USING GPS AND GIS FOR NAVIGATION AND MARK-RECAPTURE FOR SIGHTABILITY CORRECTION IN MOOSE INVENTORIES

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ABSTRACT: To increase survey efficiency and accuracy we used Global Positioning System (GPS) and Geographic Information System (GIS) technologies during a stratified random block survey of moose (*Alces alces*) in northeastern British Columbia. We used on-board computer mapping for navigation and data recording, and assessed the use of a mark-recapture procedure to correct for moose sightability bias. Aircraft position was visible on a GIS base map on a laptop computer. We used function keys to place numbered labels on the map indicating the sex and age class of the animals observed. The mapping program helped ensure that survey unit (SU) coverage was complete and aided in location decisions close to SU boundaries. We immediately resurveyed 1/4 of each SU at approximately twice the intensity, noting whether animals seen were previously observed or new moose. We calculated a sightability correction factor (SCF) for each stratum (1.31, 1.06, and 1.33 for low, medium, and high density strata, respectively) using standard double sampling methods, and obtained a population estimate about 15% lower than calculated using the mark-recapture based SCF of 1.44. The GPS and GIS technologies we used appeared to enhance survey efficiency, and we recommend these technologies in most survey situations. We also suggest further examination of mark-recapture correction factors and increased efforts to test aerial sightability models.

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Recently, Lynch and Shumaker (1995) reported on the use of Global Positioning System (GPS) and Geographical Information System (GIS) technologies during stratified random block design surveys (Gasaway *et al.* 1986) for moose in Alberta. Their technique involved using hard copy maps produced by GIS to show survey unit (SU) boundaries within the study area. GPS was used to navigate to the SU, to follow lines of latitude during the stratification and census parts of the survey, and to record locations of moose, all of which were downloaded at the end of the day for processing and mapping. The authors reported increased efficiency and decreased aircraft and manpower costs using these applications (Lynch and Shumaker 1995). However, real-time navigation decisions were not possible using these techniques since a visual display was not available. In addition, the authors acknowledged that their intensive search procedure conducted during the survey to obtain moose sightability corrections (intensively re-flying a line of latitude on which ≥6 moose were observed) may not have corrected well for undercounting bias (Lynch and Shumaker 1995).

In January 1998, we conducted a moose inventory in the Prophet River area in northeastern British Columbia (BC). Much of the area was relatively flat with large uniform tracts of forest or complex mixtures of heterogeneous habitats. Identifying SU boundaries and accurate mapping of animals using conventional mapping and navigation under these conditions is difficult, costly, and prone to error. We therefore decided to build on the techniques and recommendations of Lynch and Shumaker (1995) to conduct the inventory. Our primary objectives of the study were to estimate moose density and age and sex composition in a portion of the Prophet River area (Poole *et al.* 1998). Here we report on our use and assessment of on-board computer mapping for navigation and data recording, and tender the possibility of using a mark-recapture procedure to correct for moose sightability bias.

STUDY AREA

We conducted a survey for moose in a 3,825 km^2 block which included parts of the Prophet River and Sikanni Chief River drainages in northeastern BC (57°26' - 58°12' N; 122°15' - 123°00' W). The area lies within the boreal white and black spruce biogeoclimatic zone (Meidinger and Pojar 1991). Elevations ranged from 610 - 1,275 m. Percent vegetation cover (measured obliquely) ranged from 5% or less in swamps, clearcuts and open stands, to approximately 70% in mature conifer stands. Frequent fire disturbances and a range of growing sites have resulted in a mosaic of successional coniferous and deciduous forests (MacKinnon *et al.* 1992). Habitat/stand patch size ranged from several hectares to large continuous tracts of coniferous forest up to 25 km^2 in size. The relatively flat topography and large continuous patches of a single vegetation type made traditional methods of navigation difficult. The variation in habitats made for large variation in sightability of moose from close to 100% in open habitats to very low visibility in mid-seral coniferous forests. Snow cover during the survey was complete but lower than usual (20-40 cm), with low vegetation showing in places.

