Received: 16 January 2021 | Revised: 17 October 2021 | Accepted: 19 October 2021

DOI: 10.1002/jwmg.22172

RESEARCH ARTICLE

THE JOURNAL OF WILDLIFE MANAGEMENT
THE WILDLIFE SOCIETY

Do hunters target auxiliary markers? An example using black brant

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Funding information

Ducks Unlimited, Inc.; National Science Foundation, Grant/Award Numbers: DEB 0743152, DEB 1252656, DEB 9815383, OPP 0196406, OPP 9214970, OPP 9985931; Alaska Biological Research; Phil Jebbia; U.S. Fish and Wildlife Service; James C. Kennedy Wetland & Waterfowl Conservation Endowment; Alaska Science Center, U.S. Geological Survey

ABSTRACT

Auxiliary markers play an essential role in understanding migration, movement, demography, and behavior of migratory birds. Use of such markers relies on the assumption that the markers do not affect the traits of interest. Neck collars, among the most conspicuous of markers, substantially affect risk of harvest, and survival even in the absence of harvest. Effects of less-conspicuous markers, such as colored plastic tarsal bands, are not well understood. We used 30 years (1986–2015) of banding, recovery, and recapture data from the Yukon-Kuskokwim Delta in Alaska, USA, to assess differences in direct band recovery rates (DRRs) between black plastic and brightly colored plastic bands applied to black brant (*Branta bernicla nigricans*). We also assessed the effect of the color of plastic tarsal bands on annual survival, risks of natural mortality harvest, and fidelity to the breeding colony of adult female black brant. When assessing only DRRs we found that brightly colored bands were recovered at higher rates than black plastic bands in the early 2000s, but DRRs for black bands increased more rapidly through time, resulting in similar DRRs for the 2 band colors at the end of the study. Using a Burnham model structure, our results demonstrated that individuals fitted with colored bands had slightly lower hazards of dying from natural causes or hunting than individuals carrying less-conspicuous black tarsal bands. Differences on annual probability scales were small and credible intervals broadly overlapped between band types, indicating minimal differences between individuals with different band types; however, we could not resolve all confounding in our study design and we suggest that specific studies directed at assessing marker effects are warranted. We encourage education of hunters about their roles as citizen scientists and the potentially detrimental effect of targeting birds with auxiliary markers.

KEYWORDS

auxiliary marker, band recovery, black brant, *Branta bernicla nigricans*, harvest, population dynamics, population estimation, survival, targeting

Auxiliary markers are ubiquitous tools (Silvy et al. 2020) that are used for the study of movement (Hestbeck et al. 1991, Sheaffer et al. 2004), habitat use (Smith et al. 2020), and other behavior (Lank et al. 2002) of wildlife. The most important use of auxiliary markers has been for the estimation of demographic parameters (Williams et al. 2002), especially survival (Calvert and Gauthier 2005, Arnold et al. 2016) but also birth rates (Bishop et al. 2007) and other reproductive parameters (Sedinger et al. 2001). The simplest of these markers may be the metal leg bands first applied to birds as early as the sixteenth century to learn about movement and migration (Lincoln 1921, Wood 1945).

Use of metal bands increased in the mid-twentieth century as managers began to realize their potential for estimating population parameters (Anderson et al. 2018). For metal leg bands to provide useful biological information, however, marked individuals must typically be recaptured alive or be recovered and reported as dead (e.g., hunter harvest of a banded bird; Henny and Burnham 1976). These necessities reduce the information gained from the marking effort because typically only a small fraction of individuals are reencountered (Anderson and Burnham 1976). Nevertheless, leg banding has yielded valuable estimates of migratory movements (Crissey 1955, Nichols and Hines 1987), harvest rates (Bartzen and Dufour 2017), and survival (Rice et al. 2010, McDougall and Amundson 2017) because of the large number of individuals banded each year.

Plastic neck collars have been used to successfully follow movements during migration in numerous populations of geese (Eichholz and Sedinger 2006, Ely et al. 2013, Clausen et al. 2018). Unique plastic tarsal bands have also provided substantial information about movements and life histories in geese (Cooch et al. 2001, Lindberg et al. 2007, Cleasby et al. 2017), seaducks (Cooke et al. 2000, Descamps et al. 2009), pochards and dabbling ducks (Arnold and Clark 1996, Anderson et al. 2001), seabirds (Golet et al. 2004, Aubry et al. 2011), and shorebirds (Handel and Gill 2000, van de Pol et al. 2006, Johnson et al. 2010). Visual markers like plastic neck collars and tarsal bands have the advantage that individuals can be resighted multiple times without having to be shot or captured, allowing for substantially more data from a single marking event than is the case with metal leg bands (Williams et al. 2002).

A key assumption of all auxiliary markers is that they do not influence the behavior or demography of marked individuals, relative to unmarked individuals in the study population. Neck collars, however, reduce reproduction in black brant (*Branta bernicla nigricans* [brant]; Lensink 1968). Neck collars also affect other behaviors in geese (Ely 1990). Some researchers demonstrated that individuals with neck collars are also more likely to be shot by hunters (Craven 1979, Castelli and Trost 1996), although it is unclear whether increased risk of harvest results from behavior of the geese or targeting by hunters. One study demonstrated that increased risk of harvest most likely resulted from changed behavior by the geese themselves, rather than targeting, because harvest rates of geese with conspicuous neck collars were similar to those with neck collars that matched the plumage (Caswell et al. 2012). In addition to increased risk of harvest, neck-collared individuals suffer higher mortality whether hunted or not (Zicus et al. 1983, Schmutz and Morse 2000, Alisauskas and Lindberg 2002), and other types of auxiliary markers could also affect survival by influencing predation risk (Sorenson 1989). Some exceptions to these findings have been documented (Samuel et al. 1990, Reed et al. 2005), but it is still recommended that neck collars not be used for demographic studies of waterfowl (Alisauskas and Lindberg 2002).

In contrast to neck collars, plastic tarsal bands have been assumed to have negligible impact on either behavior or demographic rates in waterfowl and we have used individuals with such markers in several studies (Lindberg et al. 1998; Leach et al. 2017, 2019*a*), as have others (Larsson and Forslund 1994, Ebbinge and Spaans 1995, Aubry et al. 2013). Although colored plastic leg bands were demonstrated to influence social status in passerines decades ago (Burley et al. 1982, Metz and Weatherhead 1991), we have continued to assume that the relatively large body size of geese and the absence of bright colors in their social displays (McKinney 1992) would reduce the potential impact on behavior and demography. That said, it has become clear based on social media that some hunters place high value on acquisition of plastic tarsal bands (e.g., https://www.refugeforums.com/threads/leg-collars.649093/page-2, accessed 15 Nov 2021).

