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METHODS TO CORRECT FOR DENSITY INFLATION BIASES IN HAWAIIAN HAWK SURVEYS USING ATTRACTANT CALLS

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ABSTRACT.—Point-count surveys with playback recordings have been used to estimate density and abundance for Hawaiian Hawks (ʻIo; *Buteo solitarius*) on Hawaii. Playbacks are necessary for effective surveys, but attract hawks toward the observer prior to their detection. This attraction inflates estimates of density and abundance based on distance analytical techniques. We quantified movement of radio-tagged Hawaiian Hawks and evaluated six methods to adjust estimates to account for attraction. We evaluated methods by comparing density estimates determined by spot mapping to adjusted point counts at two study sites (Kona Forest, Puu Waawaa) during 1998 and 1999 on Hawaii. By spot mapping, we estimated densities of 0.59 and 0.76 hawks/km^2 at the Puu Waawaa and Kona Refuge study sites, respectively. We adjusted for (1) lack of response, (2) attraction to calls, (3) attraction and lack of response, (4) view obstruction, (5) view obstruction and lack of response, and (6) movement prior to detection. All methods were effective in adjusting density at the two study areas, but simply subtracting the mean distance moved from estimated distances (attraction) provided nearly identical density estimates to spot mapping. We describe a simple computer simulation routine to accomplish this task for future Hawaiian Hawk surveys.

KEY WORDS: *Hawaiian Hawk*; *ʻIo*; Buteo solitarius; *density*; *playback recordings*; *point count*; *survey*.

MÉTODOS PARA CORREGIR LAS SOBRESTIMACIONES DE LA DENSIDAD POBLACIONAL EN MUESTREOS DE *BUTEO SOLITARIUS* QUE EMPLEAN LLAMADAS DE ATRACCIÓN

RESUMEN.—Las estimaciones de la densidad y abundancia de *Buteo solitarius* en Hawai se han realizado utilizando reproducción de sonidos previamente grabados en conteos en puntos. La reproducción de sonidos previamente grabados es necesaria para realizar muestreos efectivos, pero atrae a las aves hacia el observador con anterioridad a su detección. Esta atracción hace que se sobrestimen la densidad y la abundancia al emplear técnicas analíticas de distancia de detección. Cuantificamos los movimientos de individuos de *B. solitarius* marcados con transmisores, y evaluamos seis métodos para ajustar las estimaciones considerando los sesgos de atracción. Evaluamos los métodos comparando las estimaciones de densidad determinadas por medio del mapeo de puntos de localización con estimaciones basadas en datos ajustados de conteos en puntos en dos sitios de estudio en Hawai (Bosque Kona, Puu Waawaa) durante 1998 y 1999. Mediante el mapeo de localizaciones, estimamos densidades de 0.59 y 0.76 individuos/km^2 en Puu Waawaa y el Refugio Kona, respectivamente. Los ajustes se hicieron con base en (1) falta de respuesta, (2) atracción a los llamados, (3) atracción y falta de respuesta, (4) obstrucción de la vista, (5) obstrucción de la vista y falta de respuesta y (6) movimiento previo a la detección. Todos los métodos fueron efectivos para ajustar la densidad en las áreas de estudio, pero simplemente sustraer la distancia media de movimiento de las distancias estimadas (atracción) brindó estimaciones de densidad casi idénticas a las obtenidas mediante el mapeo de puntos de localización. Describimos una rutina simple de simulaciones de ordenador para cumplir esta tarea en muestreos futuros de *B. solitarius*.

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Surveying birds that exist in low densities across the landscape, are secretive, cryptic, and have low call rates is difficult (Fuller and Mosher 1981). Use of attractants such as playback recordings is sometimes necessary for game birds (Marion et al. 1981, Spear et al. 1999), raptors (Mosher et al. 1990, Hall et al. 1997), crows (Luginbuhl et al. 2001), and rare birds (Fancy et al. 1996). Attractants have been used effectively and without bias when surveying birds for a relative index of abundance; however, calculated densities are likely to be overestimated (Marion et al. 1981). Inflated densities result because birds often move toward the observer, who then underestimates the detection distance. This violates one of the key assumptions of distance sampling, because it incorrectly suggests a smaller than actual area was surveyed (Buckland et al. 1993) and leads to inflated density estimates.

