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ORIGINAL ARTICLE

Comparing the effects of marking techniques on the survival of Piping Plover chicks

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Abstract
The use of unique markers in ornithology has a long history and is predicated on the assumption that markers have negligible effects on behavior and survival. The assumption that marks are harmless is particularly important with imperiled species. We studied the effects of two different marking schemes on Piping Plovers (*Charadrius melodus*), a small shorebird protected under the U.S. Endangered Species Act that is intensively monitored and managed. We used two marking schemes, (1) color bands and (2) uniquely engraved flags during breeding seasons from 2013 to 2023 to determine whether the injuries were causing additive mortality and thus actually limiting populations. We estimated the effect of perceived limping and injury (e.g., swelling, laceration, etc.) on chick and hatch-year survival. We detected injuries in some years and associated with both marking schemes (range 0.0–6.0%, average = 2.7% of marked chicks each year). Interval survival for banded chicks was like that of flagged chicks ($\beta = -0.55$, 95% BCI: − 1.30–0.33, $f = 0.92$). Mean survival to fledging, however, was higher in years where flags were used ($\overline{\phi} = 0.55 \pm 0.14$) than when bands were used ($\overline{\phi} = 0.34 \pm 0.14$), but we surmise that this difference was partly conflated with negative density-dependent factors ($\beta = -0.49$, 95% BCI: − 0.73 to − 0.25, $f = 1.00$) and predation. Our results show that pre-fledge survival of birds with uniquely coded flags was similar to that of birds receiving color bands. There was also no evidence that injured birds had a significantly lower hatch-year survival than those that were not injured. However, the relatively high (up to 6%) injury rate in some years remains a concern. Injury and survival rates need to be considered and evaluated when deciding on whether to mark individuals. Ultimately, wildlife practitioners should strive to use the best methods for information gathering and management, without negatively impacting the species.

Keywords Ringing · Flags · Shorebird · Fire Island · Population dynamics

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Zusammenfassung

Vergleich der Auswirkungen von Markierungsmethoden auf das Überleben von Flötenregenpfeiferküken

Die Verwendung bestimmter Markierungen hat in der Ornithologie eine lange Geschichte und beruht auf der Annahme, dass die Auswirkungen der Markierungen auf Verhalten und Überleben vernachlässigbar sind. Diese Annahme, dass Markierungen harmlos sind, ist besonders wichtig, wenn es um gefährdete Arten geht. Wir untersuchten die Auswirkungen von zwei verschiedenen Markierungsmethoden auf Flötenregenpfeifer (*Charadrius melodus*), einem kleinen Küstenvogel, der nach dem US-Gesetz über gefährdete Arten geschützt ist und intensiv überwacht und kontrolliert wird. Dafür benutzten wir in den Brutsaisons 2013 bis 2023 zwei Markierungssysteme: (1) farbige Ringe und (2) individuell geprägte Plaketten, um festzustellen, ob diese Eingriffe zu einer erhöhten Sterblichkeit führen und so die Populationen tatsächlich beeinträchtigen. Wir schätzten den Effekt des beobachteten Hinkens und der Verletzungen (z. B. Schwellungen, Risse usw.) auf die Überlebensrate der Küken im Jahr ihres Schlüpfens ein. In einigen Jahren wurden Verletzungen festgestellt, die mit beiden Markierungsmethoden zusammenhingen (gesamter Bereich: 0,0–6,0%, Mittelwert = 2,7% der markierten Küken pro Jahr). Das Überlebensintervall der Küken war für beide Methoden ähnlich ($\beta = -0,55$, 95% BCI: $-1,30$ to 0,33, $f = 0,92$). Die durchschnittliche Überlebensrate bis zum Ausfliegen war jedoch in den Jahren, in denen Plaketten verwendet wurden, höher ($\varphi = 0,55 \pm 0,14$) als in den Jahren, in denen Farbringe verwendet wurden ($\varphi = 0,34 \pm 0,14$). Wir vermuten aber, dass dieser Unterschied zum Teil an einer Kombination mit negativen dichteabhängigen Faktoren ($\beta = -0,49$, 95% BCI: $-0,73$ to $-0,25$, $f = 1,00$) und an der Erbeutung durch Fressfeinde lag. Unsere Ergebnisse zeigen, dass vor dem Flüggewerden das Überleben von Vögeln mit individuell geprägten Plaketten ähnlich dem von Vögeln mit Farbringen war. Es gab auch keine Anzeichen dafür, dass verletzte Vögel im Jahr ihres Schlüpfens eine signifikant niedrigere Überlebensrate hatten als Küken ohne durch die Markierungen bedingte Verletzungen. Die relativ hohe Verletzungsrate (bis zu 6%) in einigen Jahren gibt jedoch weiterhin Anlass zur Sorge. Bei der Entscheidung, ob und wie ein Tier markiert werden soll, müssen die Verletzungs- und Überlebensraten berücksichtigt und mitbewertet werden. Menschen, die mit Wildtieren arbeiten, sollten letztlich immer bestrebt sein, beim Sammeln und Auswerten von Informationen die bestgeeigneten Methoden einzusetzen, die die betreffenden Arten nicht negativ beeinflussen.

