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# Survival of Barrow's Goldeneyes during Remigial Molt and Fall Staging

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**ABSTRACT** Postbreeding survival of waterfowl is rarely quantified, despite potential for constraints during this stage of the annual cycle that may subsequently affect population dynamics. We estimated survival of radio-marked adult male Barrow's goldeneyes (*Bucephala islandica*) during remigial molt and fall staging at Cardinal and Leddy Lakes in the Boreal Transition Zone of northwestern Alberta, Canada. Daily survival rate (DSR) was high during remigial molt (DSR = 0.9987, 95% CI: 0.9967–1.0000), corresponding to a 39-day period survival rate (PSR) of 0.95 (95% CI: 0.88–1.00). During fall staging, DSR was markedly lower (DSR = 0.9938, 95% CI: 0.9898–0.9978), corresponding to a PSR of 0.68 (95% CI: 0.53–0.87) over the 62-day period between the end of remigial molt and fall migration. Half of fall staging mortalities observed on Cardinal Lake were directly attributed to hunting. We conclude that remigial molt is a period with high survival in the annual cycle of Barrow's goldeneyes at our study sites. However, in light of low fall staging survival, Barrow's goldeneye harvest management strategies should be carefully evaluated with intent to reduce risk of localized high mortality at significant staging sites in western Canada. © 2013 The Wildlife Society.

**KEY WORDS** Alberta, Barrow's goldeneye, *Bucephala islandica*, fall staging, hunting mortality, postbreeding, remigial molt, survival.

Population dynamics of birds that are long-lived and exhibit delayed reproductive maturity are more sensitive to variation in adult survival than reproductive output or juvenile survival (Schmutz et al. 1997, Sæther and Bakke 2000, Stahl and Oli 2006). Sea ducks (*Mergini*) are long-lived ducks that typically reproduce first at 2 or 3 years of age, thus variation in adult survival potentially has strong influences on population dynamics for this tribe (Goudie et al. 1994) relative to other ducks. However, despite concern about many sea duck populations (Sea Duck Joint Venture Management Board 2008), the contribution of variation in adult survival to population dynamics is largely unknown, as survival rates of sea ducks have seldom been quantified. Further, direct measures of survival at specific annual cycle stages are rare for sea ducks, which constrains understanding about when and where demographic bottlenecks might occur, and subsequently limits the ability of managers to target those bottlenecks for conservation action.

The postbreeding period represents a potentially risky stage in the annual cycle of waterfowl, which could lead to demographic constraints (i.e., events or processes that negatively affect survival and subsequent population trajectory). This stage encompasses the period between arrival on molting sites until departure for wintering areas. Remigial molt typically occurs within this stage, rendering birds flightless for 20–40 days (Hohman et al. 1992). Costs associated with simultaneous remigial molt potentially include reduced foraging efficiency (Bridge 2004), reduced ability to escape predators or anthropogenic disturbances, and increased daily nutritional demands that may require catabolism of somatic nutrients (Hohman 1993, Murphy 1996, Fox and Kahlert 2005, Portugal et al. 2007, Fox and King 2011). A number of studies have quantified strategies that waterfowl use to accommodate constraints imposed by simultaneous remigial molt, including adaptive loss of mass for an earlier return to flight or greater chance of evading predators (Panek and Majewski 1990, Brown and Saunders 1998, Zimmer et al. 2010), reduced foraging activity to decrease detection by predators (Adams 2000, Dopfner et al. 2009), and selection of molt sites with abundant food, low predator density, and low anthropogenic disturbance (Salomonsen 1968, Zicus 1981, Derksen et al. 1982, Madsen and Mortensen 1987, Thompson and Drobney 1997). However, few studies have quantified survival rates of waterfowl during remigial molt to assess the potential of this stage to act as a demographic bottleneck (Bowman and Longcore 1989, Miller et al. 1992, Iverson and Esler 2007, Evelsizer et al. 2010, Fleskes et al. 2010). Furthermore, survival rates have never been quantified for sea ducks during fall staging (post-remigial molt). Some species of ducks remain at molt sites well beyond

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remigial molt, which for some species results in occurrence on postbreeding areas for over a third of the annual cycle (Gilliland et al. 2002, Iverson and Esler 2006, Savard et al. 2007, Oppel et al. 2008, Hogan et al. 2011). Understanding demographic rates at postbreeding sites is essential for assessing the potential of this period to influence population dynamics, and can aid in identifying stages in the annual cycle upon which conservation efforts should focus.