Researchers have long known that playbacks pose problems. They have responded by: (1) limiting the survey area (Luginbuhl et al. 2001), (2) multiplying density estimates by a constant to account for birds failing to respond to attractants (Marion et al. 1981), and (3) integrating probability density functions from two observers when one of the observers detects animals prior to movement (Buckland and Turnock 1992). The latter approach is the most rigorous, but requires two surveyors, one of which must be able to gather unbiased observations. Buckland and Turnock (1992) accomplished this using a helicopter, which was appropriate for the Dall's porpoises (*Phocoenoides dalli*) that they studied, but difficult to apply to birds.

Point-count surveys with playback recordings have been used to survey for Hawaiian Hawks (ʻIo; *Buteo solitarius*) on Hawaii (Klavitter 2000). Because Hawaiian Hawks are attracted toward the observer prior to detection (Klavitter 2000), distance measurements must first be corrected before density (hawks/km^2) and abundance (density multiplied by area) estimates can be calculated. Once an appropriate correction method is developed, it can be used for future Hawaiian Hawk surveys and for surveys of other *Buteo* species.

Routine use of radiotelemetry and desktop computers increases the options available to detect and correct sampling bias. Here we use telemetry to determine density on two study areas and quantify movement of Hawaiian Hawks to broadcasts during surveys. Standard database computer programs are then developed to correct surveys for a variety of biases and simulate repeated surveys to estimate variation in density. Our objective was to compare adjusted densities to spot-mapped densities to determine the most appropriate method to estimate density for Hawaiian Hawks accurately.

METHODS

Study Area. We studied hawks at the State of Hawaii Puu Waawaa Sanctuary (Puu Waawaa) and the Kona Forest Unit of the Hakalau National Wildlife Refuge (Kona Refuge; Fig. 1) on the island of Hawaii. The two study areas were chosen because extensive survival and reproductive success studies were already occurring at the sites by the authors. Puu Waawaa, located on the west side of the island and on the northwest slopes of the dormant Hualalai volcano, ranges from 610–1850 m in elevation and consists of a mixture of dry and mesic native forest dominated by an alien grass understory. The Kona Refuge, located on the southwest side of the island and the southwest slope of the dormant Mauna Loa volcano, ranges from 300–1800 m in elevation. Vegetation consists of a mixture of wet and mesic native forest with some areas dominated by an alien grass understory and other areas dominated by native understory.

Spot Map Estimates of Density. We marked and identified pairs and resident adults/subadults at Puu Waawaa and the Kona Refuge (Fig. 1) between March 1998 and April 1999. We assumed that all birds within the study sites were identified. We defined pairs and resident birds as those that nested in or defended a unique territory, or could be found consistently in the same general location in the study area during the study period. We captured and then banded birds with a unique combination of color bands. Backpack radiotransmitters (Buehler et al. 1995, Vekasy et al. 1996) were also applied to at least one member of the pair ($N = 14$). We made a minimum of 20 separate visits and spent a minimum of 250 observer hr at each site to trap and identify birds. Each potential territory was spot-mapped surveyed a minimum of five times using roads and trails (spaced <0.5 km apart), using broadcasts of Hawaiian Hawk calls (Radio Shack power horn, cat. no. 32-2037, rated for 90dB ± 6dB at 3 m). Calls were broadcasted for at least 2 min at each 10-min listening station, spaced <0.5 km apart. The number of visits, extensive coverage, and the use of broadcasts extensively throughout the territories helped to ensure that few or no birds were missed (Falls 1981).

After birds were marked or identified, we checked historical sites and used telemetry to find their nests (Puu Waawaa, $N = 9$; Kona Refuge, $N = 9$). We were not able to find nests for all pairs and located one unpaired female (Puu Waawaa, $N = 2$ pairs; Kona Refuge, $N = 10$ pairs, $N = 1$ unpaired female).