Targeting of brightly colored tarsal bands by hunters, expressed through higher direct band recovery rates (DRRs), is important because such behavior could bias estimates of band recovery rate if color-marked individuals are shot at higher rates than unmarked individuals or individuals with only metal bands. Such bias in estimates of harvest rate would also introduce bias in Lincoln-type population estimators (Sedinger et al. 2019) because such estimators assume that marked and unmarked individuals are harvested at the same rate (Williams et al. 2002). Additionally, higher harvest rates could bias estimates of survival if the harvest rate for marked individuals was sufficiently greater than for unmarked individuals.

We used samples of brant marked with a metal band plus a plastic tarsal band (black or brightly colored) to assess the potential for targeting of colored tarsal bands. We used brant marked on the Yukon-Kuskokwim Delta (YKD), Alaska, USA, to assess 2 hypotheses: brightly colored tarsal bands were harvested at higher rates than less-visible black tarsal bands, causing an overestimate of harvest rates, especially in more recent years with more active sport hunting of brant (Leach et al. 2017, 2019*b*); and annual survival and fidelity of individuals fitted with brightly colored bands was lower than those fitted with less-visible bands.

STUDY AREA

We used releases and recaptures of brant from the Tutakoke River brant colony (TRC; 61°15′N, 165°37′W) near the confluence of the Tutakoke and Kashunuk Rivers on the coast of the YKD (Sedinger et al. 1997) for the live recapture-dead recovery analysis that estimated annual survival, natural mortality, kill rates, and fidelity to the release location. We used releases of brant from all banding locations on the YKD for the analysis of the effect of band color on kill rates; Leach et al. (2017) describe the banding locations on the YKD and Leach et al. (2019*b*) describe the locations where banded brant were recovered by hunters along the Pacific Coast from Alaska to Mexico.

METHODS

Field methods and data

We banded brant during the flightless molt of adults (Sedinger et al. 1997), typically during late July, on brood-rearing areas associated with nesting colonies (Sedinger et al. 1993, Nicolai and Sedinger 2012). We determined sex by cloacal examination (Owen 1980) and assigned age as local (flightless brant in their hatch-year), second-year, or adult. We distinguished second-year brant from adults by the presence of the remnants of white wing bars on wing coverts (Harris and Shepherd 1965).

We applied a metal federal band and a 2.7-cm tall uniquely engraved plastic band on the opposite leg of the metal band (Table 1). We applied yellow or white plastic tarsal bands on the YKD in 1986–1999, except in 1992 when we applied orange tarsal bands and in 1996 when we applied silver tarsal bands (band colors in Figure S1, available online in Supporting Information). We applied yellow or white bands on the YKD in 2012–2014. We applied more-cryptic black bands on the YKD in 2000–2010, and both yellow and black bands in 2005, 2011, 2012, and 2015.

We restricted analyses to individuals that were adults when released to avoid complexities associated with differences between adults and hatch-year brant in harvest and survival rates (Sedinger et al. 2007). Additionally, hatch-year brant demonstrate annual variation in fidelity to their natal breeding colony (Sedinger et al. 2008) that could inhibit the ability to detect potentially small but important effects of band type on kill rates. Finally, hatch-year birds may also experience substantial mortality between banding and the hunting season, which could complicate inference regarding effects of band color on possible targeting by hunters (Cooch et al. 2021). We restricted analyses to brant banded on the YKD to avoid confounding between band type and risk of harvest associated with banding location (Leach et al. 2019*b*). Additionally, all nondescript (metal) bands applied in the Arctic were applied to failed or nonbreeders, which may differ from family groups in risk of harvest (Schamber et al. 2007, Madsen 2010, Sedinger et al. 2011), creating an additional confounding between band type and risk of harvest.

We also used releases and recaptures of tarsal-banded brant attained via banding drives in 2000–2015 on brood-rearing areas associated with the Tutakoke River colony (Sedinger et al. 1997) to estimate the effect of band color on true annual survival and breeding fidelity of adult female brant. We relied solely on recaptures and band recoveries for this analysis to avoid potential bias and confounding that might result from differential visibility among band types (Figure S1) that could influence encounter probabilities with potential correlated effects on survival estimates.

Analyses

Band type and kill rates

Our hypothesis was that brant fitted with bright color bands should be killed by hunters at higher rates than individuals fitted with cryptic black bands. We used releases and band recoveries during the first hunting season following initial banding (direct band recoveries) of brant shot by hunters or found dead (codes 01 or 00, respectively) and reported to the United States Geological Survey Bird Banding Laboratory between 1986 and 2015 for these analyses. We first looked for signals of possible targeting in the direct recovery data because a larger sample of banded adult brant exists to evaluate broad temporal variation relative to more detailed data required for capture-mark-recapture analyses.

We estimated kill rates for individuals fitted with each band type by modeling DRR hierarchically according to DRR = $K(1 - c)rr$, where K was the probability of being killed by hunters, c was crippling loss (which we fixed at 0.2, a common assumption in waterfowl studies), and rr was the sociological reporting rate (Bellrose 1955). Because there are no estimates of rr specifically for brant, we specified time-specific reporting rates (rr_t) using informative beta prior distributions based on the results for trophy species provided by Arnold et al. (2020). Brant hunting is a specialized pursuit and the hunters may be more informed about scientific and management benefits of reporting

TABLE 1 Summary of releases and direct band recoveries of brightly colored tarsal bands and black tarsal bands applied to adult brant on Yukon-Kuskokwim Delta (YKD), Alaska, USA, brood-rearing areas during 1986–2015

	Color		Black	
Year	Releases	Direct recoveries	Releases	Direct recoveries
1986	206	0	0	0
1987	741	20	0	0
1988	1,037	8	0	0
1989	1,305	16	0	0
1990	1,368	10	0	0
1991	1,494	12	0	0
1992	850	9	0	0
1993	1,251	5	0	0
1994	893	16	0	0
1995	1,064	15	0	0
1996	643	5	0	0
1997	428	7	0	0
1998	620	10	0	0
1999	1,229	19	0	0
2000	0	0	958	5
2001	0	0	16	0
2002	0	0	889	8
2003	0	0	26	2
2004	0	0	513	5
2005	102	2	500	4
2006	0	0	1,762	23
2007	0	0	953	9
2008	0	0	673	10
2009	0	0	548	11
2010	0	0	314	4
2011	113	0	924	13
2012	394	7	25	0
2013	316	7	13	0
2014	673	22	1	0
2015	450	11	52	3

harvested birds with a band than the average waterfowl hunter, which is why we assumed that reporting rates for brant are equivalent to those for other trophy species (e.g., northern pintail [*Anas acuta*], canvasback [*Aythya valisineria*]). A lack of information about possible differences in *rr* between band types (e.g., color bands vs. metal bands), however, may limit inference about band-type effects on *K*.

