Use of Vanishing Bearings to Locate New Wading Bird Colonies

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Abstract.—Estimating the size of breeding populations of colonial nesting wading birds is a priority for waterbird management but locating colonies can be difficult. Existing methodologies to locate wading bird colonies require use of airplanes and/or a systematic search of likely colony locations on the landscape. This study describes the use of vanishing bearings of Great Blue Herons (*Ardea herodias*) as they depart coastal foraging sites to determine the number and location of associated breeding colonies. In 2002, frequency analysis of the vanishing bearings identified 23 modes at ten sites while in 2003, 29 modes at 15 sites were identified. Of these modes, about one-half (twelve in 2002 and 15 in 2003) were associated with a known colony. Groupings of vanishing bearings unassociated with known colonies prompted searches for unknown colonies. Searches in 2002 and 2003 found three colonies missed during routine colony inventories using information from the public. Intensive searches in 2004 and 2005 at foraging sites where large colonies had previously abandoned located four previously unknown colonies. These results give confidence that all colonies associated with known foraging sites can be located using this method. *Received 28 July 2005, accepted 7 November 2005.*

Key words.—vanishing bearings, colony location, Great Blue Heron, *Ardea herodias*, wading birds, colonial nesting.

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Estimating population size and productivity of colonial breeding birds has been the focus of many studies (e.g., Forbes *et al.* 1985; Kelly *et al.* 1993; Butler *et al.* 1995; Parsons and McColpin 1995). However, one must first locate breeding colonies, which range in size from a few to several hundred birds. Methods previously used to locate wading bird colonies are plagued with inefficiencies and biases. For example, Frederick *et al.* (1996) describe an aerial and boat survey used to locate wading bird colonies, but these methodologies were biased towards light-colored birds, required searching all potential nesting sites, and were conducted in the best possible conditions for aerial surveys. A less labour intensive method that takes advantage of the behavior of the birds, and that can be used in a variety of situations, is evaluated here.

Past studies of wading birds observed the flight direction of birds departing from, and arriving to, a colony and/or roost to determine where these birds foraged (Siegfried 1971; Krebs 1974; Pratt 1980; Bayer 1981; Erwin 1984; Dowd and Flake 1985; Forbes 1986; van Vessem and Draulans 1987; Benoit *et al.* 1993; Parsons and McColpin 1995; Wong *et al.* 1999; Custer and Galli 2002). Krebs (1974) placed observers along the flight paths in order to confirm the arrival of a bird at the foraging site. Using this logic, it should be possible to follow the flight directions of wading birds returning to their colonies from foraging sites to locate previously undiscovered colonies.

This study describes the methodology used to determine the number and general location of cryptic colonies of Great Blue Herons (*Ardea herodias*) using vanishing bearings observed from coastal foraging sites in British Columbia. The methodology consists of identifying groupings of vanishing bearings that predict the location of known or unknown colonies, followed by an intensive search effort to find any undiscovered colonies predicted by the vanishing bearings. To establish the validity of this method, (1) all known colonies must be associated with vanishing bearings from one or more foraging sites and (2) all vanishing bearings from a site must be investigated to determine if they are associated with a colony. A corollary of these conditions is that herons leaving foraging sites in directions inconsistent with known colonies are likely flying to previously undiscovered colonies. This study examines the veracity of these two premises. The utility of the frequency of observed vanishing bearings for estimating the size of unknown colonies is also discussed.

METHODS

Study Area

The study area was located in the Strait of Georgia, British Columbia, a coastal ocean basin characterized by numerous estuaries of various sizes (Fig. 1). During the first stage of this study (April-June 2002 and 2003), approximately 1,000 pairs of Great Blue Herons foraged at the many estuarine and intertidal foraging sites that characterize this region. Most foraging sites are extensive, geographically discrete intertidal estuarine mudflats; consisting of eelgrass beds where up to 700 individual Great Blue Herons forage during low tide. Estuaries range in size from 18 ha to > 7,500 ha (Ryder *et al.* 2004). Within the vicinity (< 10 km) of most foraging sites are large tracts of forests of suitable nesting trees such as Red Alder (*Alnus rubra*), Douglas Fir (*Pseudotsuga menziesii*), and Western Hemlock (*Tsuga heterophylla*) (Butler *et al.* 1995).