Barrow's goldeneyes (*Bucephala islandica*) are mid-sized sea ducks primarily distributed along the western coast of North America (Eadie et al. 2000). The postbreeding period of male Barrow's goldeneyes encompasses prebasic molt (including remigial molt) and most of pre-alternate molt. Two particularly significant postbreeding sites for Barrow's goldeneyes in western North America were recently discovered in the Boreal Transition Zone of Alberta (i.e., Cardinal and Leddy Lakes; Hogan et al. 2011). Studies at these sites indicated that most birds were adult males (78–85%) and that, based on body mass and foraging trends, birds were not nutritionally constrained during remigial molt (Hogan 2012). These results suggest that these lakes currently provide high-quality postbreeding habitat for Barrow's goldeneyes. However, demographic consequences of selecting these postbreeding sites are unknown. The objective of this study was to quantify survival rates of postbreeding adult male Barrow's goldeneyes at Cardinal and Leddy Lakes, Alberta to determine if remigial molt and fall staging were periods of demographic constraint for this species.

## STUDY AREA

Cardinal Lake (56°14′N, 117°44′W, also Lac Cardinal) is a large lake (approx. 50 $km^2$) in the Boreal Transition Zone of northwestern Alberta. The lake is shallow (<2 m) and hypereutrophic with a gravel and mud substrate, and dense submergent vegetation throughout much of the basin. Leddy Lake (56°23′N, 117°27′W) is a small (approx. 4 $km^2$) lake located approximately 25 km northeast of Cardinal Lake. It is also shallow, eutrophic, and has a dense submerged vegetation mat covering the central portion of the lake. Neither basin supports populations of sport fish. These sites are 2 of only 5 sites known to support large aggregations of postbreeding Barrow's goldeneyes in western North America, with 5,000–7,000 birds (primarily adult males) using the lakes during remigial molt and fall staging annually (Hogan et al. 2011). Barrow's goldeneyes use these sites for approximately 5 months, from mid-June to mid-November (Hogan et al. 2011).

## METHODS

We captured Barrow's goldeneyes on Cardinal and Leddy Lakes using drive trapping techniques during remigial molt (late July to early September) in 2009 and 2010. We obtained morphometric measurements, including ninth primary length (mm) and body mass (g) for each individual and fit each bird with a uniquely numbered United States Fish and Wildlife Service stainless steel tarsal band. We determined sex by cloacal and plumage characteristics (Hochbaum 1942, Carney 1983) and age class by depth of the bursa of Fabricius (Mather and Esler 1999, Iverson et al. 2003). We classified individuals with bursa depth <10 mm as after-second-year (ASY; i.e., more than 2 yr since hatching).

Each year, we marked 25 ASY males from each lake with very high frequency (VHF) radio transmitters (<12 g; Advanced Telemetry Systems, Isanti, MN). We attached transmitters using subcutaneous prongs and super glue (Iverson et al. 2006). We monitored survival of each radio-marked individual by listening for its radio signal approximately every 10 days during remigial molt (late Jul to mid-Sep) and every 5 days during fall staging (mid-Sep to mid-Nov). Transmitters were equipped with mortality sensors that doubled the signal pulse-rate after 12 hours of inactivity. We confirmed all mortality signals by recovery of a carcass or location of transmitters in upland habitats (farm field or forest) that are never used by postbreeding Barrow's goldeneyes. We also identified mortalities from reports of radio-marked birds harvested by hunters. The hunting season at Cardinal and Leddy Lakes started at the end of remigial molt and the start of fall staging (1 Sep). We assigned the date of death for each harvested bird as the day the hunter reported shooting the bird. We assumed disappearance of a bird without detection of a mortality signal or harvest report from a hunter to be due to either radio failure, shedding of the radio into water, or emigration during fall staging. We treated birds that disappeared without detection of a mortality signal or report of harvest as alive, but we censored them from the analysis the day after the last day the bird was known to be alive. We performed all activities in accordance with the requirements of the Simon Fraser University Animal Care Committee (protocol # 921B-09).

