

Factors Influencing Great Blue Heron Nesting Productivity on the Pacific Coast of Canada from 1998 to 1999

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Abstract.—Surveys were conducted at 35 Great Blue Heron (*Ardea herodias*) colonies in urban and rural landscapes of south-coastal British Columbia, Canada, to investigate low nesting productivity during 1998 and 1999 compared to a decade ago. Nesting failure was common (59% of 1,247 nests) and widespread (in 90% of 31 colonies) and accounted for 96% of the variation in nesting productivity among colonies in 1999. Nesting failure was more frequent in small colonies (<50 nests) than in large colonies (≥50 nests). Human disturbance has probably increased due to growth in the human population in the region, and direct disturbance from the Bald Eagle (*Haliaeetus leucocephalus*) was more frequent in 1999 than a decade earlier. Eagles preyed on eggs, nestlings, and fledglings and were probably responsible for most of the observed nesting failure. Direct disturbance by humans was infrequent, but heron nesting productivity was negatively correlated with the frequency of human pedestrians near colonies. We suggest that Great Blue Heron breeding failure was more frequent in 1998 and 1999 compared to a decade ago because of the combined effects of human disturbance from land development and an increased frequency of eagle predation. Received 16 July 2003, accepted 17 March 2004.

Key words.—Great Blue Heron, *Ardea herodias*, Bald Eagle, *Haliaeetus leucocephalus*, predation, human disturbance, nesting, productivity, reproductive success.

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Humans disrupt the breeding of wading birds by destroying nests, disturbing adults at nests, and persecution (reviewed by Parnell *et al.* 1988; Hockin *et al.* 1992; Rodgers and Smith 1995). Consequently, many wading birds select sites away from human activities (Parnell *et al.* 1988; Watts and Bradshaw 1994). Until recently, the risk of nest predation from birds of prey had not been a serious consideration because raptor numbers have been held at artificially low levels for decades as a result of persecution and eggshell thinning caused by organochlorine pesticides (Forbes 1989; Bednarz *et al.* 1990; Kjellen and Roos 2000; Butler and Vennesland 2000; Elliott and Harris 2001). The recovery of eagle populations in some parts of North America (Bednarz *et al.* 1990; Elliott and Harris 2001) offers an opportunity to examine the relative impact of humans and eagles on nesting herons.

Threats to Great Blue Heron (*Ardea herodias*) nesting colonies in British Colum-

bia include human and Bald Eagle (*Haliaeetus leucocephalus*) activity (Butler *et al.* 1995; Butler 1997), but evidence is largely anecdotal (Butler and Vennesland 2000). The highest concentration of nesting herons in British Columbia is around the Strait of Georgia (Butler 1997), where the Bald Eagle and human numbers have increased (McAllister *et al.* 1986; Forbes 1989; Vermeer *et al.* 1989; Moore 1990; Boyle *et al.* 1997; Elliott and Harris 2001). Conversion of the formerly forested landscape into urban and rural areas has fragmented habitat and isolated some of the available nesting sites for herons into woodlots. Attacks by eagles and disturbance by humans in the region has resulted in nest and colony failure by herons in the past (Norman *et al.* 1989; Butler *et al.* 1995; Butler 1997). The purpose of this paper is to examine the relative significance of eagle and human disturbance on the nesting productivity of the Great Blue Heron in British Columbia.

METHODS

Study Area and Colony Sites

The study was conducted from 21 March to 4 August 1998 and from 17 February to 5 September 1999 at 35 Great Blue Heron colonies in south-coastal British Columbia and northern Puget Sound, Washington (Fig. 1). Colony locations were obtained from an inventory of known colonies (Gebauer and Moul 2001) and information provided by local biologists and naturalists. Sixteen colonies were visited in 1998 and 31 colonies were visited in 1999, involving a total of 35 colonies during the two years of the study. All known nesting locations in the region were visited in 1999, when the study was expanded from the mainland coast of British Columbia in 1998 to encompass Vancouver Island and northern Washington State (Fig. 1). The nesting season extended from 17 February, when herons first arrived in colonies in preparation to breed, to 5 September, when the last fledgling departed its nest. A colony was considered small if it had <50 active nests and large if it held ≥ 50 active nests. Nests were typically located 5-30 m above the ground in trees. The Bald Eagle nested in tall trees throughout the region and often near heron colonies (Forbes *et al.* 1985; Butler 1995), sometimes within 50 m.