Field Data

Observations of foraging herons were made at several estuaries and other foraging sites between 30 April and 26 June in 2002 and 2003 (Fig. 1). These dates coincide with the provisioning period of nestlings (Butler 1993). Sites visited in 2002 were Boundary Bay, the Chemainus River estuary, Cowichan Bay, Hornby Island, Maplewood and Port Moody in Burrard Inlet, the Nanaimo River estuary, the Puntledge River estuary, and portions of the Fraser River estuary at Roberts Bank and Sea Island. These, plus five other sites (Baynes Sound, the Capilano River estuary, the Englishman River estuary, Esquimalt Harbour, and the Sidney Island lagoon), were visited in 2003. Each site was visited for two to six days and vanishing bearings were recorded beginning approximately 2-3 hours preceding a low tide, as this is when most provisioning herons forage (Butler 1993; Matsunaga 2000). Observations continued for 2-3 hours following a low tide, depending upon the number of birds remaining at the foraging site.

A vanishing bearing is the relatively straight compass bearing a bird flies as it returns to its colony. Vanishing bearings of departing birds were recorded by an observer positioned in, or along the periphery, of a Great Blue Heron foraging site. A key assumption of this methodology was that to minimize energetic costs, a heron, where geographically feasible, would fly a direct route between its foraging site and its colony. Vanishing bearings were measured using GPS technology (Fig. 2) where ideally, this compass bearing would be a true vanishing bearing as the heron disappeared on the horizon while heading directly away from the observer. However, not all herons departed directly away from the observer. Sometimes the observer had restricted access to ideal observation posts, while at other times proximity to the herons could cause unwanted disturbance. Consequently, par-

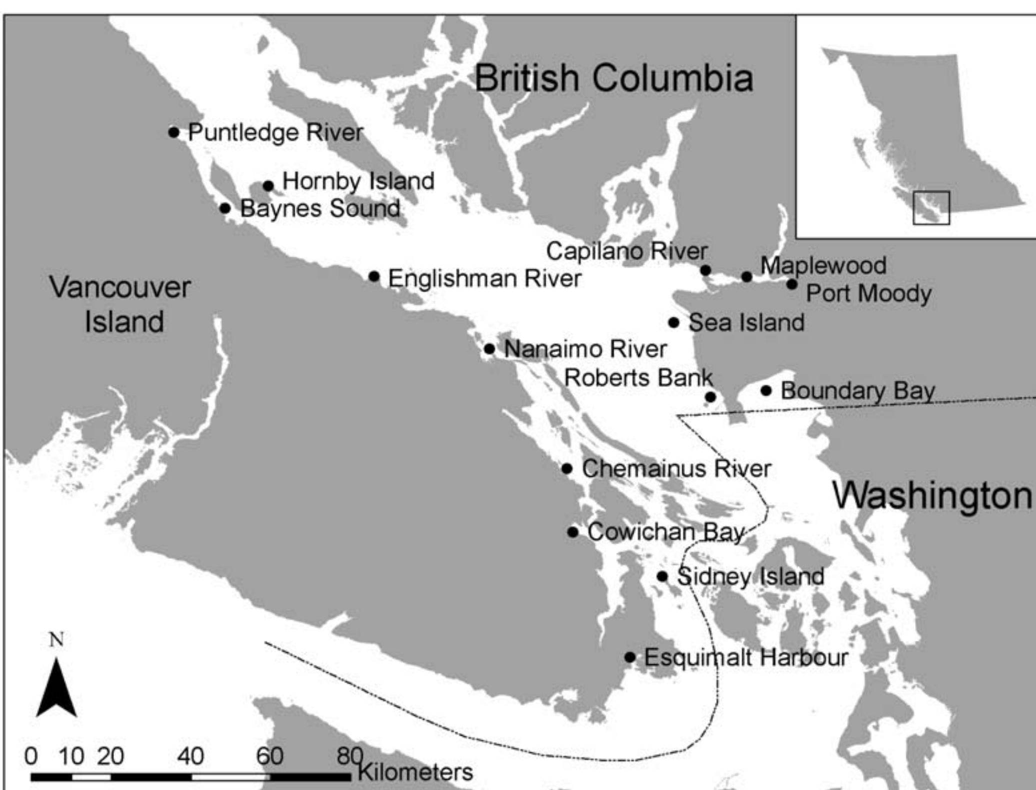

Figure 1. Map of the Strait of Georgia study area in southwestern British Columbia, Canada. Locations of Great Blue Heron foraging sites are shown.

