Phenology and duration of remigial moult in Surf Scoters (*Melanitta perspicillata*) and White-winged Scoters (*Melanitta fusca*) on the Pacific coast of North America

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Abstract: By quantifying phenology and duration of remigial moult in Surf Scoters (*Melanitta perspicillata* (L., 1758)) and White-winged Scoters (*Melanitta fusca* (L., 1758)), we tested whether timing of moult is dictated by temporal optima or constraints. Scoters (n = 3481) were captured during moult in Alaska, British Columbia, and Washington, and remigial emergence dates were determined. We provide evidence for a pre-emergence interval of 7.3 days that occurs after old primaries are shed and before new ones become visible. All age and sex classes of both scoter species exhibited a wide range of emergence dates (Surf Scoters: 26 June to 22 September; White-winged Scoters: 6 July to 21 September) suggestive of a lack of strong temporal optima for remigial moult. For both species, timing of moult was influenced by site, year, age, and sex. Relative to other waterfowl species, scoters have typical remigial growth rates (Surf Scoters: 3.9 mm·day^{-1}; White-winged Scoters: 4.3 mm·day^{-1}) but a long flightless period (34–49 days), in part because their relatively high wing-loading requires a greater proportion of feather regrowth to regain flight. Our data suggest that moulting scoters are not under strong selective pressure to complete moult quickly.

Key words: *Melanitta perspicillata*, Surf Scoter, *Melanitta fusca*, White-winged Scoter, sea duck, remigial moult, phenology, duration, primary feather.

Résumé : La quantification de la phénologie et de la durée de la mue des rémiges chez les macreuses à front blanc (*Melanitta perspicillata* (L., 1758)) et les macreuses brunes (*Melanitta fusca* (L., 1758)) nous a permis de vérifier si le moment de la mue est dicté ou non par des optima ou autres contraintes temporels. Des macreuses (n = 3481) ont été capturées durant la mue en Alaska, en Colombie-Britannique et dans l'État de Washington, et les dates d'apparition des rémiges ont été déterminées. Nous présentons des données indiquant qu'un intervalle de 7,3 jours précédant cette apparition s'écoule après la perte des vieilles ailes primaires et avant que les nouvelles ne deviennent visibles. Toutes les classes d'âge et de sexe des deux espèces de macreuses présentent une large fourchette de dates d'apparition (macreuse à front blanc : du 26 juin au 22 septembre; macreuse brune : du 6 juillet au 21 septembre), ce qui laisse croire à l'absence de forts optima temporels de mue des rémiges. Pour les deux espèces, le moment de la mue était influencé par le site, l'année, l'âge et le sexe. Comparativement à d'autres espèces de sauvagines, les macreuses présentent des taux de croissance des rémiges typiques (macreus

Introduction

Remigial moult is a distinct phase in the annual cycle of scoters south of Alaska, with upwards of 20 000 scoters (E.M. Anderson and J.R. Evenson, unpublished data).

To capture scoters, we used a floating gill-net method, adapted from a submerged mist-net technique (Breault and evaluate factors related to variation in remigial emergence dates. Data were analyzed separately for each species, using the same candidate model set. Explanatory variables included cohort (a combination of sex and age class), site (southeast Alaska versus Salish Sea), and year (2008 versus 2009). The four cohorts were female adults (FASY), female subadults (FSY), male adults (MASY), and male subadults (MSY). Each candidate model set included all additive combinations of the main effects and two-way interactions, as well as a null model (Tables 2 and 3). To run regression models, we used the lm function in R (R Development Core Team 2011).

We employed an information-theoretic approach to model selection to evaluate the candidate model sets (Burnham and Anderson 2002). Akaike's information criterion corrected for small sample sizes (AIC_c) was calculated for each candidate model. Candidate models were ranked by their ΔAIC_c values, calculated as the difference between the AIC_c score of each model and that of the best-supported model in the candidate set. The relative support for each model in the candidate set was determined by its Akaike weight (w_i), which is a normalized measure of the likelihood of a given model relative to the likelihood of all other models in the candidate set. Parameter likelihood values and weighted parameter estimates based on all candidate models were used in multimodel inference (Burnham and Anderson 2002) to assess the importance of individual variables in the candidate models.

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Table 2. Multiple linear regression model results assessing variation in 9th primary feather emergence dates in Surf Scoter (*Melanitta perspicillata*) in southeast Alaska and the Salish Sea.

