Responses of Breeding Bald Eagles, *Haliaeetus leucocephalis*, to Human Activities in Northcentral Michigan

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To characterize disturbance and analyze eagle response, we recorded 714 events of potentially disturbing human activity near six pairs of Bald Eagles (*Haliaeetus leucocephalus*) breeding in northcentral Michigan in 1990. Vehicles and pedestrians elicited the highest response frequencies, but aircraft and aquatic activities were the most common. Magnitude of response was inversely proportional to median distance-to-disturbance. Seventy-five percent of all alert and flight responses occurred when activity was within 500 m and 200 m, respectively. Adults responded more frequently than nestlings, and at greater distances-to-disturbance when perched away from nests. May was the peak month for human activity, most of which occurred on weekends (60%) and after noon (72%). Classification tree (CART) models are used to assess disturbance-specific response frequencies and to formulate management considerations.

Key Words: Bald Eagle, *Haliaeetus leucocephalus*, human disturbance, behaviour, breeding, classification trees, modeling, management, Michigan.

Interactions between humans and Bald Eagles (*Haliaeetus leucocephalus*) during the breeding season occur throughout most of the eagle's range and can be detrimental to reproductive success (Fyfe and Olendorff 1976; Fraser 1985). Different-sized protection zones and regulation of human activity around occupied nest sites have been used as management techniques by the USDA Forest Service and other agencies to decrease the potential for disturbance to nesting eagles (Mathisen 1968; Grier et al. 1983). However, specific data on the types, characteristics, and effects of potentially disturbing human activities in the vicinity of breeding Bald Eagles in Michigan were lacking. To evaluate human-Bald Eagle interactions in the northern Lower Peninsula of Michigan, we measured and analyzed human activities and associated eagle response at six breeding areas.

We also compared our results with disturbance studies from several other populations and regions, particularly recent Arizona research (Grubb and King 1991), which the present work replicates in many respects. In the context of ever-increasing disturbance of wildlife communities, every community cannot be studied individually. There is a need for clear, predictive models or other management tools that broadly apply beyond the local scale. Through an assessment of similarities and differences exhibited by the Michigan and Arizona populations, we develop a broader perspective on the management application of our disturbance findings.

Study Area

The study area was located in the northern Lower Peninsula of Michigan along the Au Sable River in Alcona, Iosco, Oscoda, and Otsego counties and the Manistee River in Manistee County. Four sites were on dam ponds created by hydro-electric facilities. Five breeding areas were in the Huron-Manistee National Forest, while the sixth was on private land within 1.6 km of the U.S. Army Air National Guard, Camp Grayling artillery and bombing range. Terrain was flat to rolling with occasional hills and an elevational range of 200 to 400 m. Vegetation was predominantly continuous mixed forest consisting of White (*Pinus strobus*), Red (*P. resinosa*), and Jack pine (*P. banksiana*). Aspen (*Populus grandidentata* and *P. tremuloides*), oak (*Quercus rubra* and *Q. alba*), maple (*Acer rubrum* and *A. saccharum*) and Paper Birch (*Betula papyrifera*) were common hardwood species. The area was rural and sparsely populated but supported recreational activity all year.

Methods

Using the nest watch procedures of Forbis et al. (1985) and Grubb and King (1991), we recorded potentially disturbing human activities within 2000 m of potentially affected eagles at four breeding areas on the Au Sable River and two on the Manistee River during March-June 1990. Observations were made from locations typically 400-600 m from nests with good views of the surrounding vicinity and fre-

TABLE 1. Disturbance and response characteristics for 714 events of potentially disturbing human activity within 2000 m of breeding Bald Eagles in northcentral Michigan, 1990.

	Disturbance				No Response		Response	
Group/ Type	Frequency (no. of events)	Median no. per event	Median distance (m)	Median duration (min)	Frequency (%)[a]	Median distance (m)	Frequency (%)[a]	Median distance (m)
Vehicle	**55**	**1.0**	**250**	**5.0**	**26**	**1000**	**74**	**250**
ATVs	24	2.5	500	3.0	29	1000	71	500
Autos	31	1.0	200	5.0	23	1500	77	200
Pedestrian	**29**	**1.0**	**250**	**6.0**	**55**	**250**	**45**	**185**
Hikers	24	1.0	250	7.0	62	250	38	250
Anglers	5	1.0	60	1.0	20	300	80	45
Aquatic	**239**	**1.0**	**110**	**2.0**	**54**	**150**	**46**	**100**
Boats	218	1.0	110	1.5	52	150	48	100
Canoes	21	3.0	300	3.0	76	350	24	50
Noise	**50**	**4.0**	**850**	**2.0**	**62**	**1000**	**38**	**500**
Gunshots	25	4.0	500	1.0	24	600	76	500
Artillery	25	7.0	1500	6.0	100	1500	0	–
Aircraft[b]	**341**	**2.0**	**800**	**10.0**	**71**	**800**	**29**	**500**
Jets	241	2.0	800	12.0	68	800	31	500
Light planes	52	1.0	1125	2.0	85	1425	15	800
Helicopters	48	1.0	700	4.5	71	750	29	700
Totals	**714**	**1.0**	**400**	**4.0**	**60**	**700**	**40**	**300**
Arizona Totals[c]	**4188**	**1.0**	**500**	**1.0**	**60**	**700**	**40**	**300**