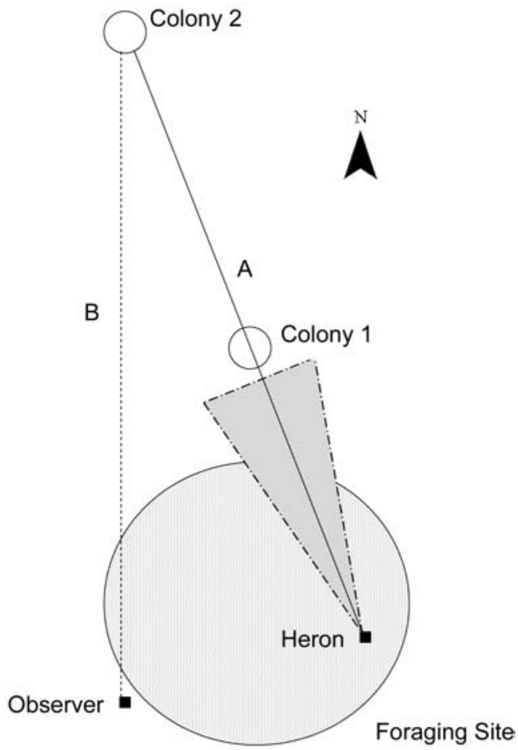

Figure 2. Diagram describing the vanishing bearing of a Great Blue Heron. When the heron leaves the foraging site, it follows a direct flight to its colony (line A). An observer determines this bearing using a GPS unit compass. However, due to parallax, when the observer loses sight of the heron as it leaves the foraging site, the measured vanishing bearing is subject to some measurement error. The hatched triangle contains the range of likely measured vanishing bearings, with the true vanishing bearing being located within this range (line A). In situations where the colony is located near the foraging site (i.e., Colony 1); this parallax can lead to the true bearing between a colony and a foraging site being inconsistent with the measured vanishing bearing. In situations where the heron can be observed for a long distance after it departs the foraging site en route to a distant colony (i.e., Colony 2), parallax is lessened as the line (line B) from the observer to the where the heron was last seen on the horizon begins to converge with the true vanishing bearing. To minimize parallax, the optimal position of the observer would be directly along the heron's flight path.

allax caused by oblique observation of heron flights affected the measurement of some vanishing bearings (Fig. 2). Thus, the true bearing between a foraging site and known colonies was calculated using trigonometry.

Investigations of vanishing bearings inconsistent with known colonies determined whether herons were flying to unknown colonies. Low intensity searches for colonies lasted for about one hour after the daily observations on a foraging site. Searches were typically constrained to roadways because extensive searches of private land were not feasible. Searches were limited to within ten kilometers of the foraging estuary as Butler *et al.* (1995) concluded heron colonies were located an average of 2.9 km from foraging sites in this region. When possible, local residents were asked for locations of any nearby colonies.

Two foraging sites (Cowichan Bay in 2004 and Boundary Bay in 2005), where large colonies had recently abandoned, presented an opportunity for a high intensity search for unknown colonies. These sites were considered as two case studies to test the utility of the vanishing bearing methodology. Groupings of vanishing bearings recorded at these sites identified the number of potential colonies. The high intensity search consisted of placing one observer on the foraging site who communicated via cellular phone with observers placed along flight paths (cf. Krebs 1974) indicated by the vanishing bearings. The observers identified the location of colonies by progressively following departing herons to their destination.

Statistical Analysis

A modal analysis of the frequency distribution of vanishing bearings for each foraging site identified patterns in vanishing bearings for each site. A maximum likelihood frequency analysis was designed specifically for analyzing these vanishing bearings and coded in Microsoft Visual Basic® (B. D. Smith, pers. comm.). The analysis builds upon the general methodology of Schnute and Fournier (1980) that has provided a template for several specific frequency analysis designs (e.g., see Smith and Botsford 1998). When conducting the modal analyses, groupings of vanishing bearings were sufficiently separated to an extent that they could be readily identified. Based on the inherent variability in vanishing bearings measurements, an arbitrary uncertainty interval of ±10° was judged sufficient to account for the deviation of the measured bearing from the true bearing due to variable flight paths and parallax.