Introduction

Marking birds with uniquely identifiable tags is a longstanding practice in ornithology (Wood 1945). In particular, the application of rings or bands to a bird's legs ("ringing" or "banding") has been critical in our efforts to understand the ecology, behavior, and population dynamics of countless species where individual identification is necessary (e.g., Baillie and Schaub 2009). Entire statistical fields have been developed to analyze banding and resighting data, as they form a keystone of wildlife management and ecology (Williams et al. 2002). Although additional methods have been developed to elucidate demography among unmarked individuals (e.g., Lukacs et al. 2004; Dail and Madsen 2011), even these may rely on some marking (Robinson et al. 2020, 2023).

Marks often are assumed to have no effect on the species being marked, but determining what, if any, effect these marks have on a species is difficult. Such marks often are necessary to assess survival (Roche et al. 2010) or other behavioral or physiological factors under study, and thus, any negative effects of marking are obscured or confounded by the necessity of the method. Questions of capture myopathy, environmental effects on bands (e.g., aluminum bands in marine environments), positioning of bands on the leg, marker size, and injuries abound for shorebird banding (Charadriiformes; Lingle and Sidle 1990; Reed and Oring 1993; Amat 1999; Amirault et al. 2006). These questions are particularly important for shorebird chicks that often can be banded soon after hatch because of their relatively well-developed legs (Gratto-Trevor 2018). Even with these unknowns, banders rarely change marking schemes, which would facilitate comparisons of marking type but also could complicate analyses that rely on consistent methodology to reduce uncertainty.

The Piping Plover (*Charadrius melodus*; hereafter, "plover") is a shorebird that experienced range-wide population declines prior to its 1986 listing under the United States Endangered Species Act (USFWS 1985). On the Atlantic Coast, recent declines primarily were attributed to habitat loss, human disturbance, and predation (USFWS 1996). Storms or flood events that overwash barrier islands or scour sandbars naturally create open sand habitat, allowing populations to increase rapidly (Wilcox 1959; Cohen et al. 2009; Catlin et al. 2015; Robinson et al. 2019, 2020; Walker et al. 2019), suggesting habitat as the ultimate limiting factor.

Numerous studies of plovers have relied on marking adults and chicks to investigate their demography, dispersal, space-use, and behavior (e.g., Amirault et al. 2006; Cohen et al. 2009; Saunders et al. 2014; Catlin et al. 2015; Hunt et al. 2018; Robinson et al. 2020). Injuries were noted in the late 1980s (Dirks 1990; Lingle and Sidle 1990; Loegering 1992; Drake et al. 2001; Amirault et al. 2006; Cohen et al. 2009), leading to a moratorium on banding across all populations starting in 1989 (USFWS 1996; Hecht and Melvin 2009). In 2005, banding resumed on the Missouri River (Catlin et al. 2015; Swift et al. 2022), extending to the wintering grounds and Atlantic populations thereafter (e.g., Gibson et al. 2017; Robinson et al. 2020). Some argued that marking plovers with taller, aluminum bands on the lower leg led to foot loss (Amirault et al. 2006), thus marking on the Atlantic Coast was limited to the upper legs (Cohen et al. 2009). Coupled with increasing marking efforts and a finite possibility of unique color combinations, there was a need for novel marking techniques that ensured ample unique combinations.

Alpha-numeric flags are used on a variety of shorebirds (Clark et al. 2005; Tucker et al. 2019), but, until recently, they were not available for smaller species. To be read properly with a spotting scope, alpha-numeric flags needed a longer tab than those used previously, and they provide $P(n,r) = n!/(n-r)!$ unique codes per flag color (where n is the total number of possible characters, and r is the number of characters issued on the flag). The flags used previously on the Missouri River (Catlin et al. 2015) were thin, had a short (approx. 7 mm) tab length, and were not field-readable. Changing the marking methods has renewed calls to evaluate the marking techniques and ensure that they have a negligible effect, a task that was codified in the Atlantic Coast Recovery Plan (USFWS 1996).

