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Line transect distance sampling in aerial surveys for double-crested cormorants in coastal regions of Lake Huron

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ABSTRACT

Line transect distance sampling was employed in aerial surveys of double-crested cormorants (*Phalacrocorax auritus*) along the coasts of Georgian Bay and the North Channel, Lake Huron. A double-observer method was used to estimate detection probability near the transect line ($g(0) = 0.724$). Detection of cormorants was not consistent but varied based on group size, location (water, land, flying), and season. Probability of detection in the area covered by the survey was often below 0.5. Incorporating both lack of detection on the flight line along with lack of detection over the covered area inherent in distance sampling provided defensible density estimates of free-ranging double-crested cormorants. Most cormorants were detected loafing on shore (land) among the many islands defining this area of the Lake Huron coast. Land detections exceeded the combined detections of birds on the water and flying. Density in 2004 ranged from a peak of 2.30 cormorants per km^2 (95% CI = 1.72–3.03) in late July to 1.21 cormorants per km^2 (95% CI = 0.78–1.70) in late August in the sampled areas extending from shore to approximately 20 km offshore. Aerial surveys employing distance sampling can be useful tools in monitoring the distribution and abundance of free-ranging double-crested cormorants and other waterbirds in the Laurentian Great Lakes.

Introduction

Waterbird distribution and abundance in the Laurentian Great Lakes is known largely from nest counts at colonies providing estimates of overall breeding adult population size (Weseloh et al., 1995, 2002; Ridgway et al., 2006). In contrast, only two studies estimating the density of free-ranging waterbirds in the Laurentian Great Lakes have been undertaken (Stapanian and Burr, 2002; Stapanian and Waite, 2003; Langen et al., 2005). Differences between nest count data aggregated at whole-lake scales and the distribution of free-ranging waterbirds stemming from food webs operating at finer scales within lakes is an important issue for understanding spatial processes governing waterbird distribution in aquatic food webs (Hebert and Sprules, 2002). Since waterbirds largely confine foraging to narrow coastal zones in otherwise large aquatic ecosystems like the Laurentian Great Lakes, then a sampling approach that captures this scale of spatial distribution is needed. From a practical perspective, estimating the distribution and abundance of waterbirds away from nesting colonies will be important for addressing issues such as wind power development.

The purpose of this study is to apply line transect distance sampling in aerial surveys as a means of estimating the density of free-ranging double-crested cormorants. Use of line transect distance sampling in wildlife population assessment is relatively widespread including procedures for estimating density from aerial surveys (Buckland et al., 2001). Distance sampling is based on the concept that the probability of detection in the surveyed area is likely less than 1.0 because detection declines with distance from an observer. The method is not limited by a set survey distance from the observer, as in a strip transect, but instead by the observer's ability to detect animals as a function of distance from the transect line. Distance sampling therefore rewards observers by having all detections included in the data analysis step. An important assumption is that detection probability adjacent to the line is 1.0 or, if not, can be estimated using double-observer methods (Buckland et al., 2001).

The detection probability for animals close to the transect line that are present and available to be detected is less than 1.0 in many surveys and clearly so in aerial surveys (Caughley, 1974; Pollock and Kendall, 1987; Graham and Bell, 1989; Conroy et al., 2008). Two kinds of bias have been described that call into question the assumption of complete detection in line transect surveys or strip counts. First, waterbirds may not be available for detection at the moment an observer is present because of diving behaviour or vegetation cover, for example (i.e., availability bias; Marsh and Sinclair, 1989). Second, waterbirds may be available for detection but are missed because observers are distracted, occasionally overwhelmed by detections, or simply because birds are difficult to detect against water or landscape backgrounds (i.e., perception bias; Marsh and Sinclair, 1989).

The importance of detection probability has been recognized in a number of aerial monitoring studies in birds (e.g., Broome, 1985; Cordts et al., 2002; Conroy et al., 2008), probably because the aerial

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survey method itself was assumed from the start to be imperfect. This issue is acknowledged to be important in ship-based and land-based counts but is rarely evaluated (Tasker et al., 1984; Nichols et al., 2000).

Estimates of density for double-crested cormorants (*Phalacrocorax auritus*) on the Laurentian Great Lakes have been based on ship-board transect sampling (Tasker et al., 1984), with transect widths either 200 m (Stapanian and Burr, 2002) or 300 m (Langen et al., 2005). On Lake Erie, only birds detected on water were included in density estimates to avoid flying birds inflating estimates due to movement in and out of the strip transects (Stapanian and Burr, 2002). On Lake Ontario, all birds encountered within the survey strip were counted (Langen et al., 2005). Lack of detection within the strip transects was not incorporated into density estimates. Double-crested cormorants occurred within a few kilometres of shore while densities offshore were lower (Stapanian and Burr, 2002; Langen et al., 2005).

Methods

The aerial survey occurred along coastal regions of the North Channel and Georgian Bay, Lake Huron, in July and August 2004. It was part of a six year (2000–2005) project to estimate density of cormorants along the coast. The survey areas were defined by seven sample frames (20×20 km) with three located in Georgian Bay and four in the North Channel (Fig. 1). Frame location and distribution were part of a larger experiment on the relationship between abundance of cormorants and inshore abundance of fish. Georgian Bay and the North Channel are characterized by complex shorelines including thousands of small rock islands used by nesting and loafing groups of double-crested cormorants.