The mean of each observed vanishing bearing mode was regressed against the true bearing between a foraging site and a known colony to determine if herons flew a direct route back to their colony and to verify the consistency of these bearings. Additionally, the frequency of observed vanishing bearings (measured as vanishing bearings per hour) consistent with known colonies (2002-2004 only, including colonies found during this study) was regressed against the size of known colonies (Vennesland 2003; McClaren 2004) to determine if the frequency of observed vanishing bearings could be used to predict colony size.

RESULTS

In 2002, 23 vanishing bearing modes were identified at ten coastal foraging sites, while 29 modes were identified at 15 foraging sites surveyed in 2003. In 2002, eleven colonies were known to exist at the start of the breeding season while 15 were known in 2003. Herons from one colony foraged at two separate estuaries in 2002, therefore twelve modes were expected to be associated with known colonies. Comparisons of the vanishing bearings consistent with a known colony and the actual bearing between the foraging site and colony validated using a ± 10° range to account for parallax (see Methods). The estimated vanishing bearings contained 75% (9 of 12) of the known colonies within this range in 2002 and 67% (10 of 15) in 2003 (Table 1). Regression of the estimated means of the vanishing bearing against the true bearings shows a high correlation ($r^2 = 0.98$, Fig. 3) once an outlier was removed to eliminate a colony at Hornby Island that had abandoned during the breeding season (McClaren 2004). This high correlation suggests that vanishing bearings accurately represent the direction of a heron's return flight

Table 1. Great Blue Heron vanishing bearings and number of herons observed using each vanishing bearing at foraging sites in the Strait of Georgia, 2002-2005. Outcome refers to whether or not the observed vanishing bearing is associated with a known colony, led to a new colony, or had an unknown outcome.

Foraging site	Vanishing bearing	Year	Herons observed	Outcome
Baynes Sound	297°	2003	20	Known Colony
Boundary Bay	36°	2005	14	Colony Found
	42°	2003	5	Unknown
	71°	2005	64	Roost and Colony Found
	73°	2002	13	Known Colony
	97°	2003	7	Unknown
	287°	2005	4	Known Colony
	307°	2002-03	110	Known Colony
Capilano River	58°	2003	4	Unknown
	160°	2003	1	Known Colony
Chemainus River	122°	2002	3	Unknown
	160°	2002-03	323	Colony Found in 2002
	190°	2002-03	42	Unknown
Cowichan Bay	41°	2002	4	Colony Found
	110°	2002-04	14	Colony Found in 2004
	193°	2002-04	472	Colony Found in 2004
	298°	2003-04	13	Foraging Site Found in 2004
	319°	2002	30	Known Colony
Englishman River	118°	2003	1	Known Colony
	253°	2003	1	Known Colony
Esquimalt Harbour	2°	2003	2	Unknown
	102°	2003	5	Unknown
	283°	2003	15	Unknown
Hornby Island	56°	2003	1	Unknown
	261°	2002	52	Known Colony
Maplewood	4°	2003	4	Unknown
	116°	2002	5	Known Colony
	343°	2002	1	Unknown
Nanaimo River	150°	2002-03	50	Known Colony
	235°	2002	43	Unknown
	333°	2002-03	10	Known Colony
Port Moody	119°	2003	3	Unknown
	145°	2002	4	Unknown
	183°	2002	1	Unknown
Puntledge River	155°	2002-03	149	Known Colony
	241°	2002	12	Unknown
Roberts Bank	33°	2002-03	9	Known Colony
	52°	2002	7	Known Colony
	65°	2003	54	Colony Found
	136°	2002-03	832	Known Colony
Sea Island	38°	2002-03	13	Known Colony
Sidney Island	95°	2003	3	Unknown
	222°	2003	46	Known Colony

