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THE INFLUENCE OF WEAPONS-TESTING NOISE ON BALD EAGLE BEHAVIOR

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Abstract.—We studied the influence of weapons-testing noise on Bald Eagle (*Haliaeetus leucocephalus*) behavior at the Aberdeen Proving Ground (APG), Maryland, in 1995. Our objectives were to document and compare eagle behavior at times with and without weapons-testing noise, determine if the frequency of behavior after noise increased with increasing sound levels and compare nest success and productivity on APG with that of adjacent areas of Maryland. Most roosting (72.7%) and nesting (92.7%) eagles showed no activity (i.e., perched motionless) in the 2-sec interval following weapons-testing noise. The most frequent activity following noise was a head turn, exhibited by 18.2% of roosting and 0.7% of nesting eagles; other eagle activities following noise (e.g., body movement, vocalization and flight) were rare at both roosts (9.1%) and nests (6.6%). Frequency of activity after noise differed between adults and juveniles at nests, but did not differ between adults and immatures at roosts. Activity after noise occurred significantly more in roosting than nesting eagles. For roosting eagles, frequency of activity after noise was similar to activity at times without noise. Frequency of no activity versus activity after noise did not vary at sound intensity levels ≥110 and <110 dBP for either nesting or roosting eagles. Nest success and productivity on APG did not differ from nest success and productivity in adjacent counties of Maryland from 1990–95, suggesting that weapons-testing noise did not influence eagle reproduction at the population level.

Key Words: *Bald Eagle;* Haliaeetus leucocephalus; *behavior; Chesapeake Bay; human disturbance; Maryland; noise effects.*

Influencia del ruido de prueba de armas en el comportamiento de águilas calvas

Resumen.—Estudiamos la influencia del ruido de la prueba de armas en el comportamiento de las águilas calvas (*Haliaeetus leucocephalus*) en el Campo de Pruebas de Aberdeen (CPA), Maryland en 1995. Nuestros objetivos fueron los de comparar el comportamiento de las águilas con y sin ruidos de prueba de armas, determinar si la frecuencia de comportamiento despues del ruido aumenta con los niveles de sonido y comparar el éxito de anidación y productividad en el CPA y en áreas adyacentes de Maryland. Las águilas en perchas (72.7%) y en anidación (92.7%) no mostraron ninguna actividad en el intervalo de 2 segundos después de la prueba de armas. La actividad mas frecuente después del ruido fue la de girar la cabeza, exhibida por el 18.2% de las águilas en perchas y 0.7% de las águilas en anidación. Otras actividades despues del ruido (movimientos de cuerpo, vocalizaciones y vuelo) fueron raras en las águilas en perchas (9.1%) y en nidos (6.6%). La frecuencia de actividad después del ruido difirió entre adultos y juveniles en los nidos, pero no entre adultos y juveniles en perchas. La actividad fue significativamente mayor en las águilas en perchas que en anidación. Para las águilas en perchas la frecuencia de actividad después del ruido fué similar a la de actividad sin ruido. La frecuencia de respuesta de inactividad versus actividad después del ruido no varió con la intensidad del sonido 110 y 110 dBP tanto para las águilas en anidación o en perchas. El éxito de anidación y productividad en el CPA no difirió del éxito de anidación y productividad de los condados adyacentes de Maryland entre 1990–95, lo cual sugiere que el ruido de la prueba de armas no afecta la reproducción de las águilas a nivel poblacional.

[Traducción de César Márquez]

