From the Field: Testing 2 aerial survey techniques on deer in fenced enclosures—visual double-counts and thermal infrared sensing

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Abstract We evaluated the accuracy of 2 aerial survey techniques over 4 large enclosures (6.0–29.4 km^2) where the deer (*Odocoileus virginianus*) population was reconstructed using hunting harvest and winter mortality data. We conducted surveys ($n=8$) along equally spaced parallel lines. Six surveys using the double-count technique involved 2 independent observers located on the same side of a helicopter who simultaneously counted animals over narrow plots (60-m width). Four of these surveys yielded deer densities 64–83% of assumed densities (based on the reconstructed population). The 2 other surveys had accuracies of 37 and 46%, respectively, and were judged unreliable because the sighting probability of the front observer was <0.40. We conducted 2 surveys with a thermal infrared sensor. One survey had the highest accuracy (89%) among all surveys while the other gave poor results (54% accuracy). We concluded that when sighting probabilities of observers exceed 0.45 of deer groups, double-count surveys provided valid estimations of densities for management purposes, although 1 deer out of 4 was missed on average. Because of closed forest canopy, thermal infrared sensing of deer along systematic survey lines was not a reliable technique.

Key words aerial survey, double count, *Odocoileus virginianus*, Petersen estimate, thermal infrared, white-tailed deer

Although widely used, aerial surveys of large mammals are biased because observers miss a significant number of animals (Caughley 1974). Sightability, the proportion of animals present that are effectively seen, is influenced by many variables. These include strip width, altitude, and speed of the aircraft (Caughley 1974), snow conditions, observer's experience (LeResche and Rausch 1974), canopy cover (Anderson and Lindzey 1996), and group size (Cogan and Diefenbach 1998). Initially, managers tried to minimize bias by using helicopters instead of fixed-wing airplanes (Novak and Gardner 1975) and by adopting strict survey procedures (Kufeld et al. 1980). Because biases remained unsatisfactory, more recent approaches aim at correcting the bias.

Bias in aerial surveys can be measured and eventually corrected by statistical techniques and by computing factors derived from populations of known size (Short and Bayliss 1985). Two statistical techniques currently used that do not necessitate a known number of animals are the line-transect (White et al. 1989) and the double-count techniques (Magnusson et al. 1978, Choquenot 1995). Animals seen are tallied according to the perpendicular distance in the line-transect technique, or the independent observer (front, rear) in double-counts. This enables developing sightability models and computing correction factors. Both techniques can only correct the perception bias, related to animals potentially visible that have been missed. Availability bias (Graham and Bell 1989, Marsh and

Sinclair 1989), caused by animals invisible because of canopy or deep water, for instance, cannot be evaluated by these techniques.

Enclosures with known numbers of animals have been used to test aerial surveys for moose (*Alces alces*) (LeResche and Rausch 1974) and mule deer (*Odocoileus hemionus*) (Bartmann 1983). In other studies, the reference population has been estimated by a technique considered more accurate than aerial surveys, such as ground surveys for kangaroos (*Macropus* sp.) (Short and Bayliss 1985), or was predicted based on harvest data and winter mortality (Bartmann 1983). An alternate approach is that of Bayliss and Yeomans (1989). These authors removed a large number of feral livestock and used this value to compute the accuracy of 2 double-count surveys conducted before and after removal. A more common technique is to survey marked animals as a sample of the known population. Such tests have been done on white-tailed deer (*O. virginianus*) (Floyd et al. 1979, DeYoung 1985, DeYoung et al. 1989), elk (*Cervus elaphus*) (Cogan and Diefenbach 1998), and moose (Anderson and Lindzey 1996).

Québec applies the double-count technique to survey the white-tailed deer over its entire range in the province on a 5-year basis (Potvin et al. 2002, 2004). Using marked deer to measure sighting probability is not feasible with this technique because the observer would not always be able to verify whether the animal seen had a collar. Since deer densities are high, it is not possible to find the animal during return flights, which is the usual procedure for moose. Because of plot size ($\geq$3.5 km long × 60 m wide), an evaluation of the accuracy of double-counts would require large enclosures with known populations. We recently had such an opportunity as part of a habitat management program for white-tailed deer undertaken on Anticosti Island, Québec. We built 4 enclosures (6.0-29.4 km^2) in forested areas that had been partially clearcut. These sites were heavily hunted to reduce the deer population and thereby protect forest regeneration from excessive browsing. The initial population could then be reconstructed from harvest and winter mortality data. We conducted 6 aerial surveys over these enclosures to evaluate the accuracy of the double-count technique. Two other surveys used a thermal infrared sensor as part of preliminary tests with this alternate technique (Wiggers and Beckerman 1993, Naugle et al. 1996).