Ten flight lines (length = 20 km) were mapped in each sample frame with flight lines divided into 2.5-km sections representing the sampling units for line transect distance sampling. Transect lines and their boundaries were mapped in a GIS and connected to an on-board geographic positioning system. The progression of the plane along the transect line, including crossing boundaries between transects, was tracked by the pilot and survey crew. The plane flew at approximately 100-m altitude and travelled at approximately 90 nautical miles h^{-1} (167 km h^{-1}). All observations and commentary on line transect identity and travel were recorded on portable tape recorders and later transcribed by the survey crew.

For each flight, two observers sat on each side of the plane and observed birds through markers on wing struts. At an altitude of *Hm*, the width (m) of an observation strip is based on the formula: strip width $= H \times \tan(90-\theta)$, where θ is the restricted downward viewing angle (Buckland et al., 2001). Wing strut markers were positioned with one survey crew member sitting in a survey position in the plane while the other crew member adjusted markers using a large protractor. Sight lines from the window horizontally outward to wing strut markers were used to position streamer material that, when in flight, provided horizontal lines for viewing distance categories. Streamer length was adjusted to prevent entangling with the propeller. Wing strut markers were placed so that five ground distance categories from the centreline of the plane were as follows: 100, 200, 350, 550, and approximately 1050 m. The area beneath the plane from the centerline to the outer edge of the pontoon was 50 m in width and unobservable. Therefore, the width of distance bands from the edge of the pontoons outward were 50, 150, 300, 500, and 1,000 m, respectively.

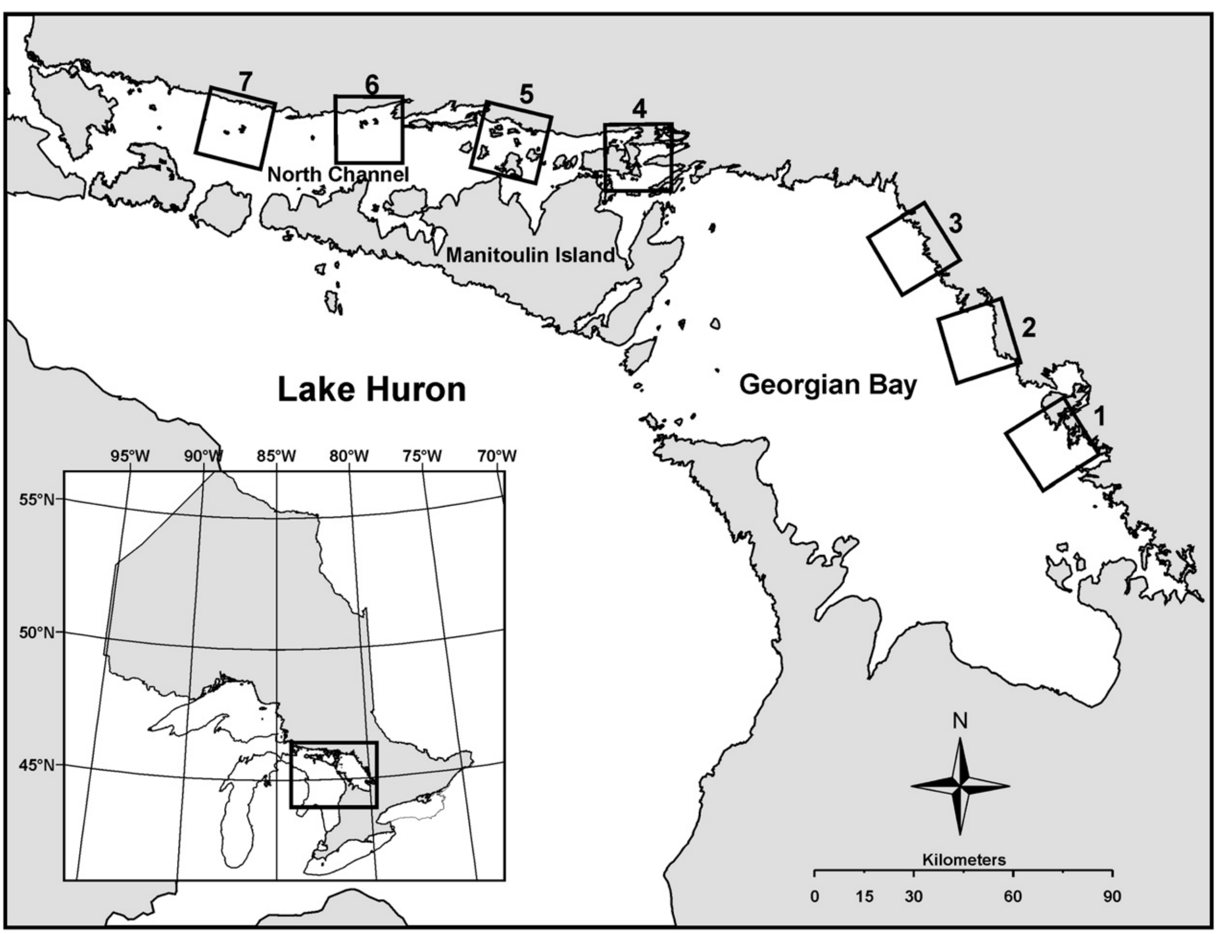

Fig. 1. Map of Lake Huron indicating location of sample frames (1–7) in Georgian Bay and the North Channel. Each sample frame is 20×20 km.

Each round of aerial survey took 4 to 7 days to complete depending on weather conditions. The flight dates were as follows: (1) Flight 1, July 6–13; (2) Flight 2, July 26–29; (3) Flight 3, August 11–16; and (4) Flight 4, August 23–30. Flights generally occurred between 0900 and 1400 hours.

