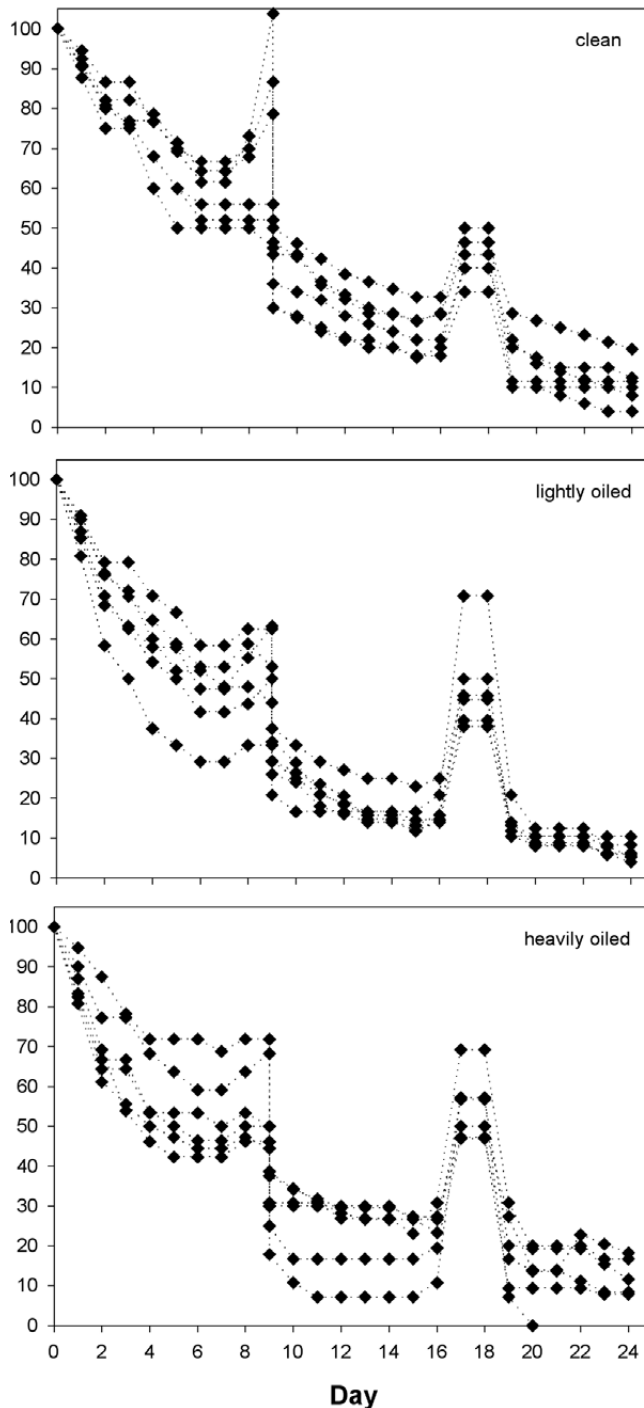
Fig. 2. Mean daily buoyancy loss (with 95 % C.I.) of unscavenged (solid diamonds) and scavenged (open circles) murre carcasses afloat in an experimental seawater pen in southeastern Newfoundland, winter 2000. Regression lines for unscavenged (r^2=0.97, F_2=315.75, P<0.0001) and scavenged carcasses (r^2=0.98, F_1=225.31, P<0.0001), and their 95 % C.I., are shown.
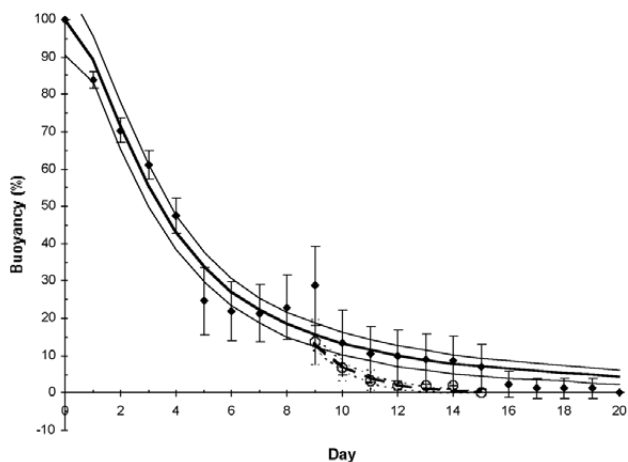
which re-floating would not occur (see discussion). Between days 7 and 9, all 17 carcasses still afloat experienced an average buoyancy gain of 34.2 ± 5.8%, relative to the buoyancy at day 7.