Study area

Our study took place on Anticosti (49°28′N, 63°00′W), a 7,943-km^2 island located in the Gulf of St. Lawrence, Québec. The forest was dominated by white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), and black spruce (*P. mariana*). Winters were long on the island, usually with snow on the ground for 6 months. White-tailed deer were introduced between 1886 and 1900, and they rapidly occupied the entire island (Potvin et al. 2003). The population has been estimated at 125,000 deer (16 deer/km^2) in a recent survey (Rochette et al. 2003).

A forest management program was begun in 2000 to restore deer habitat that is jeopardized by overbrowsing. Forest blocks (3-30 km^2) were logged to create a mosaic suitable as winter habitat. About 60% of the area was harvested, and uncut patches and strips were left as cover. Natural regeneneration or, when needed, planting should enable balsam fir forest to recover if protected from deer browsing. Therefore, blocks were fenced (3-m-high fences) for some 10 years until the terminal shoot of balsam fir stems will be high enough to escape deer browsing. Immediately after fencing, intensive hunting took place for 1-3 seasons to reduce the number of deer to about 3/km^2. Track counts, vegetation surveys, and aerial surveys were used to verify whether the reduction objective was met.

We used 4 large enclosures in this study to test aerial surveys: A (15.7 km^2), B (6.8 km^2), C (6.0 km^2), and D (29.4 km^2). We logged enclosures A and B in summer 2001 and fenced them immediately after. We partially logged enclosures C and D the first year (2001 and 2002, respectively) and fenced them 1 year later. Logging was completed inside the fenced area. Residual forest in all enclosures was composed of dense stands of balsam fir and white spruce. Canopy cover of residual forest was less dense in enclosure A than in enclosure B (54 % vs. 72 % vertical cover) because white spruce was dominant in that second enclosure. Conversely, clearcut patches in enclosure B were devoid of vegetation >1 m, providing good visibility for the aerial surveys, while an abundant regrowth of advance white spruce regeneration (1-3 m high) was present in enclosure A. Canopy cover of residual forest and density of advance regeneration were intermediate in enclosures C and D.

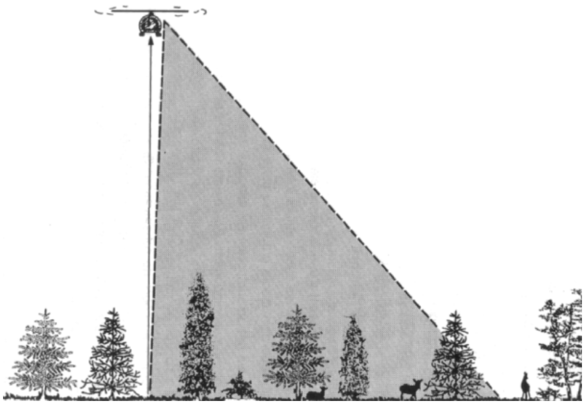

Figure 1. Illustration of the survey plot used in double-count aerial surveys as applied in fenced enclosures on Anticosti Island, Québec. Altitude is 60 m and maximum viewing angle is 45°.

Methods

Double-count aerial surveys

For aerial surveys, we counted deer in enclosures by having 2 observers sit on the left side of a Bell 206L helicopter (Bell Helicopter, Fort Worth, Tex.) (Potvin et al. 2002, 2004). The pilot maintained an altitude of 60 m above ground level, verified by a radar altimeter, and a speed of 70–100 km/hour. A bubble window installed in the back door enabled the rear observer to see under and beside the aircraft. The front observer used the front upper, side, and floor windows. The width of the narrow strip plot (60 m) extended on the left side only from 0° (below the helicopter) to a 45° angle from the vertical (Figure 1). For each observer, the outer plot boundary was delimited by 2 reference marks denoted by plastic tape, on the side window and on the bottom of a rod extending outside and perpendicular to the aircraft. The navigator sat in the back seat behind the pilot and used a bubble window to provide front and lateral vision. He was responsible for discriminating and recording the deer groups seen. To ensure independence between observers, the front observer, navigator, and pilot were connected to the communication system of the aircraft and the rear observer was in contact with the navigator through a portable system. Earphones of the navigator were modified in such a way that one ear was connected to the helicopter system and the other to the portable one. A switch enabled the navigator to speak separately to either observer.

