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Effects of leg flags on nest survival of four species of Arctic-breeding shorebirds

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ABSTRACT. Marking wild birds is an integral part of many field studies. However, if marks affect the vital rates or behavior of the marked individuals, conclusions of a study might be biased relative to the general population. Leg bands rarely have effects on birds and are frequently used to mark individuals. Leg flags, which are larger, heavier, and might produce more drag, are commonly used on shorebirds and can help improve resighting rates. To date, there have been no quantitative assessments of effects of flags on demographic performance of individual shorebirds. At seven Arctic sites, we marked individuals and monitored nest survival of four species of Arctic-breeding shorebirds: Semipalmated Sandpipers (*Calidris pusilla)*, Western Sandpipers (*C. mauri*), Red-necked Phalaropes (*Phalaropus lobatus*), and Red Phalaropes (*P. fulicarius*). We used a daily nest survival model in a Bayesian framework to test for effects of leg flags, relative to bands only, on daily survival rates of 1952 nests. We found no evidence for a difference in nest survival between the group with flags and the group with only bands. Compared to leg bands, leg flags therefore likely have little effect on nest success of Arctic-breeding sandpipers and phalaropes. However, further studies are needed to evaluate effects of flags on shorebirds that use other habitats and on survival rates of adults or chicks.

Key words: bands, markers, reproductive success, tags, waders

Individually marking birds can provide information about migratory connectivity, dispersal, survival rates, and reproductive success (Andres 2008). However, markers can affect birds, potentially producing results that are unrepresentative of the larger population (Calvo and Furness 1992). Even small markers such as metal or plastic bands can result in injury to legs and toes (Calvo and Furness 1992, Fair et al. 2010). Such injuries appear to be rare and may result from bands that were improperly applied or sized. However, detecting detrimental effects of bands is difficult, especially if the survival of affected individuals is compromised, which could explain the low frequency of reported effects (e.g., ~5% of studies reviewed by Calvo and Furness 1992).

In addition to injuries, effects of marking on demographic rates have been observed (Calvo and Furness 1992, Fair et al. 2010). Marking has sometimes been associated with abandonment of nests or broods, but whether such abandonment is due to the stress of capture and handling rather than marking per se is often unclear (Calvo and Furness 1992). Other documented effects on reproduction include mate selection for or against marked individuals (Burley et al. 1982, Brodsky 1988), removal of banded chicks from nests by parents (Lovell 1945), and reduction in rates of nestling survival when chicks or parents wear particular colors of bands (Hagan and Reed 1988).

Markers larger than leg bands might be more likely to affect birds. Larger markers such as geolocators or radio tags can be heavier and increase drag in air or water, thereby increasing energetic costs, and can reduce survival rates, return rates of migratory species, or reproductive success (Barron et al. 2010, Pennycuick et al. 2012, Costantini and Møller 2013, Chivers et al. 2015, Weiser et al. 2016, Bodey et al. 2017). In recent decades, leg flags made of hard plastic have been widely used on migratory shorebirds (Clark 1979, Clark et al. 2005). Flags are UVresistant plastic strips shaped to wrap around legs like color bands, but with a tab that extends from the leg, increasing its conspicuousness and thus the chances that an individual will be resighted and reported (Clark 1979). Double-marking individuals with both flags and a unique combination of color bands can help ensure correct identification of individual birds by observers (Roche et al. 2014). Resighting accuracy may be higher for flags than color bands in some conditions, but not all (Burns et al. 2010, Roche et al. 2014). However, flags are larger and heavier than bands, and thus could be more likely than bands to affect the birds through energetic costs, drag, or physical effects such as damage to eggs.

Despite their widespread use in studies of shorebirds and previous evidence that markers can negatively affect birds, no one to date has examined the possible effects of plastic leg flags on birds. If leg flags affect the behavior or survival of breeding shorebirds or if flags damage eggs, nest survival rates might be lower for shorebirds with leg flags. We examined the possible effects of leg flags on daily nest survival rates of four species of Arctic-breeding shorebirds by comparing nests of adults with both leg flags and bands to nests of adults with only leg bands.