We used a Bayesian generalized linear model with a binomial likelihood and vague prior distributions for all parameters to assess hypotheses for patterns in *K* and associated DRR. We assessed effects of band type (colored vs. black bands), and a linear trend across years (year), and their 2-way interaction on *K*. Our principal interest was in effects of band type and whether kill rates had increased through time. We modeled covariate effects on *K* on the log-hazard scale (loglog-link for corresponding survival probabilities; Ergon et al. 2018). To estimate all demographic and underlying regression parameters, we multiplied the model likelihood by vague prior probability distributions using Bayes' theorem to attain the joint posterior distribution.

We compared model-based hypotheses for variation in *K*, modeled on the log-hazard scale, using the leave-one-out information criteria (LOOIC), which we measured using approximate leave-one-out cross-validation with Pareto-smoothed importance sampling with the loo package (Vehtari et al. 2020) in R (R Core Team 2020). We sampled posterior distributions for each parameter using a Markov chain Monte Carlo algorithm (MCMC; Gelfand and Smith 1990) in JAGS 4.3.0 (Plummer 2003), run from the jagsUI package in R (Kellner 2016). In JAGS, we ran 6 MCMC chains for 30,000 iterations with a burn-in period of 10,000 and a thinning rate of 10. We used the Gelman and Rubin (1992) $\hat{R}$ statistic and visual assessment of trace plots to monitor chain convergence.

Band type, kill rate, natural mortality, and annual survival

We jointly modeled live recapture and dead recovery banding data for adult brant from the YKD using a Bayesian implementation of a Burnham m-array likelihood. This model allowed for the simultaneous estimation of survival (*S*), fidelity to the area of marking (*F*), band reporting probability (*f*), and the probability of recapture (*p*) conditional on being alive and faithful to the study area (Burnham 1993). We restricted the data to the study area where recapture efforts were conducted consistently between 2000 and 2015. Furthermore, we implemented staggered entry for individuals previously marked with a brightly colored band once they were recaptured in 2000 or later. We modeled *S* according to:

$$S = exp - (h\_K + h\_N)$$

$$hr = h\_K/(h\_K + h\_N)$$

$$K = (1 - S) \times hr$$

$$N = (1 - S) \times (1 - hr),$$

where *N* was mortality from non-hunting causes, *K* was the probability of being killed by hunters given that hunting had additive effects on adult brant mortality at the levels of *K* observed during our study (Sedinger et al. 2007), and *h* and *hr* were hazards and hazard ratios, respectively. We modeled *N* and *K* using annual hazards, and derived the probabilities using associations described in Ergon et al. (2018; Heisey et al. 2007). We modeled band-recovery rates (*f*) hierarchically according to $f = K(1 - c)rr$. Because there are no estimates of *rr* for brant specifically, we specified time-specific reporting rates (rr_t) as described in the section immediately above.

We specified a full model by applying the relevant effects supported in the analysis of the DRRs to the hazards for *K* and *N*. Conceivably, band type could affect social status, energetic condition, and possibly natural mortality. Therefore, we also considered band-type effects on the hazard for *N*. Given the ample recapture data, we also considered time random effects with autoregressive smoothing as an alternative model to a simpler link-linear time trend (Koons et al. 2019). We then examined simplifications of the full model one parameter at a time. We first considered simplified combinations of the aforementioned effects on *N*, including no effects (null). Using the most supported model for *N*, we next considered simplifications for *K*. In all models, we parameterized fidelity and the probability of recapture using time random effects with autoregressive smoothing on the logit scale. We compared models using the LOOIC. We present means and 95% Bayesian credible intervals (BCI) for parameter estimates.

RESULTS

We used 23,344 releases of banded adult brant and 298 direct recoveries to assess effects of band type on kill rates (Table 1). Our estimated effects of band type on apparent annual survival were based on 3,681 and 2,246 releases of brant with brightly colored and black tarsal bands, respectively, in banding drives associated with the Tutakoke River colony.

The generalized linear model of *K* based on direct band recoveries with the lowest LOOIC score included a subtle declining trend prior to 2000 when no black bands occurred in the sample (log-hazard scale for *K*: $\beta_{year} = -0.03$, 95% BCI = −0.07 to 0.02, proportion of the posterior distribution on the same side of zero as the mean (v) = 0.88), an effect of band type after 1999 ($\beta_{type} = -0.76$, 95% BCI = −1.37 to −0.18, $v = 0.99$), and an interaction between band type and the piecewise time trend that allowed for brant marked with black bands to experience a different slope ($\beta_{year,\ black} = 0.09$, 95% BCI = 0.03 to 0.15, $v = 1.00$) compared to brant marked with brightly colored bands ($\beta_{year,\ color} = 0.04$, 95% BCI = 0.01 to 0.07, $v = 1.00$; Table 2). Based on this model, the subtle declining trend in *K* up to 1999 for adult brant marked with brightly colored bands on the YKD was followed by an increasing trend. After substantial numbers of black bands were deployed beginning in 2000, adult brant marked with these cryptic bands initially had a somewhat lower *K* than brant marked with brightly colored bands. A more rapid increase in *K* over time for birds marked with black bands led to an equilibration in *K* between band types by the end of the time series (Figure 1).

We used releases of 5,927 banded adult brant in the joint analysis of live recaptures and dead recoveries (Table 3). The joint model of live recapture and dead recovery data with the lowest LOOIC score included additive effects of band type (black vs. brightly colored) and time for both *K* and *N* (Table 4), though the effect of band type was in the opposite direction of that hypothesized for each source of mortality. The probability of *K* increased linearly across years on a log-hazard scale ($\beta_{year} = 0.11$, 95% BCI = 0.07 to 0.15, $v = 1.00$) to a high of approximately 0.03, and was slightly lower for birds marked with brightly colored bands, not higher, than that for birds marked with black bands ($\beta_{type} = -0.31$, 95% BCI = −0.60 to −0.03, $v = 0.98$; Figure 2). A time random effect with autoregressive smoothing indicated that the probability of dying from non-hunting sources of mortality (*N*) was generally higher than hunting-related mortality, and declined over time with the exception of an abnormally high mortality year in 2008 (Figure 2). Moreover, *N* was also slightly lower for birds marked with brightly colored bands compared to birds marked with black bands ($\beta_{type} = -0.28$, 95% BCI = −0.48 to −0.09, $v = 1.00$). In each case