Griffin (1985) conducted Hawaiian Hawk home-range studies on eight ʻIo in several different habitat types ($N = 4$) on the island during the early 1980s. We assumed ʻIo home range at Puu Waawaa would be similar to those ʻIo studied by Griffin. Based on this assumption, we used Griffin's home range mean of 4.47 km^2 to assign an 1193-m radius home range around each nest or centroid of pair locations (for the unpaired female and pairs for which we did not locate nests). We used the perimeter formed by the outer edge of the circular home ranges to define the Puu

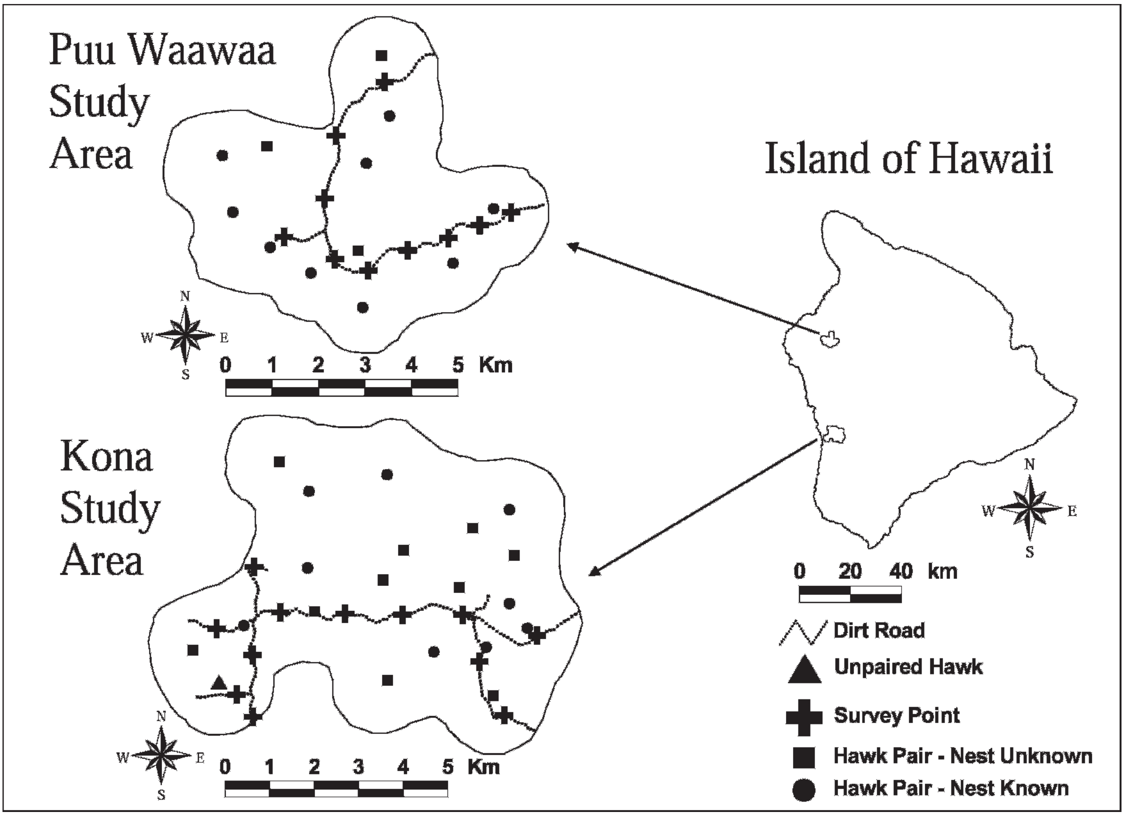

Figure 1. Hawaiian Hawk pair locations (nest sites known and unknown), an unpaired female location, survey points, and survey roads in the 40.9-km² Puu Waawaa and the 51.0-km² Kona Refuge study areas.

Waawaa (40.9 km²) and Kona Refuge (51.0 km²; Fig. 1) study areas. Density (hawks/km²) was calculated by dividing the total number of birds identified by the total amount of area.