METHODS

Data collection. We marked shorebirds and monitored nests at seven sites in Arctic Alaska and western Canada. From 2010 to 2014, we followed a common set of field protocols and data formats developed for the Arctic Shorebird Demographics Network (ASDN; Brown et al. 2014, Weiser et al. 2017, 2018) at all sites, as described briefly below. Data were collected using similar methods from 1993 to 1999 at Nome, Alaska (Sandercock et al. 1999), and from 2003 to 2009 at Utqiaġvik (formerly Barrow), Alaska (Saalfeld and Lanctot 2015). Personnel with the ASDN monitored >30 species of shorebirds across 16 field sites, but, for the present

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analysis, we used a subset of four species and seven study sites (Table 1) with sufficient data for individuals both with and without leg flags. Our four focal species have incubation periods of 19-20 days, and range in body mass from 26 g (Semipalmated Sandpiper) to 49 g (Red Phalarope; Weiser et al. 2017), Semipalmated and Western sandpipers are socially monogamous with biparental incubation of clutches (incubation shared equally between sexes; Bulla et al. 2016), whereas Red-necked and Red phalaropes are polyandrous with incubation by males (Rodewald 2015). We excluded female phalaropes from consideration in our study because they were rarely banded and do not incubate eggs.

We located shorebird nests by observing distraction displays or by walking or rope-dragging to flush incubating birds from nests. We estimated the age of each clutch at discovery based on the number of eggs if the clutch was incomplete, or by floating the eggs in water (Sandercock 1998, Liebezeit et al. 2007). We used the estimated clutch age and published estimates of the duration of incubation periods to predict expected hatch dates for nest-monitoring purposes. We visited nests every 3–5 d during incubation, every second day starting four days before the expected hatch date, and daily when signs of hatching, such as pipping or star-cracking, were found.

We recorded a nest as hatched if at least one newly hatched chick was observed in the nest, or if eggshell fragments indicative of hatching were found in the nest within four days of the expected hatch date (Mabee 1997, Brown et al. 2014). We classified nests as failed if all eggs disappeared more than four days before the predicted hatch date or if there was other evidence of failure, such as signs of predation or abandonment (Mabee 1997, Brown et al. 2014). We recorded nest fate as unknown if we found unclear or conflicting evidence of the fate, such as when all eggs disappeared within four days of hatching with no clear evidence of either hatching or predation. Shorebird chicks leave their nests within a day of hatching, so we did not track chick survival.

For a concurrent study of adult survival, we captured unbanded adults on nests during incubation, usually with a bownet or a walk-in trap, or occasionally with a mist net near the nest (Brown et al. 2014, Weiser et al. 2018). We occasionally captured previously banded adults to confirm their identity or collect blood or feather samples. The probability of capture varied between marker types as marking regimes shifted over time (e.g. banded birds were targeted for recapture when the use of flags was initiated), and daily survival rates (DSR) were significantly higher for nests where an adult was captured, because the nest must survive long enough for a capture attempt (ASDN, unpubl. data). We therefore included only nests where at least one adult had been captured to minimize differences between the marker groups. Estimates of DSR from the subset of nests included in our study were thus expected to be slightly higher than estimates for the entire population (Weiser et al. 2017).

We marked each captured adult with a numbered metal band and a unique combination of leg bands (Sandercock et al. 2000, Weiser et al. 2018). All individuals received a metal band, most received color bands (usually 3–4; 13 nests had parents with metal bands only; Fig. 1a), and 65% received a leg flag, with or without an alphanumeric code, in addition to color bands (Table 1, Fig. 1b). Marking regimes were determined by species, study site, and year (Table S1), and was not related to any characteristics of the individuals captured. Flags were more often used on Semipalmated and Western sandpipers in later years than in earlier years of our study because ASDN protocols recommended use of flags on those species from 2010 to 2014 (Brown et al. 2014). In contrast, use of flags on phalaropes became less common over time, following ASDN recommendations to avoid use of flags on phalaropes in response to concerns about the potential for icing of the legs (Brown et al. 2014).