Observations of cormorant detections in distance categories, estimates of group size (termed "cluster size" in distance sampling) for each detection, and whether birds were flying, on the lake surface, or loafing on shore (land) were recorded on portable tape recorders and later transcribed. Lengths of each transect line over the lake surface served as sample units. Counts over forested land were not possible due to very limited detection. Cormorant detections on rock islands (i.e., no trees) and on rocks near water's edge were included and considered as land detections. Data were analyzed using program DISTANCE 5.0 (Thomas et al., 2006). Total length of the survey was 1,043 km.

Transect width, w, was defined by the last distance band, 1000 m, in this study. If detection was perfect then density can be estimated from the number of cormorants observed and the basic calculation of transect strip area, $a = 2wL$, with L being transect length. The probability of detection has always been less than 1.0 in aerial surveys (Caughley, 1974; Pollock and Kendall, 1987; Borchers and Burnham, 2004) and likely so adjacent to the transect line. Lack of detection near the line is a violation of the assumption of perfect detection (i.e., $g(0) = 1.0$) and must be addressed. Therefore, the effective coverage of a transect strip will be less than 1.0. The effective strip width μ is less than w; so the effective area of a distance band covered by observers with imperfect detection is $2\mu L$. The probability that a cormorant in the transect strip is detected is $P_a = 2\mu L / 2wL$, which reduces to μ / w (Buckland et al., 2001). The effective strip width, μ, extending on either side of a transect line is the distance where as many cormorants are detected outside the strip as are undetected within the strip (Buckland et al., 2001). Density is estimated as, $\hat{D} = n/2\mu L$ or $\hat{D} = n/2wLP_a$, where n is the number of detections (Buckland et al., 2001). For grouped (i.e., clusters) animals, average cluster size is multiplied by n to arrive at $\hat{D}$. Estimating the effective strip width and the probability of detecting an animal in the covered area is a fundamental element of distance sampling.

Estimating the probability of detection in distance sampling requires a key function as a general description of declining detections as a function of distance as well as an adjustment term to better fit, if necessary, the key function to the detection data. The half-normal curve was used in this study as a general model of declining detection with distance. A polynomial adjustment term can be used to better fit the half-normal curve to the data (Buckland et al., 2001). The half-normal curve as a detection function is

$$k(y) = \exp(-y^2 / (2\sigma^2))$$

where y is distance from the observer and σ is a scale parameter affecting the steepness of the half-normal curve. With distance as a single covariate in conventional distance sampling, σ is a single parameter estimated by program DISTANCE. If, in addition to distance, other variables are used as covariates to help define the detection function then the scale parameter becomes a model of the form (Marques and Buckland, 2004):

$$\sigma = \beta_0 \exp\left(\sum_{j=1}^{q} \beta_j z_j\right)$$

where β_0 is the intercept and β_j are coefficients for covariates z_j. In this study, group size of cormorants and behavioural category of detected cormorants (on water, land, or flying) were used as covariates in the scaling parameter. In this case, the model for the scale parameter is:

$$\sigma = \beta_0 \exp(\beta_1(\text{clustersize}) + \beta_2(\text{water}) + \beta_3(\text{flying}))$$

Where water and flying are 0 or 1 depending on whether cormorants are on the water (water = 1; flying = 0) or flying (water = 0; flying = 1) when detected. Cormorants detected standing on shore (land) are accounted for since both water and flying would be 0. The estimate for σ from conventional distance sampling can be compared with the intercept in the multi-covariate distance sampling because β_0 is outside the brackets (Thomas et al., 2006). Separate detection functions based on the half-normal curve were used in multi-covariate distance sampling with cluster size and behavioural categories as covariates (Marques and Buckland, 2004). Estimates of variance in multi-covariate distance sampling were based on bootstrapping (1000 iterations).

Line transect distance sampling requires that detection probability near the line be perfect ($g(0) = 1.0$). This assumption is violated routinely in aerial surveys (Pollock and Kendall, 1987), so a double-observer approach was used in the early years of the study (2001) to estimate $g(0)$. Observers sat in tandem on one side of the plane and recorded detections into tape recorders during one complete survey. Wing strut markers were set so that cormorant detections could be allocated to two distance bands 250 and 570 m from the centerline of the plane based on formulas relating altitude and sighting angles (Buckland et al., 2001). Cormorant abundance was higher in the early years of this survey and it was thought that observers could better manage fewer distance bands. The sighting angle at the edge of the pontoon of the plane translated to 50 m from the centreline (and unobservable). Therefore the first distance category was 200 m wide and the second distance category was 320 m wide. The two observers were trained to operate independently of each other including not moving the tape recorder to minimize signalling detections made by one observer to the other. Both observers and the pilot were experienced in this survey method; the double-observer flight described in this study was their 12th coast-wide survey for cormorants. Detections were never so numerous as to generate confusion regarding common sightings of cormorants or individual observer sightings when transcribing data.