TABLE 2 Performance of models for probabilities of being killed by hunters (*K*) derived from direct band recoveries (recoveries occurring during the first hunting season following release) for adult brant banded on the Yukon-Kuskokwim Delta, Alaska, USA, 1986–2015. Shown are the expected log pointwise predictive density (ELPPD), the leave-one-out information criteria (LOOIC) for scoring the within-sample predictive ability of each model (a lower LOOIC is better), and the difference (Δ) in LOOIC between a given model and the top model (inferential thresholds for Δ have not been theoretically justified)

Models[a]	ELPPD	LOOIC	Δ LOOIC
Type + year + type:year	−92.07	184.14	0.00
Type + year	−92.25	184.50	0.36
Type	−97.21	194.43	10.29
Year	−96.61	193.22	9.08
Null (intercept only)	−100.33	200.67	16.53

[a] Variables considered in candidate models included type (band type: black or brightly colored) and year, a piecewise linear trend across years on the log-hazard scale that was allowed to change in 2000 once black bands entered the sample. Interactions between variables are indicated by a colon (:) separating variables.

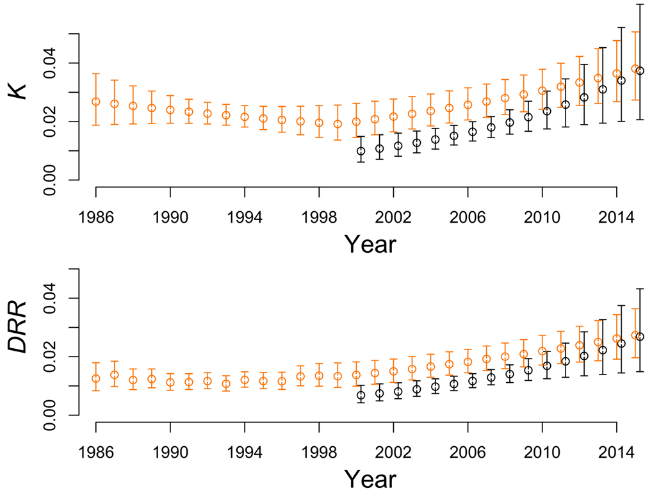

FIGURE 1 Predicted probabilities of adult brant being killed by hunters (*K*, top panel) and direct recovery rates (DRR, bottom panel) from the most supported model along with associated 95% Bayesian credible intervals (error bars). All brant were banded on the Yukon-Kuskokwim Delta, Alaska, USA, and recovered along the Alaska and Pacific coasts. The top model included interactive effects of band type (black vs. colored) and a piecewise linear trend across years on the log-hazard scale. Colored symbols denote probabilities for brant marked with brightly colored bands, whereas achromatic tones denote brant marked with black bands

TABLE 3 Numbers of annual releases of black and colored bands used for the Bayesian multistate implementation of a Burnham m-array likelihood to estimate kill rates, natural mortality, and fidelity to the Tutakoke River colony, Yukon-Kuskokwim Delta, Alaska, USA, 2000–2014

	Number of releases		
Year	Black	Colored	Total
2000	336	389	725
2001	8	2	10
2002	244	221	465
2003	14	18	32
2004	155	95	250
2005	331	215	546
2006	538	168	706
2007	349	85	434
2008	238	56	294
2009	392	65	457
2010	197	22	219
2011	349	89	438
2012	311	271	582
2013	61	166	227
2014	158	384	542
Total	3,681	2,246	5,927

TABLE 4 Performance of joint live recapture-dead recovery models for adult brant banded on the Yukon-Kuskokwim Delta, Alaska, USA, 2000–2015. We present models of effects of band type (type), a linear trend across years (year) and a year random effect (AR) on the probability of being killed by a hunter (*K*) or dying from other causes (*N*). Shown are the expected log pointwise predictive density (ELPPD), the leave-one-out information criteria (LOOIC) for scoring the within-sample predictive ability of each model (a lower LOOIC is better), and the difference (Δ) in LOOIC between a given model and the top model (inferential thresholds for Δ have not been theoretically justified)

Modeled effects[a]				
K	***N***	**ELPPD**	**LOOIC**	**Δ LOOIC**
Type + AR	Type + AR	−725.12	1,450.25	1.14
Type + AR	AR	−728.71	1,457.42	8.31
Type + AR	Type + year	−728.99	1,457.97	8.86
Type + AR	Year	−729.96	1,459.92	10.81
Type + AR	Type	−726.35	1,452.70	3.60
Type + AR	Null	−729.59	1,459.18	10.07
AR	Type + AR	−726.62	1,453.25	4.14
Type + year	Type + AR	−724.55	1,449.11	0.00
Year	Type + AR	−725.67	1,451.34	2.23
Type	Type + AR	−743.55	1,487.10	38.00
Null	Type + AR	−742.32	1,484.65	35.54

[a] Variables considered in candidate models included type (band type, either black or brightly colored), year (a link-linear trend across years), and AR (a year random effect with autoregressive smoothing of lag-order 1).

these band-type effects were estimated precisely on the modeled log-hazard scale, but the differences were less precise on the derived probability scale and the biological effect sizes were small (Figure 2). Estimated fidelity to the study area for adult brant was generally very high but declined slightly at the terminal end of the time series. Recapture probabilities varied stochastically around 0.15, with the exception of low probabilities in the first and third years after the start of the time series during major arctic fox (*Vulpes lagopus*) nest predation events (Sedinger et al. 2016).

DISCUSSION

Our analyses produced ambiguous evidence that brant fitted with brightly colored tarsal bands were targeted by hunters. An assessment of DRRs detected a higher probability of being killed by a hunter for brant with brightly colored bands versus those with black bands in the early 2000s, but DRRs of black bands increased more rapidly than those of brightly colored bands and slightly exceeded those for brightly colored bands by the end of the time series (Figure 1). We cannot envision a reasonable hypothesis that could explain this pattern as an outcome of targeting of visible bands by hunters.

A Burnham model including recaptures of brant at TRC and band recoveries by hunters away from the capture site did not produce a difference in the probability of being killed for brant fitted with the 2 band types, and point estimates indicated slightly higher kill rates for brant with cryptic black bands. Somewhat lower fidelity estimates near the end of the time series likely reflect temporary emigrants (Sedinger et al. 2008) that did not return to the breeding colony before the end of the study.