The number of days that unscavenged carcasses remained afloat was not significantly different among carcasses with different degrees of oiling (χ^2 = 4.58, P > 0.1), and averaged 8.2 ± 1.0 days

Fig. 3. Change in buoyancy of clean, lightly oiled and heavily oiled carcasses kept on land. Each line represents a single carcass. All carcasses were subjected to partial simulated scavenging at day 9 and complete simulated scavenging at day 19 (see Methods for details).

(95% C.I. 6.2 – 10.3). After day 9, birds subjected to partial simulated scavenging (n = 9) sank almost 2.5 times faster than unscavenged birds (n = 8; χ^2 = 11.99, P < 0.001), averaging 2.6 ± 0.7 and 6.9 ± 0.9 days, respectively.

Loss of buoyancy
Mean daily buoyancy losses of unscavenged birds did not differ significantly between birds with different degrees of oiling (χ^2 = 1.45, P > 0.1), and was best described by a logistic time-dependent function (Fig. 2). The nine birds subjected to partial simulated scavenging at day 9 immediately lost an average of 37.8 ± 5.1 % of their buoyancy. Four carcasses sank in less than a day after scavenging, and there were no differences in this immediate buoyancy loss among degrees of oiling (n = 9; χ^2 = 4.13, P > 0.1). After day 9, scavenged carcasses sank significantly faster than unscavenged ones (χ^2 = 22.65, P < 0.0001), and most closely followed an exponential decline in buoyancy (Fig. 2).

Birds on land
Days afloat
Only 1 of the 18 carcasses on land sank within the duration of the study, and then only after it was completely scavenged at day 19 (Fig. 3). By day 25, the others still retained an average of 9.9 ± 1.0% of their initial buoyancy but were all completely frozen due to sub-zero temperatures between days 14 and 25.

Loss of buoyancy
There were no significant differences detected in daily buoyancy losses among birds with different degrees of oiling (χ^2 = 2.25, P > 0.1) and average buoyancy losses were best described by a logistic time-dependent function (Fig. 4). Compared to carcasses in the water, carcasses on land lost their buoyancy slowly during the initial days and 61% (11 of 18) of birds experienced an average buoyancy gain of 21.1 ± 5.5 % between day 7 and 9 and all gained an average of 140.7 ± 22.1% between days 16 and 17 due to freezing. Carcasses lost an average of 43.2 ± 1.7% of their buoyancy due to scavenging at day 9 and another 66.0 ± 3.3% at

Fig. 4. Mean daily buoyancy loss (with 95 % C.I.) of murre carcasses on land in southeastern Newfoundland, winter 2000. Partial and complete scavenging took place at day 9 and 19, respectively (see Methods for details). Regression lines (r^2=0.84, F_2=63.99, P<0.0001) and its 95 % C.I. is shown.
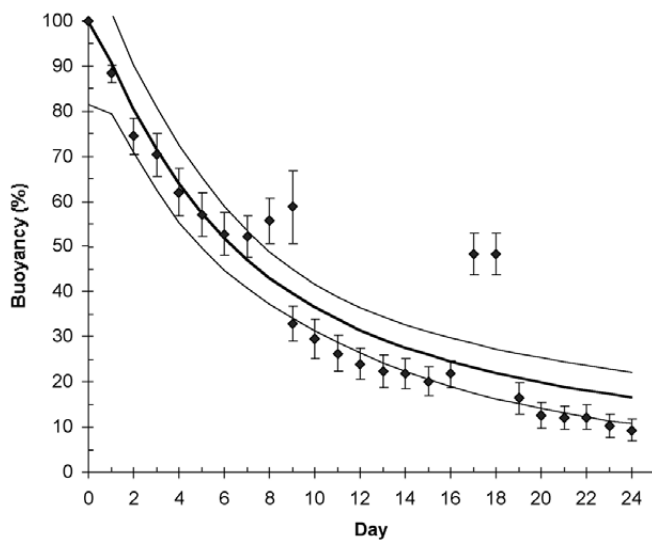
day 19. After 24 days, carcasses on land were removed because they were all frozen and had shown little change in buoyancy during the five days prior (Fig. 3).

DISCUSSION

The results provide good evidence that there is no difference between oiled and unoiled murre carcasses in the number of days that they remain afloat: the majority of floating unscavenged murre carcasses sank within 6 – 11 d. The effects of oil on buoyancy seem twofold. On one hand, large amounts of oil on the plumage increases the overall density of the bird, largely due to emulsification of the oil with seawater to form a dense mousse (National Research Council 1985). On the other hand, oil may trap the air in the plumage and partially slow down water-saturation. Overall, the two processes appear to offset each other, indicating that the proportion of birds found that are oiled on beached bird surveys may reflect the actual proportion of birds oiled at sea.