Point-count Estimates of Density. We conducted point-count surveys (Ramsey and Scott 1979, 1981, Buckland et al. 1993) using playbacks (Johnson et al. 1981, Fuller and Mosher 1987, Mosher et al. 1990, Hall et al. 1997) at Puu Waawaa (10 points) and the Kona Refuge (12 points; Fig. 1) between January 1998 and January 1999 to estimate density. We chose the initial survey point by random draw. All subsequent survey points were spaced at 1.6 km intervals from this starting point (Anderson et al. 1976, Scott et al. 1981). Points were located on dirt roads distributed throughout the study areas. Because of the difficult terrain and thick vegetation on the island, use of roads was logistically necessary (Hall et al. 1997).

Each point was surveyed for 10 min using playback recordings of adult and fledgling Hawaiian Hawks for two 1-min periods during the first and eighth minutes. Prior to each day of surveying, all observers were trained for estimating distance using laser range finders, tape measures, and automobile odometers. Calibration helped to minimize observer error, but could not eliminate it. Surveys were conducted between 0900–1700 H with winds $\leq$ Beaufort 3 (13–19 km/hr), on days without fog, steady drizzle, or prolonged rain. At each point, we recorded whether a detection was made, the distance at which the detection was first made, type of detection (audio or visual), and surveyor's percentage of view obstructed. View obstructed was any vegetation, landscape, or man-made structure that blocked a portion of the observer's survey field. Four separate surveys took place at Puu Waawaa for a total of 40 points, while two separate surveys took place at the Kona Refuge totaling 24 points. Point-count data were analyzed by program DISTANCE to estimate density (Laake et al. 1993, Thomas et al. 1998). Because vegetation types were similar, we pooled the detections from both sites and used a global detection function for a more precise estimate of effective area (Fancy 1997). We allowed DISTANCE to select the best density estimation model using minimum Akaike Information Criterion values (AIC; Akaike 1973, Buckland et al. 1993, Hall et al. 1997). We right-truncated the largest 3% of the distances to facilitate model fitting (Buckland et al. 1993) and considered the following models with cosine adjustments: half-normal, uniform, and hazard rate.

Determining Hawk Response and Movement. We tested hawk response and movement to playbacks in a variety of vegetation types throughout the island between February