In this study, we compared the injury rate and survival of cohorts of plover chicks that were banded with stacked Darvic color bands and Darvic flags (bands with an elongated tab [approx. 10 mm] on them). Leg injuries were rare, but they did occur with both marking schemes, which provided the opportunity to investigate the overall effect on chick survival. The objective of this study was to investigate what effect alpha-numeric flags had compared to color band combinations and to determine what effects injuries had on hatch-year survival. We chose to compare the schemes in chicks because they are particularly fragile during their development and pre-fledge chicks are more easily relocated than post-fledge individuals that may disperse outside the study area.

Methods

Study area

We studied plovers on Fire Island, a 50 km barrier island south of Long Island, NY, during April to August 2013 to 2023 (Fig. 1). Plovers use a mix of interdune, backshore, and foredune habitats for nesting and bring their chicks to moist substrates, such as bayside tidal flats and ephemeral pools, to feed and prepare for migration (Monk et al. 2020; Robinson et al. 2023). Since Hurricane Sandy in 2012, the population has irrupted, producing more chicks than each previous year (Robinson et al. 2019, 2020), though high-densities of nesting plovers in recent years have experienced negative density-dependent feedback, increasing predation, decreasing reproductive output, and slowing population growth (Wails et al. 2023; Robinson et al. 2024; Wails et al. in Review).

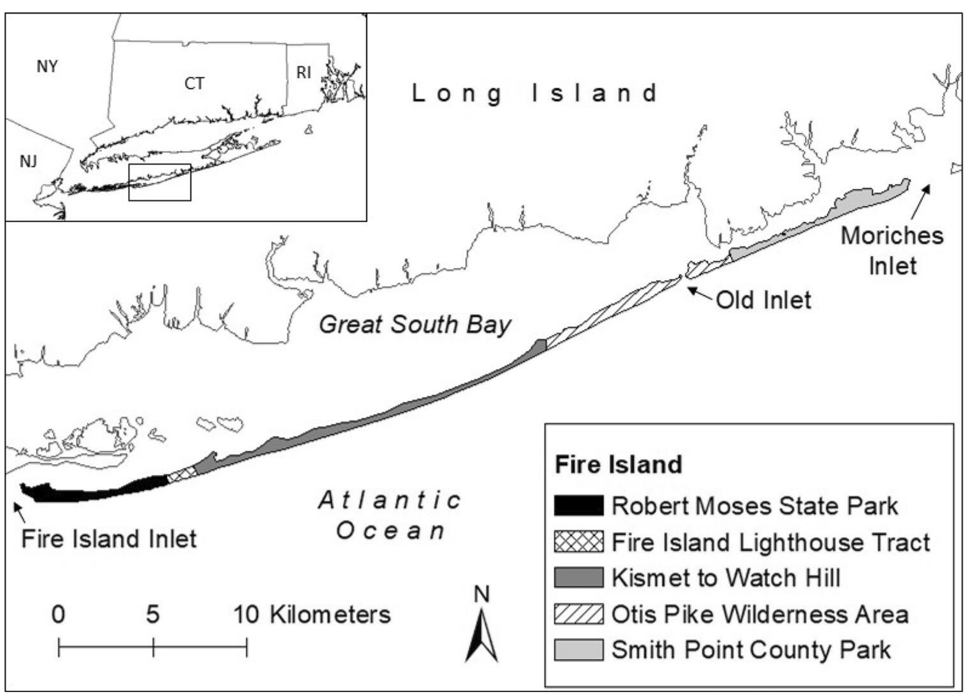

Fig. 1 Piping Plover (*Charadrius melodus*) study areas on Fire Island, New York, USA, 2013–2023. Research efforts were focused at Robert Moses State Park, Smith Point County Park, Fire Island National Seashore Lighthouse Tract, and the portions of the Fire Island National Seashore Otis Pike High Dune Wilderness Area that lie west (Western Wilderness) and east (Old Inlet East) of Old Inlet