In the initial years of the study, flags were shaped from flat pieces of Darvic obtained from Haggie Engraving (Millington, Maryland, USA). In later years, we used pre-shaped plain or engraved flags from Interrex-Rings (Lodz, Poland). In some cases, we sanded rough edges of the flags before application. We did not file down the corners of the flags, but corners of the Interrex-Rings flags were already rounded. When applied, we sealed the flat tabs of each flag together with a soldering iron or adhesives such as plastic or PVC solvent or cyanoacrylate glue. After application, the tab of flags (not including the ring around the leg) measured 9–12 mm x 5–6 mm x 1–1.25 mm (size 1A and 1B bands as per the U.S. Geological Survey). We excluded a subset of nests where adults were fit with tracking devices (radio-transmitters or geolocators) because they can negatively affect demographic rates of some small shorebirds (Weiser et al. 2016).

For some nests, one parent was not observed, so its marker status was unknown. We considered a nest to be associated with a leg flag if at least one parent with a flag was observed or captured at the nest. If only adult(s) with color bands or metal bands, but no flags, were observed at the nest, we included the nest in the bands-only category. If only unbanded birds were observed, nests were excluded from our study, because we could not be sure that both parents were unbanded for sandpiper nests (being unable to distinguish one unbanded bird from another). Also, by including only nests where at least one adult was captured as described above, we had already eliminated almost all nests with only unbanded parents from the analysis, as adults were released without bands only in rare circumstances (escaped or injured adult). A nest was placed in the corresponding category for the entire incubation period, regardless of when during incubation the flag was applied (mean nest age at capture = 6 d; SD = 4 d; range spanned the full incubation period).

***Data analysis*.** We conducted an analysis of DSR of nests in a Bayesian framework, which allowed for the inclusion of patchy data and helped to address the fact that marker types were sometimes segregated by study site and year (Table S1; Brown and Collopy 2012, Halstead et al. 2012). Unknown nest fates were treated as missing data for the days following the last confirmed record that a nest was active.

We first tested three model structures to evaluate an appropriate modeling framework. The first structure involved species-specific models, each run separately, with nests divided into three groups: no flags on parents (only birds with bands were observed at the nest), one parent observed with a flag, and two parents observed with flags. The last group did not apply to phalaropes, where only males incubate eggs. In sandpipers, both parents were not always observed, so the number of flagged parents attending a nest could have been underestimated. Second, after finding no evidence of a difference between one flagged parent versus two flagged parents (Fig. 2a), we modeled a single effect of presence versus absence of flagged parent(s) to improve precision around the estimated effect (Fig. 2b). Third, we modeled all species together in a single model while allowing the flag effect (presence versus absence) to vary by species, by applying a random effect of species to the slope, under the assumption that the flag effects for all species were drawn from the same distribution. Modeling all species together improved precision (Fig. 2c) and did not change conclusions relative to the species-specific model. All subsequent analyses and results, therefore, use the single model with species-specific effect sizes estimated for the presence versus absence of flagged parent(s).

To ensure that methodology (e.g. changes in marker type) did not confound the test for an effect of flags on nests, we also analyzed several subsets of the dataset. First, as most of our band-only sandpiper nests were from one site (Nome; Table 1), we modeled the effect of presence vs. absence of a flag at Nome only. At that site, marker type was strongly confounded with year (only two flags in the 1990s, and no band-only nests in later years), but there was no change in the population mean daily nest survival rate between the two periods (Kwon et al. 2018). Second, for the species with the best mix of markers within a subset of sites and years (Red-necked Phalarope in 2012-2014 at Utqiaġvik, Cape Krusenstern, Canning River, and Ikpikpuk), we ran the model for that year only. Third, to evaluate whether unknown parents affected our results for sandpipers, we ran the model on the subset of nests at which the marker type of both parents was known. We used these additional results to support the conclusions derived from the main model that included all species, sites, and years. In each model, we included a linear effect of day-of-season that we allowed to vary among species because DSR declined over the season for some of our study species (Weiser et al. 2017). Day-of-season was centered to the mean for each site, year, and species to account for differences in timing of breeding. We applied a random effect of site and a site-specific random effect of year to the intercept to account for spatial and temporal heterogeneity. In the model that included all species, we included a random effect of species on the intercept, although we expected differences in DSR across species to be minor (Weiser et al. 2017). We used uninformative priors on the log scale for all parameters, drawing from uniform distributions for the intercept (range = -5 to 5) and standard deviations (range = 0 to 7), and a normal distribution with a mean of zero and the corresponding estimated standard deviation for the effects of flag, day-of-season, site, and year.