Despite studies directly or indirectly addressing the influence of unnatural sound energy, hereafter referred to as noise, from military activities on raptors (e.g., Andersen et al. 1986, Manci et al. 1988, Andersen et al. 1989, Stalmaster and Kaiser 1997), there is little consensus on the overall influence of noise on them. Nine of 17 Red-tailed Hawks (*Buteo jamaicensis*), not previously exposed to helicopter overflights, flushed from nests exposed to helicopter activity (Andersen et al. 1989), although noise and visual parameters of helicopter disturbance were not examined separately. Grubb et al. (1992) reported noise from artillery fire located a median distance of 1.5 km from nesting Bald Eagles (*Haliaeetus leucocephalus*) elicited no visible behavioral response in 100% of 25 eagle-noise observations. Stalmaster and Kaiser (1997) reported that 8% of 1452 Bald Eagles flushed during 373 weapons-firing events on the Fort Lewis Army Reservation, Washington. The influence of weapons-testing noise on raptor behavior or reproductive fitness has not been quantitatively examined in other studies, and decibel levels associated with raptor behavior following weapons-testing noise have not previously been documented. Because military installations comprise approximately 9.7 million ha in the U.S. (Pfister 1988), applied information on the effects of weapons-testing noise could be useful in developing raptor management guidelines for military installations.

We studied the influence of noise from military weapons-testing at the Aberdeen Proving Ground (APG), Maryland, on nesting and roosting Bald Eagle behavior, nest success, and productivity. Our objectives were to document eagle behavior following weapons-testing noise, determine if frequencies of behavior after noise differed by age, test the null hypothesis that roosting eagle behavior after noise did not differ from behavior at times without noise, test the null hypothesis that the frequency of active behaviors after noise did not increase with increasing sound levels and compare nest success and productivity on APG with that of adjacent areas of Maryland. In addition to using nest success and productivity on APG as an indirect measure of the influence of weapons-testing noise, this comparison served as a relative indicator of habitat quality. The study area was an ideal locale to examine the influence of noise on eagle behavior because of the abundance of eagle nests and roosts (Buehler et al. 1991a, 1991b) and because of high levels of weapons-testing noise prior to and during our study.

METHODS

APG is a 350 km^2 military installation located on the western shore of the northern Chesapeake Bay, 30 km north of Baltimore, Maryland. Access to much of APG is restricted, greatly reducing human-associated activities that may negatively influence eagle behavior and distribution (Buehler et al. 1991c, Chandler et al. 1995). The area is dominated by forests of various ages except for the developed Aberdeen and Edgewood cantonment areas and scattered test ranges with open fields. Most of APG is at or near sea level with a largely undeveloped shoreline characterized by marshes and forested wetlands. Testing of ordnance and weapons has been the primary mission of APG since 1917. Up to several thousand impulsive (<1 sec) noise events/day may occur at various test ranges across the installation as a result of explosive detonations and small arms, tank and artillery fire (U.S. Army 1994). Weapons-testing noise rarely occurs at night.

Observations on eagle behavior after weapons-testing noise were gathered at three nests (11 total individuals sampled) in May and June 1995; observations on roosting eagle behavior after noise events were made throughout 1995 at two large communal roosts (≤58 eagles/roost). Monthly aerial surveys from 1993–95 located up to 94 nesting and roosting eagles on APG. Eagles were not banded or marked, and we were unable to differentiate between most eagles of similar age. Therefore, we were not able to determine the extent of pseudoreplication in roosting eagles, but estimated it to be very low due to large daily variance in eagle abundance at roosts (Buehler et al. 1991b) and seasonal turnover in roosting populations due to migration (Buehler et al. 1991a). Levels of prior exposure to weapons-testing noise was unknown for individual eagles.

All nests and roosts were at least 0.5–4 km from test ranges and typically experienced noise events from more than one range. No ranges were visible from nests or roosts due to intervening forests. All noise events resulted from scheduled weapons-testing activities and none were staged for the purpose of this study. Nest observations were made throughout the day and roost observations were made from about 1.5 hr before sunset until dark. Observers used 15–45× spotting scopes from either a fixed blind or stationary vehicle. A 1–60× video camera was used to record and later review some eagle behavior after noise. Eagle ages were classified as adult (white head and tail), immature (mottled or all-dark plumage), or juvenile (nestling) (Bortolotti 1984).