Marking and resighting

During the breeding season (April–August), we searched for plover nests by walking through sand habitats, closely watching the ground, and observing adult plover behavior. All birds were checked for marks, and we attempted to read those marks at each visit. Once discovered, we determined the hatch date through egg floating (Westerskov 1950) and visited nests every one to three days until failure or hatch. We banded chicks after hatch (2.5 ± 4.5 d [1 SD]) with either: (1) a unique combination of four, colored, Darvic bands (2013 and 2022–2023; 3.1 mm internal diameter, 4 mm height per band [8 mm total], Avinet, Dryden, NY; Fig. 2a) placed two each on both upper legs, or (2) a two- or three-digit, uniquely identifiable, alpha-numeric etched Darvic plastic flag (2014–2021; 3.1 mm internal diameter, 10 mm tab length [area with code], 6 mm height Interrex, Łódź, Poland; Fig. 2b) placed on one upper leg, and a single color band (4 mm height) placed on the opposite upper leg. Regulatory restrictions dictated which marking scheme we used in each year. We conducted brood surveys every 1–7 days (average 2.73 ± 0.03 [1 SE]) by searching for banded chicks and associated adults. To reduce the potential disturbance associated with resighting each individual chick at each visit, we followed broods, counting the number of chicks present at each visit (Lukacs et al. 2004) until they fledged. We considered a plover chick fledged at 25 days post-hatch (nominally, fledging; Hunt et al. 2013; Catlin et al. 2015). Due to restrictions associated with COVID-19, no birds were marked in 2020. In 2021–2023, our monitoring of certain broods was limited, thus we removed some broods ($n = 85$ chicks) from the survival analysis but not the evaluation of injuries or hatch-year survival.

Analytical methods

Injuries

We recorded any apparent injuries (e.g., limping, swelling; Appendix 1) for all chicks that were banded. Though we did seldom observe foot or leg loss in adults that returned in years following the banding, we did not see band-related leg loss in pre-fledge chicks (Wails et al. 2023). We monitored any injuries until fledging or the issue resolved (individual no longer displayed signs of their injury). Any injuries that were not visibly resolved by the end of the study were considered “unresolved”. We present the number of injuries (deemed related to marking) per marked chick each year as a measure of the potential effect of marking scheme on chick survival. Injuries were considered unrelated to banding when they affected a lower portion of the leg or another body part.

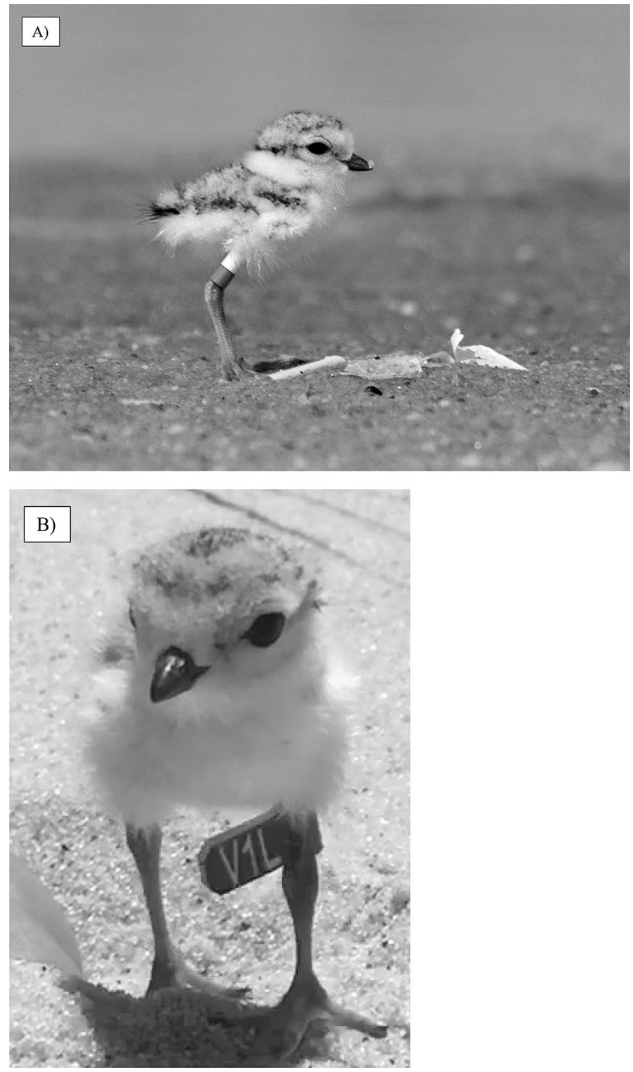

Fig. 2 Piping Plover (*Charadrius melodus*) marking schemes, showing one-day old chicks with A) two Darvic color bands on the tibiotarsus (two others were placed on the opposite leg), and B) a coded Darvic flag, also placed on the tibiotarsus (one Darvic color band was placed on the opposite leg). We compared the survival of plover chicks between the two marking schemes on Fire Island, New York, USA. Photo **A** by K. Lapenta. Photo **B** by K. Oliver