### Data Analysis

We applied a 7-day censor period following radio attachment to each bird before inclusion in data analyses to account for any influence of capture and handling (Kirby and Cowardin 1986, Cox and Afton 1998, Esler et al. 2000). We did not include birds in the analysis that died during the censor period or were found dead upon the first observation following the censor period ($n = 1$). We calculated daily survival rate (DSR) using a modified Mayfield method of nest survival analysis (Bart and Robson 1982, Dinsmore et al. 2002) for ragged telemetry data (Program MARK 6.1, http://www.phidot.org/software/mark/, accessed 23 Sep 2011). Calculation of DSR using this method required 4 pieces of information from each radio-marked bird: 1) first day observed (in this case, first day post-censor period), 2) last day the bird was known alive, 3) last day the bird was checked, and 4) fate of the bird. For birds that disappeared without detection of a mortality signal or report of harvest, the last day the bird was known alive was the same as the last day the bird was successfully checked.

We used multiple linear logistic regression models to investigate variation in DSR as a function of postbreeding stage, lake, and year. We used a logit link function in our analysis. Postbreeding stage was a 2-level categorical variable (remigial molt and fall staging). We classified birds as

undergoing remigial molt between the first day the new ninth primary was visible from the skin of the wing to the day the ninth primary was fully grown (39 days, Hogan 2012), and as fall staging birds afterwards. We also treated lake (Cardinal vs. Leddy) and year (2009 vs. 2010) as 2-level categorical variables.

We used an information theoretic approach to contrast support for a suite of 12 models (Burnham and Anderson 2002). The candidate model set included a null model that tested the hypothesis that survival was constant across postbreeding stage, lake, and year. Survival might differ between remigial molt and fall staging, so we included a model to specifically address this hypothesis. Survival also might vary with different conditions encountered at different lakes or in different years, so we included lake and year variables in models to test those hypotheses. We included models with all additive combinations of main effects. We also included models with each possible 2-way interaction along with the corresponding main effects. Finally, we included a global model with all main effects and all 2-way interactions. The model set was balanced in terms of numbers of models in which each main effect occurred (7) and in which each interaction term occurred (2).

We used Akaike's Information Criterion corrected for small samples sizes ($AIC_c$; Burnham and Anderson 2002) to identify the most parsimonious model in the candidate set. We calculated the difference between each model and the most parsimonious model ($\Delta AIC_c$) and $AIC_c$ weights ($w_i$) to evaluate relative support for each model. We calculated cumulative parameter weights ($\Sigma w_i$) for each variable to evaluate the level of support for variables within the candidate model set. We also calculated model averaged estimates of DSR (with unconditional 95% CIs) in Program MARK. We calculated the period survival rate (PSR) during remigial molt and fall staging as $DSR^n$ where $n$ = days in the period, 39 days during remigial molt and 62 days during fall staging. We calculated confidence intervals for PSR by raising the 95% confidence intervals of DSR to the power of $n$.

## RESULTS

Among the birds included in our survival estimates, 1 of 25 molting birds died on Cardinal Lake in 2009, 1 of 25 molting birds died on Leddy Lake in 2009, and 2 of 24 molting birds died on Leddy Lake in 2010. No birds died during remigial molt on Cardinal Lake in 2010. Two radio-marked birds on Cardinal Lake, and 1 on Leddy Lake, went missing before the end of remigial molt, presumably due to radio failure or shedding. Thus, we monitored 92 birds during the fall staging period (mid-Sep to mid-Nov). Among these, 16 birds moved from Leddy to Cardinal Lake during the course of fall staging in 2009, and 19 birds made the same move in 2010. We treated these birds as Cardinal Lake birds for the time period following the move. Birds that underwent remigial molt on Cardinal Lake never moved to Leddy Lake. Four birds died during fall staging on Cardinal Lake in 2009 and 10 died in 2010. Two birds died on Leddy Lake during fall staging in 2009 and none during 2010. Cumulatively, 7 of 14 mortalities during fall staging (50%) on Cardinal Lake were directly attributable to hunting. Carcasses or mortality signals of all dead birds were found in upland habitats never used by Barrow's goldeneyes; however, we could not determine if birds had died as a result of predation or if they had been scavenged after death from some other factor.