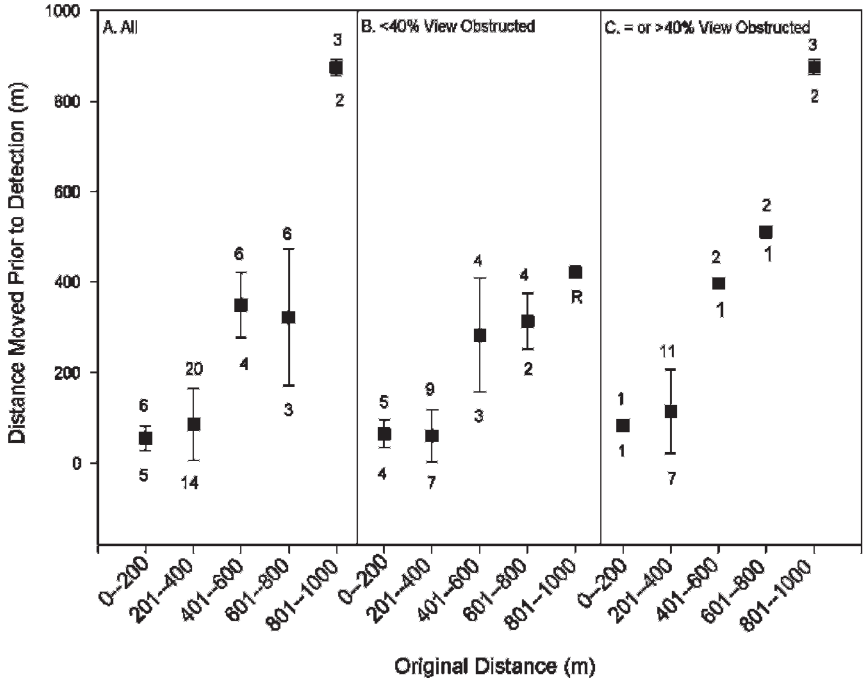

Figure 2. Hawaiian Hawk movement (mean ± SE) in response to broadcasts of adult and fledgling hawk calls played at various distances (panel A – all movements combined, panel B – movements when <40% of the observer's view is obstructed, panel C – movements when ≥40% of the observer's is obstructed). Fifty hawk broadcast tests were conducted. No hawks responded beyond 1000 m ($N = 9$); thus their movements were not plotted. Twenty-eight of 41 hawks responded when <1000 m away. The numbers found above plotted detection distances are the number of tests performed in each distance category, and the numbers below are the number of hawks responding to calls. The letter ''R'' indicates that the distance was estimated by linear regression.

and December 1999. We did this by locating a perched or soaring hawk (20 radiotagged, four color-marked, 26 unmarked). Hawks were located through telemetry or opportunistically while driving on unpaved roads. One observer then watched the hawk from a concealed location and another observer moved away 150–2008 m to perform a 10-min point count as described above (Hall et al. 1997). The surveyor recorded the percentage of their view obstructed by vegetation or other features, whether they detected the bird (audio or visual), distance at which the detection first occurred (verified by laser range finder), and whether the bird had responded to the playback. The observer near the hawk ensured that the bird stayed in relatively the same location until the test began and used a GPS receiver to measure the distance from the bird to the surveyor at the start and end of the point count. Most individuals were only tested once (45 of 50). When multiple testing occurred on an individual bird, we waited ≥3 mo between tests.

Adjusting Point-count Estimates of Density. We adjusted uncorrected point-count densities for lack of response to playbacks following Marion et al. (1981). This method corrects for all birds not counted at the point (0 m from the observer), one of the assumptions of the point-count method. The point-count method also recognizes that the observer's ability to detect hawks decreases the further away they are. To increase our sample size for the number of birds tested at 0 m, we included all birds that were tested out to 400 m. We determined that 19 of 26 birds (73%) responded to playbacks within this distance. Therefore we multiplied our density estimate(s) by

$$p\left(\frac{26}{19}\right) = 1.37.$$

To adjust point counts only for hawk attraction to playbacks we grouped detection distances into the following categories: 0–200, 201–400, 401–600, 601–800, 801–1000, >1000 m. The mean distance moved prior to detection was calculated for each group (Fig. 2A). For each detection distance recorded during our point counts, we randomly added one of our five mean movement distances (64, 85, 350, 337, or 874 m) to it. We randomly added a movement distance to each detection distance because we assumed that hawks were equally likely to be found in any distance category (0–200, 201–400, 401–600, 601–800, 801–1000 m) from the observer. Hawks only moved toward the surveyor if they were <1000 m away, so distances were not added to any observation ≥1000 m. We also investigated a model that assumed that hawks would be found in greater proportion as one moved away from the observer because of the increasing amount of area represented in each larger concentric interval (Buckland et al. 1993, Klavitter 2000). This model produced extreme (>1 SE) underestimates (overly conservative) of density, and therefore was discarded from subsequent consideration.

We wrote computer code in program ACCESS (Microsoft Corp. 1997) to perform the distance corrections (copy of code available from Klavitter). After all distances were corrected for a survey, we reanalyzed the point counts with DISTANCE and stored the outputs in a computer spreadsheet. We repeated the process of correcting the survey data and reanalyzing with DISTANCE 100 times to add a component of randomization to the method. The adjusted density and variance was the mean of the 100 simulations.

We adjusted for attraction and lack of response by multiplying the density estimate obtained from the attraction method by 1.37 following Marion et al. (1981) and the methods described above.