Estimating the probability of detecting cormorants (a single bird or group of cormorants) was based on double-observer transect survey methods (Borchers et al., 1998, 2002, 2006). The total number of detections (birds on water, flying, or land combined) by observer 1 and observer 2 are n_1 and n_2, respectively. The number of detections in common by both observers is n_3. Because perfect detection in aerial surveys has rarely been achieved (Caughley, 1974), n_3 will be $\leq n_1$ and n_2. The total observed detections is $n_{\bullet} = n_1 + n_2 - n_3$. The probability of detection for observer 1 ($\hat{p}_1$) and observer 2 ($\hat{p}_2$) is

$$\hat{p}_1 = \frac{n_3}{n_2}; \hat{p}_2 = \frac{n_3}{n_1}$$

Based on the number of detections, the probability that either observer 1 or observer 2 detects a cormorant or group of cormorants is (modified from Graham and Bell, 1989):

$$\hat{p}_{\bullet} = \frac{n_1 n_3 + n_2 n_3 - n_3^2}{n_1 n_2}$$

Alternatively, $\hat{p}_{\bullet}$ can be estimated based on the probabilities of detection by each observer:

$$\hat{p}_{\bullet} = \hat{p}_1 + \hat{p}_2 - \hat{p}_1 \hat{p}_2$$

From Borchers et al. (2002; Appendix C), the asymptotic variances for $\hat{p}_1$ and $\hat{p}_2$ are:

$$\text{var}[\hat{p}_1] = \frac{n_3(n_1 - n_3)}{n_1^3}; \text{var}[\hat{p}_2] = \frac{n_3(n_2 - n_3)}{n_2^3}$$

The estimated variance for $\hat{p}.$ based on detections is (modified from Graham and Bell (1989):

$$\text{var}[\hat{p}.] = \frac{(n_1 - n_3)(n_2 - n_3)[(n_1 - n_3) + (n_2 - n_3)]\hat{p}.}{n_1^2 n_2^2}$$

Note that standard error $= \sqrt{\text{var}[p_i]}$.

The Horvitz–Thompson-like estimator for $\hat{N}_d$, the number of single bird or group detections, d, of cormorants is $n./\hat{p}.$, equivalent to the Petersen estimate of $\hat{N}_d$:

$$\hat{N}_d = \frac{n_1 n_2}{n_3}$$

The variance of the Petersen estimate of $\hat{N}_d$ (Borchers et al., 2002; Appendix C) is:

$$\text{var}[\hat{N}_d] = \frac{n_1 n_2^2 (n_1 - n_3)}{n_3^3}$$

A population estimate of cormorants based on detections is the average group size of birds multiplied by $\hat{N}_d$.

Results

Detection probability

Detection probability was less than 1.0 for both observers in the band closest to the transect line and in the band furthest from the line. It was similar in magnitude between each observer and decreased from the closest distance band to the plane to the second distance band (Table 1). In the 50- to 250-m distance band detection probability ($\hat{p}$) ranged from 0.70 to 0.80 with observer 1 showing a marginally higher detection probability than observer 2. In the 250- to 570-m distance band, detection probability declined and ranged from 0.51 to 0.69.

Combining detections from both observers greatly improved the probability of detection adjacent to the line and furthest from the line ($\hat{p}. = 0.94$ in the 50- to 250-m band; 0.82 in the 250- to 570-m band; Table 1). The combined probability of detection was still short of the assumption of perfect detection ($\hat{p}. = 1.0$) even when data are combined from two experienced observers recording detections from the same side of plane.

Table 1
Detections of double-crested cormorants (as single, pairs, or larger groups of birds) in coastal regions of Lake Huron in two distance bands[a]. Standard errors of probability of detection are in brackets. The number of detections by observer 1 and 2 are n_1 and n_2, respectively. Detections common to both observers 1 and 2 and total detections by both observers are n_3 and $n.$, respectively.

	Georgian Bay		North Channel		Total	
	50–250 m	250–570 m	50–250 m	250–570 m	50–250 m	250–570 m
n_1	50	53	63	56	113	109
n_2	49	48	55	57	104	105
n_3	37	33	44	29	81	62
$n.$	62	68	74	84	136	152
$\hat{p}_1$	0.75	0.69	0.80	0.51	0.78	0.59
	(0.062)	(0.067)	(0.058)	(0.067)	(0.042)	(0.047)
$\hat{p}_2$	0.74	0.62	0.70	0.52	0.72	0.57
	(0.061)	(0.067)	(0.054)	(0.066)	(0.041)	(0.048)
$\hat{p}.$	0.94	0.88	0.94	0.76	0.94	0.82
	(0.025)	(0.038)	(0.022)	(0.056)	(0.017)	(0.034)

[a] Data from double-observer detections in 2001. The probability of detecting cormorants by observer 1 ($\hat{p}_1$) and observer 2($\hat{p}_2$) are combined to estimate probability of detection by both observers ($\hat{p}.$). See Methods for details.

The Petersen estimate for the number of detections ($\hat{N}_d$) in the inner distance band is 145 (var[$\hat{N}_d$] = 73.6; 95% CI = 128–162) and 184 (var[$\hat{N}_d$] = 237.0; 95% CI = 154–214) for the outer distance band. Because the inner distance band was smaller than the outer band by a factor of 1.6 (200 m width vs. 320 m width), adjusting the Petersen estimate upwards for the inner band shifts the original estimate to 232 detections. This was above the confidence interval for the number of detections in outer distance band.

The average group size of cormorants detected simultaneously by both observers in the 200-m-wide inner band adjacent to the plane was 4.73 birds (95% CI = 2.16–7.30). In the 320-m-wide outer band, the average group size of cormorants detected simultaneously by both observers was 8.0 birds (95% CI = 1.23–14.77). Although both group size estimates overlap there was a clear tendency for an upward bias in group size likely reflecting a lack of detection of single or pairs of birds in the outer band relative to the inner band. One possibility was that birds were displaced away from the approaching plane resulting in larger groups further from the plane. This behaviour did not occur during preliminary work with one observer on the ground watching groups of cormorants in response to the plane flying overhead at an altitude of 100 m. In addition, only 14 detections out of the total 288 detections (4.86%) included apparent flushing behaviour of cormorants at the time of the plane passing. This was equivalent to 1.34 flushes per 100 km of survey (95% CI = 0.68 – 2.66 flushes/100 km). The probability of detection in the band closest to the transect line was incorporated into density estimates as $g(0) = 0.724$ (SE = 0.059).