**Table 1.** Model selection results explaining variation in survival (S) of adult male Barrow's goldeneyes during the postbreeding period on Cardinal and Leddy Lakes, Alberta in 2009 and 2010 based on differences in Akaike's Information Criterion for small sample sizes ($\Delta AIC_c$). We did not include models with $AIC_c$ weights ($w_i$) < 0.02 in the table. Postbreeding stage is a categorical variable with 2 levels (remigial molt or fall staging). Lake is a categorical variable with 2 levels (Cardinal or Leddy). Year is a categorical variable with 2 levels (2009 or 2010).

| Model | $\Delta AIC_c$ | $w_i$ | No. parameters | Deviance |
|---|---|---|---|---|
| $S_{STAGE}$ | 0 | 0.31 | 2 | 188.498 |
| $S_{STAGE+LAKE+STAGE\times LAKE}$ | 0.31 | 0.27 | 4 | 184.806 |
| $S_{STAGE+LAKE}$ | 1.54 | 0.14 | 3 | 188.037 |
| $S_{STAGE+YEAR}$ | 1.94 | 0.12 | 3 | 188.437 |
| $S_{STAGE+LAKE+YEAR}$ | 3.54 | 0.05 | 4 | 188.030 |
| $S_{STAGE+YEAR+STAGE\times YEAR}$ | 3.94 | 0.04 | 4 | 188.431 |

The model containing the main effect of postbreeding stage received the most support from the data ($w_i = 0.31$; Table 1). The model containing the main effects of postbreeding stage and lake, as well as the interaction between these variables was next best supported in the model set ($w_i = 0.27$; Table 1), though cumulative parameter weights suggest that postbreeding stage was more influential on DSR than lake (Table 2). Although the stage and lake, stage and year, stage, lake and year, and stage × year models received modest support from the data, their model deviance did not differ substantially from the simpler postbreeding stage model, suggesting that the additional parameters were uninformative (Table 1; Arnold 2010). This conclusion was supported by cumulative parameter weights (Table 2) that were lower than postbreeding stage. All other models received poor support ($w_i < 0.02$).

The overall model-averaged estimate of DSR during remigial molt was 0.9987 (95% CI: 0.9967–1.000), which corresponded to a PSR of 0.95 (95% CI: 0.88–1.00) over the 39-day remigial molt period (Fig. 1). The overall model-averaged estimate of DSR during fall staging was 0.9938 (95% CI: 0.9898–0.9978), which corresponded to a PSR of 0.68 (95% CI: 0.53–0.87) over the 62-day fall staging period. Model-averaged estimates of DSR by stage and lake were 0.9987 (95% CI: 0.9967–1.000) and 0.9983 (95% CI: 0.9962–1.000) during remigial molt on Cardinal and Leddy lakes, respectively, and 0.9938 (95% CI: 0.9898–0.9978) and

**Table 2.** Cumulative parameter weights ($\Sigma w_i$) of variables explaining variation in daily survival rate of postbreeding Barrow's goldeneyes at Cardinal and Leddy Lakes, Alberta in 2009 and 2010.

| Parameter | $\Sigma w_i$ |
|---|---|
| Stage | 0.96 |
| Lake | 0.50 |
| Year | 0.24 |
| Stage × lake | 0.28 |
| Stage × year | 0.06 |
| Lake × year | 0.02 |