Eagle behavior was recorded in an arbitrary 2-sec interval immediately following each weapons-testing noise event. A 2-sec interval was chosen because our preliminary evaluations of eagle behavior following noise events suggested this was an appropriate interval to detect noise-related behaviors, if any, and because intervals >2 sec had an increasing probability of detecting behaviors unrelated to noise. Behaviors were categorized as follows: 0 = no discernible activity (i.e., perched motionless); 1 = head turn; 2 = body or wing movement; 3 = vocalize; 4 = take to flight; 5 = preen; and 6 = other. We assumed that categories 0–4 described increasing energetic levels of activity; categories 5–6 represented miscellaneous behaviors. A head turn toward the source of an auditory stimulus is known as an orienting response (Brown 1990). However, head turns recorded in our study included those toward the noise source, away from the noise source and up.

We did not attempt to classify eagle behavior as a response or no response to noise because of inherent subjective assumptions involving cause and effect and because all behaviors we classified were within eagles' normal behavioral repertoire and could have occurred at any time, regardless of noise. Sample sizes of ≥1 often resulted from single noise events if several eagles were under observation. Eagles exposed to occurrences that could have influenced their behavior after noise (e.g., interactions with other eagles) were eliminated from analysis.

We collected control data to test the null hypothesis that no difference existed between roosting eagle behavior after noise compared to times without noise, using the seven previous categories. Control roosting behavior was collected in 30 consecutive 2-sec intervals/0.5 hr beginning about 1.5 hr before sunset and continuing until dark from January–December 1995 on the same days and at the same roosts that experimental roosting behavior was being gathered.

Levels of weapons-testing noise were measured in unweighted peak decibels (dBP) using a Larson Davis Laboratories 870 precision integrating sound level analyzer, a Larson Davis 2100 preamplifier and a Larson Davis 2541 microphone. Sound level analyzers were calibrated using either a Bruel and Kjaer 4230 sound level calibrator or a Metrosonics CL304 acoustic calibrator. Microphones were located 3.0 m above ground and within approximately 100 m of nests and roosts. Inaccuracies in dBP levels due to the distance between microphones and eagles were estimated to be <1 dBP based on the nature of impulsive sound energy and the dBP scale, the relatively large distances (≥0.5 km) from firing range to microphone and the standard acoustical formula for determining sound level differences between two receiving locations (Harris 1979). Observers synchronized their watches to the nearest sec with sound level analyzers so behavioral observations could be paired with corresponding noise events. Some dBP data were gathered using a Larson Davis portable sound level analyzer 800B (type I), a Larson Davis 826B pre-amplifier and a Larson Davis 2559 microphone; the sound level analyzer was calibrated before and after use with a Metrosonics CL304 calibrator.

We monitored eagle nest success and productivity on APG (experimental) versus adjacent areas (control) from 1990–95 to indirectly evaluate the possibility that weapons-testing noise influenced eagle reproduction on APG by affecting nest abandonment and failure. Nest sites were aerially monitored during three visits/season from February through May to determine occupancy and fate We analyzed four measures of eagle reproduction: nest success (% of successful nests/occupied territory) and productivity (number of young assumed fledged/occupied territory, young assumed fledged/breeding pair and young assumed fledged/successful nest [Postupalsky 1974, Steenhof 1987]). Adjacent areas of Maryland included Baltimore, Cecil, Harford and Kent counties.

Behavior categories 1–6 were combined and compared to category 0 in all statistical tests because categories 2–6 were rarely observed. Thus, all behavior comparisons evaluated the difference between frequencies of no discernible activity versus some activity. Chi-square tests for association were used in all behavioral comparisons and in comparison of nest success. Mean nesting productivity on APG versus adjacent counties from 1990–95, was compared using independent sample *t*-tests with SPSS software (Norusis 1993). Statistical significance was accepted at $P \leq 0.05$.

RESULTS

The most common eagle behavior in the 2-sec interval following weapons-testing noise at nests and roosts was no activity, recorded after 92.7% and 72.7% of noise events, respectively (Table 1). The most frequent activity after noise at nests and roosts was a head turn, recorded after 0.7% and 18.2% of noise events, respectively. Other activity categories (2–6) were recorded for 6.6% and 9.1% of eagle behavior after noise at nests and roosts, respectively.