Encounter rate

The encounter rate (detections per 10 km flight distance) of double-crested cormorants differed among the three behavioural states (Table 2). Cormorants standing on shore were encountered more frequently in all four surveys. The higher encounter rate for birds on land was significant based on the non-overlap between the 95% CI for land-based birds relative to cormorants detected on the water or flying (Table 2). The encounter rate for cormorants was very similar for birds detected either on water or flying. Overall, the encounter rate for cormorants in all three behavioural states peaked in the second survey and declined thereafter. The decline in encounter rate from the second to the fourth flight was relatively sharp with each survey showing non-overlap in confidence intervals (Table 2).

One possible factor that could affect line transect sampling using aerial surveys is cormorant response to the approaching plane. Apparent flushes from either land or water (both diving and flight) as the plane passed were low with the highest flushing rate occurring in the first flight in early July (0.3 flushes per 100 km flight distance) and the lowest rate in the second flight (0.1 flushes per 100 km flight distance). It did not appear that the aerial survey significantly affected cormorant distribution as indicated by flushing rates.

Table 2
The encounter rate (detections/10 km of flight) of double-crested cormorants observed on the water, flying, and on land.

	Flight 1	Flight 2	Flight 3	Flight 4
	Early July	Late July	Mid August	Late August
Water:				
Mean	0.71	0.86	0.17	0.02
95% CI	0.53–0.94	0.65–1.15	0.10–0.30	0.01–0.07
Flying:				
Mean	0.47	0.76	0.25	0.07
95% CI	0.32–0.68	0.55–1.04	0.16–0.39	0.03–0.20
Land:				
Mean	1.49	2.08	1.44	0.83
95% CI	1.21–1.85	1.71–2.54	1.17–1.77	0.63–1.10

Detection

The probability of detecting double-crested cormorants within the covered area of the aerial survey, P_a, did not approach full detection (i.e., $P_a = 1.0$; Table 3). The 95% CI for the mean estimates of P_a marginally incorporated 0.5 in only two of the four flights (Table 3). This effect can be seen in the distribution of P_a stemming from the bootstrap estimates given the covariates of cluster size and detection location (water, flying, or on land; Fig. 2). Relatively few of the possible estimates of P_a exceeded 0.8 with most estimates falling below 0.5 (Fig. 2).

This lack of detection within the transect width, w, is illustrated for cormorants observed standing on shore (land) or floating on the water from Flight 1. Histograms of relative detection rates in five distance categories showed a decline in detection as a function of distance from the plane for cormorants on land (Fig. 3) or water (Fig. 4). For both behavioural categories, a fitted half-normal curve described this decline in detection with land-based cormorants showing greater detection (i.e., higher encounter rate) at distance (Fig. 3) than water-based cormorants (Fig. 4). When all behaviour categories are combined, a global detection function captured the overall decline in cormorant detections as a function of distance from the transect line (Fig. 5).

The detection function for double-crested cormorants varied depending on cluster size and detection location on water, flying, or standing on shore (land). The estimated model for the scaling parameter in Flight 1 was $\sigma = 361.5^{*}\exp(0.059(\text{cluster size}) - 0.526(\text{water}) - 0.310(\text{flying}))$, which was used in calculating detection functions based on the half-normal curve. Detection functions for cormorants on water decline more sharply than detection functions of cormorants standing on shore, independent of cluster size (Fig. 6). An observer's ability to detect cormorants on water is more limited by distance than for cormorants detected on shore. Cormorants in larger clusters are easier to detect than in smaller clusters, within locations such as on water or on shore (Fig. 6).

Detection functions for clusters of cormorants (eight bird clusters) standing on shore were compared to assess differences among flight in detection patterns. For each successive flight, the detection function declined with the furthest detection distances in the first flight and the shortest detection distances in the fourth flight (Fig. 7). There is a seasonal and/or observer effect on the detection process.

Density

Density estimates incorporating variation in detection patterns range from approximately 1 cormorant km^{-2} to over 2 cormorants km^{-2} (Table 4). The decline from peak density in the second flight (2.30 cormorants km^{-2}) to the lowest density in the fourth flight (1.21 cormorants km^{-2}) represents a per capita rate of decline over a one month period of −0.646 ($r = \log_e(N_{t2}/N_{t1})$). Approximately half of the free-ranging cormorants found in late July remained in coastal areas of Georgian Bay and the North Channel by late August.

The seasonal pattern in the density of cormorant groups followed a similar pattern (Table 4). Peak density of groups occurred in the second flight with the lowest density found in the fourth flight. The decline in density of groups was significant since the 95% CI did not overlap from the second through to the fourth flight (Table 4).

The mean observed cluster size increased from the first flight to the fourth flight indicating a change in behaviour with cormorants increasingly grouped as the season progressed (Table 4). An interesting effect can be seen when comparing observed cluster size with expected cluster size, the ratio of empirical estimates of density of individuals to density of clusters. The expected cluster size was lower than the observed cluster size initially and more closely matches observed cluster size by the fourth flight (Table 4).

Table 3
The probability of detecting cormorants within the covered area (P_a) of the aerial survey. Estimates are based on bootstrapping.

