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THE INFLUENCE OF SALINITY ON PROVISIONING RATES AND NESTLING GROWTH IN BALD EAGLES IN THE LOWER CHESAPEAKE BAY

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Abstract. We measured provisioning and growth patterns in Bald Eagle (*Haliaeetus leucocephalus*) chicks from nests in two salinity zones in the lower Chesapeake Bay. Nestlings in mesohaline reaches experienced higher per capita consumable energy provisioning rates and had higher instantaneous growth rates compared to nestlings in tidal-fresh salinity zones. These results suggest that Bald Eagles nesting along mesohaline reaches are more successful at meeting the energetic demands of brood rearing compared to pairs nesting along tidal-fresh reaches, a finding consistent with documented higher reproductive rates and proportion of three-chick broods along mesohaline reaches compared to tidal-fresh reaches. The results of this study have important conservation implications for Bald Eagles by addressing issues related to variation in habitat quality within a continuous ecosystem and the determination of core breeding zones.

Key words: anadromous, Bald Eagle, Chesapeake Bay, growth, Haliaeetus leucocephalus*, provisioning, salinity.*

La Influencia de la Salinidad sobre las Tasas de Aprovisionamiento y Crecimiento de los Pichones de *Haliaeetus leucocephalus* en la Parte Baja de la Bahía Chesapeake

Resumen. Medimos los patrones de aprovisionamiento y crecimiento de los pichones de *Haliaeetus leucocephalus* provenientes de nidos de dos zonas salinas de la parte baja de la Bahía Chesapeake. Los pichones de las zonas de salinidad intermedia experimentaron tasas de aprovisionamiento de energía consumible per capita mayores y tuvieron tasas de crecimiento instantáneo mayores comparadas con las de los pichones de las zonas de agua dulce con influencia marina. Estos resultados sugieren que las águilas que nidifican a lo largo de las zonas de salinidad intermedia fueron más exitosas en alcanzar las demandas energéticas de cría de los pichones, comparado con las parejas que nidifican a lo largo de las zonas de agua dulce con influencia marina. Esto concuerda con hallazgos que documentan tasas reproductivas mayores y proporciones de nidadas de tres pichones a lo largo de las zonas de salinidad intermedia en comparación con las zonas de agua dulce con influencia marina. Los resultados de este estudio tienen implicancias importantes para la conservación de *H. leucocephalus* porque analizan aspectos relacionados a la variación en la calidad del hábitat en un ecosistema continuo y a la determinación de zonas núcleo de nidificación.

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For Bald Eagles (*Haliaeetus leucocephalus*) nesting in the lower Chesapeake Bay, shoreline areas surrounding tidally influenced freshwater reaches (i.e., tidal-fresh) currently support a greater nesting density and have experienced faster rates of population increase than areas surrounding higher salinity waters (Watts et al. 2006). These findings imply that habitat quality varies spatially along the salinity gradient of the bay, though the specific attributes that drive these patterns are not clear. Watts et al. (2006) proposed that variation in prey availability, mediated through changes in the salinity of the bay water, may be one factor responsible for the observed patterns.

A recent investigation examined the influence of salinity on diet composition in breeding Bald Eagles within this region and found that dominant prey taxa did not vary significantly between tidal-fresh and mesohaline salinity reaches (Markham 2004). This suggests that pairs nesting within each zone utilized similar prey resources despite the documented influence of salinity on fish distribution in the bay (Murdy et al. 1997, Jung 2002). However, this finding of a similarity in patterns of prey use does not preclude the possibility that nesting pairs experience spatial variation in prey abundance and availability.

In birds, provisioning rates decline with decreasing prey availability (Newton 1979), and offspring experience slower growth rates under poorer food conditions (Ricklefs et al. 1998, Schew and Ricklefs 1998). Among raptors, the amount of prey

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available to foraging adults can affect both the rate at which parents provision young and the rate of nestling growth (Moss 1979, Gebhardt-Henrich 1990, Steidl and Griffin 1991). Specifically for Bald Eagles, Bortolotti (1989) demonstrated that nestlings raised in areas of high prey availability grew faster than chicks in areas of lower prey availability, and growth rate was significantly associated with the total prey biomass delivered to nestlings. Intraspecific variation in the rate of food delivery (Collopy 1984) and the growth trajectories of young (Quinney et al. 1986) in different areas can thus be an indicator of spatial variation in habitat quality.