METHODS

Survey Preparation

We estimated moose densities using a stratified random block design, following procedures detailed in Gasaway *et al.* (1986), Timmermann (1993), and Timmermann and Buss (1997). An InterGraph Graphics Design System (IGDS) map was built by merging digital 1:20,000 scale forest cover files of the study area. Forest cover files originate from BC Ministry of Forests, and are produced from the interpretation of aerial photos and information collected during field surveys. The IGDS base map was relatively simple and included roads and other linear features, rivers and lakes but not contours. We placed a 9 x 17 grid (153 SU's) of 5 km x 5 km (25 km^2) units on the map along Universal Transverse Mercator (UTM) grid lines. We used UTM lines to avoid the problem of changing SU size if lines of longitude were followed. Each SU was divided into 4 quarters (2.5 km x 2.5 km; 6.25 km^2) for use during estimation of the sightability correction factor (SCF; Fig. 1). Stratification flight lines were placed 1 km in from the east and west edge of each SU along a north-south direction.

We used a laptop computer for mapping and navigation using a MicroStation 95 for DOS computer drafting package (Bentley Systems, Inc., Exton, PA) connected to a portable GPS unit (Trimble GeoExplorer and Scout; Trimble Navigation Ltd., Sunnyvale, CA) placed on the dash or taped to the top of the bubble in the aircraft. A front end software program (GPS Link) indicated the aircraft's position (in the NAD-83 datum) and direction of travel on the GIS map (D. Pritchard and R. Durfeld, 1997, GPS Link: aerial surveys/GPS software, Version 2.0, URHere Systems, Williams Lake, BC). GPS Link includes pan commands which allow the user to rotate the map so that the direction of travel is

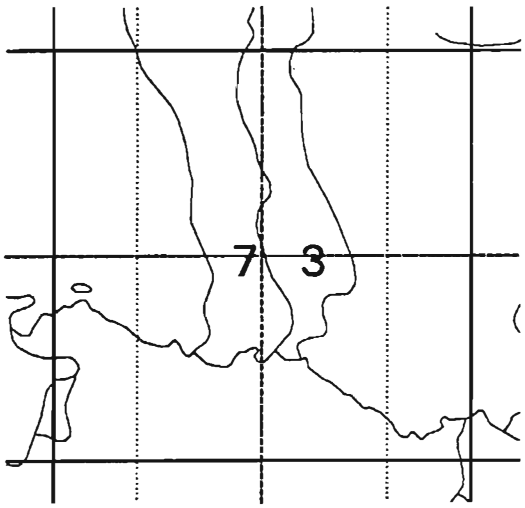

Fig. 1. Typical layout of a survey unit showing unit boundaries (solid lines), stratification lines (dotted lines), and sightability correction factor (SCF) quadrants (dashed lines).

always at the top of the screen, and select the view distance on the map. Positional data were sent to the computer using a NMEA string to the COM1 serial port. The aircraft's position and path of travel were plotted on the GIS map (3 second update); different colour plot lines were used for the stratification, standard, and intensive surveys. A MicroStation Development Language (MDL) macro enabling the function keys was used to place a numbered label on the map indicating the sex and age class of the animals observed. Further details on the mapping and navigation system can be obtained from the authors.

Stratification

We used a Cessna 206 fixed-wing aircraft with a pilot, a navigator/computer operator (next to the pilot) and 2 rear-seat observers during stratification. Using the aircraft's GPS, we flew 2 stratification lines in a north-south direction 1 km in from the east and west edges of each SU. Adherence to the planned stratification lines was verified by visually monitoring the flight path on the GIS map on the computer screen. Flight speed was 150 - 160 kph at an altitude of 120 - 150 m above ground level. The pilot and navigator participated in locating animals. Moose numbers were recorded on the GIS map and on paper data forms by 1 observer; sighting locations were placed on the GIS map. We stratified SU's into 3 strata (low, medium, and high density; Gasaway *et al.* 1986).

Helicopter Census

SU's were randomly selected for survey within strata. We used 2 Bell 206B helicopters during the census. Each helicopter had a pilot, navigator/computer operator (next to the pilot), and 2 rear-seat observers, 1 of whom also recorded data. We used the computer mapping and navigation program to travel directly to the starting points on SU's. The entire SU was flown at an airspeed of about 100 - 120 kph and a height above ground of 100 - 180 m (higher over dense cover and very open areas). We searched the SU along 300 - 400 m wide strips; the mapping program helped ensure that SU coverage was complete (Fig. 2). Coverage was usually flown along parallel lines back and forth across the SU, but occasionally steep terrain required contouring coverage. Variations in vegetation cover, such as when surveying open bogs with excellent visibility, often resulted in deviations from straight flight lines (Fig. 2). All crew members participated in locating animals. We circled all groups of moose to determine sex and age of each animal (Timmermann and Buss 1997) and to verify whether or not the group was within the SU when they occurred along boundaries.