[a] Response frequency (%) = response sample size divided by number of events x 100%.
[b] Aircraft figures strongly influenced by proximity of military air base near one breeding area (N = 282, *see* Table 2).
[c] From 13 breeding areas, 1983-1985 (Grubb and King 1991). Within-group response frequencies were 52% vehicle, 72% pedestrian, 53% aquatic, 54% noise, and 33% aircraft.

quently used perches. Binoculars (7-10X) and spotting scopes (15-60X) aided viewing. Nest watchers were deployed in pairs for safety and to facilitate data collection/recording. To increase standardization and strengthen within- and between-site comparisons, standard sample days (two weekdays and two weekend days every two weeks) were designated for dawn-to-dusk data collection at all nest sites.

Eleven types of human activity in five potential disturbance groups (vehicle, pedestrian, aquatic, noise, aircraft; Table 1) were identified. Aquatic is defined as water-based recreational activity. Within groups, "boats" refers to powered craft and "canoes" includes kayaks. "ATVs" includes motorcycles and personal all-terrain vehicles; "autos" indicates cars, jeeps, and trucks. Noise includes gunshots and distant artillery, which were sudden, often loud, and usually sound only. Distances for noise were only recorded when the source was known.

Our dependent variables for assessing disturbance were the type (none, alert = noticeably agitated, and flight) and severity (frequency or percent) of response (Grubb and King 1991). For each disturbance group, we determined frequency of occurrence (F_N) and frequency of response (F_R), then calculated relative occurrence (O_R), within-group response (R_G), and overall response (R_O) as follows:

$$O_R = \frac{F_N}{\Sigma(F_N)},$$

$$R_G = \frac{F_R}{F_N}, \text{ and}$$

$$R_O = \frac{(R_G \times F_N)}{\Sigma(F_R)} \text{ or } \frac{F_R}{\Sigma(F_R)}.$$

For percentages the above figures were multiplied by 100. For CART modeling (see below) and some analyses of frequency and distance, response was treated as none/any (any = alert + flight).

We recorded distance-from-affected-eagle-to-disturbance, duration-of-disturbance (min), number-of-units-per-event (e.g., number of canoes within a group), visibility-of-disturbance-to-affected-eagle (none/any), position-relative-to-affected-eagle (above/below), and sound-at-affected-eagle (none/any) for each event. Observations, referenced to age class of affected eagle (12 adults and 10 nestlings), began near hatching and ceased at fledging. Nestling response was not recorded until the young became visible at about 5-6 weeks of age. We recorded adult eagle activity as nest attending or perching away from nest.

All human activity data were collected passively. We could not establish definitive cause and effect relationships because we did not under controlled, experimental conditions disturb breeding eagles to the point of failure or reduced productivity. Disturbances were not initiated but only recorded as they occurred. Distances were measured on topographic maps and aerial photographs, or otherwise estimated from available landmarks. Medians were used in summary statistics to represent central tendencies because of skewness in the data caused by a preponderance of nearby, short-duration human activities. For analysis, times were rounded off to the previous whole hour (e.g., 1700-1759 = 1700). Frequencies, descriptive statistics, and chi-square tests of independence (P to thousandths) were calculated with SPSS/PC+ (Norusis 1986). We used notched box and whisker plots ($P=0.05$; Chambers et al. 1983; STSC 1987) to evaluate variation in distance-to-disturbance among classes of several variables, including response type.

We developed classification and regression tree (CART) models to measure disturbance, estimate response severity, and develop disturbance-specific management considerations (Brieman et al. 1984; California Statistical Software, Inc. 1985; Grubb and King 1991). Only the classification tree aspects of CART were used in our analyses. Classification analysis identifies the most accurate classifiers (predictor or splitting variables) and provides predictive, discriminant models in the form of nonparametric, dichotomous keys (Brieman et al. 1984; Verbyla 1987). The variable that best partitions the data into the purest classes of response (none/any) is incorporated at each step of the model. Each variable is also ranked for its splitting ability by assigning the primary (first) splitting variable a value of 100% and expressing the relative value of secondary variables as a percentage of it. We developed CART models for pooled disturbances (all disturbance groups for all sites) and for each of the five disturbance groups. Cross-validation provided an estimate of classification accuracy for each tree.

Results

Disturbance summary

We recorded 714 events of potentially disturbing human activity for analysis. Aircraft was the most common activity type observed near breeding eagles, followed by aquatic, vehicle, noise, and pedestrian disturbance (Figure 1, Table 1). Vehicles elicited the highest within-group response frequency and aircraft the lowest; aquatic and pedestrian activities were about equal ($P<0.001$). Overall response was highest for aquatic and aircraft activity, because these two activities were the most frequent near breeding eagles in northcentral Michigan (Figure 1). Aquatic disturbance had the shortest median distance to affected eagles, and noise the greatest ($P<0.05$). Aircraft activity, influenced by circling military jets near one nest on the Au Sable River (Table 2), had the longest median duration ($P<0.05$), followed by pedestrian and vehicle traffic ($P>0.05$).