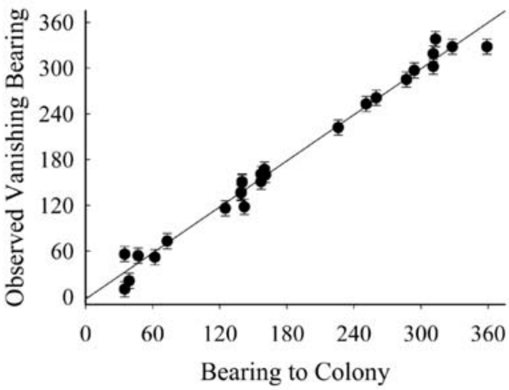

Figure 3. Correlation between the estimated mean vanishing bearing of departing Great Blue Herons and the true bearing between a foraging site and a known colony. The high correlation ($r^2 = 0.98$) suggests herons tend to fly directly to their colonies. Error bars are ±10° to account for uncertainty due to parallax and other sources of measurement error.

to its colony. If the analysis is restricted to vanishing bearing modes with a sufficient sample size ($N \geq 5$), then 73% (8 of 11) in 2002 and 87.5% (7 of 8) in 2003 of known colonies are contained within the estimated vanishing bearing ranges. Combining both years yields 79% (15 of 19) of known colonies being consistent with the estimated vanishing bearings. The estimated vanishing bearings suggest that there may have been eleven and 14 undiscovered colonies in 2002 and 2003, respectively. The number of modes unassociated with known colonies suggests that potentially 48% of all colonies were undetected. Of these undiscovered colonies, two (seven and 42 nests) were found in 2002 while only one (35 nests) was found in 2003 using low intensity searches.

High intensity searches in 2004 and 2005 attempted to confirm that vanishing bearings unassociated with a known colony were associated with undiscovered colonies. Analysis of observed vanishing bearings at Cowichan Bay and Boundary Bay identified three modes at both sites (Fig. 4, although one mode was consistent with a previously known colony at Boundary Bay towards the northwest). At Cowichan Bay (Fig. 4a), intensive searching along these vanishing bearings resulted in confirmation of two new colonies, one to the south (57 nests) and one to the southeast (seven nests), while at Boundary Bay (Fig. 4b), searches resulted in a new colony to the northeast (31 nests) and east (3 nests). These colonies were located within four hours of beginning the search. A second foraging site, rather than a colony, was found along the third vanishing bearing (towards the northwest) at Cowichan Bay after two days of tracking individual heron flights, although this does not prove that a colony did not exist. For example, the vanishing bearing towards the east at Boundary Bay (Fig. 4b) led to the discovery of a roost site in a tidal marsh in addition to the three-nest colony found along the same vanishing bearing.

The frequency of vanishing bearings and the size of known colonies was correlated ($P = 0.0007$, $r^2 = 0.35$, Fig. 5). However, the predictive ability of this relationship allows estimates of colony size to range by two orders of magnitude.

DISCUSSION

The two premises supporting the use of vanishing bearings to estimate the number and location of heron colonies on the landscape have generally been validated. Supporting the first premise, virtually all known colonies had vanishing bearings that accurately estimated the actual bearing between the colony and the foraging site. In the few cases where this condition was not fulfilled, the actual bearing is minimally outside of the predicted range (Fig. 3). Only one known colony (Hornby Island) had no observed vanishing bearings associated with it, but this colony abandoned during the breeding season (McClaren 2004). The second premise, that all vanishing bearings must be investigated to determine if they are associated with a previously unknown colony, was generally fulfilled. Over all foraging sites, seven colonies were found over the course of four years, although not all vanishing bearings from some foraging sites were intensely searched. More specifically, the intensive search method at the first case study site, Cowichan Bay in 2004, confirmed two out of three vanishing bearing modes to be associated with previously undiscovered colonies. At the second