By observing hawks during point counts, we determined that as the obstruction (by vegetation, landscape, or other structure) of the observer's view increased, the movement that occurred before hawks were detected also increased. We calculated the mean movement by hawks for each of the five distance groupings at points with <40% of the view obstructed and ≥40% of the view obstructed (Fig. 2). As with the attraction method, the mean distance moved prior to detection was calculated for each of the five distance groupings (Fig. 2). We did not test any birds between 801–1000 m with <40% view obstructed, so we used linear regression to estimate a mean response distance for this distance category. When survey detections occurred with <40% view obstructed, we randomly added 64, 60, 283, 313, or 422 m to the detection distance (Fig. 2). When survey detections occurred with ≥40% view obstructed, we randomly added 82, 144, 397, 511, or 874 m to the detection distance (Fig. 2). As described above, we corrected distances using ACCESS, reanalyzed the point counts with DISTANCE, and repeated the process of correcting the survey data and reanalyzing with DISTANCE 100 times. The adjusted density and variance were the mean of the 100 simulations.

After adjusting our data for obstruction, we also multiplied our density estimate by 1.37 to account for unresponsive birds (Marion et al. 1981). This allowed us to correct density for the combination of obstruction, attraction, and lack of response.

Buckland and Turnock (1992) developed field and analysis methodology for estimates robust to departure from the assumptions that animals do not move in response to the observer before detection and that all animals 0 m from the point, g_0, are detected. We used our movement test data to correct using Buckland and Turnock methods as follows:

n_s = all birds tested and their actual distances to the observer as measured without error using GPS receiver.

n_{ps} = the birds detected by the surveyor and their actual distance prior to movement.

We used DISTANCE to analyze n_{ps} and n_s as unique surveys, resulting in the probability density functions, $f_{ps}(r)$ and $f_s(r)$.

The Buckland and Turnock bias-corrected density estimate, $\hat{D}_c$, (animals/km^2) is calculated as follows:

$g_p(r)$ = probability that an animal detected by the observer at distance r from the surveyor is subsequently detected by the surveyor.

$$\hat{g}(r) = \frac{n_{ps}\hat{f}_{ps}(r)}{n_s\hat{f}_s(r)} = \text{detection function for the surveyor.}$$

$$\hat{f}_p(r) = g_p(r)/v_p, \text{ with } v_p = 2\pi\int_0^w r g_p(r)dr = \text{effective area;}$$

k = the number of points occurring in a survey.

$$EDR = \sqrt{\frac{v}{\pi}} = \text{effective detection radius}$$

$$\hat{D}_c = \frac{n_p}{(k\pi EDR^2)/1000} = \text{animals/km}^2$$

RESULTS

Hawk density varied slightly between Puu Waawaa and Kona. We identified 24 hawks (12 pairs) at Puu Waawaa for a density of 0.59 hawks/km^2 (Fig. 1). At the Kona Refuge, we identified 39 hawks (19 pairs, one unpaired female) for a density of 0.76 hawks/km^2 (Fig. 1).

Uncorrected densities estimated from point counts were significantly greater than those obtained by spot mapping (Fig. 3). At Puu Waawaa we detected 29 birds for a point-count density of 1.97 ± 0.56 hawks/km^2. Detection distances ranged between 61–1361 m. At the Kona Refuge, we detected 21 birds for an estimated point-count density of 2.38 ± 0.68 hawks/km^2. Detection distances ranged between 38–1009 m.

Twenty-eight of 50 birds responded and were detected by the surveyor during movement response tests. Perched birds failed to respond beyond 600 m, while soaring birds failed to respond beyond 1000 m. Birds that responded either: (1) called from their location and did not move ($N = 3$), (2) flew toward the observer and called ($N = 17$), or (3) flew toward the observer silently ($N = 8$). The distance a bird was from the surveyor affected the amount of movement in response to the playback (Fig. 2). Hawks moved further before detection in heavily obstructed versus more open points ($Z = 2.59$, $P = 0.01$; Fig. 2).