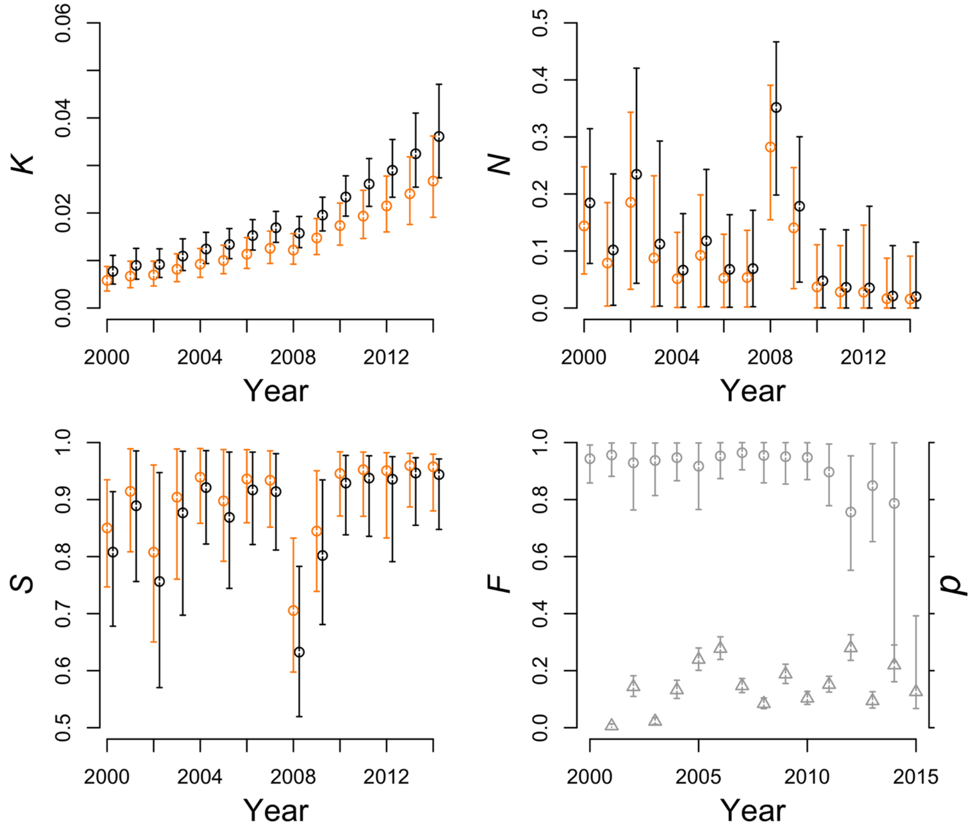

FIGURE 2 Predicted probabilities of adult female brant from the Yukon-Kuskokwim Delta, Alaska, USA, being killed by hunters (*K*) and dying from non-hunting sources of mortality (*N*), annual survival (*S*), fidelity (*F*, grey circles), and recapture probabilities (*p*, grey triangles) with 95% Bayesian credible intervals (error bars) associated with the most supported model of live recapture–dead recovery data. Colored symbols denote estimates for brant marked with brightly colored bands, whereas black symbols denote estimates for brant marked with black bands. Grey denotes estimates for which there was not a modeled effect of band type

Tarsal bands are clearly less visible than neck collars and are only visible in flight when individuals lower their legs before landing. One of us (CAN) is an experienced brant hunter but has not observed tarsal bands on birds in flight before they were shot. We are aware that a small number of brant hunters try to spot tarsal bands (sometimes in teams) before shooting as brant lower their legs to land, but we are not sure this behavior is sufficiently prevalent to completely explain higher recovery rates in color versus black bands at the population level in only some years. Band color seems extremely unlikely to influence reporting rate for bands that are in hand, but we cannot directly address this possibility in this study. The reporting rate parameter in traditional Burnham models (e.g., program MARK; http://www.phidot.org/software/mark/, accessed 15 Nov 2021) does not provide information about the probability of a hunter reporting a band from a bird that is in the hand but rather the probability that the band from a bird that dies is reported to the Bird Banding Lab. For harvested species, the latter probability is almost entirely the product of the probability that a bird that dies was shot by a hunter and retrieved, and the probability that the band from a retrieved bird was reported to the Bird Banding Lab (Otis and White 2002). Reliable estimates of the probability that hunters report bands on retrieved birds are based entirely on reward band studies since the 1960s (Arnold et al. 2020); such studies are lacking for brant and generally for waterfowl fitted with auxiliary markers. Studies to improve understanding of band reporting rates for waterfowl fitted with auxiliary markers would substantially improve our understanding of the impact of such markers on harvest rate, demography, and population dynamics of harvested species.

Both the Bayesian generalized linear model and Bayesian Burnham approaches indicated that kill rates increased between 2000 and 2015 (Figures 1 and 2), although there was uncertainty about the magnitude of the increase. Estimated kill rates increased between a 2-fold change (brightly colored bands in the generalized linear model) and a 4-fold change (black bands in the generalized linear model). Thus, results in this paper are generally consistent with the increase in recovery rates reported by Leach et al. (2017, 2019*b*), who reported a 2.5-fold increase in harvest rates since the 2000s that does indeed affect the entire population.

We found no discernable difference in annual survival between adult brant marked with black versus brightly colored bands. The modified Burnham analysis suggested that mortality from causes other than hunting declined over the time series, counterbalancing the increase in harvest rate. At very low harvest rates, there is some indication that harvest mortality may not be completely additive to natural mortality in adult geese (Sedinger et al. 2007, Alisauskas et al. 2011), although a longer time series detected a decline in survival of adult brant (Leach et al. 2017).

We did not directly compare DRRs of black plastic bands against the potentially less-conspicuous metal-only bands. One sample ($n = 984$) of brant (YKD in 2006) was released with both metal-only and black plastic bands. While estimates were imprecise, DRRs were similar for the 2 band types, (black band DRR = 0.0097, 95% CI = 0.0024–0.021]; metal-only band DRR = 0.0137, 95% CI = 0.0045–0.032), suggesting similar vulnerability to harvest for brant with black plastic and metal-only bands.

One source of uncertainty is the effect of harvest near banding sites. In our study few recoveries from sport hunters occur at the banding sites because of their remoteness, which virtually eliminates the potential for sport hunters to target banded brant by hunting at banding sites. Local subsistence hunters on the YKD can hunt relatively near banding locations, which could have affected availability of bands applied in those areas to hunters farther south, thereby influencing DRRs. Subsistence hunters have in the past infrequently reported their bands to the Bird Banding Lab. Unfortunately, unbiased estimates of subsistence harvest are not currently sufficient to control for potential effects of such harvest in our analyses. While we do not have data indicating that subsistence hunters intentionally target bands, this type of inadvertent targeting could be influencing DRRs in our study. In contrast, even in cases where only metal bands are applied, if sport hunters intentionally hunt near banding sites in more temperate areas of North America, with the goal of increasing their chances of shooting a banded bird, DRRs could be biased.