Heron Nesting

Heron colonies were visited at about five day intervals through the nesting season to count nests and nestlings, determine the dates of nesting, and document the presence of human and predator disturbances. We are confident that the steps taken to minimize disturbance while collecting data were sufficient to have no measurable impact on the nesting productivity of herons. The perimeter of colonies was quietly approached to a partially concealed vantage point outside the radius at which any heron responded by calling (about 10 m to 100 m). No difference was seen in the behavior of her-

ons near and far from our vantage point and herons went about their normal nesting activities while we were present. Furthermore, excluding the seven colonies that failed completely (those with a small number of visits), heron nesting productivity per initiated nest was unrelated to the number of disturbance surveys at colonies in 1999 ($r_{13} = 0.17$, n.s.). In 1998, 16 colonies were visited 5 to 20 times from 21 March to 4 August. In 1999, 31 colonies were visited 5 to 40 times from 17 February to 5 September. Total time spent at colonies in 1999 was 582 h. We confirmed that a colony had failed for the season by making repeated visits until at least 1 June. No failed colonies were re-colonized by herons after 6 April, and in 1999, only two of 147 nests initiated by herons after 1 June were successful in fledging young.

Nesting productivity was estimated by determining the success or failure of samples of initiated nests followed through the nesting season. To avoid inflation of nesting failure and productivity estimates due to within season re-use of nests, only the final result of each nest was used. Sample sizes varied from 1 to 190 initiated nests per colony, depending on the size of colonies and the ease of viewing nests. In general, all nests were followed at small colonies, while samples were taken at large colonies. An initiated nest was one where incubation was observed on two or more occasions. Nests failed due to predation, parental desertion, or the nest being blown down. A failed colony was one where no herons fledged young. Nestlings were considered to have fledged when seen on branches near the nest or when they were about eight weeks old (Moul *et al.* 2001).

Disturbance

A disturbance was defined as any adverse behavioral response from more than one heron when an antagonist was present (after Sutherland 1996). Humans and avian predators were potential antagonists, and were considered present when within 250 m of a colony perimeter. Presence of these antagonists farther than 250 m rarely caused a disturbance. Exceptions were loud and unusual events, such as logging machinery or rock music concerts, which we considered antagonistic at greater distances. An incursion was defined as a disturbance resulting from the presence of an antagonist inside the colony perimeter and under the canopy. Antagonist activity and disturbances were documented by conducting 30-minute surveys at 22 colonies in 1999. Disturbance observations were not available from all 31 colonies documented in 1999 because data at nine colonies were provided by local biologists who did not conduct disturbance surveys. Visits to colonies were rotated through available daylight hours (04.00 h to 22.00 h). During surveys, the duration and estimated distance from the colony perimeter of all potentially antagonistic events were recorded. We then calculated the number of surveys that an antagonist was present, the number of surveys that an antagonist was present and herons were disturbed (i.e., responded), and the number of incursions into colonies by antagonists during surveys. During the 1999 breeding season, eagle incursions were observed whenever eggs or young were present (18 March to 8 July) and through most daylight hours (06.43 h to 20.08 h). When an eagle settled on a heron's nest, adult herons present uttered continuous and loud alarm calls until the eagle departed. We confirmed predation events by the occurrence of these stationary alarm calls for more than 10 s from the same heron and



Figure 1. Locations of 35 Great Blue Heron colonies in the Strait of Georgia, Strait of Juan de Fuca and northern Puget Sound in 1998 and 1999. Major urban centers are shown.

direct observations of eagles predated the contents of heron nests. Avian predators typically open a heron egg by punching a hole along the long axis, whereas a hatched eggshell is perforated around the equator (Butler 1997). We entered abandoned colonies to search for damaged eggshells on the ground to confirm that predation had occurred.

We used 1:50,000 scale topographical maps to classify the level of human development within a 250 m radius of 31 colonies in 1999. Ten colonies were categorized as rural (>50% land undeveloped or in agricultural use), 13 colonies were categorized as "residential" (>50% land with housing and small roadways), and eight colonies were categorized as "urban" (>50% land heavily developed with large buildings and/or highways).