	Flight 1	Flight 2	Flight 3	Flight 4
	Early July	Late July	Mid August	Late August
Minimum	0.28	0.33	0.31	0.28
Mean	0.43	0.45	0.40	0.33
%CV	8.55	5.98	8.70	11.30
95% CI	0.37–0.51	0.40–0.51	0.34–0.48	0.27–0.42

Note. $P_a = \mu / w$, $w = 1000$ m in this study.

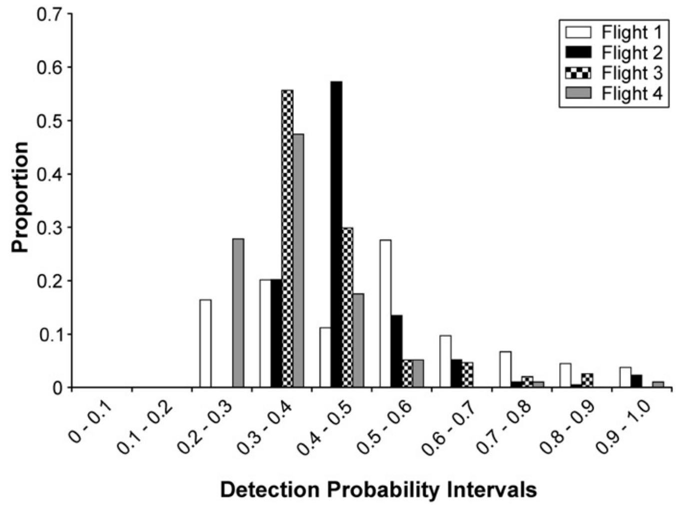

Fig. 2. The probability distribution that a cormorant or cluster of cormorants is detected in the covered area (P_a) given the covariates cluster size and detection location (on water, flying, or on land) for each flight of the 2004 aerial survey. Each distribution is based on bootstrap estimates using multi-covariate distance sampling.

Discussion

Coastal surveys of double-crested cormorants revealed a detection probability less than 1.0 for experienced observers conducting aerial surveys at an altitude of 100 m. More importantly, detection probability near the transect line ($g(0)$) was less than 1.0. Lack of detection near the line remained to some degree even when detections from both observers are combined. Detection probabilities less than 1.0 should always be assumed present when conducting

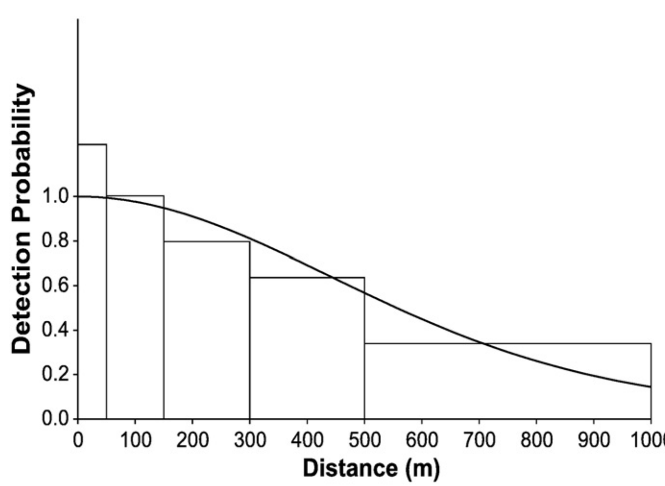

Fig. 3. A fitted half-normal detection function for cormorants standing on shore from Flight 1 represented by the curve. Histogram represents relative number of detections for cormorants standing on shore in five distance categories. Y-axes for Figs. 3–5 are on the same relative scale.

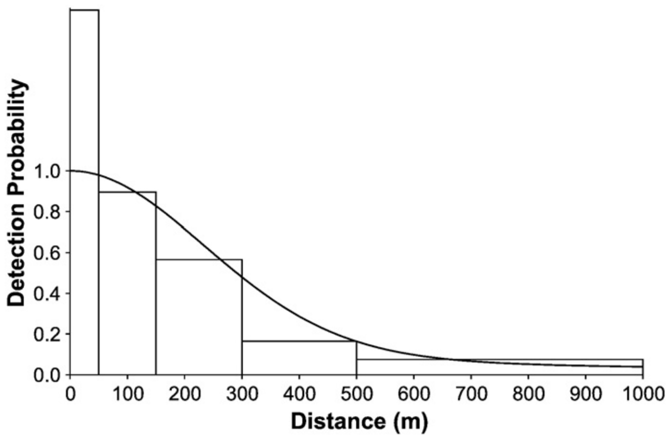

Fig. 4. A fitted half-normal detection function for cormorants detected on the water from Flight 1 represented by the curve. Histogram represents relative number of detections for cormorants on the water in five distance categories. *Y*-axes for Figs. 3–5 are on the same relative scale.

surveys of waterbirds in the Laurentian Great Lakes. There is widespread recognition that detection near an observer is an issue in bird monitoring studies but receives little direct attention (Bachler and Liechti, 2007; Conroy et al., 2008). Double-observer methods help address this issue with respect to detection near the transect line (Buckland et al., 2001).

Detection in the second distance band was lower in the North Channel ($\hat{p}_1 = 0.51$; $\hat{p}_2 = 0.52$) than in Georgian Bay ($\hat{p}_1 = 0.69$; $\hat{p}_2 = 0.62$) for both observers. There are three possible explanations for this consistency. First, there were more detections of cormorants in the North Channel than in Georgian Bay and observers may have been paying particular attention to detections near the transect line ('guarding the line') to a greater degree in the North Channel in response to more frequent detections. Second, the east-west orientation of the North Channel may have generated glare conditions for observers. Third, the North Channel is characterized by larger islands and channels among islands in many locations relative to Georgian Bay where numerous small islands and channels characterize the coast. Both observers may have adjusted their detection process inwards in response to the landscape change along the North Channel coast relative to Georgian Bay.