We examined provisioning and growth rates in nestling Bald Eagles, as well as the ability of adults to provision broods of varying sizes, in two salinity zones in the lower Chesapeake Bay. Results from these analyses are discussed in the context of potential variation in habitat quality between the salinity reaches, with a specific focus on the relationship of observed trends to documented nest distribution patterns within the ecosystem.

METHODS

We monitored Bald Eagle nests along the shorelines of the James, York, and Rappahannock Rivers during the 2002–2004 breeding seasons (Fig. 1). Three salinity zones were recognized along the salinity gradients of these tributaries: tidal-fresh (0.0–0.5 parts per thousand [ppt] salinity), oligohaline (0.5–5.0 ppt), and mesohaline (5.0–18.0 ppt; Data Analysis Work Group 1997). We selected nests within tidal-fresh and mesohaline reaches that were accustomed to a moderate level of human interaction, that were within territories used for ≥5 years (to control for parental experience), and that were distant from boundaries of salinity zones. Studies that have quantified home ranges in similar systems (Garrett et al. 1993, Thompson and McGarigal 2002) have shown that the length of shorelines used for foraging vary between 3.6 and 10.6 km (suggesting birds are moving 2–5 km in one direction). The majority of nests used in this study were greater than 50 km from the closest reach with a different salinity type, with the closest more than 20 km, suggesting that there is very little likelihood that birds crossed over between salinity zones. Our observations suggested that pairs included within this study were foraging within target salinity zones. We quantified both chick provisioning and growth during 2002–2003 for 10 nests and eight nests along tidal-fresh and mesohaline reaches, respectively. We also measured only chick growth in 2004 at an additional six nests in the tidal-fresh reaches and four nests in the mesohaline reaches. One nest was included in all three years of this study, and one nest was used for two years. Because nests were considered individual samples in all analyses, sample sizes presented here reflect unique pairing of nest location with year.

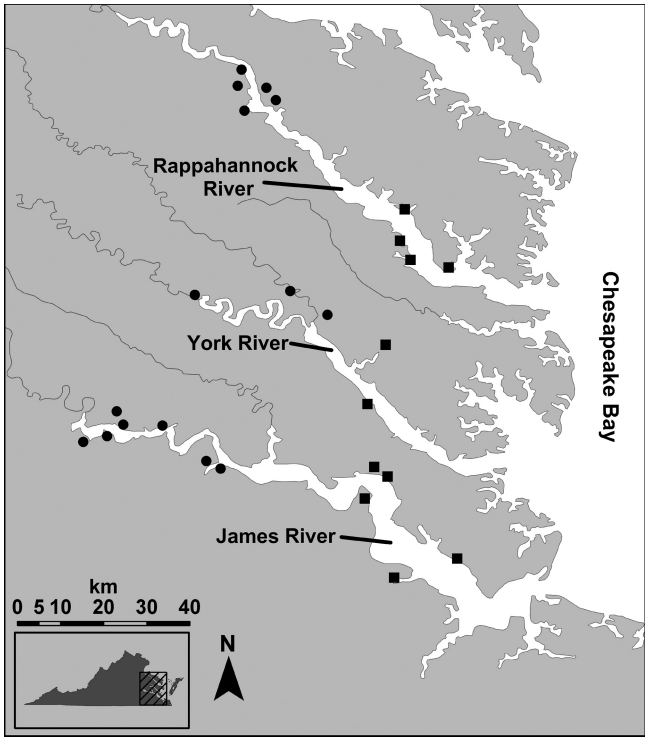


FIGURE 1. Locations of Bald Eagle nests studied (2002–2004) in the lower Chesapeake Bay area. Nests are distinguished between those in tidal-fresh (circles) and mesohaline (squares) salinity zones.

We quantified brood provisioning and chick growth during an age range when chicks were expected to achieve 10%–90% of growth (t_{10-90}; Bortolotti 1984). Nestlings in this phase experience their fastest growth rate (Ricklefs et al. 1998) and, accordingly, prey delivery rates have the greatest impact on overall growth patterns (Bortolotti 1989). Because energetic requirements are influenced by chick age (Cairns 1987), standardizing data collection relative to hatching date removes a potential confounding influence on provisioning. Video recording (used to quantify provisioning) and nestling measurements were synchronized such that camera installation and first measurements occurred when chicks were 15–20 days old, and camera removal and second measurements occurred when chicks were 40–45 days old. Although we observed no disturbance effects due to camera placement or nestling handling in this study, it is important to caution that Bald Eagles can be sensitive to disturbance, and some disruption caused by human contact is unavoidable.