Survival to fledge

We used a modified Dail–Madsen model (Dail and Madsen 2011) described by Robinson et al. (2020) to estimate pre-fledging (0–25 days after hatch) chick survival (φ) each year from 2013 to 2023. This model approximates a young survival model (Lukacs et al. 2004) and uses counts of chicks in known broods at regular intervals to estimate individual chick survival. In addition, the model estimates a brood-mixing parameter to account for movement of chicks among broods. For a full description of the model, see Robinson et al. (2023). We estimated daily survival over a 25-day period using 5-day chick detection occasions (thus, four survival intervals). The capture histories were brood-specific and we entered the maximum number of chicks seen for each 5 day capture occasion. Both survival and recapture rate were estimated for each interval, and we used a random effect to describe annual variation (mean = 0, SD estimated from the data). We set the recapture rate for the final two intervals equal to one another to allow for a survival estimate for the final period that was not confounded with recapture rate.

To test for a difference between the marking schemes, we created a covariate for banding scheme (1 for years where bands were used, 0 for years where flags were used). We also included ordinal hatch date and brood-specific plover nesting density (pairs/ha of dry sand habitat) based on previous studies (Walker et al. 2019; Robinson et al. 2023, 2024). We standardized all continuous covariates prior to analysis by subtracting the mean and dividing by 2 SD. We scaled by 2 SD to make direct comparisons among beta estimates, including the unscaled binary variable (i.e., banding scheme; Gelman 2008). We estimated the probability of reaching fledging (approx. 25 days post-hatch) as the product of the four interval survival rates.

Hatch-year survival

In addition to investigating the effect of banding scheme on chick survival, we analyzed hatch-year survival (from banding to the following year) for birds banded as chicks in our study. Rather than compare years, we estimated the difference in hatch-year survival between chicks identified as injured and those that were never seen injured. We used a Cormack-Jolly-Seber model (Lebreton et al. 1992) to estimate hatch-year survival. We estimated hatch-year survival separately from after-hatch-year survival, and we used a random effect to represent annual variation (mean = 0). We used the age at banding as an individual covariate to control for differing survival probabilities relative to age (i.e., a younger chick has a lower probability of surviving to the following year than an older chick because significant mortality occurs between hatching and immediately following fledging). Because of effort-related differences related to the COVID pandemic, we modeled recapture rate as three constants: before the COVID pandemic (2013–2019), during the pandemic (2020), and after (2021–2023). We estimated the effect of whether the bird was seen injured as a chick on survival for hatch-year survival and after-hatch-year survival, separately, in case there was a latent effect on adults.

All models were built and implemented in a Bayesian framework, using the "jagsUI" package to call JAGS version 4.3.0 in R ver. 4.2.2 (Kellner 2018; R Core Team 2022). We used vague priors for all estimated parameters (see supplemental materials for full description of models). We considered the model converged when $\hat{R} \leq 1.1$ (Gelman and Rubin 1992). We present estimates using the mean of the posterior distributions and the 95% Bayesian credible intervals and we use the proportion of the posterior for each parameter that is above or below zero ('f') as a measure of significance. Means are presented as mean ± 1 SD unless otherwise noted. Full model code for both analyses is available in the supporting information (Appendix 2).

Results

Injuries

We marked 1358 chicks that were used in this analysis during the seasons 2013 to 2023. The number of chicks with marking-related injuries ranged from zero to eleven chicks annually (0.0–6.0%, average = 2.7% of marked chicks each year; Table 1). Although variable, injuries occurred under both marking schemes, but there appeared to be a greater injury rate in years when flags were used (0.9% for banded birds vs. 3.6% for flagged birds; Table 1, Appendix 1). Types of injuries recorded were abrasions and swelling. Of the marked chicks that were injured, 15 (1.1% of the marked chicks in the study) had injuries that were not resolved as of fledging (Table 1, Appendix 1).