TABLE 2. Comparison of disturbance and response characteristics of breeding Bald Eagles near a military air base with five other breeding areas in northcentral Michigan, 1990.

	Disturbance				No Response		Response	
Group/ Type	Frequency (no. of events)	Median no. per event	Median distance (m)	Median duration (min)	Frequency (%)[a]	Median distance (m)	Frequency (%)[a]	Median distance (m)
Military Site:								
Aircraft	**280**	**2.0**	**800**	**12.0**	**73**	**800**	**27**	**400**
Jets	214	2.0	800	13.0	71	800	29	400
Light Planes	23	1.0	1500	3.0	100	1500	0	–
Helicopters	43	1.0	700	5.0	72	800	28	700
Other Breeding Areas:								
Aircraft	**61**	**1.0**	**800**	**1.0**	**59**	**800**	**41**	**800**
Jets	27	1.0	800	1.0	44	800	56	800
Light Planes	29	1.0	800	1.0	72	800	28	800
Helicopters	5	1.0	400	2.0	60	407	40	400

[a] Response frequency (%) = response sample size divided by number of events x 100%.

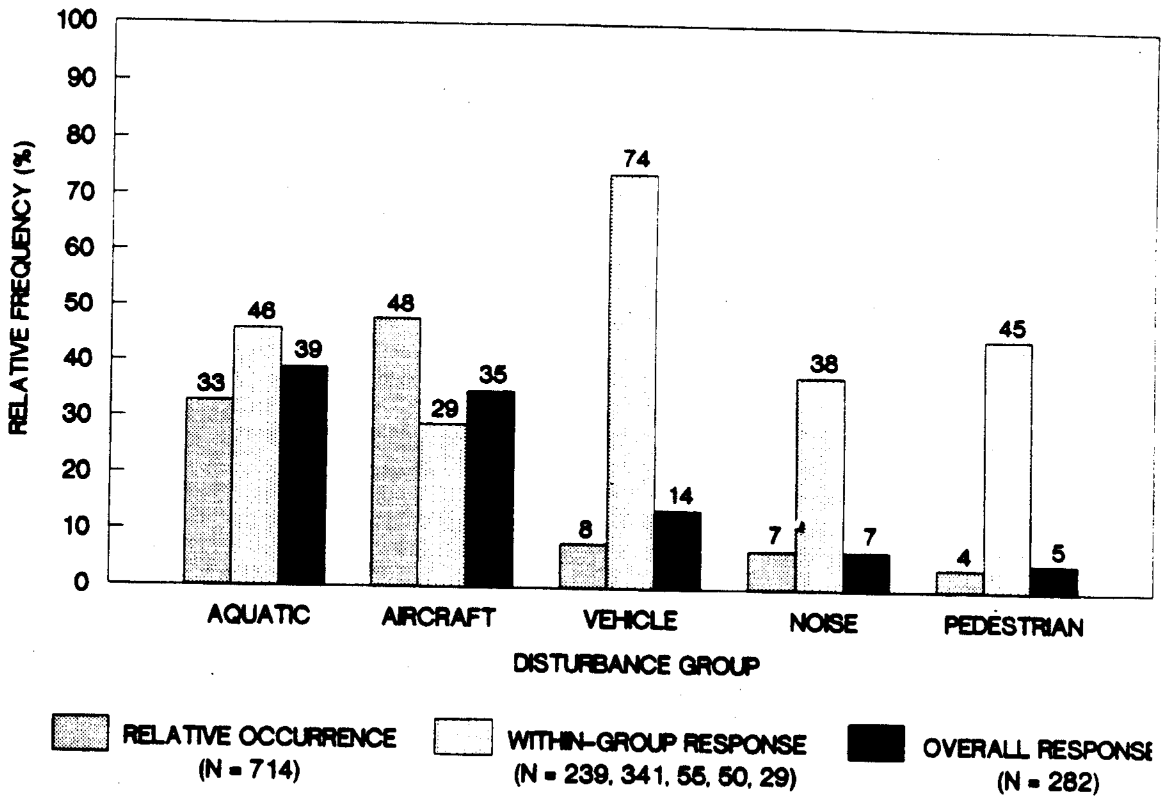

FIGURE 1. Relative frequency of occurrence, within-group response, and overall response for 714 events of, and 282 responses to, five human disturbance groups near breeding Bald Eagles in northcentral Michigan, 1990 (N = 341 aircraft, 239 aquatic, 55 pedestrian, 50 noise, and 29 vehicle).

Among specific disturbance types, artillery, gunshots, canoes, ATVs, and jets typically occurred with multiple units-per-event, whereas all other activities tended to occur singly (Table 1). Anglers, autos, and gunshots elicited the highest frequencies of response ($P<0.001$). Among aircraft, light planes caused the lowest response. Helicopters occurred closest to eagles of any aircraft ($P<0.05$) and tended to have the longest duration in non-military situations ($P>0.05$, Table 2). Jets and helicopters elicited comparable response frequencies ($P = 0.663$), but the median distance for response was 200 m greater for helicopters ($P<0.05$). Median distance-for-response was smallest for anglers and canoes, but there was more than a three-fold difference in response frequency between these pedestrian and aquatic activities ($P = 0.018$). Excluding the separate noise category in Table 1, ground-related disturbance elicited highest response (64%), followed by water (46%) and airborne (29%) activities ($P<0.001$).