Nesting adults and juveniles showed activity after noise in 1 (1.8%) of 55 and 10 (10.4%) of 96 observations, respectively. Roosting adults and immatures exhibited activity after noise in 8 (25%) of 32 and 28 (28%) of 100 observations, respec-

Table 1. Nesting and roosting Bald Eagle behavior in the 2-sec interval following weapons-testing noise (experimental) and at times without noise (control), Aberdeen Proving Ground, Maryland, 1995. Behavior categories included: 0 = no discernible activity; 1 = head turn; 2 = body or wing movement; 3 = vocalize; 4 = take to flight; 5 = preen; and 6 = other.

Eagle Location	Noise Status	Number of Eagle Behaviors by Category							Total
		0	1	2	3	4	5	6	
Nest	Experimental	140	1	0	0	0	10	0	151
Nest	Control	None gathered							
Roost	Experimental	96	24	2	4	0	6	0	132
Roost	Control	5596	1201	76	72	15	1038	229	8227

tively. Frequencies of no activity compared to activity behavior categories after noise differed between adults and juveniles at nests (χ^2 = 3.82, df = 1, P = 0.05), but did not differ between adults and immatures at roosts (χ^2 = 0.11, df = 1, P = 0.74), although our study was not designed to test for differences between age classes. Therefore, all age classes were combined for subsequent analyses. The frequency of active behaviors following noise was higher for roosting eagles than for nesting eagles (χ^2 = 20.32, df = 1, $P < 0.001$).

The most frequent behavior recorded for roosting eagles at times without weapons-testing noise was no activity, accounting for 68.7% of control observations (Table 1). Frequencies of no activity versus activity categories did not differ between control and experimental roost observations (χ^2 = 1.28, df = 1, P = 0.26). Because it appeared unlikely that preening and other behavior (categories 5 and 6, respectively) were reactions to noise events, we compared control and experimental roosting data in two additional ways: without inclusion of these two categories and including these categories as no activity. We could not detect a difference between control and experimental behavior at roosts (χ^2 = 3.12, df = 1, P = 0.08 and χ^2 = 1.27, df = 1, P = 0.26, respectively) in either comparison.

Table 2. Nesting and roosting Bald Eagle behavior in the 2-sec interval following weapons-testing noise by decibel (dBP) level, Aberdeen Proving Ground, Maryland, 1995. Behavior categories have been summarized into no activity (category 0) and activity (categories 1–6).

dBP Levels	Number of Eagle Behaviors by Category					
	Nesting Eagles			Roosting Eagles		
	0	1–6	Total	0	1–6	Total
80–89	—	—	—	1	1	2
90–99	—	—	—	—	—	—
100–109	52	7	59	32	21	53
110–119	68	2	70	2	3	5
120–129	20	2	22	6	10	16

Despite a lack of difference between experimental and control roost behavior, a small number of activity behaviors following ordnance noise appeared to be a direct result of noise. For example, a roosting immature eagle that was preening appeared to lose its balance and nearly fell off its perch immediately after an explosion measuring 120.1 dBP on 11 September. However, we did not observe any eagles taking to flight immediately after noise during the study period, although we observed this activity once after noise during a 1994 preliminary study.

Behavioral observations at nests and roosts following weapons-testing noise were paired with dBP levels ranging from 82–126 dBP (Table 2). We recorded dBP data for all observations at nests but for only 58% of observations at roosts because of wind interference and equipment malfunction. Because of small sample sizes for some dBP levels and because we had no reason to divide dBP categories at any particular level for analysis, we chose to compare frequencies of activity after noise between <110 dBP and ≥110 dBP. The 110 dBP threshold was chosen to attempt to obtain approximately equal sample sizes for roosts and nests. We did not detect a difference in frequencies of no activity versus activity at sound levels ≥110 than at <110 dBP for nesting (χ^2 = 3.01, df = 1, P = 0.08) and roosting eagles (χ^2 = 2.94, df = 1, P = 0.09).

Overall nest success did not differ for 1990–95 between APG (61 occupied territories, 41 successful nests, 67% nest success) and adjacent areas of

Table 3. Summary measures of Bald Eagle reproduction (N = 209 occupied territories) on Aberdeen Proving Ground (APG) compared to adjacent areas (ADJ) along the northern Chesapeake Bay, Maryland, 1990–95. Test statistics are from analyses to determine if differences existed between APG and ADJ for 1990–95.