Immediately upon completion of the standard survey of the SU, we resurveyed 1/4 of the SU at approximately twice the intensity (air speed of 80 - 90 kph and 200 - 250 m wide strips). The SCF quadrant was standardised as the quarter of the SU oppo-

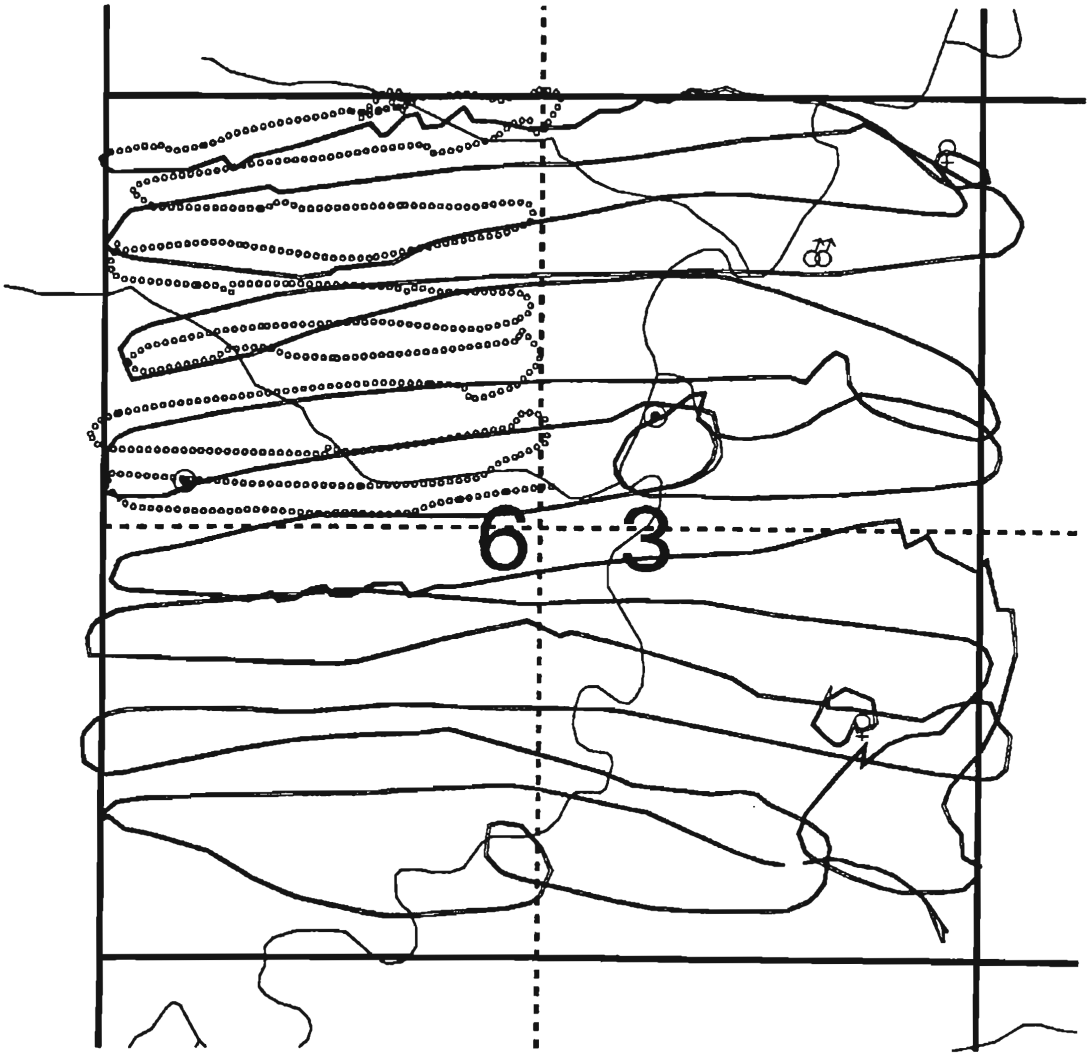

Fig. 2. Representative survey unit showing standard (long dashed line) and intensive (dotted line) flight lines and locations where animals were sighted.♂ adult bull; ♀ adult (lone) cow; ⊙ cow-calf pair.

site the starting corner of the standard survey; the starting corner was random. All moose observed during the intensive survey were determined to be either previously observed during standard survey coverage or new animals. Labels on the mapping program greatly facilitated identification of groups.