Disturbance characteristics

Magnitude of response, as indicated by type and/or frequency, consistently increased as median distance-to-disturbance decreased for all disturbance types, although distance ranges for each type of Bald Eagle response overlapped (Table 1). The median distance for awareness for all disturbance types, as indicated by alert behavior, was 300 m, and for flight, 100 m (Figure 2). Tops of boxes indicate the distance within which 75% of the recorded responses occurred. Non-overlapping notches in the boxes indicate significant differences among median distances for the three levels of response ($P<0.05$). Number, position, and visibility when analyzed independently had little apparent, direct effect on response type or severity. However, when disturbances were audible to eagles, frequency of response appeared to increase (from 22 to 40%, N = 18 and 696, respectively).

Eagle age and activity

We recorded 421 (59%) adult and 293 (41%) nestling responses to human activity. Adults consistently exhibited greater response frequencies than nestlings (45 versus 31%, $P<0.001$), but median distance-to-disturbance for response (300 m) did not differ between age classes ($P>0.05$). Adult and nestling response frequencies were similar for most distur-

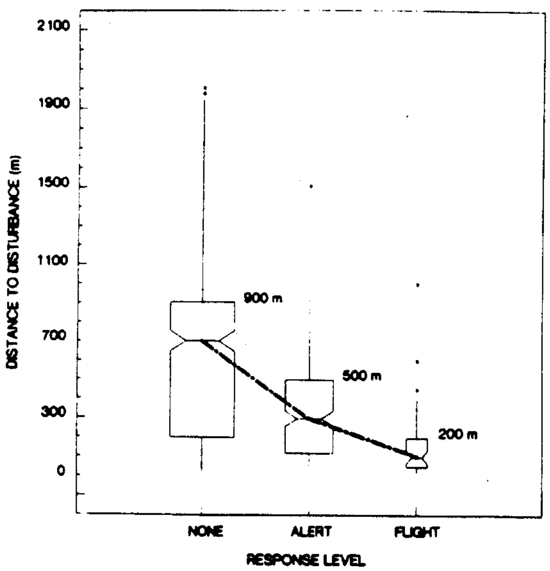

FIGURE 2. Median distance-to-disturbance by response level for 714 events of human activity near breeding Bald Eagles in northcentral Michigan, 1990 (N = 432 none, 235 alert, 47 flight). (Boxes cover middle 50% of data. Whiskers indicate range but do not exceed 1.5 times box length. Box width is proportional to sample size. Center lines are medians, with position indicating skewness. Notches are width of 95% confidence intervals for pairwise comparisons.)

bance types, but adults showed higher response to light planes (20 versus 9%), boats (57 versus 30%), and canoes (33 versus 17%), although only the boat increase was statistically significant (P = 0.281, 0.002, and 0.375, respectively). Adults also exhibited an 80% response to anglers, but anglers were not recorded in view of nestlings. Flight response frequencies for adults by disturbance group were pedestrian 17%, vehicle 11%, aquatic 8%, aircraft 5%, and noise 2% (N = 36, P = 0.022). Overall flight response was 9%. Nest-attending adults responded at a greater median distance-to-disturbance than when perched away from the nest (300 versus 100 m, P<0.05). However, frequency of response remained unchanged (45 and 47%, respectively).

Breeding area variation

Relative frequency and type of disturbance, response frequency, median distance-to-disturbance for response, and weekend activity varied among breeding areas (Table 3). The military site experienced the most human activity (N = 382) but these eagles showed the least response (33%). Aircraft (79%) was the predominant activity at nest sites on the Au Sable River (N = 445), and aquatic activity (69%), on the Manistee (N = 269). Median distance-to-disturbance (700 m) and median distance-for-response (350 m) on the Au Sable were both greater than on the Manistee (200 and 142 m, respectively; P<0.05). The Manistee, however, had a higher response frequency (49 versus 34%, P<0.001).

Timing

May was the peak month for human activity near breeding Bald Eagles in northcentral Michigan in 1990 (Table 4). Median distance-to-disturbance and median response distance tended to decline from March to June, with the largest decrease occurring in June. Response frequency also decreased over the period. Aquatic activity increased (22% April, 35% May, 48% June), whereas other disturbance groups showed little monthly change. In April and June, 75 and 74% of recorded human activity, respectively,

TABLE 3. Individual breeding area variation in disturbance and response characteristics for Bald Eagles in northcentral Michigan, 1990.

	Breeding Areas					
	Au Sable River				Manistee River	
Characteristic	1[a]	2	3	4	5	6
Sample size (N)	382	9	4	50	132	137
Disturbance						
Vehicle (%)	13	0	0	2	4	0
Pedestrian (%)	5	0	75	4	0	4
Aquatic (%)	0	89	0	38	80	77
Noise (%)	9	0	0	4	0	10
Aircraft (%)	73	11	25	52	16	9
Weekend (%)	46	89	50	76	85	70
Median distance (m)	800	50	250	750	100	300
Response						
Frequency (%)	33	44	50	33	48	50
Median distance (m)	350	80	230	800	100	300

[a] Breeding area adjacent to military air base.