We conducted 1 survey in early winter (January) and 5 surveys in summer (August). Summer surveys were possible on the island because deciduous cover was generally sparse and there was a good contrast between the reddish summer coat of deer and the green vegetation background. Surveyed enclosures were delineated on 1:20,000 topographical maps. Strip plots were on parallel lines equally spaced over enclosures, oriented along an east-west or north-south azimuth (latitude or longitude headings). Each line corresponded to a single plot of variable length. Spacing between lines ranged from 154–362 m, for a sampling fraction between 15.5 and 36.5%. The pilot used the aircraft's Global Positioning System (GPS) to stay on line or to change line (Boer et al. 1989, Leptich et al. 1994).

Observers counted deer groups and classified them according to size (1, 2, 3, ≥4) and activity (moving or inactive [bedded or standing immobile]). The navigator recorded deer sightings separately for each observer. Observers reported groups at the moment they were perpendicular to the helicopter, even if detected in advance. Deer that had moved outside the strip before passage of the helicopter were recorded if they were inside when initially seen. This method does not represent a bias because deer tend to move away from the helicopter rather than toward the strip. We did not tally groups located outside the strip. When observers counted a different number of deer in a group, we used the higher value as the actual group size in the computations.

To obtain the deer density in enclosures for each survey, we first computed the corrected number of deer on each strip plot, using double-count formulas (Magnusson et al. 1978, Potvin et al. 2004). Let $i = 1, \ldots, m$ and $h = 1, \ldots, H$ denote the subscripts representing the strip plot sampled and the group size, respectively. The following notation is used:

n_{ihk} = number of groups of h animals in plot i seen by front observer only (k = 1), rear observer only (k = 2), or both observers (k = 3),
$n_{.hk}$ = sum of the n_{ihk}'s for m plots sampled,
n_{ih} = total number of groups of h animals seen in plot i ($n_{ih.} = n_{ih1} + n_{ih2} + n_{ih3}$),
$n_{.h.}$ = total number of groups of h animals seen in m plots surveyed.

For sighting probabilities, we considered 4 group sizes: single deer, groups of 2, groups of 3, and groups of ≥4. Sighting probabilities by observer (p_{hk}) were computed according to the Petersen estimate (Magnusson et al. 1978) for each group size:

$$p_{h1} = \frac{n_{.h3}}{(n_{.h2} + n_{.h3})}, \quad \text{and} \quad p_{h2} = \frac{n_{.h3}}{(n_{.h1} + n_{.h3})}.$$

The estimate of the corrected number of deer uses 3 correction factors (c_h), 1 for single deer, 1 for groups of 2 deer, and 1 for groups of 3 deer (Rivest et al. 1995):

$$c_h = 1 + \frac{n_{.h2} \times n_{.h1}}{n_{.h.}(n_{.h3} + 1)} .$$

For groups of ≥4 deer, we assume a correction factor of 1 (Potvin et al. 2002). We computed an estimate of the total number of deer in each plot (N_i) as:

$$N_i = c_1 n_{i1.} + 2c_2 n_{i2.} + 3c_3 n_{i3.} + \sum_{h=4}^{H} h n_{ih.} .$$

In a second step we used a ratio estimate to compute the deer density in the enclosures (Caughley 1977). We considered strip plots as sampling units, with the area of each unit z_i (km^2) computed as:

$$z_i = \text{length (km)} \times 60 \text{ m}/1{,}000.$$

We estimated total deer number in the enclosures as

$$\tilde{N} = RZ ,$$

where $R = \sum N_i / \sum z_i$, Z being the area of the enclosure. We computed the estimate's variance using the formula for sampling without replacement:

$$\text{Var}(\tilde{N}) = \frac{M(M-m)}{m(m-1)} \left(\sum N_i^2 + R^2 \sum z_i^2 - 2R \sum N_i z_i\right),$$

where m is the number of strip plots among the M units constituting the enclosure.

Infrared aerial surveys

We conducted 3 sets of tests with thermal infrared sensing, but only the first one (October 2001) provided deer density estimates, 1 over enclosure A and 1 over enclosure B. In the second test (mid-January 2002), deer did not emit enough heat to be detected. In the third test (early June 2002), we encountered technical problems with the FLIR system. We will describe only the methodology pertaining to the first test. We used a FLIR 2000 A/B sensor (FLIR Systems, Portland, Oreg.) that operated in the 8–12-µm spectral band and had a resolution of 1.4 miliradians in wide mode (0.14 m at a 100-m distance). The FLIR was connected to a digital video recorder (Sony GV-D900, Sony Corporation, Tokyo, Japan) using mini DV cassettes. The sensor was attached to the floor of an AS 350B2 helicopter (Eurocopter, Marignane, France). Speed was maintained at 70–100 km/hour and altitude at 91 m above ground level, verified by a radar altimeter. Survey lines were the same as for visual double-counts (east–west along latitudes) and flown the same way with a Global Positioning System (GPS). We kept the FLIR in wide angle mode (28° horizontal × 15° vertical) and oriented it at a 30° forward-looking angle from nadir. The maximum width of the strip at this angle and a 91-m altitude was 57.5 m.