We used the program MOOSEPOP for analysis (Version 2.0, R.A. DeLong and D.J. Reed, Alaska Dept. of Fish and Game, Fairbanks). We used optimal allocation to guide survey effort of additional SU's until 90% confidence intervals (CI) were less than ±25% of the mean.

To derive a SCF based on mark-recapture, we used program CAPTURE (Otis *et al.* 1978, White *et al.* 1982) to estimate moose population size on the SCF quadrants. We then divided this population estimate by the number of moose counted in the SCF quadrants during the standard survey to derive an alternative SCF to the one calculated by MOOSEPOP.

RESULTS

We spent 9.0 hours on stratification flights over 2 days. Immediately following stratification, we surveyed 28 SU's during 6 consecutive days. We spent 25.8 hours for the standard surveys (averaging 55 min/SU; 2.2 min/km^2) and 11.1 hours for the intensive resurveys (24 min/SCF quadrant; 3.8 min/km^2). Survey intensity during resurveys averaged 1.7 times greater than during standard surveys.

We obtained a naive (unadjusted) estimate of 1,580 moose (0.41/km^2) for the study area. We applied SCF's for each stratum (1.31, 1.06, and 1.33 for low, medium, and high density strata, respectively) to obtain an adjusted estimated moose population of 1,909 animals (±23.4%; CI 1,463 - 2,356; 0.52 moose/km^2). We did not have an estimate of the SCF constant (SCF$_c$) for our area and conditions so we followed the suggestion of Gasaway *et al.* (1986) and assumed that the observed SCF (SCF$_o$) was the true SCF, though the mark-recapture correction factor suggested that our SCF$_o$ was conservative.

We observed 72 moose in 28 SCF quadrants during standard surveys. During intensive surveys 64 of these moose were resighted and 28 new moose were observed. We used model M_t (which reduces to a simple Lincoln-Petersen model with 2 sessions) in program CAPTURE to analyze these data. The estimated population on the SCF quadrants was 103 (95% CI 101 - 109). The resulting correction factor was 1.44 which suggested that the Gasaway *et al.* (1986) double sampling method (as calculated by MOOSEPOP) may have underestimated moose numbers by about 15% in this case. The moose population estimate using mark-recapture correction was 2,260 moose or 0.59 moose/km^2.

DISCUSSION

GPS/GIS Navigation and Mapping

As noted by Lynch and Shumaker (1995), GPS and GIS mapping technologies have several advantages over conventional surveys. Digital pre-survey mapping was simplified, enabling considerable cost saving in map preparation; hard copy maps of the SU's produced by GIS generally were not needed. Navigation during stratification was relatively easy because the pilot followed straight lines and any deviation of the aircraft from the stratification line was quickly apparent on the computer map. Systematic visual coverage of the SU's was ensured because the helicopter flight path was mapped. Mapping and locating of animals was accurate and immediate, a great aid during the SCF flights to distinguish "new" versus "previously seen" animals. Survey results were recorded twice, once on the computer GIS map and again on data forms, minimizing data loss and confusion. UTM locations of animals observed could be easily obtained by querying the GIS file. We found UTM grid lines easy and intuitive to follow, although all pilots were initially unfamiliar with the UTM grid system. After the initial equipment problems were overcome on 1 GPS-laptop system, no further survey time or data were lost. We believe that the GPS and GIS technologies we employed during this survey likely saved 10-20% of our aircraft time compared to a conventional survey.

Moose Sightability

The SCF$_o$ estimated by MOOSEPOP for the habitats surveyed in the Prophet River area may not be an accurate correction for sightability. During the standard portion of the helicopter census we often had to circle and scatter moose to determine sex. During the intensive SCF surveys we occasionally were unable to account for all of the moose previously observed on the quadrant, and we regularly found new moose. Counting SCF quadrants may be more accurate during fall/early winter surveys because males retain their antlers at that time and do not need to be approached as closely for classification. Estimates of moose sightability are correlated to vegetation cover (measured obliquely); estimated detection probabilities in a study in Wyoming were close to 1.0 in open habitats (<15% vegetation cover) but dropped to less than 0.2 with >50% cover (Anderson and Lindzey 1996). Percent cover varied widely across the Prophet River study area, and in some areas (albeit possibly poor moose habitat) oblique canopy cover was >50%.