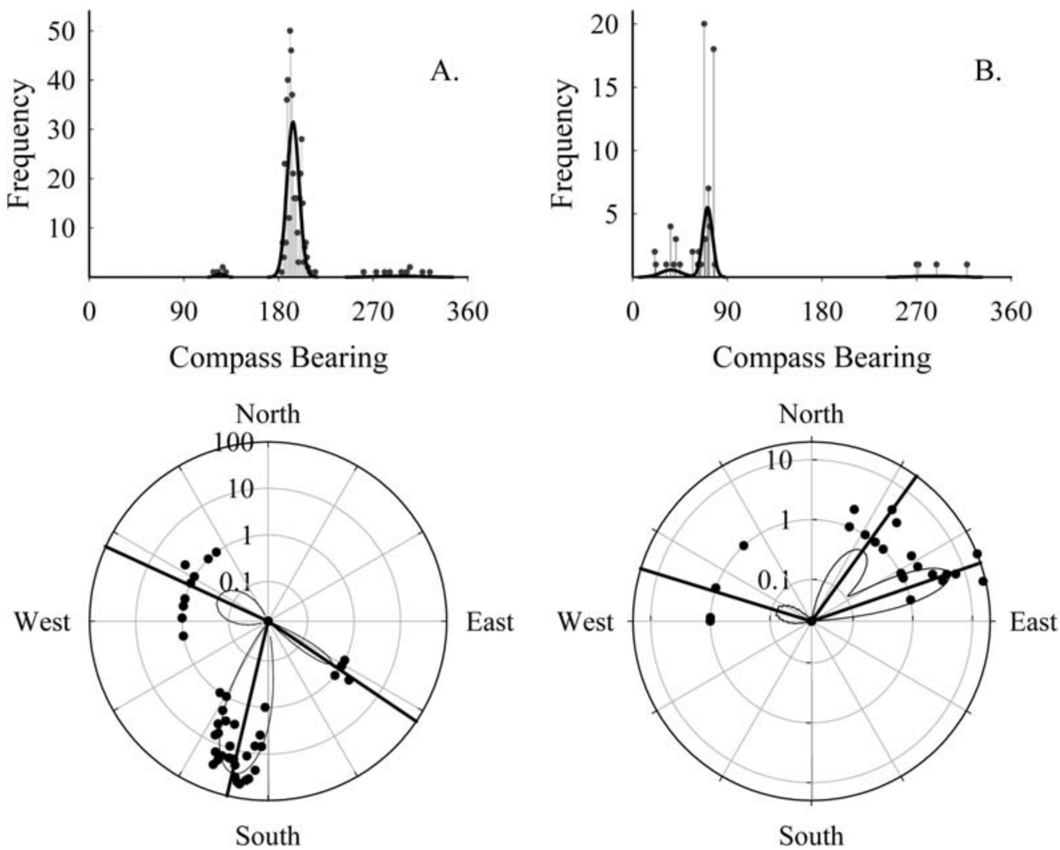

Figure 4. Vanishing bearing frequencies for Great Blue Herons departing from (A) Cowichan Bay (N = 472) in 2004 and (B) Boundary Bay (N = 82) in 2005. Frequency analysis identified three modes at each foraging site (upper graphs) where the dots are the observed vanishing bearings for 1° intervals and the line is the expected frequency. The lower graphs transform the upper graphs to polar plots to indicate compass directions. In the polar projection, thick, dark lines indicate the mean flight direction for a particular mode.

case study site, Boundary Bay in 2005, both vanishing bearing modes not associated with a known colony led directly to a previously undiscovered colony. However, the intensive search of vanishing bearings at both Cowichan Bay and Boundary Bay also revealed that vanishing bearings might lead to a roost site or a secondary foraging site. Thus, a complete accounting of existing colonies at all foraging sites requires a committed effort to track identified vanishing bearings.

The goal of this study was to investigate a method to be incorporated into current population monitoring programs, leading to a more accurate estimate of the heron population size in the Strait of Georgia. In both 2002 and 2003, when conducting low intensity searches, the three colonies discovered using vanishing bearings accounted for 3.5 - 5% of the total estimated population each year (approximately 1,000 pairs along the coast). However, vanishing bearings predicted up to twice as many colonies may exist. A 3.5-5% increase in estimated population size when only three new colonies are discovered suggests that investing in locating colonies can substantially improve estimates of population size. However, not verifying the existence of a colony predicted by a vanishing bearing could lead to an overestimate of the number of colonies, if the bearing leads to other foraging or roost sites (a false positive). Thus, it is imperative to validate the vanishing bearings using the intensive search methodology.