The two authors simultaneously viewed video tapes in the lab to count deer on each survey line. The tape recorder had slow motion, still image display, and zoom modes. The fence was visible on the image so that animals inside the enclosure could easily be discriminated from those outside. We counted only bright or moving dots, clearly identified as deer. Besides deer and moose (*Alces alces*), the largest animals present on the island were red foxes (*Vulpes vulpes*), making confusion with other species improbable on infrared images. In the open, the whole shape of the deer was visible, with the head and ears (brightest spot), body, and legs. In forest, movement of the animal often was used to confirm that bright dots were not fixed objects. Deer density was computed with a ratio estimate the same way as visual counts. In this case, N_i was the number of deer detected on each survey line on the infrared images and z_i (km^2) was computed as

$$z_i = \text{length (km)} \times 57.5 \text{ m}/1{,}000.$$

Evaluation of actual deer numbers in enclosures

The actual number of deer in the enclosures was evaluated by reconstructing the population using registered hunting harvest and winter mortality data. Up to 3 hunting seasons took place after aerial surveys were conducted. Therefore, we used the age of harvested animals to discriminate those born before or after each survey. For example, only deer $\geq$2.5 years harvested during the autumn season of 2003 (therefore born in 2001 or earlier) were tallied in the population present on the October 2001 surveys. We added crippling losses of 8% to the registered harvest to account for animals not recovered by hunters. We derived this value from interviews of hunting guides and hunters in the enclosures (A. Gingras, Ministère des Ressources naturelles, de la Faune et des Parcs, personal communication). It is almost impossible for hunters to extirpate deer in large enclosures (Van Etten et al. 1965). We applied an arbitrary residual density of 3 deer/km^2 for all enclosures. This density was derived from a smaller enclosure (3.2 km^2) that was heavily hunted during 3 seasons and was based both on predictive curves of deer density as a function of hunting effort and on snow tracking for residual animals (G. Laprise, Ministère des Ressources naturelles, de la Faune et des Parcs, personal communication). When a winter season took place between the aerial survey and the hunting season, natural losses also were added to reconstruct the population. In enclosure A, a dead-deer survey conducted in May 2002 evaluated losses for winter 2001–2002 at 45% (A. Gingras, personal communication). In all other cases, we applied a 40% mortality rate to the deer population present in early winter. This rate had been measured on the island during a severe winter in a previous telemetry study (Potvin et al. 1997). Winters of 2001–2002 and 2002–2003 were classified as severe on Anticosti. We assumed that no natural mortality took place in enclosures outside winter.

Statistical analysis

For each survey, we computed the 90% CL of the deer density using the formula for ratio estimates (Cochran 1977):

$$90\%\,\mathrm{CL} = \hat{Y} \pm t_{0.10,m-1}\sqrt{\mathrm{var}(\hat{Y})}.$$

If the 90% CL of the aerial estimate encompassed the density of the reconstructed population, we considered that both estimates were not statistically different.

Results

Reconstructed deer densities were extremely high in enclosures A and B on 1 September 2001, exceeding 60 deer/km^2. In enclosure A, 625 deer (including crippling losses) were removed by hunters over 3 seasons and some 390 additional animals were presumably dead over winters 2001–2002 and 2002–2003. The remaining population at the end of year 2003 was estimated at 1.9 deer/km^2, for animals that were born before the fence was built, or 3.0 deer/km^2 if we included animals born since then (Table 1). The situation was similar in enclosure B, where 343 deer (including

Table 1. Reconstruction of the deer population in fenced enclosure A (15.7 km^2) on Anticosti Island, Québec, based on animals that were alive on 1 September 2001 or 1 September 2003.

Population	Dates	Source (# deer) [a]	Losses (# deer)	Deer population at earlier date	
				Number	Deer/km^2
Deer alive on 1 Sep 2001	31 Dec 2003			30 [b]	1.9
	1 Sep–31 Dec 2003	Hunting $\geq$2.5 yr (59)	64 [c]	94	6.0
	1 Jan–30 Apr 2003	Winter mortality	63 [d]	157	10.0
	1 Sep–31 Dec 2002	Hunting $\geq$1.5 yr (173)	190 [c]	347	22.1
	1 Jan–30 Apr 2002	Winter mortality from dead deer survey	331	733	46.7
		Hunting $\geq$0.5 yr (50)	55 [c]		
	26 Oct–31 Dec 2001	Hunting $\geq$0.5 yr (175)	193 [c]	926	59.0
	1 Sep–25 Oct 2001	Hunting ($\geq$0.5 yr) (88)	97 [c]	1023	65.2
Deer alive on 1 Sep 2003	31 Dec 2003			47 [b]	3.0
	1 Sep–31 Dec 2003	Hunting ($\geq$0.5 yr) (83)	90 [c]	137	8.7

[a] Registered harvest.