TABLE 4. Monthly comparison of disturbance and response characteristics for breeding Bald Eagles in northcentral Michigan, 1990.

	Disturbance				No Response		Response	
Month	Frequency (no. of events)	Median no. per event	Median distance (m)	Median duration (min)	Frequency (%)[a]	Median distance (m)	Frequency (%)[a]	Median distance (m)
March	3	–	–	–	33	–	67	–
April	223	2.0	500	3.0	54	800	46	300
May	326	1.0	450	5.0	62	700	38	300
June	162	1.0	200	1.5	67	350	33	100

[a] Response frequency (%) = response sample size divided by number of events x 100%.

occurred on weekends, but in May, weekend occurrence was 44%.

During this study 60% of observed human activity occurred on weekends (N = 431, versus 283 for weekdays). Weekend activity predominated at four breeding areas and was nearly equal to weekday activity at two others. Median distance-to-disturbance was less on weekends (300 versus 600 m, $P<0.05$). The increase in median distance-for-response from 200 to 300 m on weekends was not significant ($P>0.05$). Weekend response frequency was 44%, and weekday, 32% ($P = 0.001$). Weekend frequencies of occurrence by disturbance group were vehicle 56%, pedestrian 41%, aquatic 80%, noise 62%, and aircraft 48%. Boats, autos, ATVs, and anglers occurred more commonly on weekends, while canoes and hikers were more frequent on weekdays.

Human activity near breeding Bald Eagles was recorded throughout daylight hours. However, most human activity occurred after noon (72%, N = 513), with a midday peak between approximately 1300-1500, and secondary peaks between 0900-1100 and 1600-1900 (Figure 3). Frequency patterns varied

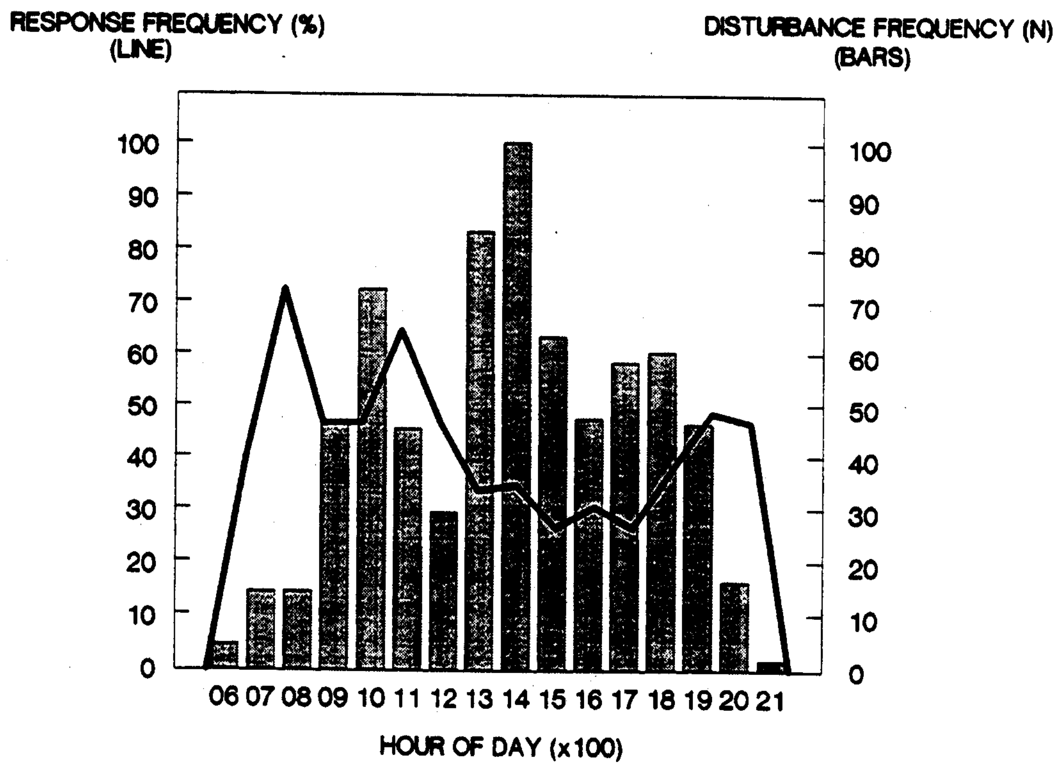

FIGURE 3. Disturbance (N) and response (%) frequency by hour for 714 events of human activity near breeding Bald Eagles in northcentral Michigan, 1990.

among disturbance groups ($P<0.001$), but most pedestrian activity (72%) occurred during the afternoon peak. Response was highest at 0800, followed by lesser peaks at 1100 and 1900 (Figure 3). Response frequency was lowest between 1300-1700, when the occurrence of human activity was greatest. Both median distance-to-disturbance (500 versus 300 m, $P<0.05$) and response frequency (51 versus 35%, $P<0.001$) were higher before 1200. Median distances-for-response were similar before and after noon (300 and 250 m, $P>0.05$).