We used waterproof, bullet security cameras to quantify diet and prey delivery patterns. We mounted a camera to each nest tree approximately 1 m above the nest (entire nest surface in view) and wired the camera down the tree to a standard videocassette recorder and a deep-cycle, 12 volt marine battery. The videocassette recorder and battery were placed in waterproof containers and positioned at a remote location approximately 250 m from nests to reduce disturbance and improve access for maintenance activities.

We focused recording time on the morning hours (beginning at sunrise) to include the expected peak period of chick provisioning (Jaffe 1980, Wallin 1982, Mersmann et al. 1992). Each recording bout typically lasted 8 hr (the duration of standard T-160 videocassette tape). We recorded approximately four days per week with effort made to maintain equal video coverage between salinity zones in each study year. Subsamples of all-day (dawn to dusk) coverage were recorded to allow for extrapolation from the normal morning coverage to daily provisioning rates. Delivery rates during the normal (sunrise–14:00) recording time were not statistically different (one-way ANOVA, $F_{1,10} = 1.2$, $P > 0.28$) from the remainder of the day (14:00–sunset), and provisioning within the morning hours showed consistent variation with daily provisioning rates (linear regression, $F_{1,54} = 92.4$, $P < 0.001$, $r^2 = 0.62$).

We identified prey items on videotapes to the lowest taxonomic level possible and recorded date, delivery time, and prey size (estimated as a multiple of adult's bill length, to the nearest

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half-bill length). We converted length estimates to delivered biomass, and then converted delivered biomass to estimates of delivered energy using published conversions specific to each prey species, per Markham (2004).

In estimating consumable portions, we considered major prey taxa separately and referred to both video footage and previous studies of Bald Eagle feeding behaviors. For fish, generally all species and size classes were assumed to be totally edible based upon video review, though large catfish (Ictaluridae) were a notable exception. For this family, we used the size limit applied by Dykstra et al. (1998) of 305 mm as a distinction between totally and partially edible prey—catfish <305 mm were assumed to be completely edible, whereas catfish >305 mm were estimated to be 90% edible. For birds and mammals, we used the estimation of Stalmaster and Gessaman (1982) that prey items in these classes were 85% edible. For turtles, we considered shell weight to represent the only unusable biomass of intact prey items. We determined percent edible to be 24% from measurements of 18 turtle shells collected in and below nests during 2002–2003. We measured the carapace length with dial calipers (±0.1 mm) and weighed each shell on an electronic balance (±0.1 g). We then used carapace length to calculate expected total weight (as derived from length-weight equations of locally measured specimens; J. Mitchell, University of Richmond, unpubl. data). Shell weight was subtracted from expected total weight and divided by total weight, leaving a value indicative of the percent biomass available for consumption.

Morphometric measurements were taken on each chick twice during the expected maximum growth period. Nestlings were lowered to researchers on the ground, banded with U.S. Geological Survey aluminum bands, and weighed on an electronic balance (±0.5 g). We estimated crop fullness by palpation and used a categorical scale to approximate crop mass as follows: full crop = 0.3 kg, more than half-full crop = 0.2 kg, less than half-full crop = 0.1 kg, empty crop = 0 kg (based on values for White-tailed Eagles [*Haliaeetus albicilla*]; Helander 1981). The resulting weight (i.e., gross weight – crop weight) thus more accurately reflected the actual body mass of chicks and was the value used in growth analyses.

We derived three standard estimates of provisioning for analysis: delivery rate of prey (*n* per 10 hr), delivery rate of consumable biomass (g hr^{-1}), and delivery rate of consumable energy (kJ hr^{-1}). All three measures were intercorrelated (all $r_s > 0.9$, all $P < 0.05$). To reduce redundancy, delivery rate of consumable energy was selected for presentation. Because brood sizes varied (1–3), we standardized provisioning estimates on brood size and evaluated per capita rate of consumable energy provision. We used a two-way ANOVA to test for treatment effects, with salinity (i.e., tidal-fresh or mesohaline) and year (i.e., 2002 or 2003) as factors, per capita delivery rate as the dependent variable, and nests as independent samples.