All adjustments except simply correcting for lack of response estimated density more accurately than did unadjusted point counts (Fig. 3). Adjusting for lack of response inflated already overestimated densities. The Buckland and Turnock method was the most conservative adjustment as it gave the lowest density estimate in both areas. None of the adjust-

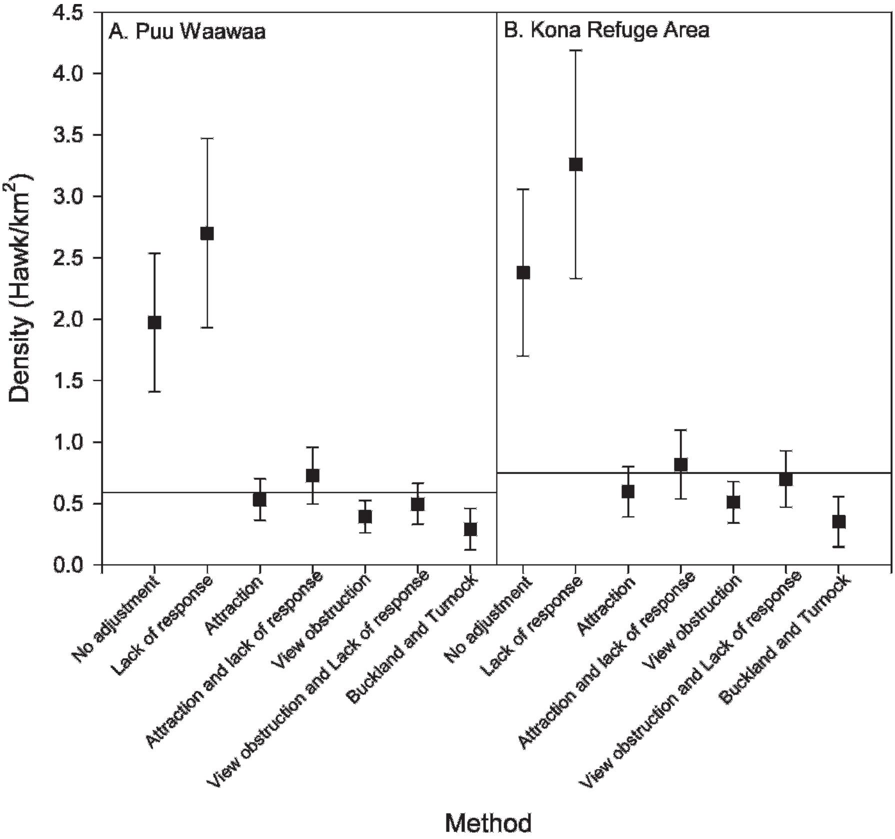

Figure 3. Methods used to adjust point-count densities (hawks/km^2; mean ±SE) in Puu Waawaa study area (panel A) and the Kona Refuge study area (Panel B). "Lack of response" = densities adjusted for lack of response. "No adjustment" = no adjustments to point-count detection distances before analyzing with DISTANCE. "Attraction" = detection distances adjusted for movement. "Attraction and lack of response" = detection distances adjusted for movement and resultant density adjusted for lack of response. "View obstruction" = detection distances adjusted for movement stratifying by cover. "View obstruction and lack of response" = detection distances adjusted for movement stratified by cover and resultant density adjusted for lack of response. Horizontal reference lines represent "true" hawk densities determined by spot mapping (panel A: 0.59 hawks/km^2 and panel B: 0.76 hawks/km^2).

ment methods except simple lack of response produced significantly different density estimates (95% CIs around each estimate overlap considerably).