Other studies examining detection probability in aerial surveys of waterbirds have found similar results to this study. In aerial surveys of waterfowl, probabilities of detection were generally less than 0.7 for most species when comparing surveys conducted from an altitude of 100 m with low altitude flights (Broome, 1985). Helicopter surveys of nesting waterfowl following a quadrat sampling approach had probabilities of detection ranging from 0.6 to 0.9 from an altitude of 50 m and incorporating multiple passes at each wetland (Cordts et al., 2002). Similar ranges for probability of detection are not restricted to birds. Indeed, counting domestic sheep from an altitude of 100 m results in probabilities of detection ranging from 0.6 to 0.7 (Caughley et al., 1976). For polar bears, double platform observations resulted in estimates of $\hat{p}_{\bullet} = 0.89$ and 0.82 in two consecutive years with individual observer probabilities of detection ranging from 0.62 to 0.72 with a low estimate of 0.36 in one year for one observer (based on data in Crete et al., 1991). Despite advances in sampling design and data analysis in population estimation, the cognitive limitations of humans conducting aerial surveys continues to limit probabilities of detection at levels first summarized over thirty years ago (Caughley, 1974). Approximately one quarter to one third or more of animals are not detected that are available to be detected.

Double-observer methods in bird monitoring directly address detection probabilities. Although this approach has been known for many years (Cooke and Jacobson, 1979; Pollock and Kendall, 1987; Graham and Bell, 1989), there is a need to incorporate double-observer methods as either a mark-recapture Petersen approach, as adopted in this study, or as a removal method where the second

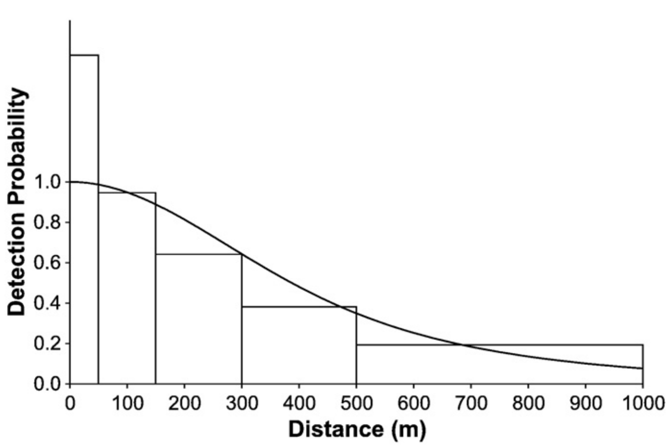

Fig. 5. A fitted half-normal 'global' detection function for all cormorants regardless of location (land, water, flying) represented by the curve. Histogram represents relative number of detections for all cormorants in five distance categories in Flight 1. *Y*-axes for Figs. 3–5 are on the same relative scale.

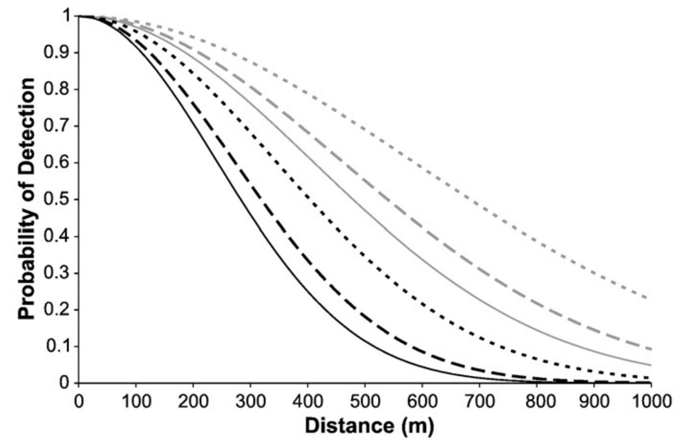

Fig. 6. Detection functions for cormorants in different cluster sizes detected on water or on land in Flight 1 of 2004. Black solid, dashed, and dotted lines represent double-crested cormorants detected on water. Grey solid, dashed, and dotted lines represent double-crested cormorants detected on shore (land). Solid lines represent 2 bird clusters, dashed lines represent 4 bird clusters, and dotted lines represent 8 bird clusters.

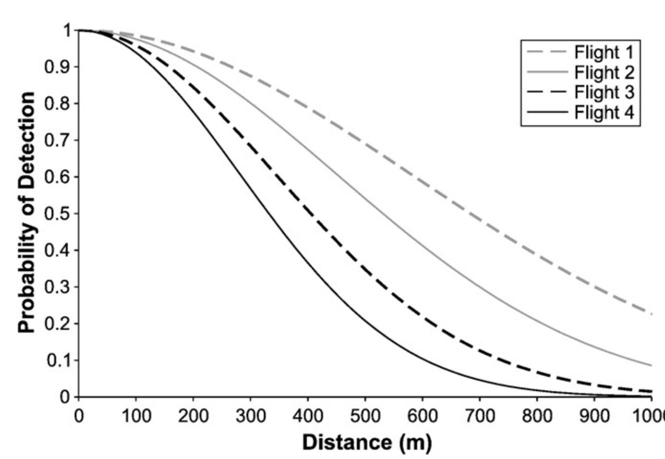

Fig. 7. Detection functions for cormorants in 8 bird clusters detected on land for each flight. Detection functions were derived from flight-specific scaling parameters used in estimating the half-normal curve.