We implemented the models in JAGS v. 4.0 (Plummer 2003) via the package “runjags” (Denwood 2016) in R v. 3.3.1 (R Core Team 2017). We discarded estimates from adaptation and burn-in periods (1000 and 3000 iterations, respectively) to produce good mixing across three chains. We then ran the model for a further 6000 iterations and saved the output from every third iteration to reduce autocorrelation, resulting in 2000 saved iterations used to generate posterior distributions for the estimated parameters. We checked that convergence was achieved as indicated by Gelman-Rubin statistics of <1.10 for all parameters (Brooks and Gelman 2012). To determine whether flags affected DSR, we evaluated 95% Bayesian credible intervals (BCIs) of the species-specific flag effect from our final model that shared information across species. To demonstrate the biological significance (or lack thereof) of the flag effects, we also generated species-specific estimates of DSR and of nest success (mean DSR raised to the power of the average number of days of incubation) from the final model. Our R scripts (https://doi.org/10.5066/P9K9CANL) and source dataset (Brown et al. 2014) are publicly available online.

RESULTS

We monitored 205–780 nests for each of four species of Arctic-breeding shorebirds, with 36–82% having at least one adult with a leg flag (Tables 1 and S1). Of the biparentally incubated sandpiper nests with flags, 66% were attended by two parents with flags, 33% were attended by only one parent confirmed to have a flag and the other parent was either not observed or not banded, and 1% of nests were attended by one parent with a flag and one with only bands. Of the biparentally incubated nests where neither parent had a flag, both parents were banded at 86% of nests and, at the other 14%, one parent was confirmed as banded and the other parent was either not observed or not banded. Only one parent (male) attended each phalarope nest, so that parent determined the group identity of the nest.

The proportion of nests where eggs hatched ranged from 67% (Red-necked Phalaropes) to 84% (Red Phalaropes) across the four species, whereas 9 to 23% of nests failed and 7 to 10% had unknown fates. The 95% BCI of the estimated flag effect overlapped zero for all species regardless of model structure (Fig. 2), indicating no evidence for effects of leg flags on DSR. Accordingly, expected DSR and the proportion of nests expected to hatch did not differ between nests with or without flagged adults (Fig. 3). Variation among years and species was higher than variation among sites (Table S2). Marker type was confounded with year at some of our study sites, but annual estimates of DSR did not vary with marker type (Fig. 4). Similarly, in our tests of subsets of data for one site (Semipalmated Sandpiper: 0.20, -1.61–1.75; Western Sandpiper: 0.33, -0.91–1.83), a subset with a mix of markers within sites and years (Red-necked Phalarope: 0.53, -1.60–2.73), or only nests with two known parents (Semipalmated Sandpiper: 0.81, -0.16–0.80; Western Sandpiper: -0.14, -1.08–0.79), we also found no effect of the presence of a leg flag on DSR (values show mean, 95% BCI of the estimated flag effect in each case). These additional tests supported our main model with evidence that flags did not affect DSR regardless of the post-hoc study design.

DISCUSSION

In comparison with nests where parents carried only leg bands, we found no evidence of harmful effects of leg flags on nest survival for four species of Arctic-breeding shorebirds. In addition, nest survival did not covary with site or year, suggesting that the test for effects of flags was not confounded by spatial or temporal variation in nest survival. Previous studies have found a mix of effects of markers across species and study areas (Barron et al. 2010, Costantini and

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Møller 2013, Weiser et al. 2016, Bodey et al. 2017), but our multi-species, multi-site comparison provides strong evidence that leg flags of incubating adults did not damage eggs (direct effect) or alter parental behavior in ways that affected nest survival (indirect effects, e.g., increased visibility of adults increasing the likelihood of predators locating nests).

Direct effects of flags on nests could include physical damage to the eggs by the flag. We did not have sufficient data for both marker types on eggs that remained unhatched in otherwise successful nests to test for variation in egg viability, so we were unable to evaluate whether leg flags might cause physical damage to individual eggs. Future studies should carefully record the presence or absence of eggs remaining in hatched nests to fully evaluate potential effects of markers on eggs.