Seber (1982) and Pollock and Kendall (1987) discuss ways of correcting aerial surveys for visibility bias and Caughley (1977) and others have shown that sightability bias can be a severe negative bias for many types of aerial surveys. Moose surveys conducted during October - December in open and semi-open habitats appear to have small negative biases, virtually all of which are correctable using the double sampling technique recommended in Gasaway *et al.* (1986). However, Gasaway *et al.* (1986) were far less optimistic about correcting for sightability of moose during surveys conducted from January - March and in areas with closed or semi-closed canopies. The double sampling technique will only accurately correct visibility bias when 2 different sightability factors are used. The observed correction factor (SCF$_o$) is estimated using a ratio comparison of the number of moose seen during standard and intensive surveys. The constant sightability factor (SCF$_c$) is taken from research using radio-collared moose. SCF$_c$ accounts for that proportion of moose that were not seen during the standard or intensive surveys; these moose were essentially unsightable with the survey technique. Gasaway *et al.* (1986) point out that this proportion can be substantial in late winter or in closed forests. The Prophet area has more closed forests than found in Alaska and Yukon [where the method of Gasaway *et al.* (1986) was tested], and our survey was conducted during January when moose sightability is known to be lower compared to October - December (Gasaway *et al.* 1986). Generally, SCF's are higher in denser cover, although there is great variation in the size of SCF's reported in the literature (Timmermann 1993, Anderson and Lindzey 1996). For these reasons we were concerned that our population estimate based on SCF$_o$ may be biased low compared to surveys from other areas and times of year.

The moose population estimate that used the mark-recapture sightability correction factor estimated the population size to be 15% greater than our estimate following the calculations given by Gasaway *et al.* (1986). We expected a larger estimate from the mark-recapture results because we did not account for those animals that were missed on the intensive survey in our Gasaway *et al.* (1986) based estimate (i.e., we did not incorporate a SCF$_c$). The fact that some moose were missed during the intensive search that were seen during the standard survey further suggests that our Gasaway *et al.* (1986) based estimate was biased low. While some of the moose that were seen during the standard survey and not during the intensive survey may have moved off the quadrant, we find it improbable that this was the case for many of these individuals because moose did not appear to move long distances after we sighted them and our SCF quadrants were quite large. It is more likely the individuals moved a short distance into a more closed stand and were less visible during the intensive surveys.

Both the double sampling method and the mark-recapture method suffer from the fact that a subjective decision must be made as to whether a given moose was in the SCF quadrant on the previous survey. Gasaway *et al.* (1986) present subjective ways of dealing with this problem. The mark-recapture method necessitates a further decision as to whether an individual seen on the intensive survey was seen previously during the standard survey. We found that once we decided whether the individual was on or off the quadrant during the standard survey (aided by the computer-mapping program), the decision as to whether it was a new individual was not difficult. The computer mapping program helped with this decision because the previous location, and the sex and age class of the individual(s) were clearly shown on the screen. The process of identifying individuals was antagonized by the fact we were working in mid-winter so most adult moose were approached closely to verify the sex, and consequently were disturbed more than would occur during an early winter survey.

There are several assumptions inherent to the use of a Lincoln-Petersen type model for correcting for visibility bias. The model assumes that all individuals have the same capture probability during a given session. This assumption is unlikely to be true because we know moose visibility changed, probably because they moved into areas with different canopy obstruction, from our experience recounting the SCF quadrants. However, the majority of moose (89%) were resighted, suggesting that differences in sightability within a session may also be small. The model does not assume sightability is the same among sessions, however, if both sets of observers (standard and intensive surveys) have difficulty seeing the same individuals then a negative bias will result (Pollock and Kendall 1987, Pollock *et al.* 1990). Our data suggest that 97% of the moose present were seen on both surveys combined so there is some justification for assuming that many individuals that were difficult to see on the standard survey were detectable on the intensive survey.

Mark-recapture models also assume that each survey session is independent of the other. Our surveys were not completely independent because we did the second survey immediately after the first using the same observers. However, the intensive survey was conducted using greater intensity, which would give the observers different viewpoints than for the previous survey. Habitat heterogeneity combined with moose movement would tend to make the 2 surveys independent by mildly changing the sightability for each individual. The bias resulting from deviating from the above assumption is likely to be negative, and notwithstanding the possible bias, the results of our comparison demonstrate that the double sampling SCF we calculated was likely low. A further complication regarding this bias is when moose are in groups, which causes a lack of independence of sighting of individuals. Neal *et al.* (1993) investigated this bias in mark-resight models and found it caused an underestimate of variance and confidence intervals.