Given these caveats, we recommend some caution in interpreting our results. Investigators should allow for the potential that targeting, even of plastic tarsal bands, may introduce bias into estimates that managers rely on to inform decision making. Studies like ours use auxiliary markers as treatments because comparisons can only be made among other auxiliary marker colors, or to metal-only banded birds. It would be very useful to understand the extent to which hunters target metal-only banded birds because this is the most common method of marking in waterfowl. Such a study, however, would be complex and at present we are not confident that the requisite data could be collected to support estimates of targeting that would have sufficient precision. In the longer term we recommend that targeting be strongly discouraged through education programs provided to hunters.

MANAGEMENT IMPLICATIONS

Most importantly, we recommend that managers increase education of hunters to facilitate better understanding of banding and to discourage targeting of auxiliary markers, including hunting near banding locations, which has the potential to introduce bias into estimates of all parameters of interest. We encourage educators and managers to make hunters aware that they are essential citizen scientists in our efforts to effectively manage wildlife populations. This could include encouraging participation by hunters and other members of the public in banding operations themselves, as has been done successfully in some locations, including Nevada, USA. Our findings do not contradict numerous findings of negative effects of neck collars, but they suggest that investigators relying on less-conspicuous plastic tarsal bands should be aware of the potential for bias in estimates of demographic and harvest-related parameters, although in our study such effects appear to be minimal. Managers should invest in improving understanding of the effects of auxiliary markers on hunter behavior and harvest rates.

ACKNOWLEDGMENTS

We thank the numerous individuals that have been involved in banding brant over the last 4 decades and the scores of hunters that reported their bands to the Bird Banding Laboratory. We sincerely appreciate the friendship and logistic support provided by the residents of Chevak, Alaska, for our work on the Yukon-Kuskokwim Delta. G. C. White, J. Pierce, and V. Patil provided helpful comments on the manuscript. Banding activities were supported by the United States Fish and Wildlife Service, United States Geological Survey Alaska Science Center, the United States Geological Survey Changing Arctic Ecosystem Initiative, Canadian Wildlife Service, Alaska Biological Research, Ducks Unlimited, Phil Jebbia, in memory of Marnie Shepherd, and the National Science Foundation (OPP 9214970, DEB 9815383, OPP 9985931, OPP 0196406, DEB 0743152, DEB 1252656), the Arctic Office of the Bureau of Land Management, and the North Slope Borough departments of Planning and Community Services and Wildlife Management. The Arctic Goose Joint Venture is supporting ongoing efforts to estimate abundance of maritime geese using Lincoln estimators, which in part supported our efforts here. DNK was supported by the James C. Kennedy Wetland and Waterfowl Conservation Endowment.

CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest.

ETHICS STATEMENT

Banding and capture methods were approved by the Institutional Animal Care and Use Committees of the University of Alaska Fairbanks and the University of Nevada Reno (protocol number 00056).

DATA AVAILABILITY STATEMENT

Code for both analyses is available in Code S1 in Supporting Information. Data for the joint recapture-band recovery analyses are available in Tables S1 and S2 in Supporting Information.

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REFERENCES

Alisauskas, R. T., and M. S. Lindberg. 2002. Effects of neckbands on survival and fidelity of white-fronted and Canada geese captured as non-breeding adults. Journal of Applied Statistics 29:521–537.

Alisauskas, R. T., R. F. Rockwell, K. W. Dufour, E. G. Cooch, G. Zimmerman, K. L. Drake, J. O. Leafloor, T. J. Moser, and E. T. Reed. 2011. Harvest, survival, and abundance of midcontinent lesser snow geese relative to population reduction efforts. Wildlife Monographs 179.

Anderson, D. R., and K. P. Burnham. 1976. Population ecology of the mallard: VI. The effect of exploitation on survival. U.S. Fish and Wildlife Service Resource Publication Number 128. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Anderson, M. G., R. T. Alisauskas, B. D. J. Batt, R. J. Blohm, K. F. Higgins, S. L. King, M. K. Laubhan, M. C. Perry, J. K. Ringelman, J. S. Sedinger, et al. 2018. The migratory bird treaty and a century of waterfowl conservation. Journal of Wildlife Management 82:247–259.

Anderson, M. G., M. S. Lindberg, and R. B. Emery. 2001. Probability of survival and breeding for juvenile female canvasbacks. Journal of Wildlife Management 65:385–397.

Arnold, T. W., R. T. Alisauskas, and J. S. Sedinger. 2020. A Meta-analysis of band reporting probability for North American waterfowl. Journal of Wildlife Management 84:543–541.

Arnold, T. W., C. N. De Sobrino, and H. M. Specht. 2016. Annual survival rates of migratory shore and upland game birds. Wildlife Society Bulletin 40:470–476.

Arnold, T. W., and R. G. Clark. 1996. Survival and philopatry of female dabbling ducks in southcentral Saskatchewan. Journal of Wildlife Management 60:560–568.

Aubry, L. M., E. Cam, D. N. Koons, J.-Y. Monnat, and S. Pavard. 2011. Drivers of age-specific survival in a long-lived seabird: contributions of observed and hidden sources of heterogeneity. Journal of Animal Ecology 80:375–383.

Aubry, L. M., R. F. Rockwell, E. G. Cooch, R. W. Brook, C. P. H. Mulder, and D. N. Koons. 2013. Climate change, phenology, and habitat degradation: drivers of gosling body condition and juvenile survival in lesser snow geese. Global Change Biology 19:149–160.

Bartzen, B. A., and K. W. Dufour. 2017. Northern pintail (*Anas acuta*) survival, recovery, and harvest rates derived from 55 years of banding in Prairie Canada, 1960–2014. Avian Conservation and Ecology 12(2):7.

Bellrose, F. C. 1955. A comparison of recoveries from reward and standard bands. Journal of Wildlife Management 19: 71–75.

Bishop, C. J., D. J. Freddy, G. C. White, T. R. Stephenson, L. L. Wolfe, and B. E. Watkins. 2007. Using vaginal implant transmitters to aid in capture of mule deer neonates. Journal of Wildlife Management 71:945–954.

Burley, N., G. Krantzberg, and P. Radman. 1982. Influence of colour-banding on the conspecific preferences of zebra finches. Animal Behaviour 30:444–455.

Burnham, K. P. 1993. A theory for combined analysis of ring recovery and recapture data. Pages 199–213 *in* J.-D. Lebeton and P. M. North, editors. Marked individuals in the study of bird populations. Birkhauser Verlag, Basel, Switzerland.

Calvert, A. M., and G. Gauthier. 2005. Effects of exceptional conservation measures on survival and seasonal hunting mortality in greater snow geese. Journal of Applied Ecology 42:442–452.