In addition to finding no evidence for direct effects of flags on nests, the lack of a difference in nest survival between groups suggests that flags were also not acting indirectly to harm nests. For example, if leg flags affected parental movement at the nest or to and from the nest (e.g. by changing incubation rhythms), predators might be more likely to find the nest (Smith et al. 2007, Bulla et al. 2016) and reduce nest survival rates. Alternatively, if carrying a leg flag represented an energetic burden to adult shorebirds, parents might be more likely to abandon a nest in favor of maximizing their own chances of survival (Bustnes et al. 2002, Spée et al. 2010). Parental mortality during incubation typically results in nest failure, even in our study species with biparental care of the nest (Bulla et al. 2017). Any substantial increase in adult mortality due to the presence of leg flags thus would have been evident as an effect of flags on nest survival. However, effects of flags could accumulate over time or be more pronounced outside of the breeding season, so a test for effects of flags on adult survival would still be

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worthwhile if confounding differences in detectability of tags can be controlled (Clark 1979, Burns et al. 2010, Roche et al. 2014).

Our study included both sandpipers and phalaropes, which have contrasting life-history traits and provide examples of species that are terrestrial versus aquatic and have biparental versus uniparental care of the nest. Our finding that none of these diverse species was affected by leg flags suggests that nest survival of other shorebirds might also be likely to be unaffected. Our study species were also relatively small and thus likely more susceptible than larger species to any energetic effects of carrying flags (Costantini and Møller 2013, Weiser et al. 2016). Additional study would still be useful, however, because effects of leg flags could differ for species based on body mass, foraging strategy, or breeding habitat, as has been found for other large tags (Barron et al. 2010, Costantini and Møller 2013). If flags affect parental behavior, results might also differ in areas where nest predators respond differently to parental behavior (Smith et al. 2007). Further study is also needed to assess whether chick growth or survival might be affected when flags are applied to either parents or chicks.

Although our results indicate that adding leg flags to a color-marking scheme probably does not reduce nest survival in small-bodied species of Arctic-breeding sandpipers and phalaropes, *a priori* testing for effects of any type of marker would be useful for future studies. Instead of post-hoc tests, investigators could randomly assign marker types to birds at the same sites and in the same years to maximize the statistical power to detect any effects. If markers are found to have negative effects, then eliminating or minimizing those effects would be essential to reduce any harmful effects on the birds and to ensure that the results of studies are not biased.

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Table 1. Study sites in the Arctic Shorebird Demographics Network and the number of nests monitored in each group (with or without leg flags) for four species of shorebirds.

					Number of nests monitored							
					Semipalmated Sandpiper		Western Sandpiper		Red-necked Phalarope		Red Phalarope	
Site	Code	Latitude	Longitude	Study years	Bands only	Flags	Bands only	Flags	Bands only	Flags	Bands only	Flags
Nome, AK, USA	NOME	64.443	-164.962	1993–1996, 1998–1999, 2009–2014	143	86	169	155	61	-	-	-
Cape Krusenstern, AK, USA	CAKR	67.114	-163.496	2010–2014	-	77	3	86	13	15	-	-
Utqiaġvik (Barrow), AK, USA	BARR	71.302	-156.760	2003–2014	-	216	-	63	19	19	216	213
Ikpikpuk River, AK, USA	IKPI	70.553	-154.735	2011–2014	1	71	-	-	2	16	3	20
Colville River, AK, USA	COLV	70.437	-150.676	2011–2014	-	61	-	-	9	2	13	5
Canning River, AK, USA	CARI	70.118	-145.851	2010–2014	-	115	-	-	6	21	12	9
Mackenzie Delta, NWT, Canada	MADE	69.373	-134.893	2011–2014	-	10	-	-	21	1	-	-
Total					144	636	172	304	131	74	244	247