Model	k	ΔAIC_c	w_i
Cohort[a] + site[b] + year[c] + cohort × site + cohort × year + site × year	14	0.0	0.99
Cohort + site + year + cohort × year + site × year	11	8.4	0.01
Cohort + site + year + cohort × site + site × year	11	22.9	0.00
Cohort + site + year + site × year	8	31.7	0.00
Cohort + site + year + cohort × year	10	53.1	0.00
Cohort + site + year + cohort × site + cohort × year	13	54.3	0.00
Cohort + site + year	7	101.5	0.00
Cohort + site + year + cohort × site	10	104.1	0.00
Cohort + site	6	109.4	0.00
Cohort + site + cohort × site	9	111.2	0.00
Cohort + year + cohort × year	9	174.3	0.00
Cohort + year	6	231.1	0.00
Cohort	5	242.2	0.00
Site + year + site × year	5	2091.9	0.00
Site + year	4	2215.4	0.00
Site	3	2235.8	0.00
Year	3	2515.9	0.00
Null	2	2551.0	0.00

Note: The number of parameters (*k*) includes +1 for intercept and +1 for model variance estimated for each model.

[a]Cohort is either femaleASY, femaleSY, maleASY, or maleSY, where ASYis after second year and SY is second year.

[b]Site is either southeast Alaska or Salish Sea.

[c]Year is either 2008 or 2009.

Table 3. Multiple linear regression model results assessing variation in 9th primary feather emergence dates in White-winged Scoters (*Melanitta fusca*) in southeast Alaska and the Salish Sea.

Model	k	ΔAIC_c	w_i
Cohort[a] + site[b] + year[c] + cohort × year + site × year	11	0.0	0.46
Cohort + site + year + cohort × year	10	0.3	0.40
Cohort + site + year + cohort × site + cohort × year + site × year	14	3.8	0.07
Cohort + site + year + cohort × site + cohort × year	13	3.8	0.07
Cohort + site + year	7	17.1	0.00
Cohort + site + year + cohort × site	10	17.7	0.00
Cohort + site + year + site × year	8	18.8	0.00
Cohort + site + year + cohort × site + site × year	11	19.5	0.00
Cohort + site	6	31.9	0.00
Cohort + site + cohort × site	9	32.2	0.00
Cohort + year + cohort × year	9	98.5	0.00
Cohort + year	6	109.9	0.00
Cohort	5	141.7	0.00
Site + year	4	258.2	0.00
Site + year + site × year	5	260.3	0.00
Site	3	276.1	0.00
Year	3	388.8	0.00
Null	2	431.1	0.00

Note: The number of parameters (*k*) includes +1 for intercept and +1 for model variance estimated for each model.

[a]Cohort is either femaleASY, femaleSY, maleASY, or maleSY, where ASY is after second year and SY is second year.

[b]Site is either southeast Alaska or Salish Sea.

[c]Year is either 2008 or 2009.

(n = 9) and 4.7 ± 0.1 $mm \cdot day^{-1}$ for White-winged Scoters (n = 8). For captive scoters at Patuxent Wildlife Research primaries to the maximum length observed for captured moulting individuals. The total duration of the 9th primary growth period, including the pre-emergence interval, was calculated using the estimated feather growth rates and the mean final length of 9th primary feathers (measured on winter-captured scoters). The time required to complete growth of the 9th primaries was 45.6 and 48.2 days for female and male Surf Scoters, respectively, and 47.2 and 49.8 days for which scoters undergo moult on the Pacific coast. The duration of the flightless period is long relative to other waterfowl, evidence that scoters are not under strong pressure to complete moult rapidly. The earliest remigial emergence dates were in late June (for SY and ASY male Surf Scoters) and the latest emergence dates were 21

row's Goldeneye (*Bucephala islandica* (Gmelin, 1789)) arrived at moulting areas over a month before shedding primary feathers (Robert et al. 2002).

Remigial moult and migration

Salomonsen (1968) suggested that adult female waterfowl moulting with males and subadults are likely nonbreeders (in that year). However, our data suggest that many adult females moulting on the coast could have spent the summer on breeding areas, and either did not successfully nest or may have

Black Brant (*Branta bernicla nigricans* (Lawrence, 1846)): Taylor 1995; Barrow's Goldeneye: Hogan 2012). Generally, we observed a wider range of emergence dates and later emergence dates in the Salish Sea than in southeast Alaska. It could be that individuals migrating from breeding areas to the coast later in the season are more likely to go to southern moulting areas or that individuals moulting in the Salish Sea spend a longer period on the coast before beginning moult.

Feather growth rates

Our estimates of scoter primary feather growth rates are similar to those obtained for adults of other duck species (4.2–5.2 mm·day^{-1}) and fall within the typical range of 2%–3% daily change in length, relative to final primary length (Hohman et al. 1992). However, they are higher than values

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