Castelli, P. M., and R. E. Trost. 1996. Neckbands reduce survival of Canada geese in New Jersey. Journal of Wildlife Management 60:891–898.

Caswell, J. H., R. T. Alisauskas, and J. O. Leafloor. 2012. Effect of neckband color on survival and recovery rates of Ross's geese. Journal of Wildlife Management 76:1456–1461.

Clausen, K. K., J. Madsen, F. Cottaar, E. Kuijken, and C. Verscheure. 2018. Highly dynamic wintering strategies in migratory geese: coping with environmental change. Global Change Biology 24:3214–3225.

Cleasby, I. R., T. W. Bodey, F. Vigfusdottir, J. L. McDonald, G. McElwaine, K. Mackie, K. Colhoun, and S. Bearhop. 2017. Climatic conditions produce contrasting influences on demographic traits in a long-distance Arctic migrant. Journal of Animal Ecology 86:285–295.

Cooch, E. G., R. T. Alisauskas, and F. E. Buderman. 2021. Effect of pre-harvest mortality on harvest rates and derived population estimates. Journal of Wildlife Management 85:228–239.

Cooch, E. G., R. F. Rockwell, and S. Brault. 2001. Retrospective analysis of demographic responses to environmental change: a lesser snow goose example. Ecological Monographs 71:377–400.

Cooke, F., G. J. Robertson, C. M. Smith, R. I. Goudie, and W. S. Boyd. 2000. Survival, emigration, and winter population structure of Harlequin ducks. Condor 102:137–144.

Craven, S. R. 1979. Some problems with Canada goose neckbands. Wildlife Society Bulletin 74:268–273.

Crissey, W. F. 1955. The use of banding data in determining waterfowl migration and distribution. Journal of Wildlife Management 19:75–84.

Descamps, S., H. G. Gilchrist, J. Bêty, E. I. Buttler, and M. R. Forbes. 2009. Costs of reproduction in a long-lived bird: large clutch size is associated with low survival in the presence of a highly virulent disease. Biology Letters 5:278–281.

Ebbinge, B. S., and B. Spaans. 1995. The importance of body reserves accumulated in spring staging areas in the temperate zone for breeding in dark-bellied brent geese *Branta b. bernicla* in the high Arctic. Journal of Avian Biology 26: 105–113.

Eichholz, M. W., and J. S. Sedinger. 2006. Staging, migration, and winter distribution of Canada and cackling geese staging in interior Alaska. Journal of Wildlife Management 70:1308–1315.

Ely, C. R. 1990. Effects of neck bands on the behavior of wintering greater white-fronted geese. Journal of Field Ornithology 61:249–253.

Ely, C. R., D. J. Nieman, R. T. Alisauskas, J. A. Schmutz, and J. E. Hines. 2013. Geographic variation in migration chronology and winter distribution of midcontinent greater white-fronted geese. Journal of Wildlife Management 77:1182–1191.

Ergon, T., Ø. Borgan, C. R. Nater, and Y. Vindenes. 2018. The utility of mortality hazard rates in population analyses. Methods in Ecology and Evolution 9:2046–2056.

Gelman, A., and D. B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7:457–472.

Golet, G. H., J. A. Schmutz, D. B. Irons, and J. A. Estes. 2004. Determinants of reproductive costs in the long-lived black-legged kittiwake: a multiyear experiment. Ecological Monographs 74:353–372.

Handel, C. M., and R. E. Gill, Jr. 2000. Mate fidelity and breeding site tenacity in a monogamous sandpiper, the black turnstone. Animal Behaviour 60:471–481.

Harris, S. W., and P. E. K. Shepherd. 1965. Age determination and notes on the breeding age of black brant. Journal of Wildlife Management 29:643–645.

Henny, C. J., and K. P. Burnham. 1976. A reward band study of mallards to estimate band reporting rates. Journal of Wildlife Management 40:1–14.

Heisey, D. M., T. L. Shaffer, and G. C. White. 2007. The ABCs of nest survival: theory and application from a biostatistical perspective. Studies in Avian Biology 34:13–33.

Hestbeck, J. B., J. D. Nichols, and R. A. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. Ecology 72:523–533.

Johnson, M., D. R. Ruthrauff, B. J. McCaffery, S. M. Haig, and J. R. Walters. 2010. Apparent survival of breeding western sandpipers on the Yukon-Kuskokwim river delta, Alaska. Wilson Journal of Ornithology 122:15–22.

Kellner, K. 2016. jagsui: a wrapper around 'rjags' to streamline 'jags'analyses. Version 1.5.0. <https://github.com/kenkellner/jagsUI>. Accessed 29 Oct 2020.

Koons, D. N., L. M. Aubry, and R. F. Rockwell. 2019. Liberalized harvest regulations have not affected overabundant snow geese in northern Manitoba. Condor Ornithological Applications 121:1–13.

Lank, D. B., C. M. Smith, O. Hanotte, A. Ohtonen, S. Bailey, and T. Burke. 2002. High frequency of polyandry in a lek mating system. Behavioral Ecology 13:209–215.

Larsson, K., and P. Forslund. 1994. Population dynamics of the barnacle goose *Branta leucopsis* in the Baltic area: density-dependent effects on reproduction. Journal of Animal Ecology 63:954–962.

Leach, A. G., J. S. Sedinger, T. V. Riecke, A. W. VanDellen, D. H. Ward, and W. S. Boyd. 2019*a*. Trade-offs between current and future reproduction in a long–lived species with precocial young. American Naturalist 193:458–471.

Leach, A. G., D. H. Ward, J. S. Sedinger, M. S. Lindberg, W. S. Boyd, J. W. Hupp, and R. Ritchie. 2017. Survival and harvest rates of black brant from Arctic and sub-Arctic breeding areas. Journal of Wildlife Management 82:1210–1218.

Leach, A. G., D. H. Ward, J. S. Sedinger, T. V. Riecke, J. W. Hupp, and R. Ritchie. 2019*b*. Spatial distribution of band recoveries of black brant. Journal of Wildlife Management 83:304–311.

Lensink, C. J. 1968. Neckbands as an inhibitor of reproduction in black brant. Journal of Wildlife Management 32:418–420.

Lincoln, F. C. 1921. The history and purposes of bird banding. Auk 38:217–228.

Lindberg, M. S., J. S. Sedinger, R. F. Rockwell and D. V. Derksen. 1998. Population structure and natal and breeding movements in a black brant metapopulation. Ecology 79:1893–1904.

Lindberg, M. S., D. H. Ward, T. L. Tibbitts, and J. Roser. 2007. Winter movement dynamics of black brant. Journal of Wildlife Management 71:534–540.