Statistical Analyses

Statistical analyses were conducted using Minitab Version 11 for Windows and SAS Version 6 for Windows (SAS Institute 1990). All variables were tested for normality using the Shapiro-Wilks method. All significantly non-normal distributions ($P < 0.05$) were transformed for statistical analyses that assume a normal distribution. Productivity and colony size data were treated with $\ln(x + 1)$ transformations and nesting failure and antagonist survey data were treated with arcsin square root transformations. Due to unequal sample sizes across the study period, only 1999 data were used for inter-colony comparisons. Data were analyzed using Z-test, t-test, linear regression, and one-way ANOVA. A Z-test comparing two means with variance calculated from a Poisson distribution was used for pair wise comparisons of proportions and means of proportions.

RESULTS

Productivity, Breeding Failure and Colony Size

The recorded population dynamics and nesting productivity per breeding pair of

herons in 1998 and 1999 are summarized in Table 1. Mean nesting productivity for 16 colonies in 1998 was 1.66 fledglings per initiated nest, and 2.32 fledglings per successful nest. Mean nesting productivity for 31 colonies in 1999 was 0.82 fledglings per initiated nest, and 1.98 fledglings per successful nest. Overall means of nesting productivity for the two years of this study were 1.24 fledglings per initiated nest (SE \pm 0.42) and 2.15 fledglings per successful nest (SE \pm 0.17).

Six of 16 colonies failed to fledge any young in 1998 (38%) and 13 of 31 failed to fledge any young in 1999 (42%). Of 16 colonies that failed at least once over the study period, 14 failed prior to the eggs hatching and only two failed when young were in the nests. The largest nesting failure event occurred in 1999 when 399 of 400 nesting pairs failed to fledge young in one colony. Excluding this unusual event, nesting failure was still common in large colonies. Nesting failure in the remaining ten large colonies accounted for more than half of all failed nests in 1999, and nearly half of all initiated nests in large colonies failed to fledge young.

Nesting failure was common (59% of 1,247 initiated nests) and widespread (occurred in 90% of 31 colonies) in 1999 (Table 1). Nesting failure accounted for 96% of the variation in productivity per initiated nest among all heron colonies in 1999 ($r_{29} = 0.98$, $P < 0.001$; Fig. 2a). Even when the 13 colony

Table 1. Summary of Great Blue Heron population dynamics and nesting productivity in south-coastal British Columbia in 1998 and 1999.

	1998	1999
No. of colonies	16	31
No. of nests observed	662	1,247
Total estimated no. of nests	725	1,928
Mean colony size	45	62
Median colony size	26	26
No. of failed colonies ¹	6	13
No. of failed nests	174	735
No. of colonies failed during incubation	5	12
No. of colonies failed during chick rearing	1	1
Nesting productivity per initiated nest	1.66	0.82
Nesting productivity per successful nest	2.32	1.98
Mean productivity per initiated nest 1998-1999 (\pm SE)	1.24 (\pm 0.42)	
Mean productivity per successful nest 1998-1999 (\pm SE)	2.15 (\pm 0.17)	

¹All nests failed to raise fledged young.

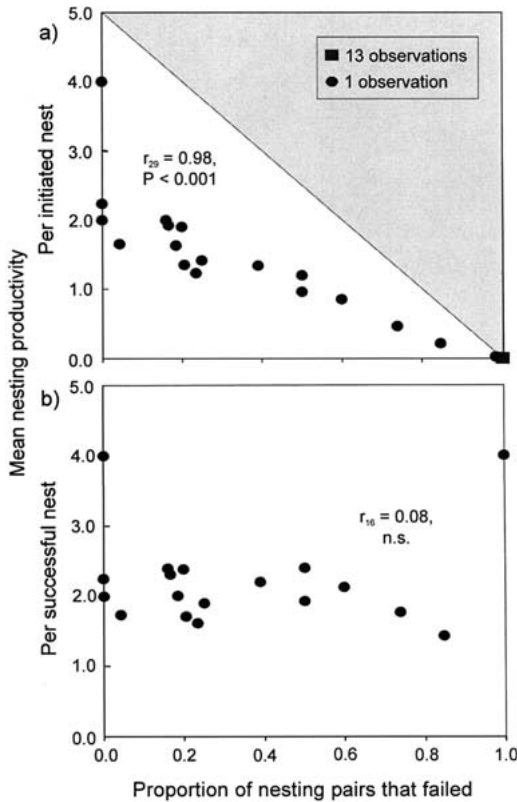


Figure 2. Nesting productivity as the mean number of young fledged per nest plotted against the proportion of nesting pairs that failed to fledge young in 31 Great Blue Heron colonies in 1999. Nesting productivity is presented for a) all initiated nests, and b) only successful nests. All productivity observations by initiated nests must fall within the unshaded region of the figure. In b) when all three colonies with less than five successful nests were excluded from the analysis (to avoid outliers), the relationship was not significant ($r_{13} = 0.34$, n.s.). Statistics are based on transformed data.

failures were excluded from the data, nesting failure still accounted for 88% of the variation in productivity per initiated nest among the remaining heron colonies ($r_{16} = 0.94$, $P < 0.001$). The productivity of successful nests was not significantly related to the extent of nesting failure in colonies in 1999, even when outliers were excluded (Fig. 2b).