Collecting information on vanishing bearings, then subsequently locating colonies, is

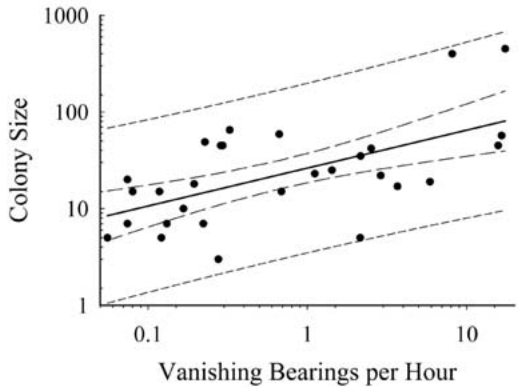

Figure 5. Log-log relationship predicting the size of a Great Blue Heron colony (from Vennesland 2003; McClaren 2004) using the observed frequency of vanishing bearings between the colony and a foraging site. Although this relationship is statistically significant ($p = 0.0007$, $r^2 = 0.35$), predictive uncertainty as shown by the 95% prediction interval (short dashes) is unacceptably high at almost two orders of magnitude, for several reasons (see Discussion). The regression line (solid line) and the 95% confidence interval for that regression (long dashes) are also shown.

efficient in its use of resources, requiring only binoculars, cellular phones, and a GPS unit. During the provisioning season, a sufficient number of vanishing bearings can be observed during a single foraging period. The intensive search for colonies conducted in 2004 required only four observers for two days plus cellular phones, while searches conducted in 2005 required only two observers. Benefits of this methodology include no need for aerial surveys, no capture or handling of birds, and no use of radio-transmitters and their associated costs. However, this study benefited from reliable cellular phone coverage and road access in a mixed suburban-rural landscape as well as readily identifiable and geographically discrete foraging sites.

Using the behavior of birds to determine the location of a colony is advantageous over systematic aerial searches or flushing birds from potential nesting sites as described by Frederick *et al.* (1996). In areas with numerous potential colony locations such as this study area, a systematic search would be impractical because of difficulties performing the low-level flying required due to geography (large hills) and human development. Furthermore, the dark color of Great Blue Herons and obscurity of nests in trees makes sighting difficult. The vegetation density and size of potential nesting sites prevent the use of vehicles for flushing birds from cover. However, similar to this study, Frederick *et al.* (1996) acknowledge the unique conditions available in their study.

Nevertheless, there are some caveats to consider when implementing this methodology. There are two reasons for a vanishing bearing not to have the same bearing as a known colony: equipment error or observer measurement error due to parallax. Most standard errors of each identified mode were calculated to be quite small, suggesting that measurements were precise. The GPS unit used for measuring vanishing bearings was rated for ± 2°, well less than the parallax discrepancies observed. However, observer bias due to parallax is a likely cause of the ± 10º uncertainty interval required. Proper positioning of the observer either on the flight path or very near to where the birds depart the foraging site can considerably reduce parallax, thereby yielding a more accurate estimate of the vanishing bearing measurement.

It cannot be recommended that the frequency of vanishing bearings be used as a predictor of colony size as there are too many uncontrolled factors confounding the relationship between colony size and the number of heron flights between the colony and a foraging site. First, energy demands of the nestlings increase through the provisioning period (Bennett *et al.* 1995) such that adults should make more provisioning trips as the breeding season progresses to meet these increased energy demands. As nestlings' energy demand increases, it becomes more likely that both parents will be provisioning their nestlings, therefore, more herons are likely to be observed foraging later in the breeding season (Butler 1995) and more vanishing bearings being observed. The variable time required for completion of a provisioning trip for different distances between a foraging site and a colony is also problematic. It must also be realized that herons from a single colony might use more than a single foraging site. Erwin (1981) described a standardized approach of using a similar "flight-line count" and showed that even when standardizing as many variables as possible, the method performed poorly at predicting the size of an individual colony.

To conclude, this methodology is effective and efficient at estimating the number, and determining the potential locations, of Great Blue Heron colonies, particularly small, cryptic colonies. Notwithstanding the caveats discussed above, this methodology could be applied to most species of wading birds, along with other communally roosting or colonial nesting birds in all types of habitats.

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