Intact carcasses lost buoyancy rapidly during the first five days when large amounts of air trapped in the plumage were replaced by water. This initial loss may have been somewhat accelerated as compared to previously unfrozen, free-floating carcasses (Ford *et al*. 1996) because air in the plumage is dislodged as carcasses continuously bump against the sides of the cage. As bodies decompose, gases may get trapped inside the body cavity and slow down buoyancy loss or even increase buoyancy (Burger 1991). This was seen in this study between days 5 and 9. Because floating birds were placed in a cage with a bottom that prevented carcasses from sinking more than 1 m below the surface, buoyancy gained by decomposition was enough to re-surface some of the carcasses that had sunk previously. Under natural conditions, resurfacing is unlikely, as sinking bodies are subjected to large increases in relative atmospheric pressure in the first 10 m, compressing any trapped gases and increasing the degree of negative buoyancy. Also, carcasses would most likely be scavenged by fish and invertebrates once at or near the bottom, which would allow internal gases to escape, and prevent sunk birds from re-surfacing.

If birds are scavenged at sea, the number of days carcasses remain afloat under natural conditions may be substantially shorter than the 6 – 11 d estimate derived from these experiments. Although scavenging of carcasses at sea has not been quantitatively documented, it is often observed by duck and murre hunters in Newfoundland, especially close to shore. In most instances, gulls pick at these carcasses until they open their body cavity, at which point internal gases can escape, bodies get water-logged, get too heavy for gulls or other aerial scavengers to keep afloat, and sink.

The importance of assessing the number of seabirds lost at sea due to sinking was first recognized by Hope Jones *et al*. (1970) while trying to estimate total seabird kill after the *Hamilton Trader* oil spill in 1969. It was determined that at least 50 % of drifting murres sank within two weeks. Based on these results, Ford *et al*. (1987), applied a constant loss-rate for murres drifting at sea due to sinking of 15% per day. This same per day loss rate was also used by Page *et al*. (1990) to assess the number of seabirds killed after the *Apex Houston* spill in 1986 off the California coast. Both studies pointed out that this rate might not be constant, and that loss at sea may vary among species, with more neutrally buoyant birds such as loons, alcids and cormorants sinking more quickly than birds such

as gulls that float higher in the water (Ford *et al*. 1987, Burger & Fry 1993). Ford *et al*. (1996) compared sinking rates of free-floating radio-tagged carcasses in Alaska and found no differences between large and small alcids (murres and auklets, respectively). The latter finding is consistent with my observations that body mass does not influence the number of days murre carcasses remained afloat, although I did not investigate differences among species in this study. Hence, my results should be applicable to seabird mortality both from large spills, where carcasses are often heavy and in good body condition, and from chronic spills, where carcasses are mostly emaciated because they generally live for a period of time after contacting the oil and deplete their fat reserves before dying (Wiese & Ryan 2003).

Comparison with previous flotation experiments

Estimates of accurate sinking rates for seabirds at sea are sparse. Ford *et al*. (1991) found that tethered murres in sheltered and exposed seas in Oregon remained afloat for an average of 8.4 and 7.6 days respectively (about 13% lost per day), with more than 90 % disappearing within 14 days. Burger (1991) tested heavily oiled Common Murres (*Uria aalge*), Ancient Murrelets (*Synthliboramphus antiquus*) and Horned Grebes (*Podiceps auritus*) in a tank simulating benign sea conditions. He found that the former two species were similar and measured sinking rates of 2% per day, while the latter sank more quickly at 9% per day. He concluded that a loss exceeding 5 or 10 % of oiled carcasses at sea per day (i.e. all birds lost after 10-20 d) is probable under normal at-sea conditions. Experiments during spring with free-floating radio-tagged murres and auklets in Prince William Sound, Alaska showed median days afloat of 15-20 d, but included many birds that washed up and remained on the beach for up to 5 d before re-floating (Ford *et al*. 1996). The present study, however, shows that birds on the beach retain their buoyancy significantly longer than when they are afloat, biasing that study towards longer floating rates. An identical experiment during summer in the Gulf of Alaska, where no birds beached, showed median days afloat of 7, 9, 11 and 18 days respectively (Ford *et al*. 1996). The latter higher value was attributed to much calmer sea conditions.