At 18 colonies that succeeded in raising more than one fledgling, mean colony productivity per initiated nest was not significantly related to colony size ($r_{16} = 0.07$, n.s.). However, mean productivity per initiated nest exhibited a significant and positive relationship to colony size when all 31 colonies

were included ($r_{29} = 0.39$, $P < 0.05$; Fig. 3). Nearly two-thirds of 20 small colonies failed and all failed colonies were small colonies. Small colonies contained 15% of all nesting pairs and 9% of all failed nests ($N = 1,928$).

Disturbance

Nesting herons responded to the presence of humans, Northwestern Crow (*Corvus caurinus*), Bald Eagle, Red-tailed Hawk (*Buteo jamaicensis*) and Common Raven (*Corvus corax*) (Table 2). At least one of these antagonists was present on 86% of 446 surveys conducted in 1999. Humans and crows were the most frequent antagonists followed by eagles, hawks and ravens. The proportion of surveys with humans present was not significantly different from that of crows ($Z_1 = 0.6$, n.s.), and humans were present significantly more often than eagles ($Z_1 = 7.3$, $P < 0.001$) and hawks ($Z_1 = 9.6$, $P < 0.001$). Eagles were present significantly more often than hawks ($Z_1 = 2.6$, $P < 0.01$), and hawks were present significantly more often than ravens ($Z_1 = 2.0$, $P < 0.05$).

Adult herons responded more frequently to the presence of eagles than to any other antagonist (Table 2) and eagles elicited a re-

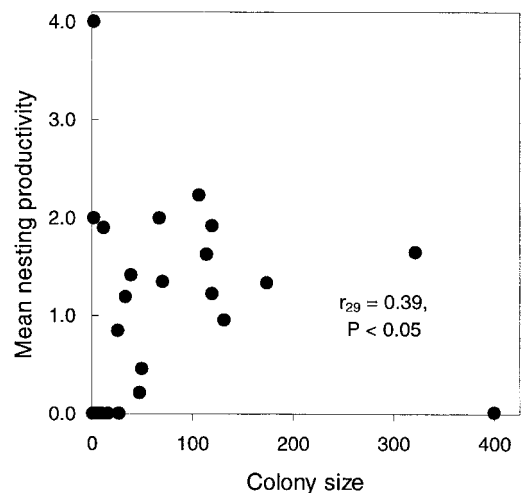


Figure 3. Nesting productivity as the mean number of young fledged per initiated nest plotted against colony size for 31 Great Blue Heron colonies in 1999. Statistics are based on transformed data. The cluster of failed colonies near the origin totals 13 colonies.

Table 2. Antagonists and disturbance at Great Blue Heron colonies in 1999. The number of surveys in which each antagonist was present, the number of surveys that each antagonist was present on which herons responded (i.e., were disturbed), and the number of surveys where each antagonist was present and incursions occurred. Different superscripts in vertical columns denote frequencies that are statistically different.

Antagonist	Frequency		
	No. of surveys present (out of 446 surveys)	No. of these surveys with disturbance	No of surveys with incursions
Human	239 ^a	10 ^b	0
Northwestern Crow	226 ^a	3 ^c	0
Bald Eagle	104 ^b	63 ^a	55 ^a
Red-tailed Hawk	70 ^c	6 ^b	1 ^b
Common Raven	48 ^c	2 ^b	0

sponse from nesting herons significantly more often than from all other antagonists (hawks, $Z_1 = 6.2$, $P < 0.001$; humans, $Z_1 = 7.3$, $P < 0.001$). There was no significant difference between the frequency of disturbances by humans and hawks ($Z_1 = 1.2$, n.s.), humans and ravens ($Z_1 = 0.005$, n.s.), or hawks and ravens ($Z_1 = 0.96$, n.s.). Incursions occurred on 53% of surveys with a disturbance by eagles and 1% of surveys with a disturbance by hawks (Table 2). During disturbances, incursions by eagles were significantly more frequent than incursions by hawks ($Z_1 = 7.1$, $P < 0.001$; Table 2).