[b] Assuming a residual density of 3.0 deer/km^2, including fawns (23%) and yearlings (13%), or 1.9 adult deer/km^2 ($\geq$2.5 yr).

[c] Crippling losses of 8% are added to the registered harvest.

[d] Assuming a 40% mortality rate for deer present on 1 January 2003.

Table 2. Reconstruction of the deer population in fenced enclosure B (6.8 km^2) on Anticosti Island, Québec, based on animals that were alive on 1 September 2001.

Dates	Source (# deer) [a]	Losses (# deer)	Deer population at earlier date	
			Number	Deer/km^2
31 Dec 2003			13 [b]	1.9
1 Sep–31 Dec 2003	Hunting ≥2.5 yr (19)	21 [c]	34	5.0
1 Jan–30 Apr 2003	Winter mortality	23 [d]	57	8.4
1 Sep–31 Dec 2002	Hunting ≥1.5 yr (16)	17 [c]	74	10.9
1 Jan–30 Apr 2002	Winter mortality Hunting ≥0.5 yr (52)	49 [d] 56 [c]	179	26.3
25 Oct–31 Dec 2001	Hunting ≥0.5 yr (126)	136 [c]	315	46.3
1 Sep–24 Oct 2001	Hunting ≥0.5 yr (105)	113 [c]	428	62.9

[a] Registered harvest.

[b] Assuming a residual density of 3.0 deer/km^2, including fawns (23%) and yearlings (13%), or 1.9 adult deer/km^2 (≥2.5 yr).

[c] Crippling losses of 8% are added to the registered harvest.

[d] Assuming a 40% mortality rate for deer present on 1 January 2003 and 2002.

crippling losses) were removed by hunters, mostly during the first year, and some 72 animals were estimated as winter mortalities (Table 2). For enclosures C and D, estimated densities at the time the fence was in place and logging completed were 22 and 11 deer/km^2, respectively (Tables 3 and 4).

All 6 surveys with visual double-counts estimated lower densities than the reconstructed deer population densities (Table 5). The 90% CL of 2 estimates encompassed the density of the reconstructed population and therefore cannot be declared statistically different. In these surveys the aerial estimates amounted to 83% (enclosure A, 8 Aug 2002) and 76% (enclosure C, 11 Aug 2002) of the assumed density. The deer estimate of the winter aerial survey in enclosure A (10 Jan 2002) also came close to the reconstructed population (81%). The largest discrepancies involved 2 summer surveys in Aug 2003 that yielded densities only 37% (enclosure A) and 46% (enclosure D) of the assumed densities. In these 2 surveys, the reconstructed deer densities were the lowest among all surveys (8.7 and 10.9 deer/km^2) and the sighting probabilities of deer groups computed for the front observer also were the lowest (0.25 and 0.39).

The infrared count in enclosure A had the closest agreement (89%) with the density of the reconstructed population among all aerial surveys (Table 5). In the second infrared survey (block B), the evaluated density was only 54% that of the reconstructed population.

Discussion

Validity of reconstructed deer populations in enclosures

In our study the evaluation of the accuracy of aerial survey techniques was dependent on the validity of the reconstruction of deer populations, a task more difficult for large enclosures than for smaller ones. While the number of deer harvested can hardly be disputed as not being accurate, other data are weaker. The 8% rate added for crippling losses was derived from interviews of hunting guides and hunters. This figure seems reasonable and had a small effect on assumed density evaluations. A residual density of 3 deer/km^2 after intensive hunting has been used for all enclosures. Residual density is difficult to verify in large enclosures. The residual number of deer represents a small fraction

Table 3. Reconstruction of the deer population in fenced enclosure C (6.0 km^2) on Anticosti Island, Québec, based on animals that were alive on 1 September 2002.

Dates	Source (# deer) [a]	Losses (# deer)	Deer population at earlier date	
			Number	Deer/km^2
31 Dec 2003			14 [b]	2.3
1 Sep–31 Dec 2003	Hunting ≥1.5 yr (6)	6 [c]	20	3.3
1 Jan–30 Apr 2003	Winter mortality	13 [d]	33	5.5
1 Sep–31 Dec 2002	Hunting ≥0.5 yr (88)	95 [c]	128	21.3

[a] Registered harvest.