Classification tree modeling

Distance was the most important classifier, or splitting variable determined by the CART analyses; it occurred at the first or primary split of all models (Figure 4). The relative importance of other parameters for classifying observations (Table 5) varied among sites and disturbance groups, but duration (evident in four of the six models) and number were consistently ranked second and third. The exception was pedestrian activity where sound and visibility were more critical than duration or number. Overall rankings were similar to Grubb and King's (1991) in Arizona. Throughout the CART models, response severity varied inversely with distance and increased with disturbance duration, number-per-event, visibility, and sound. The pooled model shows 55% response when disturbance occurred within 545 m of an eagle versus 17% farther away. Within 545 m, a duration >3.5 min caused 71% response, and <3.5 min, 44%. If sound was associated with the longer disturbance, response was 75%, versus 25% if quiet. Estimated classification accuracy for this model was 0.74.

By disturbance group, vehicles elicited 95% response within 750 m. Short duration (≤ 2.5 min) reduced this frequency to 60%. The primary split for pedestrian disturbance was 185 m. Beyond that distance, quiet activity lowered eagle response. Response frequencies were relatively high on both sides of the 66-m split in the aquatic tree, with shorter durations tending to reduce responsiveness at greater distances. Median distance to disturbance for the 41%-response side of this model was 200 m (n = 198, range 75–1500 m). Noise had the largest primary split of the disturbance groups considered, with 76% response within 850 m and no response beyond. Visibility of the noise source more than halved response within 850 m. Aircraft caused the lowest left-side, response frequency of the five disturbance groups. Short duration flights (≤ 2.5 min) within the 550-m primary splitting distance greatly reduced response. Accuracy estimates for these models were vehicle 0.96, pedestrian 0.69, aquatic 0.57, noise 0.88, and aircraft 0.85.

Discussion

General summary

Within-group response provides a measure of relative impact among specific disturbance groups, whereas overall response combines occurrence (frequency of a disturbance group) with the within-group response to give an assessment of current disturbance levels. Vehicles caused the highest within-group response, yet aquatic and aircraft activities appeared to be having a greater effect on breeding eagles because of more frequent interactions. The question of which is more detrimental, few high-response activities or frequent low-response ones, requires further research into the relationship of response frequencies to behavior modification and ultimately to productivity. Grubb and King (1991)

TABLE 5. Relative importance[a] of independent (splitting) variables in CART analyses for pooled and five groups of human disturbance recorded near breeding Bald Eagles in northcentral Michigan, 1990.

	Disturbance						Overall Ranking	
Variable	Pooled	Vehicle	Pedestrian	Aquatic	Noise	Aircraft	MI	AZ[b]
Distance	100	100	100	100	100	100	1	1
Duration	61	42	34	99	35	89	2	2
Number	53	0	37	42	33	49	3	4
Visibility	16	0	41	2	29	5	4	3
Sound	11	0	67	7	0	0	5	6
Position	21	1	0	0	0	3	6	5

[a] Standardized so primary splitting variable = 100% and secondary variables are expressed as a percentage of it.
[b] From 13 breeding areas, 1983-1985 (Grubb and King 1991).