Survival to fledge

We monitored 399 broods (134 banded, 265 flagged) with 1358 banded chicks (431 banded, 927 flagged, Table 1). The interval recapture rate was high, ranging from 0.81 to 0.82 and the mixing parameter was relatively small (mean = 0.04, SD = 0.02). Survival to fledging ranged from 0.22 to 0.70, peaking in the middle years of the study (Fig. 3).

Interval survival was similar for chicks that were banded compared to those that were flagged; the credible interval included zero, but 92% of the probability was negative ($\beta = -0.55$, 95% BCI: -1.30 to 0.33, $f = 0.92$). Survival to fledging in years where bands were used ($\overline{\phi} = 0.34 \pm 0.14$) was lower than for years when flags were used ($\overline{\phi} = 0.55 \pm 0.14$). We found that survival decreased with increasing nest density ($\beta = -0.45$, 95% BCI: -0.68 to 0.22, $f = 1.00$; Fig. 4) and also with increasing ordinal hatch date, but the effect of hatch date was much smaller than for the other covariates, bordering on biologically insignificant ($\beta = -0.001$, 95% BCI: -0.003 to 0.000, $f = 0.99$).

Hatch-year survival

There was no indication that chicks seen with injuries in the year they hatched ($n = 37$, 2.7% of marked chicks) had

Table 1 Number of Piping Plover (*Charadrius melodus*) broods and chicks marked and monitored on Fire Island, NY during the 2013–2023 breeding seasons (April–August). We marked chicks with either: 1. A unique combination of four, colored, Darvic bands (2013, 2022, and 2023; 3.1 mm internal diameter, Avinet, Dryden, NY) or 2. a two or three-digit, uniquely identifiable, alpha-numeric etched Darvic plastic flag (2014–2021; 3.1 mm internal diameter, 10 mm tab length, Interrex, Łódź, Poland; (Fig. 2). No chicks were marked in 2020 due to restrictions associated with the COVID-19 pandemic

Year	Broods	Chicks	Average brood size	Marking scheme	Total injuries (%)	Resolved[2]	Plover density (pairs ha^{-1})[1]	Mean Ordinal hatch date
2013	11	40	3.6	Bands	0 (0.0)	NA	0.14	185
2014	11	43	3.9	Flags	2 (4.7)	2	0.18	174
2015	16	49	3.1	Flags	0 (0.0)	NA	0.29	175
2016	33	109	3.3	Flags	6 (5.5)	4	0.20	175
2017	39	135	3.5	Flags	3 (2.2)	3	0.30	174
2018	50	183	3.3	Flags	11 (6.0)	2	0.34	171
2019	73	261	3.6	Flags	10 (3.8)	6	0.42	172
2021	43	147	3.4	Flags	1 (0.7)	1	0.63	170
2022	42	119	2.8	Bands	2 (1.7)	2	0.60	176
2023	81	272	3.4	Bands	2 (0.7)	2	0.42	167