We derived individual growth curves for each nestling based on logistic models, following methods outlined in Ricklefs (1983) and under the assumption that the growth of Bald Eagles was best approximated by the Gompertz equation (Bortolotti 1984). First, approximation of asymptotic weight for eagles of the lower Chesapeake Bay was estimated from the mean weight (±SD) of 134 adult-plumaged, bay-area birds—male: $n = 68$, weight = 3149 ± 971 g; female: $n = 66$, weight = 4225 ± 1313 g (BDW, unpubl. data). We derived five parameters from growth curves as estimates of growth: asymptotic weight, instantaneous growth rate, average growth rate during maximum growth phase, the time required to reach 90% asymptotic weight (t_{90}), and the time required to grow from 10%–90% asymptotic weight (t_{10-90}). Instantaneous growth rate was determined by calculating the slope of the line tangent to the inflection point on the growth curve.

All growth indices were intercorrelated ($r_s > 0.5$, all $P < 0.05$). We used instantaneous growth rate to evaluate the influence of salinity on chick growth. In order to avoid pseudoreplication, we analyzed first-hatched chicks only. We evaluated growth rate using a two-way ANOVA with salinity (i.e., tidal-fresh or mesohaline) and year (i.e., 2002, 2003, or 2004) as factors, instantaneous growth rate as the dependent variable, and nests as independent samples. We used linear regression to evaluate associations between brood provisioning rates and changes in brood mass. The alpha value for statistical significance was set to 0.05 for all statistical analyses.

TABLE 1. Results of ANOVA showing effects of year and salinity on per capita delivery rate of consumable energy for Bald Eagles within the Chesapeake Bay. Rates were significantly higher for pairs nesting within mesohaline compared to tidal-fresh reaches.

Source	SS	df	MS	*F*	*P*
Year	19 385	1	19 385	1.2	0.30
Salinity	113 428	1	11 3428	6.9	0.02
Year∗salinity	35 166	1	35 166	2.1	0.17
Error	180 659	11	16 424		

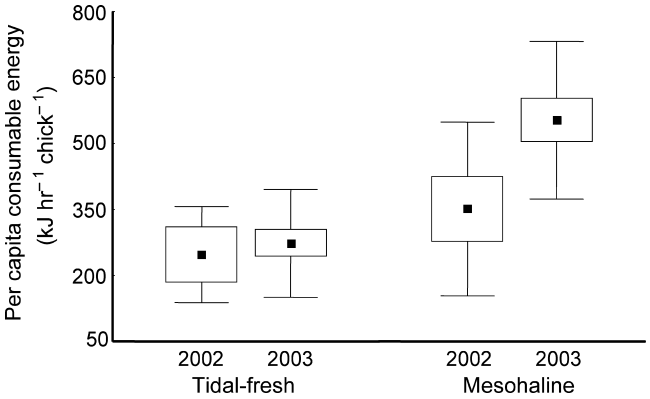


FIGURE 2. Influence of salinity and year at Bald Eagle nests in the lower Chesapeake Bay during the 2002–2003 breeding seasons on per capita rates of consumable energy delivery. Points are mean values, boxes are standard errors, and error bars are standard deviations.

RESULTS

Salinity had a significant influence on the per capita delivery rate of consumable energy (Table 1). Per capita delivery rates were 1.5–2.0 times higher for nests along mesohaline waters compared to those along tidal-fresh waters (Fig. 2), suggesting that young along mesohaline waters were receiving more energy regardless of brood size. Although delivery rates were higher in 2003 compared to 2002, there was no significant effect of year or interaction of year and salinity (year∗salinity; Table 1).

Consistent with provisioning patterns, salinity had a significant influence on the instantaneous growth rate of first-hatched chicks (Table 2). Across all years examined, mean rate of growth (g per day) for first-hatched chicks along mesohaline waters was

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TABLE 2. Results of ANOVA showing effects of year and salinity on instantaneous growth rates of first-hatched Bald Eagle chicks within the Chesapeake Bay. Growth rates were significantly higher for chicks within the mesohaline compared to the tidal-fresh reaches.

Source	SS	df	MS	*F*	*P*
Year	1238	2	619	1.4	0.26
Salinity	2852	1	2852	6.6	0.02
Year∗salinity	218	2	109	0.3	0.78
Error	9031	21	430		

10 g higher compared to chicks along tidal-fresh reaches (151.4 ± 19.5 g and 142.1 ± 28.2 g, respectively) but ranged as high as 20 g higher in 2003 (145.7 ± 19.9 g and 125.3 ± 26.8 g, respectively). There was no significant effect of year or year*salinity (Table 2).