The number of days that carcasses remained afloat in the present study are thus comparable to the findings of Ford *et al*. (1991) and to the Gulf of Alaska study (Ford *et al*. 1996). However, the authors point out that tethered birds and previously frozen birds may sink faster than fresh carcasses and although this may have been the reason why the initial loss in our experiment was greater (70 % of birds sank within 5 days), overall daily sinking rates in this study were comparable, at 9 – 16 % (6 – 11 days). Overall sinking rates may be non-linear (Ford *et al*. 1987, Page *et al*. 1990) and Ford *et al*. (1996) fitted a Weibull distribution to their data. Declines in buoyancy observed in the current study were certainly steeper during the first 5 days and if scavenged during this period, sinking rates may approach linearity. However, I found that the overall pattern of seabird carcasses loss-at-sea is best described by a logistic time-dependent model that takes into account some degree of buoyancy gain due to the formation of decomposing gases, as well as carcasses that may float substantially longer than the average.

The average number of days unscavenged carcass remained afloat was 8.2 d, and although the error around this estimate predicts that 95 % should sink with 10-11 d, the sinking rate model predicts the same loss at 15 d. This skew in the later is mostly due to one out of 27 unscavenged carcasses (almost 5 % of the sample size) that remained afloat for 20 d, and perhaps less representative than the former estimate. Based on this and the extensive free-floating studies conducted by Ford *et al*. (1996), I therefore recommend using a 10-14 d estimate for murres and other auks floating at sea, and to use a time dependent logistic function in a model to estimate proportion of birds lost at sea. Such rates will result in conservative estimates of overall mortality because the majority of carcasses likely sink during the first week, and more so if some or all get scavenged at sea.

Application to past drift block experiments

Based on the current and published results it seems reasonable that studies using drift blocks to assess the numbers of birds lost at sea should only include blocks that come ashore within 10-14 d after they are dropped. Wiese and Jones (2001) summarized results of past drift block experiments and examined possible biases of recovery estimates due to faulty drift block design. I conclude that recovery estimates from most past drift block experiments are generally large overestimates, because they included blocks that were recovered far after seabird carcasses would have sunk. The degree to which these estimates are biased varies, and little information is generally provided about chronology of block arrival on shore to allow for a re-interpretation in light of the present findings.

Threlfall and Piatt (1982) concluded that roughly 24 % (0-66 %) of birds that die in offshore Newfoundland waters eventually reach beaches, and acknowledged the high variance and dependency on weather. However, only 5 % of blocks set adrift reached the shore within a period of 10 – 14 d (Threlfall & Piatt 1982). Chardine and Pelly (1994) concluded that 7% of birds that died in Placentia Bay, Newfoundland during their study arrived ashore, but included blocks recovered up to almost 2 years after being dropped. Very few arrived during the first 2 weeks (J. W. Chardine pers. comm.). Flint and Fowler (1998) concluded that up to 61 % of birds could be recovered after an oil spill close to St. Paul Island, Alaska during onshore winds. However, systematic surveys to find blocks did not start until 11 d after they were dropped at sea, likely making this estimate high. Finally, Burger (1991) illustrated the need to integrate accurate sinking into oil spill mortality models, and calculated a 23% higher mortality estimate from the *Nestucca* spill (equal to 6860 birds) after he accounted for birds lost at sea due to sinking.

Birds on land

As expected, carcasses resting on land lost their buoyancy more slowly than those in the water and only one bird sank during the 24 d of the experiment. Scavenging, which under natural conditions in Newfoundland usually occurs almost immediately after carcasses are cast ashore (Wiese 2002), sharply decreased buoyancy, although not to the point where sinking took place. In addition, the buoyancy of carcasses that freeze after being washed ashore may be markedly increased for long periods of time, especially during winter in Newfoundland. Because even carcasses scavenged on land are likely to retain some buoyancy in the absence of dense muscle mass, it appears that subsequent sinking after backwash into the sea is not likely to remove many carcasses from beaches. However, backwash and subsequent burial in the beach substrate is likely, because birds of the beach can retain positive buoyancy for long periods of time.

CONCLUSIONS

Unless large numbers of fresh, intact carcasses that have not been subject to prior periods of floating at sea are available, drift block experiments, if interpreted correctly, are the most accurate and efficient way to determine the proportion of those birds that die at sea which reach the shore (Wiese & Jones 2001). Based on the present results, in areas where murres, or similarly-sized alcids are the main victims of oil spilled at sea, I recommend that only those drift blocks that reach the shore within 10-14 d after they are dropped at sea be included in models estimating seabird mortality due to spilled oil. Recognizing that most birds may sink within the first week, this is a conservative approach.

This study points to the importance of determining scavenging rates of birds floating at sea, as they strongly influence sinking rates. In areas where other species are commonly killed by marine oil pollution, it would be useful to determine their sinking rates using the approach presented here, although evidence exists that it may not vary between large and small alcids (Ford *et al*. 1996).

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