[b] Assuming a residual density of 3.0 deer/km^2, including fawns (23%), or 2.3 deer/km^2 yearlings and adults.

[c] Crippling losses of 8% are added to the registered harvest.

[d] Assuming a 40% mortality rate for deer present on 1 January 2003.

Table 4. Reconstruction of the deer population in fenced enclosure D (29.4 km^2) on Anticosti Island, Québec, based on animals that were alive on 1 September 2003.

		Losses	Deer population at earlier date	
Dates	Source (# deer) [a]	(# deer)	Number	Deer/km^2
31 Dec 2003			88 [b]	3.0
1 Sep–31 Dec 2003	Hunting ≥0.5 yr (214)	231 [c]	319	10.9

[a] Registered harvest.

[b] Assuming a residual density of 3.0 deer/km^2.

[c] Crippling losses of 8% are added to the registered harvest.

of the initial population estimates in enclosure A, for the 2001 and 2002 surveys, and B, for the 2001 survey (≈3% of the initial population). Therefore, even a large error associated with this figure would have a minor effect on the assumed deer densities. In the other enclosures and surveys, the residual population may account for more than 25% of the initial population estimate. Inaccurate winter mortality estimates also may have influenced the accuracy of deer population reconstructions. In enclosures A and B, 2 winters were involved in the reconstruction process for the October 2001 and January 2002 surveys. In enclosure A, although winter mortality represented 39% of the evaluated initial population, most losses happened during winter 2001-2002 and have been estimated by a specific dead deer survey. In enclosure B winter mortality made up 17% of the initial deer population and was computed using an arbitrary 40% rate for each winter. If this rate was too high, the reconstructed population might have been slightly overestimated. Winter mortality was not involved in reconstructing deer populations for the 2 surveys in August 2003 (enclosures A and D) and had a minor contribution to reconstructed population estimates in the other 2 surveys (enclosure C in August 2002).

Accuracy of double-count aerial surveys

Deer densities estimated by the 6 double-count aerial surveys averaged 65% of the densities assumed to be present in enclosures, based on reconstructed populations. For mule deer, Bartmann (1983) reported that an experienced observer missed only 1 of 37 animals present in small enclosures (97% accuracy). Accuracy estimates in studies for white-tailed deer, with marked animals, were much lower: 50% and 56% in Minnesota (Floyd et al. 1979), 36% and 65% in Texas (DeYoung 1985), and 42% also in Texas (DeYoung et al. 1989). In our study accuracy estimates exceeded 80% in the first 2 surveys over enclosure A, which took place respectively in winter and in summer. Conversely, the third count in the same enclosure was the least accurate (37%). In this survey the front observer had the lowest sighting probability of deer groups among all surveys (0.25). Based on replicated surveys, Potvin et al. (2002) suggested that results from the double-count technique are valid if sighting probability exceeds 0.45, but might underestimate deer densities when sighting probability is <0.40. Magnusson

Table 5. Comparison between deer densities estimated by aerial surveys (VDC: visual double-count, IR: thermal infrared) and assumed densities (reconstructed population) in 4 fenced enclosures on Anticosti Island, Québec.

				Sighting probability [a]		Deer/km^2			
			n			Aerial survey			Reconstructed
Technique	Enclosure	Date	strips	Front	Rear	$\bar{x}$	SE	90% CL	population
VDC	A	10 Jan 2002	17	0.46	0.63	37.7	4.3	30.2–45.2	46.7
	A	8 Aug 2002	24	0.53	0.50	18.3 [b]	2.5	14.0–22.6	22.1 [b]
	A	12 Aug 2003	24	0.25	0.67	3.2	1.2	1.1–5.3	8.7
	C	8 Aug 2002	11	0.80	0.57	13.6	2.8	8.5–18.7	21.3
	C	11 Aug 2002	11	0.50	0.60	16.1	3.7	9.4–22.8	21.3
	D	8 Aug 2003	20	0.39	0.56	5.0	0.9	3.4–6.6	10.9
IR	A	26 Oct 2001	17			52.8	5.7	42.8–62.8	59.0
	B	25 Oct 2001	23			25.0	3.8	18.5–31.5	46.3

[a] Sighting probability of deer groups for each observer in VDC.