Mean colony nesting productivity per initiated nest was significantly and negatively correlated with nearby human pedestrian activity (Fig. 4). All five colonies with human pedestrians present on more than 50% of surveys experienced either total colony failure ($N = 4$) or low productivity ($N = 1$; 0.22 fledglings per initiated nest; Fig. 4). However, these results were confounded by eagles that heavily disturbed four of these five colonies. Eagles were implicated in three of the four colony failures. Humans were responsible for one colony failure when heavy land-clearing machinery was operated within 50 m of the colony on 30 June 1999. The general level of urbanization near colonies did not have a significant relationship with mean colony productivity per initiated nest ($F_{2,28} = 0.26$, n.s.). Total colony failure occurred in three colonies in urban areas, nine colonies in residential areas, and one colony in a rural area ($N = 31$). Colony failure in residential areas was significantly more frequent than in urban ar-

reas ($Z_1 = 2.2$, $P < 0.05$) but not rural areas ($Z_1 = 1.7$, n.s.). There was no significant difference between the frequencies of colony failure in urban and rural areas ($Z_1 = 0.82$, n.s.).

Eagles predated heron eggs, nestlings or fledged young on 9.8% of 239 incursions. Eagles had little difficulty taking heron broods due to the propensity of adult herons to abandon them when threatened. During the two years of this study, heron nesting productivity per initiated nest was significantly lower in the year when eagle incursions were more frequent (Table 3). Eagles were seen to predate nest contents in seven colonies in

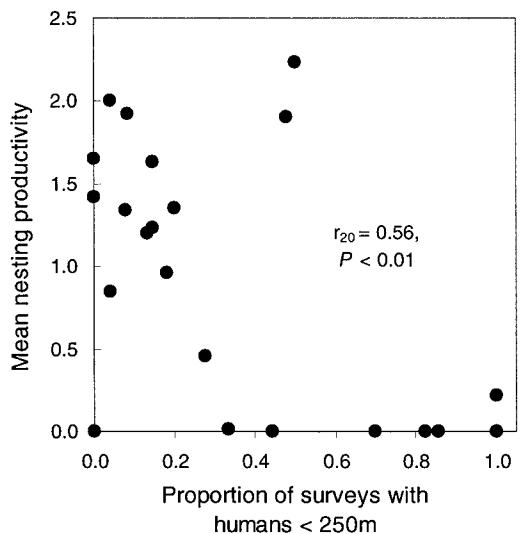


Figure 4. Nesting productivity as the mean number of young fledged per nest plotted against the proportion of surveys where human pedestrian traffic was less than 250m from the colony edge based on 30 min surveys at 22 Great Blue Heron colonies in 1999. Statistics are based on transformed data.

Table 3. Nesting productivity and the frequency of eagle incursions observed during observations at Colonies 16 and 23 in 1998 and 1999. The number of nests used to calculate mean productivity and the number of h of disturbance observations with colony sizes are presented. Subscripts refer to the statistical comparisons listed in the table. Productivity data were transformed prior to statistical tests; incursion data were analyzed as incursions per hour per nest.

Colony	Year	Productivity per initiated nest			Eagle disturbance			
		N	Mean	SE	No. of nests	Observation time (h)	No. of incursions	Incursions per h per nest
16	1998	54	2.2 ^a	0.1	83	15	0	0
	1999	27	1.6 ^a	0.2	114	36	15	0.004
^a ($t_{79} = 2.3, P < 0.05$)								
23	1998	165	0.6 ^b	0.09	190	47	120	0.01 ^c
	1999	170	1.4 ^b	0.1	174	69	39	0.003 ^c
^b ($t_{333} = 5.7, P < 0.001$)					^c ($Z_1 = 34.4, P < 0.001$)			

1999 that then failed. Five colonies in 1999 failed for unknown reasons, although we suspected that eagles were involved in each of these events because eggshells damaged by a predator were found in each colony and other antagonists were rarely observed attacking nesting herons or their broods.

DISCUSSION

The mean nesting productivity per initiated nest for the Great Blue Heron in south-coastal British Columbia during 1998 and 1999 was lower than estimates from other breeding studies in North America and other years in British Columbia (reviewed by Butler 1997; see also Pratt 1970; Vos *et al.* 1985). However, it is too early to conclude whether the low breeding productivity observed during this study represented an extreme observation or part of an important trend.