Daily mass gain for all chicks in a brood was related to the consumable energy provided by adults ($F_{1,13} = 11.4$, $P = 0.005$, $R^2 = 0.47$). This general pattern suggests that brood condition is related to a pair's ability to provide energy, which in turn is related, in part, to its breeding location.

DISCUSSION

The results of this study provide evidence that birds nesting in mesohaline reaches are more successful at meeting the energetic demands of brood rearing compared to pairs nesting in the tidal-fresh reaches. Adults provided more energy to nests, and chicks grew at higher rates within mesohaline reaches compared to tidal-fresh reaches. Parents within mesohaline reaches also appeared to be better able to provide for maximum brood sizes compared to those in tidal-fresh reaches.

Intraspecific variation in provisioning and chick growth is often associated with food availability (Harris 1969, Monaghan et al. 1989). An investigation of diet within this system indicated that Bald Eagles were utilizing similar prey species within the two salinity zones (Markham 2004). This study suggests that although eagles in different salinity zones exploit similar food resources, pairs are able to extract more prey from mesohaline waters. Similar conclusions were reached by Bortolotti (1989), who attributed relatively lower rates of growth and provisioning within a subpopulation of nesting Bald Eagles in Saskatchewan to decreased local prey availability, as assessed by lower gill net capture rates.

The result that energetic conditions are better in mesohaline compared to tidal-fresh zones is counterintuitive, given that Bald Eagle breeding densities are significantly higher in tidal-fresh compared to mesohaline reaches (Watts et al. 2006). However, this result is further validated by the related finding that mesohaline reaches supported higher proportions of three-chick broods between 1990 and 2000 when compared to tidal-fresh reaches (BDW, unpubl. data). Why settling patterns of pairs do not match expected foraging and reproductive payoffs remains unclear. The influence of social factors, namely competition with migrant Bald Eagles, is one possible explanation. Bald Eagles from populations south of the Chesapeake Bay annually migrate into the bay system, concentrating in shoreline areas within tidal-fresh reaches (Watts et al., in press). The impact these migrants have on nesting pairs is uncertain. Migrant influx may increase competition for resources (e.g., prey and perch trees), raise energy expenditure in antagonistic encounters, and require greater breeder investment in territory defense at the expense of foraging effort. Because migrants reach their highest densities in low salinity waters, these effects may differentially affect breeding pairs distributed along the salinity gradient. Though high conspecific density has been associated with lower provisioning rates and nest productivity in other raptors (Virani and Harper 2004), further research is necessary to elucidate these interactions for Bald Eagles.

Despite higher provisioning rates, growth rates were lower in 2003 compared to 2002 for both salinity zones. This disparity suggests that chicks throughout the study area were growing more per unit energy in 2002 compared to 2003. Record rainfall and lower than average temperatures were observed throughout the southeast United States, including Virginia, in the spring of 2003 (Gleason et al. 2004). The influence of weather anomalies on growth rates has been documented in several raptor species, such that during poor weather conditions, parents experience lower breeding success than during years with mild weather (Ridpath and Brooker 1985, Mearns and Newton 1988, Pietiainen 1989, Dawson and Bortolotti 2000). During 2003, the breeding population throughout the lower Chesapeake Bay experienced a higher than normal nest failure rate and a lower than normal average brood size (Watts and Byrd 2003). In our study, brood reduction between the two dates of nestling measurement was documented twice in 2003 but not at all in 2002 or 2004. The greater increase in provisioning rates for nests in mesohaline compared to tidal-fresh reaches during 2003 suggests that pairs within these areas are better able to accommodate poor weather conditions, lending additional support to the finding that parents in these regions are better able to meet the energetic demands of nestlings.

Spatial variation in provisioning and associated growth rates have conservation implications for Bald Eagles within the lower Chesapeake Bay. While tidal-fresh waters have been shown to support higher breeding densities and a greater number of young per unit area (Watts et al. 2006), results from this study indicate that young reared along mesohaline waters receive greater amounts of prey, grow faster, and are likely in better condition at fledging. Differences between the two salinity zones were particularly pronounced when pairs were stressed by poor weather conditions. These findings suggest that breeding density alone should not be the sole criterion used to delineate and prioritize core breeding areas for conservation action.

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