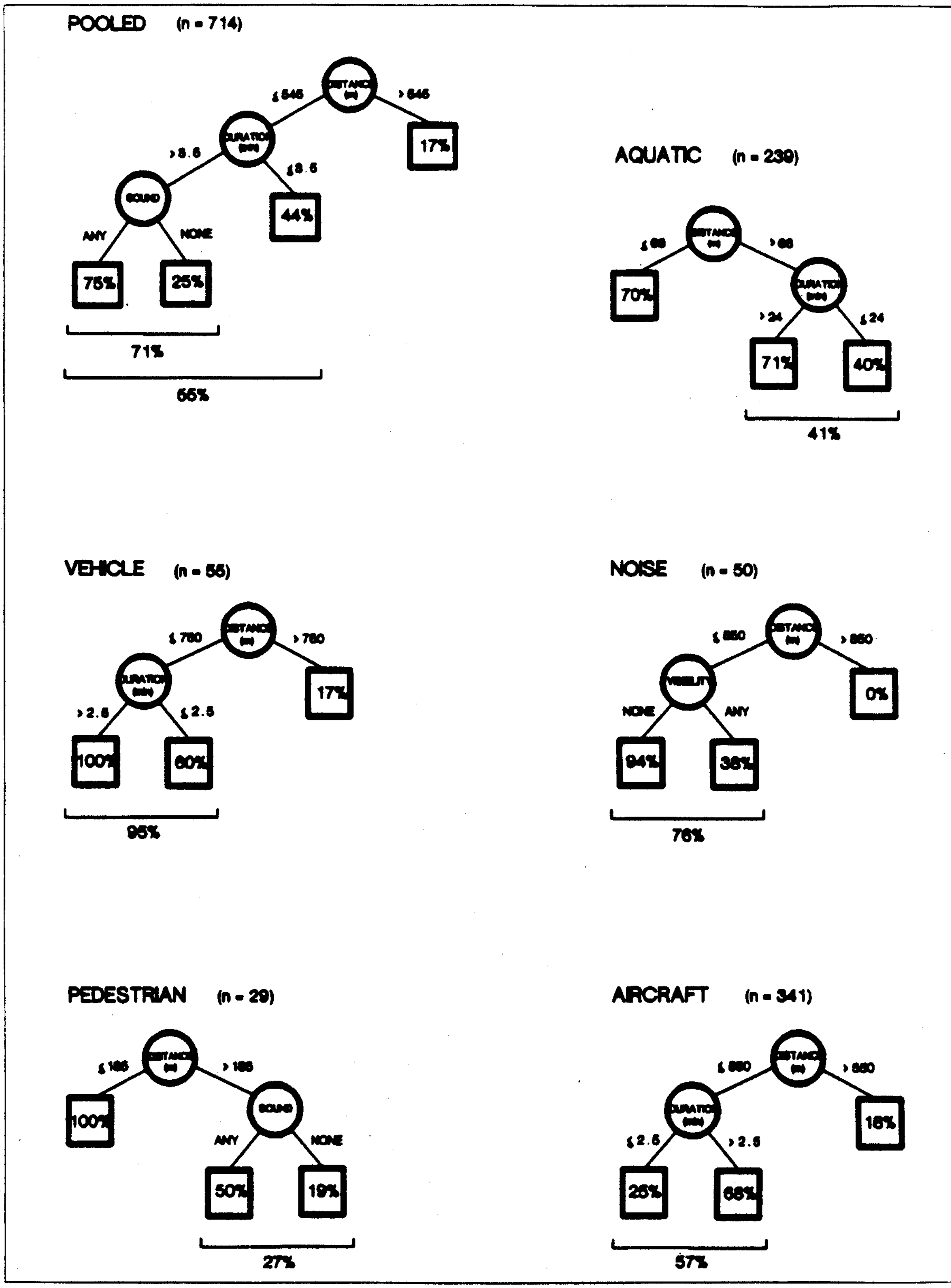

FIGURE 4. Classification tree (CART) models, with associated eagle response frequencies, for pooled and five separate human disturbance groups, recorded near breeding Bald Eagles in northcentral Michigan, 1990.

recommended at least nine parameters, relating to the nature and timing of the disturbance and the status of the affected eagle, for consideration on a case-by-case basis in evaluating relative effects of human activity on breeding eagles.

In the current analysis, an increase in distance-to-disturbance for response generally implied greater sensitivity, or intolerance, by eagles because they reacted to the activity farther away (e.g., ATVs elicited the same response as autos but at 2.5 times the distance). However, in some cases greater distances for response may simply reflect distant occurrence (e.g., light planes elicited the fewest responses among aircraft, yet at the greatest median distance). That ground activities showed the highest response, followed by water and air, is consistent with findings in Minnesota (Fraser et al. 1985) and in Arizona (Grubb and King 1991). Similar disturbance and response characteristics for Michigan and Arizona (Table 1) are evidence for consistency in the nature of disturbance around breeding Bald Eagles, and substantiate observed levels of response within each geographic area.

Although the frequencies of response to pedestrian (45%) and aquatic (46%) activities were similar, median distances for response indicated that aquatic activity can occur closer to eagles with no increase in effect (100 versus 185 m). Canoes, presumably because of their usually quiet unobtrusive occurrence, elicited half the response of power boats at half the distance (24% at 50 m versus 48% at 100 m). The wide disparity in response frequencies for noise types (0% artillery, 76% gunshots) suggests that eagles near the military base tolerate the sound of distant artillery. The response to gunshots is more likely representative of the effect of abrupt loud noise, or perhaps associating previously witnessed mortalities. In Arizona, eagle responses to gunshots and sonic booms were 52 and 63%, respectively (Grubb and King 1991).

Median number-per-event, median durations, and response frequencies for aircraft at other breeding areas (Table 2) better reflect the normal, non-military situation. A larger sample would likely show helicopters cause greater response. Arizona response frequencies for jets, light planes, and helicopters were 30, 27, and 47%, respectively (Grubb and King 1991). The lower aircraft response frequency and much smaller response distance for the military site in comparison with the other areas (400 versus 800 m), especially as both groups had the same median distance of occurrence (800 m), also indicates a habituation to military air activity.

Disturbance characteristics

Generally, if the median distance-to-disturbance for occurrence of any disturbance group or type (Table 1, column 4) was much less than the median distance-for-no-response (column 7), response frequency was high (e.g., all vehicle categories). When these distances were approximately equal, response frequency was typically lower (e.g., all aircraft categories). Although the median distance-to-disturbance for initial (alert) response was 300 m (Figure 2), a better estimate of threshold for response is 500 m, the distance within which 75% of the alert responses occurred. Similarly, 200 m is a more appropriate estimate of a threshold for flight. In Oregon, McGarigal (1988) recorded an alert distance for boating activity of 400–500 m and flight distance of 150–220 m. In Minnesota, Fraser et al. (1985) have determined 500 m to be a minimum distance to avoid disturbance near breeding Bald Eagles.

Age and activity

Nestlings were not as responsive to human activities as adults, but when they responded, they did so at the same median distance-to-disturbance as the adults. This may suggest learned awareness and instinctive reaction. Free-flying immatures have also been found to respond by flying at distances similar to adults (Buehler et al. 1991). Reduced visibility out of the nests, as compared to adults' high perches, may partially account for nestlings' reduced responsiveness to light planes, boats, and canoes. The greater distance-to-disturbance for response indicates adults were less tolerant of disturbance when attending young at the nests than when perched elsewhere.