[1]Average density experienced by broods in the analysis each year

[2]Number of chicks where injuries were no longer apparent

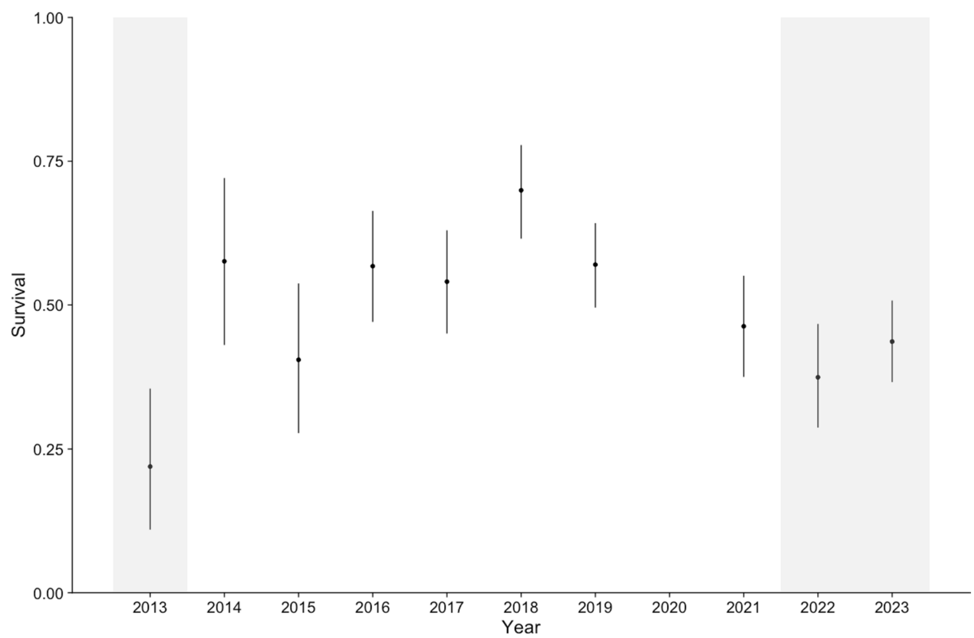

Fig. 3 Piping Plover (*Charadrius melodus*) survival to fledge (25 days) for chicks in 2013–2023 on Fire Island, New York, USA. Estimates are derived from a Dail–Madsen model modified for chick survival and are the product of the 5-day interval specific probability of survival. Shaded estimates are years that birds received color bands, and the unshaded estimates are years when chicks were marked with alpha-numeric flags

lower hatch-year ($\beta =- 0.08$, BCI: − 0.89 to 0.68, $f = 0.57$) or after-hatch-year survival ($\beta = 0.26$, BCI: − 0.64 to 1.22, $f = 0.70$) than those that were not seen injured ($n = 1400$). Hatch-year survival was significantly correlated with age at banding, such that chicks that were closer to fledging before being marked had higher survival ($\beta = 0.05$, BCI: 0.02–0.08, $f = 0.99$). Recapture rates were only slightly lower during ($p = 0.84 \pm 0.04$) and after the pandemic ($p = 0.84 \pm 0.03$) than before ($p = 0.90 \pm 0.02$).

Discussion

We did not find any negative effects of alpha-numeric flags on survival to fledging relative to banding with color bands. On the contrary, we found that pre-fledge survival was higher in years when alpha-numeric flags (mean survival to fledging = 0.55) than years when color bands were used (mean survival to fledging = 0.34). The use of the two

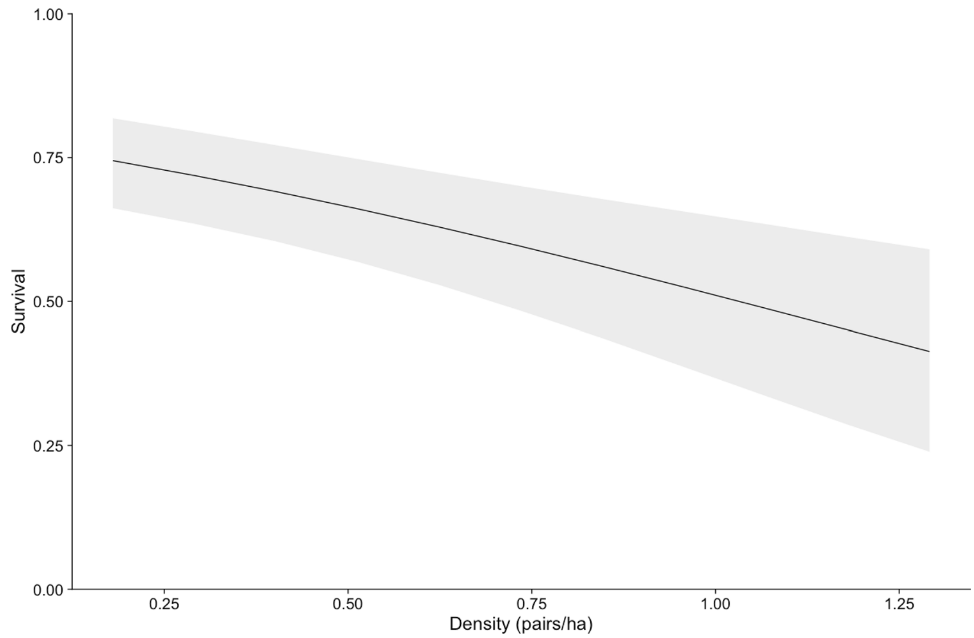

Fig. 4 Piping Plover (*Charadrius melodus*) survival to fledge (25 days) relative to nesting pair density for chicks on Fire Island, New York, USA. Estimates are derived from a Dail–Madsen model modified for chick survival and are the product of the five-day interval specific probability of survival. The shaded area represents 95% credible intervals

different techniques for plovers at Fire Island was conflated with nesting density and predator density (Robinson et al. 2023; Wails et al. 2023; Wails et al. unpublished manuscript), and without samples of each scheme in the same year, our conclusions are limited. Regardless, the injury rate for both schemes was low. Other similar studies compared marked to unmarked birds. For example, Roche et al. (2010) found that color banding young did not affect their survival to fledging relative to unmarked plovers. Sharpe et al. (2009) used radio-tags to confirm that color banded Northern Lapwings (*Vanellus vanellus*) had the same survival rate as those without them.