	SUMMARY DATA			TEST		
PARAMETERS STATISTICS	STATISTIC	APG	ADJ	t	df	P
Young fledged/occupied territory	N	61	148			
	mean ± SD	1.13 ± 0.90	1.09 ± 0.96	0.26	207	0.80
Young fledged/breeding pair	N	59	136			
	mean ± SD	1.17 ± 0.89	1.19 ± 0.94	−0.15	193	0.88
Young fledged/successful nest	N	41	96			
	mean ± SD	1.68 ± 0.52	1.69 ± 0.64	−0.04	135	0.97

Maryland (148 occupied territories, 96 successful nests, 65% nest success; $\chi^2 = 0.11$, df = 1, P = 0.75). Overall numbers of young/occupied territory, young/breeding pair, and young/successful nest for 1990–95 combined were not significantly different on APG compared to adjacent areas of Maryland (Table 3).

DISCUSSION

Behaviors that were likely indications of severe noise disturbance, such as body or wing movement and flight, occurred infrequently or were absent during both control and experimental observations. Although some eagles apparently reacted, our findings suggest that most eagles have habituated to weapons-testing noise. We did not demonstrate that habituation has occurred, but our findings were consistent with a habituation hypothesis. Habituation is an active learning process that permits individuals to discard a response to a recurring stimulus for which constant response is biologically inappropriate without impairment of their ability to respond to other stimuli (Lorenz 1965, Alcock 1979, Peeke and Petrinovich 1984). Because this constitutes tolerance for prolonged and repetitive activities, then the thousands of noise events caused by weapons testing on a typical day at APG would be a likely basis for habituation. Habituation could occur in a relatively short time even for nonresident eagles that migrate into the area. Apparent habituation by many vertebrates to similar noise has been widely documented (e.g., Andersen et al. 1989, Grubb and King 1991, Weisenberger et al. 1996). Perhaps most unexpected was our finding of apparent eagle habituation to most weapons-testing noise exceeding 120 dBP. For comparison, naturally-occurring thunder ranges from 82–103 dBP at distances of 700–2100 m (Holmes et al. 1971).

An alternative hypothesis is that some eagles reacted to weapons-testing noise by more frequently ceasing activity (i.e., they "froze"). For example, a decrease in flight activity was reported in cave-roosting bats exposed to noise from low-level supersonic aircraft overflights at Organ Pipe Cactus National Monument in Arizona (V.M. and D.C. Dalton unpubl. data). However, we did not address this hypothesis, which would require evaluating behavior immediately before and after noise.

The null hypothesis that eagle activity after noise did not increase with increasing sound level was not rejected. Sensitization, defined as successively stronger responses to specific stimuli (Peeke and Petrinovich 1984), apparently did not occur in eagles exposed to weapons-testing noise at APG.

Based on our finding that most eagles exhibited no activity following relatively loud noise events, we concluded that Bald Eagles at nests and roosts at APG do not show a significant behavioral reaction to weapons-testing noise. This conclusion is supported by the finding that sensitization to noise was apparently not occurring. Our finding that eagle nest success and productivity from 1990–95 was similar for APG and adjacent areas of Maryland suggests that weapons-testing noise did not influence overall reproductive performance of the nesting eagle population at APG.

Loud noise can induce stress in some animals, resulting in physiological changes such as increased heart and respiratory rates, altered blood chemistry and hormone production, hypertension and vasoconstriction (Manci et al. 1988). For example, Weisenberger et al. (1996) reported that heart rates of ungulates increased relative to increasing noise levels produced by simulated jet aircraft overflights but returned to pre-disturbance conditions in 60–180 sec. Our study addressed visible behavior only, and no existing studies of the influence of noise have examined raptor physiology. We recommend that future research on the effects of noise on Bald Eagles or other raptors should focus primarily on physiology and should attempt to test for a quantitative link between noise, physiology and reproductive fitness.

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