[b] Excluding fawns born in 2002.

et al. (1978) and Graham and Bell (1989) recommend sighting probabilities >0.45 and >0.50, respectively. The second less accurate survey in our study also had a low sighting probability for the front observer (0.39). All other surveys had probabilities >0.45 for either observer. These results tend to confirm that sighting probability is a good measure of the quality of a double-count survey and that surveys with probabilities <0.45 should be considered not reliable. There also may be a link between deer density and accuracy of double counts. The 2 surveys that had the lowest agreement with reconstructed populations have been conducted in enclosures having densities lower than 11 deer/km^2. Other research is needed in order to answer this question.

Accuracy of thermal infrared sensing

Our results on thermal infrared sensing are limited and contradictory. One survey (block A) had the closest agreement with the reconstructed deer population (89%), while the second had an accuracy lower than most visual counts (54%). This last survey took place in enclosure B, where the estimation of natural mortality over 2 winters may be slightly overestimated. If we use a lower mortality rate (20% instead of 40%), the deer density at the time of the infrared sensor becomes 41/km^2. With 25 deer/km^2, the infrared survey still amounts to only 61% of this revised reconstructed deer density. In nonforested areas in South Dakota, surveys with the same infrared sensor that we used detected 88% of the white-tailed deer counted on the ground (Naugle et al. 1996). In Louisiana 5 biologists counted 70–93% of the white-tailed deer present in small enclosures on infrared images (Wiggers and Beckerman 1993). Heavy coniferous canopy remains a problem for thermal infrared sensing because it prevents detection (Garner et al. 1995, Dunn et al. 2002). In our study block A was surveyed in early morning (7:00–9:02) while block B was surveyed in the afternoon (15:45–17:03), both on cloudy days. Although clearcut patches in block B were devoid of vegetation >1 m and were well suited for infrared sensing, we hypothesize that a large fraction of the deer in this block might have been present in residual uncut forest at the time of the survey in that block, making their detection more difficult.

Management implications

Double-count aerial surveys underestimate deer densities. Although this technique enables computation of sighting probabilities for each observer (front, rear) and corrected deer densities, it cannot totally compensate for this bias. In our study surveys with sighting probabilities <0.40 detected less than half of the deer present and appeared unreliable. Surveys with sighting probabilities >0.45 had density estimates that amounted to 76% (range = 64–83%) of the actual deer densities (reconstructed populations). In our situation this suggested that we missed 1 deer out of 4 and that aerial survey estimates should be increased by one-third to estimate actual densities. We conclude that aerial surveys provide valid estimations for management purposes but that their negative bias should be taken into account and measured when possible.

As regards thermal infrared sensing, although this technique provided the most accurate estimate in 1 survey (89%), its use remains limited for closed-canopy forest. Detection of all animals (or a large and "constant" fraction) along systematic survey lines does not appear reliable. This technique certainly has greater potential in open areas (Wiggers and Beckerman 1993, Reynolds et al. 1994) or for intensive survey of species such as moose, at relatively low density, using circular flight patterns and alternating between zoom and wide-angle modes with the infrared scanner (Bontaites et al. 2000).

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Literature cited

Anderson, C. R., Jr., and F. G. Lindzey. 1996. Moose sightability model developed from helicopter surveys. Wildlife Society Bulletin 24:247–259.

Bartmann, R. M. 1983. Appraisal for a quadrat census for mule deer in pinyon-juniper vegetation. Colorado Division of Wildlife Game Information Leaflet 109.

Bayliss, P., and K. M. Yeomans. 1989. Correcting bias in aerial survey population estimates of feral livestock in northern Australia using the double-count technique. Journal of Applied Ecology 26:925–933.

Boer, A. H., G. Redmond, and T. J. Pettigrew. 1989. Loran-C: a navigation aid for aerial surveys. Journal of Wildlife Management 53:228–230.

Bontaites, K. M., K. A. Gustafson, and R. Makin. 2000. A Gasaway-type moose survey in New Hampshire using infrared thermal imagery: preliminary results. Alces 36:69–75.

Caughley, G. 1974. Bias in aerial survey. Journal of Wildlife Management 38:921–933.

Caughley, G. 1977. Sampling in aerial survey. Journal of Wildlife

Management 41:605–615.

Choquenot, D. 1995. Species- and habitat-related visibility bias in helicopter counts of kangaroos. Wildlife Society Bulletin 23: 175–179.

Cochran, W. G. 1977. Sampling techniques. John Wiley & Sons, New York, New York, USA.

Cogan, R. D., and D. R. Diefenbach. 1998. Effect of undercounting and model selection on a sightability-adjustment estimator for elk. Journal of Wildlife Management 62:269–279.

DeYoung, C. A. 1985. Accuracy of helicopter surveys of deer in south Texas. Wildlife Society Bulletin 13:146–149.