We did record higher incidence of leg injury in years when chicks were flagged than in years when they were banded. Leg injuries are uncommon but often are an issue when marking shorebird chicks, affecting as many as 7.1% of the birds banded in some studies that assessed injury rate (Lingle and Sidle 1990; Reed and Oring 1993; Amat 1999; Amirault et al. 2006; this study). While unsettling, there were no previous assessments of whether the injuries were causing additive mortality and thus actually limiting populations.

Plovers are relatively robust to researcher disturbance (Hunt et al. 2013), but some forms of disturbance do have negative effects on survival (DeRose-Wilson et al. 2018). Despite these risks, much information has been gained from marking studies of Plovers (e.g., Cohen et al. 2009; Saunders et al. 2014; Catlin et al. 2015; Robinson et al. 2020). While our survival analysis did not necessarily require banded chicks (Dail-Madsen 2011), we did use adult and chick band combinations to determine brood membership (Robinson et al. 2020) and banding was essential to estimating hatch-year survival and population growth (Robinson et al. 2020). By marking plover chicks early, there is less risk during capture, because they are less mobile, requiring less effort to capture them by hand. Moreover, fewer escape without marks, and most of the disturbance is focused on the early marking.

Plover populations show negative density-dependent fluctuations mediated by nesting habitat (Cohen et al. 2009; Catlin et al. 2015; Robinson et al. 2019), and our results further support that conclusion for chick survival. Hurricane Sandy created an abundance of nesting habitat (Walker et al. 2019), but as the population grew and habitat was filled, nesting density increased (Robinson et al. 2020). Here, we show that nesting density was negatively correlated with chick survival to fledging, an important component of population growth (Robinson et al. 2020). Although population level density-dependence was visible without the aid of marked individuals, the demographic mechanisms of this relationship required marking to identify (Robinson et al. 2019).

Conservation implications

Marking studies are assumed to have negligible effect on the organisms marked and this assumption is key to interpreting results for management (Roche et al. 2010). This assumption is particularly important when dealing with imperiled species, reflected in permits issued to researchers and managers for their conservation actions. At a minimum, negative effects need to be accounted for when using data to make management recommendations and demographic predictions. The effort to understand a species' ecology and population dynamics ought to strive to do so in a way that best reflects the world without research intervention.

The management of plovers, however, is a public affair, particularly on the Atlantic Coast, where plovers often breed on busy, public beaches (Hecht and Melvin 2009). This fact can lead to management aimed at public opinion as much as conservation efficacy. While this may seem like a conflict, maintaining a positive public opinion is one part of conserving this species. Thus, injuries to birds, even if these injuries do not affect attempts to recover the species, may hinder efforts to engage the public in conservation efforts. While we did not find a significant difference in survival between the two banding schemes, this issue remains unresolved particularly for other marking schemes, populations, and species, which could have different results. Future studies that evaluate marking schemes issued in the same year and across different breeding populations are needed.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10336-024-02211-x.

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Data availability The datasets used in the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

Ethical approval All capture, handling, and observation procedures were conducted under Institutional Animal Care and Use Committee protocols #11-027-FIW, #14-003, #16-244, #19-248, #22-190; U.S. Geological Survey Federal Bird Banding permit #21446; U.S. Fish and Wildlife Service Endangered Species permit #TE-697823 and #ESPER0033920; U.S. National Park Service Scientific Research and Collecting permits FIIS-2013-SCI-002, FIIS-2015-SCI-0011, FIIS-2016-SCI-0003, FIIS-2017-SCI-0004, FIIS-2018-SCI-0004, FIIS-2021-SCI-0003, FIIS-2022-SCI-0005, and FIIS-2023-SCI-0003; New York State Department of Environmental Conservation Endangered Species permit #314; New York State Office of Parks, Recreation and Historic Preservation permits 15-0700, 16-0393, 17-0755, 18-0168, 19-0128, 21-031, 22-0040, and 23-0058; and permits for research in Suffolk County Parklands. The findings and conclusions in this article are those of the author(s) and do not represent the official views of the U.S. Fish and Wildlife Service.

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