Breeding area variation

Variation in response among individual pairs of eagles and among disturbance groups for the six breeding areas demonstrates the need for disturbance (human activity), site (habitat), and pair (behavior) specificity in Bald Eagle research and management (Mathisen et al. 1977; Fraser 1985; Grubb and King 1991). The higher response frequency on the Manistee River appears to be associated with the closer proximity of human activity and most of that activity being aquatic, which generally elicits higher response than airborne activity. These trends all remained intact when the military site was removed from the Au Sable data set.

Timing

Since all six study pairs were at approximately the same stage in the nesting cycle, the seasonal decline in frequency and median distance-to-disturbance for response is likely related to a reduction in nest attentiveness that typically occurs as nesting progresses (Newton 1979). Increased visual and audio buffering by developing canopy foliage during the breeding season may also be a factor. Buehler et al. (1991) postulated seasonal variation in responsiveness of eagles on Chesapeake Bay resulted from decreased sensitivity to increased human interactions. In Michigan, the May peak in human activity was likely influenced by a combination of good weather and a spring time increase in recreation activity with the opening of fishing seasons, Memorial Day, etc. The high response frequency shown for March may not be unrealistic even though the sample was small (2 days versus 9–10 each for the other months). Eagles and other birds of prey are most vulnerable to, and most highly impacted by, disturbance early in the breeding season (Fyfe and Olendorff 1976; U.S. Fish & Wildlife Service 1981). Increased eagle response on weekends was apparently caused by a higher frequency of human activity and closer proximity of that activity. The morning and smaller evening peaks of eagle responsiveness were likely related to nest-attending and foraging activity. Similarly, low eagle response in the afternoon period of highest human activity may relate less to conditioning than to eagles' typical diurnal pattern of perching quietly, sunning or loafing for hours during this period.

Classification Tree Modeling

CART analysis provides insight into critical distances associated with different response frequencies, and into the synergistic interaction among disturbance characteristics. Although CART readily accommodates small data sets such as encountered in these analyses, reliability and general applicability of such models must be viewed with caution. Inclusion of a variable in the CART models reflects its ability to separate responses for the subset of data occurring at that node, not necessarily its relative importance within a disturbance group. Splits solely on distance indicate any type of disturbance within the group, regardless of other characteristics (number, sound, duration, etc.), evoked response at the frequency shown.

The implied acceptance of pedestrian activity closer than vehicles both in the CART models and Table 1 is more likely an artifact of pedestrian activity occurring closer rather than the result of a greater tolerance to pedestrians, which would not be expected (Grubb and King 1991). The small splitting distance for aquatic activity also reflects proximity, and perhaps in this case, greater tolerance. However, the relatively high response frequencies on the right or low-response side of this model limit its usefulness, beyond implying a benefit to shorter duration activity. This was also the least accurate of the models constructed. The mitigating influence of visibility in the noise model is best explained by a reduced startle effect when the source of noise is seen (Fyfe and Olendorff 1976).

Differences between primary splitting distance in the CART models and the median distance-for-response for each disturbance (Table 1, column 9) are explained by CART's consideration of the range rather than frequency of distances. In most cases, CART splits occurred at distances greater than the median response distance. Deviations in either direction indicated a wide range of distances-to-disturbance eliciting response. Comparison of overall rankings with Arizona findings (Grubb and King 1991) substantiated the primary and secondary importance of distance and duration, while suggesting number and visibility were next and comparable in general effect, followed similarly by sound and position. Rankings of primary and secondary splitting variables provided by CART can be used to compare and contrast the relative importance of different characteristics within specific disturbance groups or at individual nest sites.

Management Implications

Although CART facilitates improved specificity for site, disturbance, and temporal analyses, consistencies in the Michigan and Arizona results indicate broadly applicable management criteria, while dissimilarities evidence those aspects of disturbance requiring local analysis. Median distances to disturbance for different types or levels of response were similar for both studies and consistent with results from other areas as referenced above. Thus, without local data to the contrary, management of human activities for the protection of breeding Bald Eagles should begin with a no-activity primary zone (Mathisen et al. 1977) at 500–600 m from nest sites, followed by a secondary zone at 1000–1200 m. Flight is typically induced by disturbance at 200–300 m; effective breeding area management should avoid this response.

The Michigan and Arizona studies confirm the traditional importance of distance as the primary characteristic of human disturbance influencing Bald Eagle response. Classification analyses indicated disturbance duration is the second most important criterion for management. Number and visibility are tertiary considerations, followed by sound and position. These rankings are generally applicable; however, the relative importance of these characteristics can vary among populations and disturbances. Therefore, local verification is recommended. Frequency of disturbance types or groups and associated response rates must be determined locally. With sufficient local data, management can be effectively tailored to specific situations, especially since eagle responsiveness indicates potential for impact. Unfortunately, current analyses cannot be directly related to productivity because of the small number of breeding pairs sampled, the narrow range in productivity measures (1-3 eggs or young), too few years of data, and the inappropriateness of controlled experimentation.

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