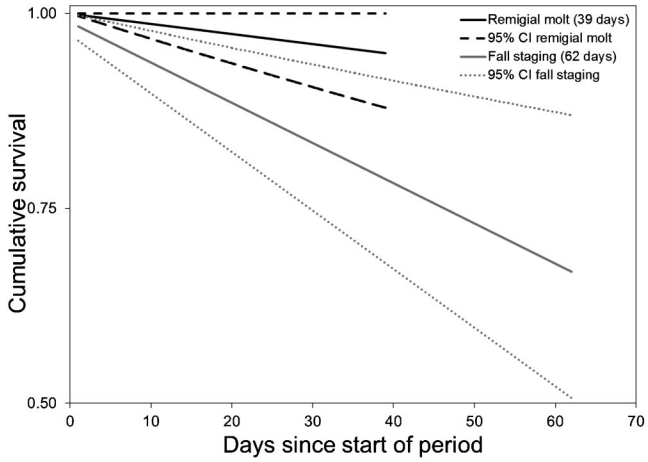


**Figure 1.** Cumulative survival of adult male Barrow's goldeneyes on Cardinal and Leddy Lakes, Alberta during remigial molt and fall staging based on model-averaged daily survival rates (DSR). We calculated survival rates using a modified Mayfield method. Remigial molt DSR = 0.9987 and fall staging DSR = 0.9938. Remigial molt and fall staging are 39 and 62 days, respectively.

0.9955 (95% CI: 0.9909–1.000) during fall staging on Cardinal and Leddy lakes, respectively.

## DISCUSSION

Postbreeding survival of adult male Barrow's goldeneyes was high during remigial molt, suggesting that this was not a period of demographic constraint for this species at our study sites. Survival during fall staging was substantially lower, and half of the observed fall staging mortality on Cardinal Lake was directly attributable to hunting. Furthermore, given relatively high wounding rates for many species of waterfowl (Norton and Thomas 1994, Tavecchia et al. 2001), and particularly sea ducks (Hicklin and Barrow 2004, Merkel et al. 2006), as well as the potential for un-reported hunting mortality (Nichols 1989, Nichols et al. 1991), hunting was likely responsible for an even larger fraction of the observed mortality on Cardinal Lake during fall staging.

Simultaneous remigial molt can impose elevated nutritional costs and increase risk of predation on waterfowl (Murphy 1996, Brown and Saunders 1998, Portugal et al. 2007, Dopfner et al. 2009, Fox and King 2011). Body mass and foraging studies of adult male Barrow's goldeneyes molting on our study sites suggested that birds were not nutritionally constrained (birds gained mass with little effort), nor were they adaptively losing mass or restricting foraging to avoid predators (Hogan 2012), suggesting that mortalities that occurred during remigial molt were not due to starvation or predation. It is more likely that deceased goldeneyes found in upland habitats were scavenged after some other cause of death (e.g., disease). Also, given our estimates of high DSR and PSR during remigial molt, we suggest that males are not experiencing a demographic bottleneck during this stage of the annual cycle. The average DSR of 0.9987 corresponded to a 95% survival rate over the 39-day molting period, which is similar to rates estimated for other sea duck species during molt (Iverson and Esler 2007, B. Uher-Koch, Simon Fraser University, unpublished data) and higher than estimates for some dabbling ducks (Bowman and Longcore 1989, Miller et al. 1992, Fleskes et al. 2010). However, survival during other stages of the annual cycle, with the exception of fall staging, is likely higher than during remigial molt, as a DSR of 0.9987 would yield an annual survival rate of approximately 0.62, which is low compared to other adult sea ducks (Mittelhauser et al. 2008, Oppel and Powell 2010).

High survival rates of molting males on Cardinal and Leddy Lakes suggest that these sites provide high-quality molting habitat and that Barrow's goldeneyes employ successful strategies to accommodate risks associated with the flightless period. Previous, associated studies (Hogan 2012) found that body mass and foraging dynamics varied considerably between lakes and years, which was interpreted to represent optimized nutritional strategies based on variation in local conditions. Our survival findings reinforce the conclusion that these strategies, although different, are all tenable and result in completion of molt without demographic constraints.