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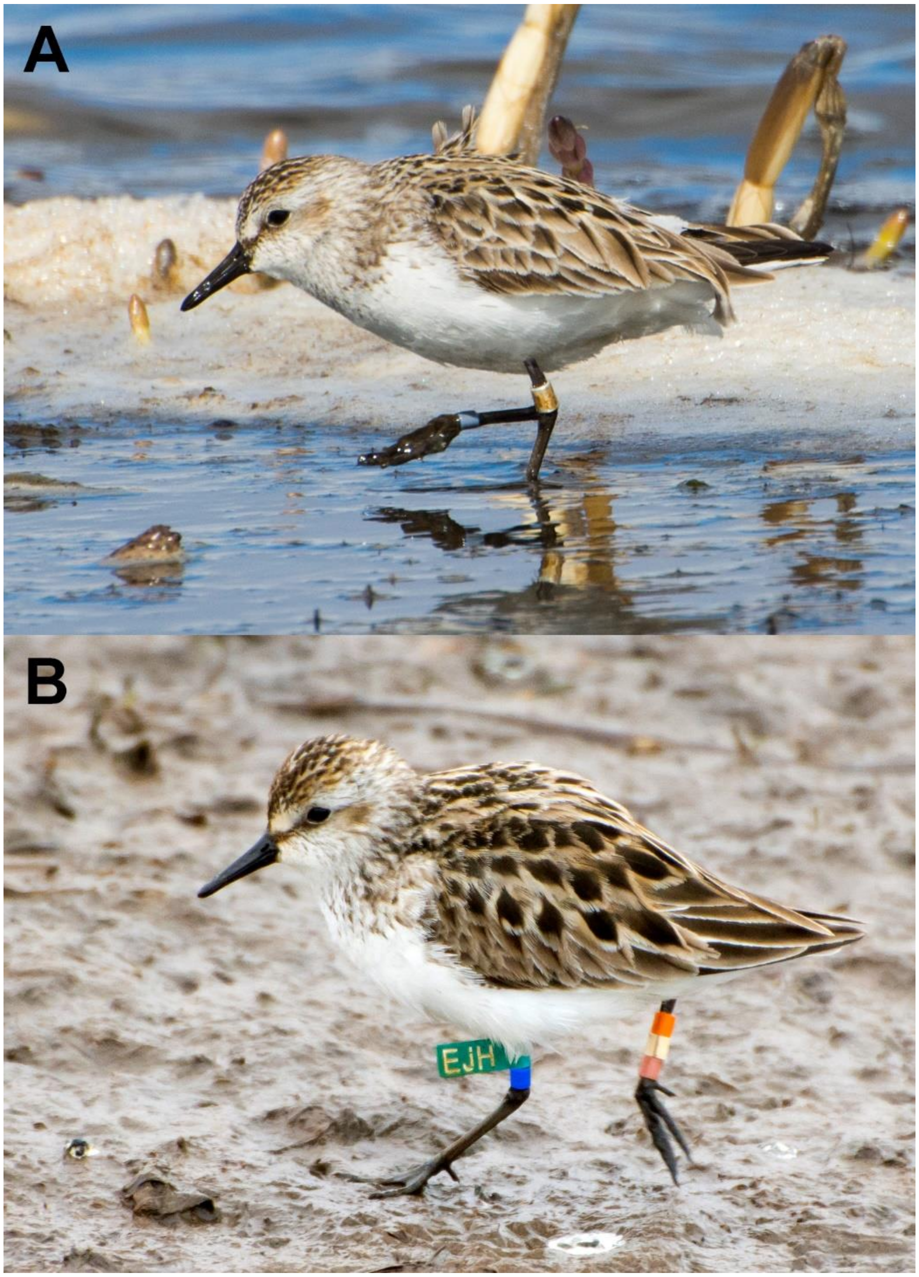

Fig. 1. Examples of the types of markers included in our study, shown here on Semipalmated Sandpipers at Nome, Alaska (photos by ELW). a) Leg bands only (no flag), or b) leg bands plus flag, here engraved with a unique alphanumeric code; some flags were not coded.