The Lincoln-Petersen model also assumes the population did not change size between or during the 2 surveys. This is the assumption of topographic closure described by White *et al.* (1982). We tried to minimize movement of moose by surveying fairly large SCF quadrants (6.25 km^2) and doing the intensive surveys immediately after finishing the standard surveys. Accurate mapping of moose locations and tracks in the snow also helped to detect moose movement. We attempted to locate moose that ventured off the block to avoid bias. Regardless, there was likely some undetected movement of moose on and off the survey blocks. Lack of closure was most likely to have caused a negative bias in this study because moose that were on the periphery of survey blocks were more likely to have moved off the blocks, due to helicopter disturbance, than those in the interior of the blocks. Again, we are mainly comparing the SCF and the mark-recapture correction factor in this study, and these 2 estimates were likely affected in a similar fashion by this bias. This negative bias is not measurable with the study design used herein, but could be addressed by choosing a study design that minimizes movement errors.

Mark-recapture analysis also assumes that we can positively identify moose that were seen on previous surveys. Meeting this assumption has been problematic for many workers considering the use of mark-recapture during aerial surveys, and this error was likely to have caused the largest bias to the mark-recapture results of this study. While we did not specifically test this assumption, there were relatively few instances during the intensive survey when we had difficulty deciding whether an animal had previously been seen. Though the computer mapping system greatly aided the classification of new and recaptured moose, ultimately this remained a subjective decision. Regardless of the mapping and data recording system used, special attention must be paid to moose located near the periphery of SCF quadrants. While we were comfortable with the subjective decisions made during this survey, decisions may be more difficult at higher moose densities or when moose are found in larger groups. We suggest further testing of this error using simulations, re-recording data and locations of "previously seen" moose, and applying this method in an area that has marked moose.

Several questions remain regarding the use of mark-recapture for sightability correction. We combined the resighting results for all SCF quadrants and both crews and ran our analysis on the combined results. This may have caused greater heterogeneity of capture probabilities. One possibility to reduce this bias is to calculate correction factors for each stratum separately as suggested by Becker and Reed (1990). During a larger study one could also compare correction factors among crews to test for the effect of observer bias. Habitat heterogeneity probably causes heterogeneity of capture probabilities as well. We did not present a comparison of precision between the double sampling and mark-recapture methods because we were unsure of how to add the variance components of the standard survey, the intensive survey, and the mark-recapture results. Clearly, our use of mark-recapture violates many of the assumptions of the method, and the resulting estimates must be considered approximate. In a review of methods used to correct for sightability bias Pollock and Kendall (1987) present an example using mark-recapture that was similar to the application used here. Pollock and Kendall (1987) also state that this use of mark-recapture is unlikely to be valid for mobile animals because of the impossibility of the exact mapping required. Perhaps mapping technology has improved enough since Pollock and Kendall's (1987) review to allow the extension of mark-recapture sightability correction to mobile animals. We feel that the mark-recapture correction factor may give more accurate estimates of moose population size than current methods, especially in semi-open forests, and warrants further testing.

MANAGEMENT RECOMMENDATIONS

GPS and GIS technologies enhanced the efficiency and accuracy of navigation during this survey, thereby reducing aircraft costs. Digital mapping of survey boundaries and flight lines saved many days of pre-flight mapping. We would recommend these technologies in most transect or block survey situations, especially where topography or habitat may render accurate map reading difficult. We caution users to thoroughly test field equipment (laptops, GPS units, interfaces, and power sources) and become familiar with programs prior to commencing actual fieldwork; testing in a vehicle is considerably less expensive than with an aircraft. In addition we suggest future examination of the utility of mark-recapture correction factors (especially when using GPS/GIS mapping systems) along with the ongoing efforts to test sightability models for use in correcting aerial surveys (Unsworth *et al.* 1994, Andersen and Lindzey 1996). Sightability and mark-recapture models are theoretically more robust estimators of sightability bias than the double sampling used in the Gasaway *et al.* (1986) method because they estimate the entire fraction missed during the standard survey intensity, not just the difference between the 2 survey intensities. Only through further testing will we be able to make decisions as to which method is most practical.

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