DeYoung, C. A., F. S. Guthery, S. L. Beasom, S. P. Coughlin, and J. R. Heffelfinger. 1989. Improving estimates of white-tailed deer abundance from helicopter surveys. Wildlife Society Bulletin 17:275–279.

Dunn, W. C., J. P. Donnelly, and W. S. Krausmann. 2002. Using thermal infrared sensing to count elk in the southwestern United States. Wildlife Society Bulletin 30:963–967.

Floyd, T. J., L. D. Mech, and M. E. Nelson. 1979. An improved method of censusing deer in deciduous-coniferous forests. Journal of Wildlife Management 43:258–261.

Garner, D. L., H. B. Underwood, and W. F. Porter. 1995. Use of modern infrared thermography for wildlife population surveys. Environmental Management 19:233–238.

Graham, A., and R. Bell. 1989. Investigating observer bias in aerial survey by simultaneous double-counts. Journal of Wildlife Management 53:1009–1016.

Kufeld, R. C., J. H. Olterman, and D. C. Bowden. 1980. A helicopter quadrat census for mule deer on Uncompahgre Plateau, Colorado. Journal of Wildlife Management 44:632–639.

Leptich, D. J., D. G. Beck, and D. E. Beaver. 1994. Aircraft based Loran-C and GPS accuracy for wildlife research on inland study sites. Wildlife Society Bulletin 22:561–565.

LeResche, R. E., and R. A. Rausch. 1974. Accuracy and precision of aerial moose censusing. Journal of Wildlife Management 38: 175–182.

Magnusson, W. E., G. J. Caughley, and G. C. Grigg. 1978. A double-survey estimate of population size from incomplete counts. Journal of Wildlife Management 42:174–176.

Marsh, H., and D. F. Sinclair. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. Journal of Wildlife Management 53:1017–1024.

Naugle, D. E., J. A. Jenks, and B. J. Kernohan. 1996. Use of thermal infrared sensing to estimate density of white-tailed deer. Wildlife Society Bulletin 24:37–43.

Novak, M., and J. Gardner. 1975. Accuracy of moose aerial surveys. Transactions of the North American Moose Conference 11:154–179.

Potvin, F., P. Beaupré, and G. Laprise. 2003. The eradication of balsam fir stands by white-tailed deer on Anticosti Island, Québec: a 150-year process. Écoscience 10:487–495.

Potvin, F., L. Breton, and A. Gingras. 1997. Déplacements et survie hivernale des biches d'Anticosti de 1986 à 1990: une étude télémétrique. Québec Ministère de l'Environnement et de la Faune, Report 3643–97–08.

Potvin, F., L. Breton, and L. P. Rivest. 2002. Testing a double-count aerial survey technique for white-tailed deer, *Odocoileus virginianus*, in Québec. Canadian Field-Naturalist 116:564–572.

Potvin, F., L. Breton, and L. P. Rivest. 2004. Aerial surveys for white-tailed deer with the double-count technique in Québec: two 5-year plans completed. Wildlife Society Bulletin 32:1099–1107.

Reynolds, P., C. Duck, D. Youngson, and D. Clem. 1994. An evaluation of airborne thermal imaging for the census of red deer (*Cervus elaphus*) populations in extensive open habitats in Scotland. Pages 162–168 *in* I. Thompson, editor. Proceedings of the International Union of Game Biologists XXI congress. Canadian Forest Service, FO18–33.

Rivest, L. P., F. Potvin, H. Crépeau, and G. Daigle. 1995. Statistical methods for aerial surveys using the double-count technique to correct visibility bias. Biometrics 51:461–470.

Rochette, B., A. Gingras, and F. Potvin. 2003. Inventaire aérien du cerf de Virginie de l'île d'Anticosti - Été 2001. Société de la faune et des parcs du Québec, Québec, Report 8080–03–05.

Short, J., and P. Bayliss. 1985. Bias in aerial survey estimates of kangaroo density. Journal of Applied Ecology 22:415–422.

White, G. C., R. M. Bartmann, L. H. Carpenter, and R. A. Garrot. 1989. Evaluation of aerial line transect for estimating mule deer densities. Journal of Wildlife Management 53:625–635.

Van Etten, R. C., D. F. Switzenberg, and L. Eberhardt. 1965. Controlled deer hunting in a square-mile enclosure. Journal of Wildlife Management 29:59–73.

Wiggers, E. P., and S. F. Beckerman. 1993. Use of thermal infrared sensing to survey white-tailed deer populations. Wildlife Society Bulletin 21:263–268.

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