Nesting failure was common, widespread, and explained most of the variation in nesting productivity per initiated nest in 1999. The failure of 399 of 400 nests in one colony in 1999 was the largest failure event observed in this region. Prior to our study, the largest failure was about 100 nesting pairs on Sidney Island (Butler 1995). Furthermore, nesting productivity per initiated nest was positively related to colony size due to the higher frequency of colony failure in small colonies. These results suggest that nesting failure represented the strongest determinant of heron nesting productivity per initiated nest in colonies of all sizes in south-

coastal British Columbia. Our conclusion concurs with that of Frederick and Collopy (1989) who showed that one-third of nesting pairs in five ciconiiform species (not including the Great Blue Heron) in Florida failed to raise fledged young.

We used only the last nesting attempt in each nest in our analyses. This method will result in an underestimate of failed nesting attempts. Furthermore, any herons moving between colonies could be counted twice. We believe these biases will not affect our conclusions because our conservative estimate of nesting failure still explained most of the variation in nesting productivity per initiated nest. Further, failed nests were usually quickly re-initiated, suggesting that the same pair was re-nesting, and the number of newly recruited pairs to a colony, indicated by new nests built late in the season, was small.

There are many potential factors that could cause a decline in heron nesting productivity, but disturbance near breeding colonies is the most likely explanation for the low productivity and common nesting failure reported in this study. Nesting failure was the primary mechanism through which heron productivity per initiated nest varied across colonies and regions, and nesting failure has been cited as a consequence of human and predator disturbance for many species (reviewed by Ricklefs 1969; Parnell *et al.* 1988; Hockin *et al.* 1992). Increased nesting failure has been related to increased human disturbance in the Brown Pelican (*Pelecanus occidentalis*; Anderson 1988). Factors other than

human and eagle disturbance did not appear to have a strong influence on heron nesting failure. Habitat availability is a potential problem in developed areas (Parnell *et al.* 1988; Butler 1997), but would be likely to cause a decline in numbers of nesting herons. Regional declines in heron numbers have been documented (Downes and Collins 1996; Gebauer and Moul 2001), but they have occurred in the least developed regions of the study area. Contaminants have been declining over the past decade and currently there is no widespread problem (Elliott *et al.* 2003). No unusually adverse weather conditions were observed in 1998 or 1999. Heron colony size is related to food availability near colonies (Lack 1954; Fasola and Barbieri 1978; Gibbs 1991; Butler 1992; Gibbs and Kinkel 1997), and food availability probably limits the number of young raised by successful pairs (Butler 1995), but food shortage is not a likely explanation for the widespread nesting failure observed. A deficiency of food would probably have caused reductions in the number of fledglings from successful nests in addition to increased nesting failure. The productivity of successful nests was not related to the level of nesting failure in colonies in 1999, feeding trips were frequently observed at colonies, fish were observed under nests in abandoned colonies, and little starvation or unexplained nestling mortality was observed.

Heron nesting productivity per initiated nest was significantly and negatively correlated with the frequency of eagle incursions. Many raptors have been increasing over the past half-century, probably in response to lower levels of human persecution and contamination (Forbes 1989; Bednarz *et al.* 1990; Kjellen and Roos 2000; Butler and Vennesland 2000; Elliott and Harris 2001). Eagle numbers in south-coastal British Columbia have increased over the past half-century (McAllister *et al.* 1986; Forbes 1989; Vermeer *et al.* 1989; Elliott and Harris 2001) and this has probably resulted in increased numbers of eagle incursions. Eagle incursions were significantly more frequent in this study than in the study of Norman *et al.* (1989) in the same region in 1988 ($Z_1 = 2.3$,

$P < 0.05$). Norman *et al.* (1989) documented 56 incursions during 578 h of observation at eight heron colonies in 1988 (one incursion on average every 10.3 h). We observed 55 eagle incursions during 223 h of observation at 22 colonies in 1999 (one incursion on average every 4.1 h).

Although only one case of human disturbance was documented that directly caused a colony to abandon, the presence of humans might have been a contributing factor to increased eagle incursions. Heron nesting productivity per initiated nest was negatively, but not closely related to the level of pedestrian traffic within 250 m of colonies. However, eagles also disturbed four of five colonies with high levels of pedestrian activity, suggesting that there might have been an interaction between human and eagle disturbances at heron colonies.

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