U e f Vani hing Bea ing L ca e Ne Wading Bi d C l nie

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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 (*A a o a*) 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. *R - 28 Ju 2005, a 7 N b 2005.*

Key words.—vanishing bearings, colony location, Great Blue Heron, *A a o a*, 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 *a* . 1985; Kelly *a* . 1993; Butler *a* . 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 *a* . (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 *a* . 1993; Parsons and McColpin 1995; Wong *a* . 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 (*A a o a*) 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), ap-

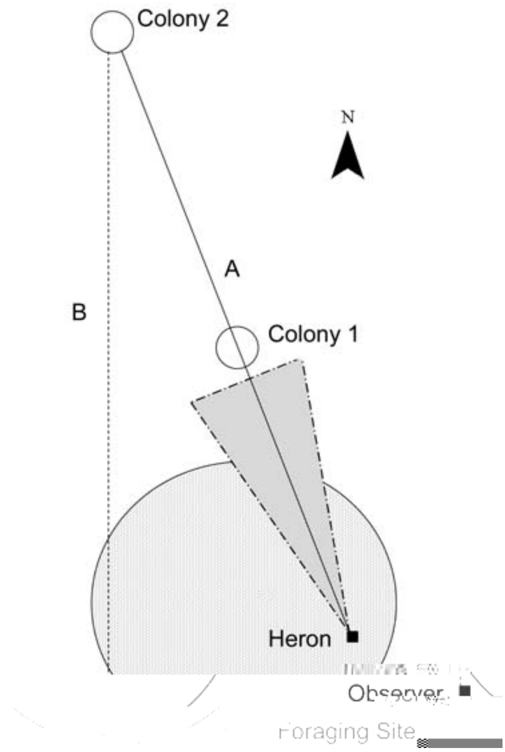

Figure 2. Diagram describing the vanishing bearing of a Great Blue Heron. When the heron leaves the foraging site, it follows a direct flight to its colony (line A). An observer determines this bearing using a GPS unit compass. However, due to parallax, when the observer loses sight of the heron as it 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 sea de ustance aftpr dt de-6.51 -54.335 -1.125 TD0.0364 Twoa(Grdizo forgel)]Toof le

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 *a*. (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

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

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 van-

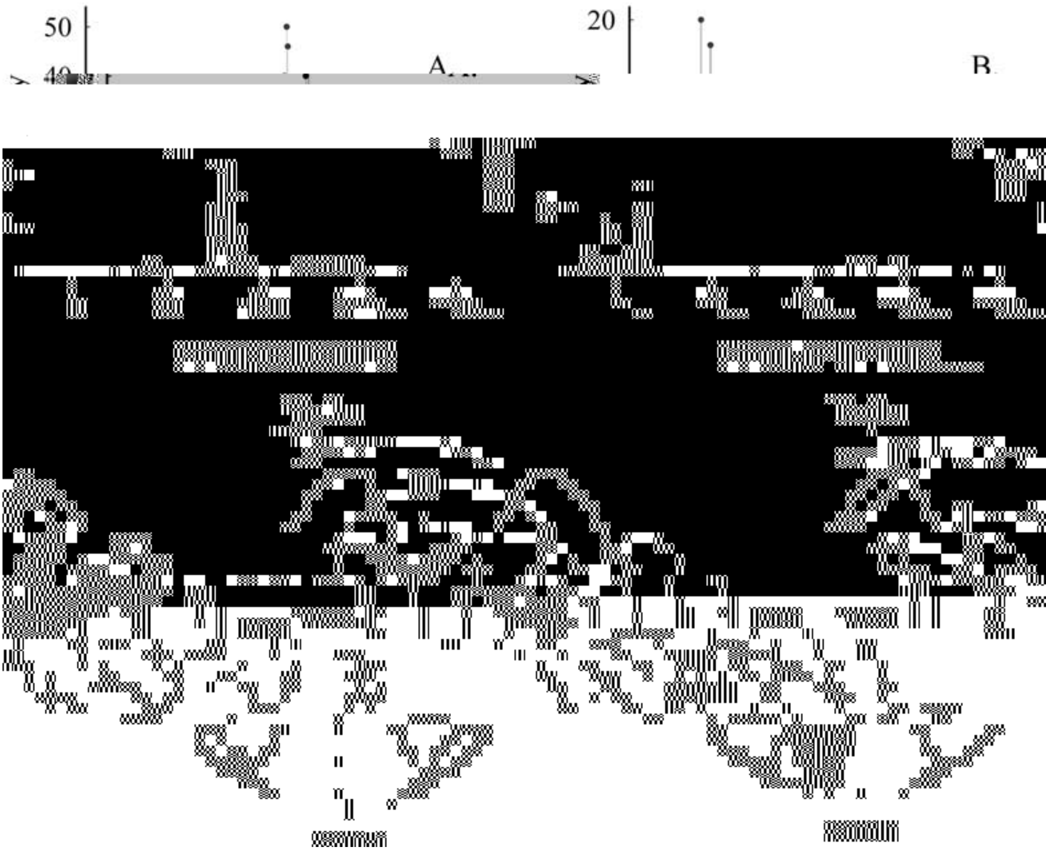

Figure 4. Vanishing bearing frequencies for Great Blue Herons departing from (A) Cowichan Bay (N = 472) in 2004 and (B) Boundary Bay (N = 82) in 2005. Frequency analysis identified three modes at each foraging site (upper graphs) where the dots are the observed vanishing bearings for 1° intervals and 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

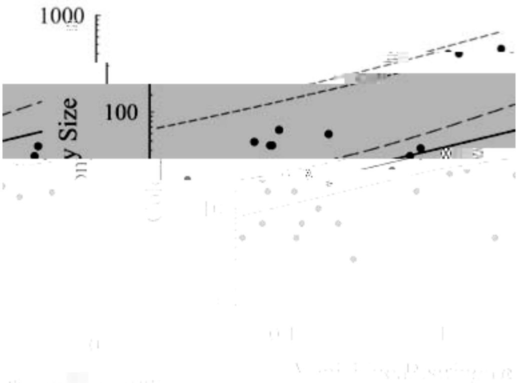

Figure 5. Log-log relationship predicting the size of a Great Blue Heron colony (from Vennesland 2003; McClaren 2004) using the observed frequency of vanishing bearings between the colony and a foraging site. Although this relationship is statistically significant ($p = 0.0007$, $r^2 = 0.35$), predictive 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 *a* . (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 *a* . (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 ± 10° 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 *a* . 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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