Madsen, J. 2010. Age bias in the bag of pink-footed geese *Anser brachyrhynchus*: influence of flocking behaviour on vulnerability. European Journal of Wildlife Research 56:577–582.

McDougall, M. B., and C. L. Amundson. 2017. Harvest dynamics and annual survival of mallards and grey ducks. Journal of Wildlife Management 81:449–460.

McKinney, F. 1992. Courtship, pair formation, and signal systems. Pages 214–250 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis, USA.

Metz, K. J., and P. J. Weatherhead. 1991. Color bands function as secondary sexual traits in male red-winged blackbirds. Behavioral Ecology and Sociobiology 28:23–27.

Nichols, J. D., and J. E. Hines. 1987. Population ecology of the mallard VIII: winter distribution patterns and survival rates of winter-banded mallards. U.S. Fish and Wildlife Service Resource Publication Number 162. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Nicolai, C. A., and J. S. Sedinger. 2012. Trade-offs between offspring fitness and future reproduction of adult female black brent. Journal of Animal Ecology 81:798–805.

Otis, D. L., and G. C. White. 2002. Re-analysis of a banding study to test the effects of an experimental increase in bag limits of mourning doves. Journal of Applied Statistics 29:479–495.

Owen, M. 1980. Wild geese of the world: their life history and ecology. Batsford, London, United Kingdom.

Plummer, M. 2003. JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. Proceedings of the 3rd International Workshop on Distributed Statistical Computing, volume 124, Vienna, Austria.

R Core Team. 2020. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reed, E. T., G. Gauthier, and R. Pradel. 2005. Effects of neckbands on reproduction and survival of female greater snow geese. Journal of Wildlife Management 69:91–100.

Rice, M. B., D. A. Haukos, J. A. Dubovsky, and M. C. Runge. 2010. Continental survival and recovery rates of northern pintails using band-recovery data. Journal of Wildlife Management 74:778–787.

Samuel, M. D., D. H. Rusch, and S. Craven. 1990. Influence of neck bands on recovery and survival rates of Canada geese. Journal of Wildlife Management 54:45–54.

Schamber, J. L., J. S. Sedinger, D. H. Ward, and K. R. Hagmeier. 2007. Population structure and body size of black brant during winter. Journal of Field Ornithology 78:74–82.

Schmutz, J. A., and J. A. Morse. 2000. Effects of neck collars and radiotransmitters on survival and reproduction of emperor geese. Journal of Wildlife Management 64:231–237.

Sedinger, J. S., N. D. Chelgren, M. S. Lindberg, and D. H. Ward. 2008. Fidelity and breeding probability related to population density and individual quality in black brent geese (*Branta bernicla nigricans*). Journal of Animal Ecology 77:702–712.

Sedinger, J. S., C. J. Lensink, D. H. Ward, R. M. Anthony, M. L. Wege and G. V. Byrd. 1993. Current status and recent dynamics of the black brant breeding population. Wildfowl 44:49–59.

Sedinger, J. S., M. S. Lindberg and N. D. Chelgren. 2001. Age-specific breeding probability in black brant: effects of population density. Journal of Animal Ecology 70:798–807.

Sedinger, J. S., M. S. Lindberg, E. A. Rexstad, N. D. Chelgren, and D. H. Ward. 1997. Testing for handling bias in survival estimation for black brant. Journal of Wildlife Management 61:782–791.

Sedinger, J. S., C. A. Nicolai, C. J. Lensink, C. Wentworth, and B. Conant. 2007. Harvest, density dependence and survival in black brant: a record of population dynamics. Journal of Wildlife Management 71:496–506.

Sedinger, J. S., C. A. Nicolai, A. W. VanDellen, A. G. Leach, H. M. Wilson, and R. M. Anthony. 2016. Predation and reduced grazing interact to reduce recruitment and population growth in a small herbivore. Condor 118:433–444.

Sedinger, J. S., T. V. Riecke, A. G. Leach, and D. H. Ward. 2019. The black brant population is declining based on mark recapture estimates. Journal of Wildlife Management 83:627–637.

Sedinger, J. S., J. L. Schamber, D. H. Ward, C. A. Nicolai, and B. Conant. 2011. Carryover effects associated with winter location affect fitness, social status, and population dynamics in a long distance migrant. American Naturalist 178: E110–E123.

Sheaffer, S. E., D. H. Rusch, D. D. Humburg, J. S. Lawrence, G. G. Zenner, M. M. Gillespie, F. D. Caswell, S. Wilds, and S. C. Yaich. 2004. Survival, movements, and harvest of eastern prairie population Canada geese. Wildlife Monographs 156:1–54.

Silvy, N. J., R. R. Lopez, and M. J. Peterson. 2020. Techniques for marking wildlife. Pages 236–261 *in* N. J. Silvy, editor. The wildlife techniques manual. Johns Hopkins University Press, Baltimore, Maryland, USA.

Smith, J. T., B. W. Allred, C. S. Boyd, J. C. Carlson, K. W. Davies, C. A. Hagen, D. E. Naugle, A. C. Olsen, and J. D. Tack. 2020. Are sage-grouse fine-scale specialists or shrub-steppe generalists? Journal of Wildlife Management 84:759–774.

Sorenson, M. D. 1989. Effects of neck collar radios on female redheads. Journal of Field Ornithology 60:523–528.

van de Pol, M., L. W. Bruinzeel, D. I. K. Heg, H. P. van der Jeugd, and S. Verhulst. 2006. A silver spoon for a golden future: long-term effects of natal origin on fitness prospects of oystercatchers (*Haematopus ostralegus*). Journal of Animal Ecology 75:616–626.

Vehtari, A., J. Gabry, M. Magnusson, Y. Yao, P. C. Bürkner, T. Paananen, A. Gelman, B. Goodrich, J. Piironen, and B. Nicenboim. 2020. loo: efficient leave-one-out cross-validation and WAIC for Bayesian models. R package version 2. 3.1. https://mc-stan.org/loo/

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Diego, California, USA.

Wood, H. B. 1945. The history of bird banding. Auk 62:256–265.

Zicus, M. C., D. F. Schultz, and J. A. Cooper. 1983. Canada goose mortality from neckband icing. Wildlife Society Bulletin 11:286–290.

Associate Editor: Daniel Collins.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Sedinger, J. S., M. S. Lindberg, T. V. Riecke, A. G. Leach, B. W. Meixell, C. A. Nicolai, and D. N. Koons. 2022. Do hunters target auxiliary markers? An example using black brant. Journal of Wildlife Management 86:e22172. https://doi.org/10.1002/jwmg.22172