Average DSR and PSR were considerably lower during fall staging at Cardinal and Leddy Lakes than during remigial molt. Further, Leddy Lake birds experienced higher fall staging survival than Cardinal Lake birds. We did not observe hunting activity on Leddy Lake, but observed nearly daily activity on Cardinal Lake during the fall staging period. We directly attributed 7 of 14 mortalities on Cardinal Lake during fall staging to hunting. The remaining mortalities on both lakes were due to unknown causes, though some, particularly on Cardinal Lake, were likely due to crippling associated with hunting (Goudie et al. 2000, Byers and Dickson 2001, Hicklin and Barrow 2004, Merkel et al. 2006). Also, previous studies of band returns for mallards (*Anas platyrhynchos*) showed that not all banded birds that were shot were reported by hunters, and that shot birds were not always retrieved (Nichols 1989, Nichols et al. 1991, Reinecke et al. 1992). Given these potential confounding circumstances, our estimate of hunting mortality at Cardinal Lake is likely conservative.

The PSR of 0.68 during fall staging was lower than PSR for other duck species (0.79–1.00) during fall staging and winter periods (Kirby and Cowardin 1986, Esler et al. 2000, Mittelhauser et al. 2008). If winter survival of adult male Barrow's goldeneyes is similar to that of other sea duck species (Esler et al. 2000, Mittelhauser et al. 2008), then fall staging at Cardinal and Leddy Lakes could represent the period of lowest survival in the annual cycle. Annual apparent survival of adult male Barrow's goldeneyes was estimated at 58–60% at a breeding site in central British Columbia, though these estimates are presumably lower than true survival (Savard and Eadie 1989, Boyd et al. 2009). Although adult survival is likely a strong driver of population dynamics for Barrow's goldeneyes, how adult male survival at these sites influences population dynamics of Barrow's goldeneyes at a larger scale is still unclear. However, given relatively high (67%) levels of postbreeding site fidelity observed in satellite-marked birds (S. Boyd, Environment Canada, unpublished data), high localized mortality during fall staging at Cardinal

Lake could significantly affect Barrow's goldeneyes breeding in the intermountain region of British Columbia and potentially erode use of this high-quality postbreeding site in the future.

Some potential population-level consequences of high fall staging mortality of adult male Barrow's goldeneyes include alteration of population sex ratios and loss of long-term pair bonds. Sex ratios of Barrow's goldeneyes on breeding and wintering grounds are male biased by a factor of 1.2–1.5, suggesting intraspecific competition between males for females (Bellrose 1980, Savard and Eadie 1989). However, high adult male mortality could influence population dynamics if it skewed sex ratios in favor of females. As an annually monogamous sea duck, Barrow's goldeneyes might be particularly sensitive to unequal sex ratios (Lehikoinen et al. 2008), as extra-pair copulations have never been documented and some females may not find a mate if too few males occur in the population. Also, Savard (1985) documented existence of long-term pair bonds in some Barrow's goldeneyes breeding at Riske Creek, British Columbia, which could increase the influence of adult male survival on population dynamics. Inter-annual monogamy is generally thought to increase fitness of individuals by decreasing time spent on courtship behavior, and increasing probability of securing a territory, time spent feeding, and reproductive success (Spurr and Milne 1976, Black 2001). More recently, loss of long-term male mates has been shown to decrease subsequent female survival in black brant (*Branta bernicla nigricans*; Nicolai et al. 2012).

## MANAGEMENT IMPLICATIONS

Propensity of waterfowl to aggregate at a small number of sites during remigial molt indicates that degradation of postbreeding sites may have wide reaching implications for waterfowl populations. This study and concurrently collected body mass and foraging data (Hogan 2012) indicate that Cardinal and Leddy Lakes provided high-quality habitat for up to approximately 5% of the world population of Barrow's goldeneyes (Hogan et al. 2011). Additionally, postbreeding Barrow's goldeneyes used Cardinal and Leddy Lakes for over a third of the annual cycle, with many individuals staying for both remigial molt and fall staging (Hogan et al. 2011). Given the small number of sites in western North America that have been identified to support substantial numbers of molting Barrow's goldeneyes (Hogan et al. 2011), conservation of currently recognized sites and assurance of protection during this sensitive stage in the annual cycle is warranted. We recommend that managers consider effects of hunting on survival of staging Barrow's goldeneyes during fall and evaluate the potential of harvest to affect Barrow's goldeneye population dynamics and continuing use of traditional molting sites.

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