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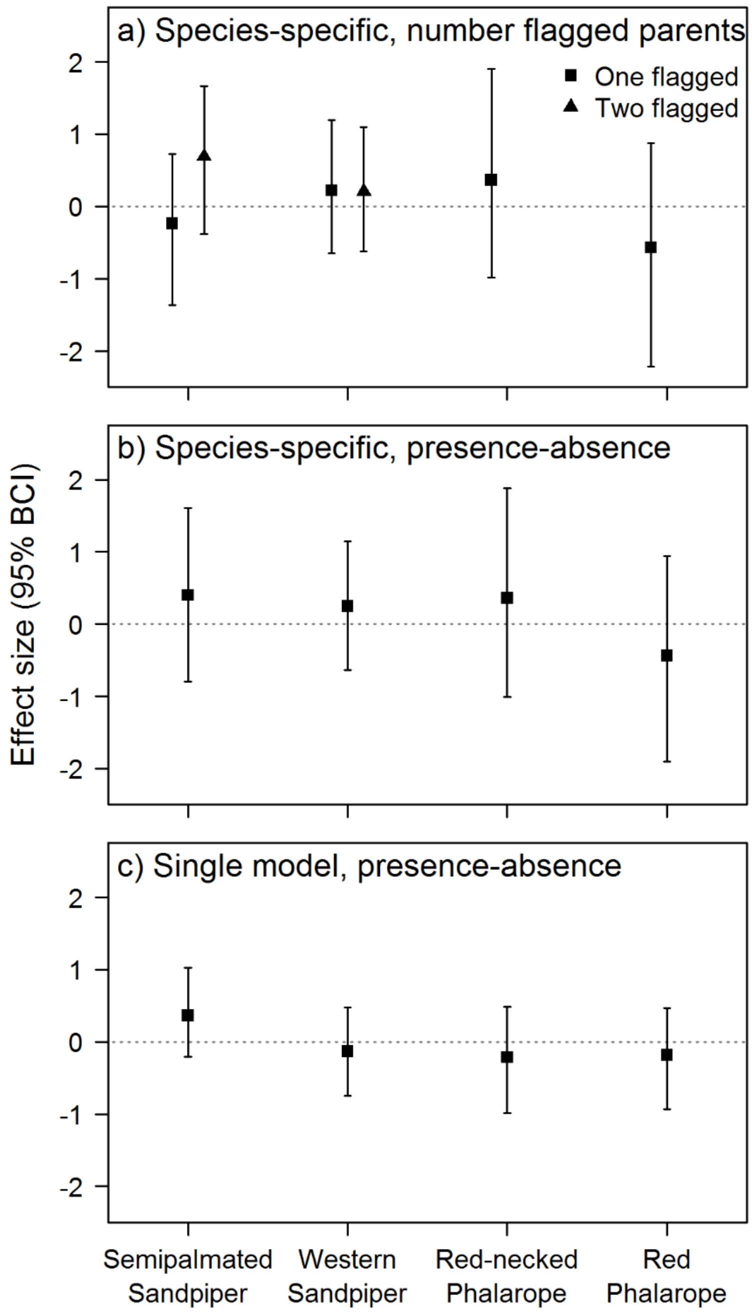

Fig. 2. Comparison of estimated effects of leg flags on daily nest survival rates from three different model structures. In all models, the baseline group was nests where parents had only leg bands (effect size of zero; dotted line). a) Estimates from one model per species where nests were grouped based on whether one or both parents were flagged. b) Estimates from one model per species, with nests grouped by the presence or absence of a flag on at least one parent. c) Estimates from one model containing all species, with the effect of flags (presence or absence) allowed to vary among species. Phalaropes (RNPH and REPH) have incubation by males only, so no nests were attended by two flagged parents and estimates are identical in (a) and (b). Estimates are on the logit scale relative to a baseline of zero (dotted line; no flag). Additional information for the final model (c) is provided in Table S2.