Table 4
Bootstrap estimates for density (per km^2) of individual cormorants ($\hat{D}_b$) and clusters of cormorants ($\hat{D}_{Cb}$). Observed cluster size (CS) and estimated cluster size (E_{CS}), based on the ratio of empirical estimates of individual density $\hat{D}_b$ to cluster density $\hat{D}_{Cb}$.

	Flight 1	Flight 2	Flight 3	Flight 4
	Early July	Late July	Mid August	Late August
$\hat{D}_b$				
Mean	1.69	2.30	1.92	1.21
%CV	18.0	15.16	15.60	19.78
95% CI	1.20–2.36	1.72–3.03	1.32–2.52	0.78–1.70
$\hat{D}_{Cb}$				
Mean	0.42	0.57	0.32	0.19
%CV	11.93	10.11	12.30	16.28
95% CI	0.33–0.53	0.46–0.69	0.25–0.40	0.13–0.26
CS				
Mean	5.57	5.50	7.85	7.88
%CV	8.73	12.92	9.77	13.32
95% CI	4.60–6.75	4.27–7.08	6.48–9.52	6.05–10.25
E_{CS}				
Mean	3.81	4.02	6.08	6.20
%CV[a]	19.56	13.38	13.71	17.03
95% CI	2.61–5.57	3.10–5.22	4.66–7.95	4.45–8.64

[a] %CV based on the bootstrap.

observer counts only those missed by the first observer (Bart and Earnst, 2002; Nichols et al., 2000). Still, a full examination of the bias associated with the detection process would entail two additional components. First, this study focused on 'point independence' near the plane and not full independence across a range of distances where detections are assumed to be independent but where variables such as group size may render detections by observers to be dependent as a function of distance (Laake and Borchers, 2004). Second, availability bias would need to be addressed based on either radio-tracking individuals that are underwater at the time of the survey passing overhead or by determining the dive–pause ratio of foraging cormorants and assuming that birds detected on the water are a proportion of birds foraging under the water at the time of the survey.

Line transect distance sampling showed that the probability of detection within the covered area of aerial surveys (P_a) for double-crested cormorants is always less than 1.0 and most often below 0.5. Detection probability adjacent to the line was 0.724 and was incorporated into the analysis for estimating density. Patterns of variation in detection functions were expected in some cases such as cormorants in larger groups being more easily detected than cormorants in smaller groups, whether on land or on the water. The difference between land and water-based birds, independent of group size, clearly shows that water-based birds have a more truncated detection function than land-based birds.

The seasonal change in detection function for land-based birds suggests a seasonal change in detection process for observers recording birds. Detection functions became steeper with each flight effectively reducing the effective strip width of each aerial survey. This pattern of change may stem from a change in seasonal behaviour leading observers to draw inwards their detection process. The change in group size is an indication in the possible change in detection. Observed group size increased with each flight and expected and observed groups sizes more closely coincided later in the season relative to the start of the season. This indicates that birds were in larger groups and were consistently found in these groups. The change in detection may reflect the additional time in estimating group size more frequently late in the season relative to earlier in the season. Whatever the precise process leading to this seasonal shift, the pattern of reduced detection distance with each flight demonstrates that even among groups of birds that are relatively easy to see, there can be change in detection functions that should be incorporated into density or population estimates.

Cormorants loafing on shore (land detections) were the most common category of detection relative to birds found flying or on water. Earlier density estimates of double-crested cormorants on Lake Ontario and Lake Erie did not include birds loafing on shore (Stapanian and Burr, 2002; Langen et al., 2005)). This study incorporated land birds in density estimates assuming that birds standing on shore in the North Channel and Georgian Bay forage in these areas. This is not an unreasonable assumption given the size of the sample frames (20 km × 20 km).

Density increased from the first flight to the second flight and declined afterwards. Two possible processes may have contributed to this pattern. First, double-crested cormorants from areas beyond the North Channel and Georgian Bay may have moved into this region near the end of the nesting period as indicated by the peak in density in the second flight. Given the scale of this survey, it is unlikely that cormorants made broad-scale shifts within the North Channel and Georgian Bay rendering detection an up and down process along the coastal regions of Lake Huron. An alternative process accounting for this seasonal pattern is a component of detection bias stemming from differences in nesting birds versus free-ranging birds. Nesting birds are concentrated and located in relatively few, small islands that are rarely encountered in the surveys (i.e., size of islands relative to size of covered area of aerial survey). The second flight may represent the fledging process and movement of both adults and young birds, or simply the re-distribution of adults once nesting is completed. Since movements increase at this time (Hatch and Weseloh, 1999), detection ought to change as well. Resolving this issue is not possible because distinguishing sub-adult from adult birds was not possible for observers in the aerial survey. The peak in density is most likely a reflection of fledging and the movements associated with the end of nesting.

The effective strip widths of this survey ranged from approximately 330 to 450 m from the plane. This range lies outside the recommended 300 m strip widths of ship-based monitoring of waterbirds (Tasker et al., 1984; Bibby et al., 2000). This difference reflects the benefit afforded greater altitude in plane-based surveys compared to ship-based surveys. Still, the advantage of greater detection distance in this aerial survey compared to ship-based surveys is less than might be expected. Assessing detection probabilities in ship-based surveys is a necessary step (Rosenstock et al., 2002). A complete examination of detection in this program would entail an assessment of the number of birds underwater and not available for detection at the time of the flight and a full mark-recapture approach to detection that would address the correlated detection process of observers because both detect animals as a function of distance (Laake and Borchers, 2004).

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