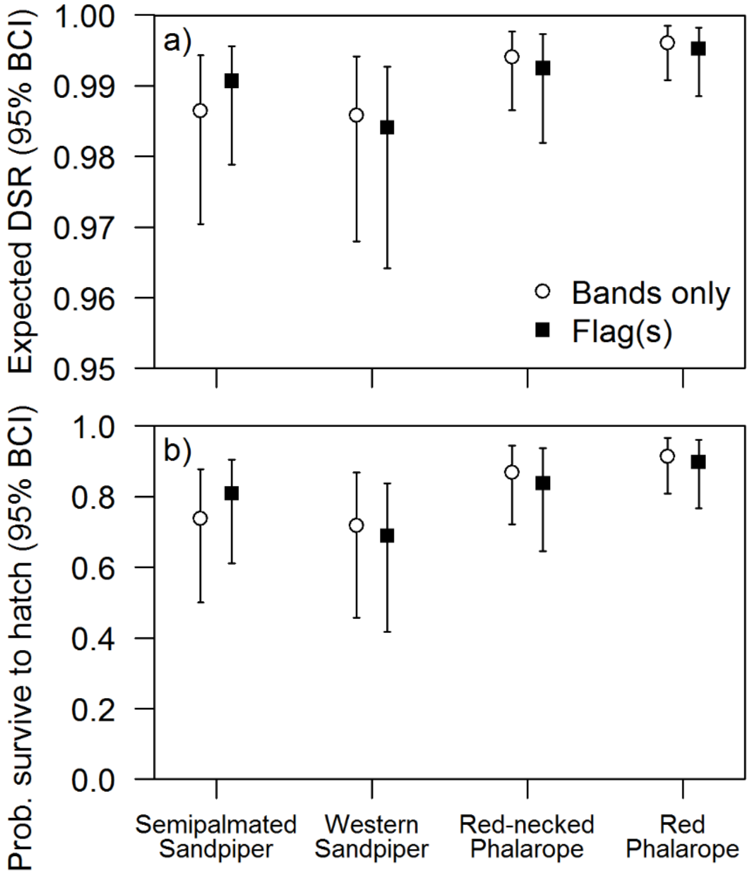

Fig. 3. Expected daily survival rate (DSR, a) and probability of surviving the full incubation period (b) for nests of four species of shorebirds, depending on whether or not at least one parent carried a leg flag (single model, presence-absence; Fig. 2c). Values are for the mean day-of-season when nest survival varied seasonally.

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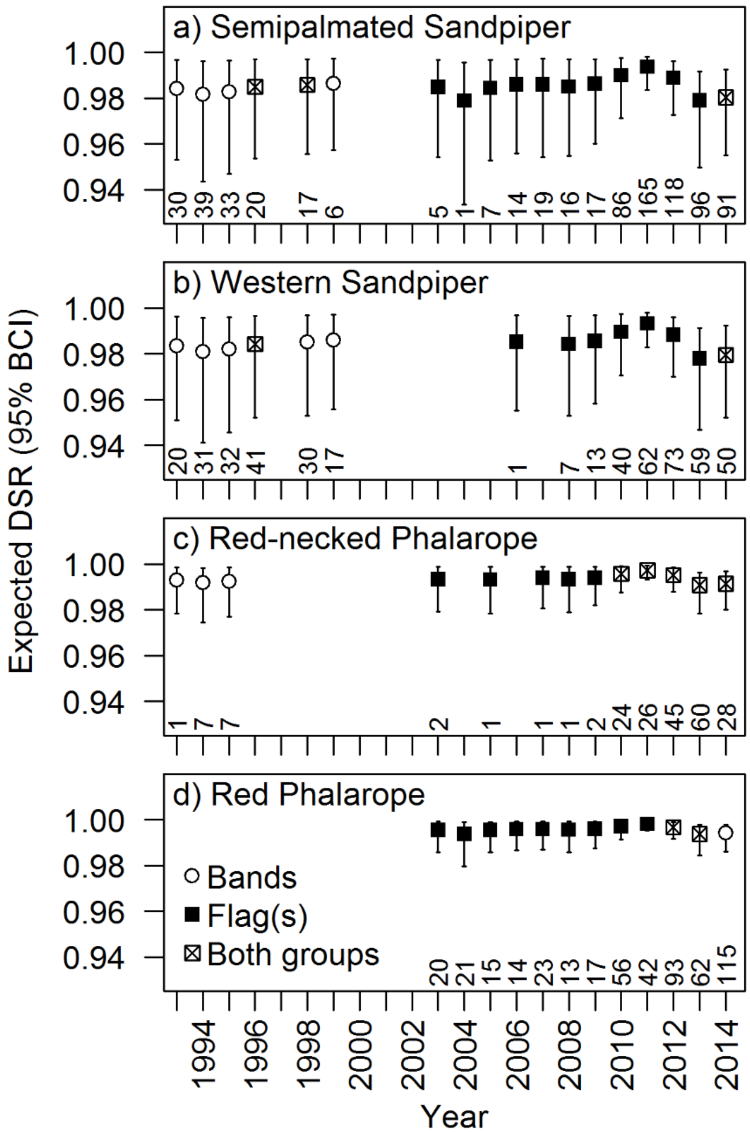

Fig. 4. Expected daily nest survival rates (DSR) for four shorebird species in each year of our study. Estimates of DSR are from the single model testing for an effect of presence or absence of flag(s) on parents (Fig. 2c). Point symbols indicate which group(s) were included in each year. Numbers along the horizontal axes indicate sample sizes (number of nests monitored).