DISCUSSION

Density of Hawaiian Hawks. Density of hawks at Puu Waawaa and the Kona Refuge was extremely high. In fact, this endangered species was as dense as several common mainland *Buteos*, the Red-tailed Hawk (*Buteo jamaicensis*), the Broad-winged Hawk (*Buteo platypterus*), and the Red-shouldered Hawk (*Buteo lineatus*). Preston and Beane (1993) reviewed 16 studies on Red-tailed Hawks that reported densities ranging from 0.04 hawks/km^2 in Ohio (Shelton 1971) to 1.54 hawks/km^2 in California (Fitch et al. 1946). Crocoll and Parker (1989) recorded some of the highest densities of both Broad-winged Hawks (2.0 hawks/km^2) and Red-shouldered Hawks (1.17 hawks/km^2) in western New York. The reason Hawaiian Hawks were so dense was likely because our study plots were dominated by mature native forest with high amounts of human-created edge habitat and extensive areas with alien grass understory. Hawaiian Hawks apparently have benefited from this habitat change just as several other raptors have benefited from habitat modification elsewhere (Donázar et al. 1993, Preston and Beane 1993, Eakle 1994, Eakle et al. 1996). This type of habitat appears to contain the highest densities of hawks across the island (Klavitter 2000, Klavitter et al. 2003), probably because of an abundance of potential nest sites and prey, and lack of human disturbance. Actual densities on our plots may be slightly higher than we report, because some non-territory-holding birds (floaters) may have gone undetected. Floaters tend to live a secretive and solitary existence in and around the territories of breeders, and therefore, are not much in evidence (Newton 1998).

Adjusting Point-count Estimates of Density. Comparing methods to adjust density, accounting for attraction is the most appropriate for obtaining accurate density estimates when conducting point counts with playbacks for Hawaiian Hawks. We chose this method, because it estimated true density within 1 SE at both sites (Fig. 3) and required the least amount of post-survey manipulation of data. We feel that a method that is accurate is most desirable, but if estimates have limited accuracy then one that produces conservative estimates and is close to true densities may be the most appropriate for species that are threatened or endangered. Conservative estimates would help to prevent management decisions that would further jeopardize these rare species.

Correcting for lack of response worked well in studies by Marion et al. (1981), but performed poorly for us. This may reflect the fact that in our studies we did not have measures of response directly at the survey point. We based lack of response on all birds tested ≤400 m, which most likely overestimated those that failed to respond or that the observer failed to detect at the point. Implicit in the underlying theory of point-count sampling is that the further birds are from the survey point, the fewer detections will be made (Buckland et al. 1993), so we should not have detected all hawks to a distance of 400 m. By correcting for lack of response based on this distance, our adjustment overestimated density. Estimates of variance also increase with this method leading to lower precision. Marion et al. (1981) did not use the correction factor after calculating densities for birds using the point-count method. These authors only used this correction factor after estimating density of birds based on a technique that estimated the effective survey area based on the maximum distance birds responded to taped calls. We suggest that no correction is typically needed to adjust for lack of response when using the point-count method, because the number of birds missed directly at the point is most likely negligible.

Adjustment for obstructed view gave conservative estimates, but in both cases, true densities did not fall within 1 SE of the adjusted densities (Fig. 2). However, with more testing, this method may be valid. Others have also noted that the effective area sampled will vary with such things as the density of the surrounding vegetation or the topography (e.g., Howell 1951, Svensson 1977, Weber and Theberge 1977, McCracken 1994). Applying a second correction for lack of response gave reliable estimates that were conservative and contained true densities within 1 SE of adjusted densities (Fig. 3). This may have been somewhat fortuitous in our study, because as mentioned previously, we feel our measure of lack of response up to 400 m was not appropriate and led to increased estimates of variance.

The Buckland and Turnock method gave the lowest density estimates and true densities did not fall within 1 SE of the estimated density (Fig. 3). Although the method did not perform well in this case, we feel it has potential to be useful in wildlife surveys and warrants additional experimentation. The method probably performed poorly in this case because of small sample sizes of survey tests, especially at distances beyond 600 m. Burnham et al. (1980) recommended a minimum of 60–80 observations during point counts to effectively model a detection function, while Buckland et al. (1993) recommended a minimum of 40. We had 28 observations with most occurring between 200–400 m due to the majority of the tests being conducted in this range. The method may have performed better if the highest number of tests were conducted at 0–200 m, the next highest in 201–401 m, and so on to 2008 m or to a distance at which surveyors can no longer detect animals.

The Buckland and Turnock method is interesting to consider further, because it considers the movement of the animals and not the survey distance. Estimating distance is one of the most difficult aspects to point-count surveys. Although laser range finders have made estimation more accurate, large amounts of time are usually required for training and calibrating surveyors in distance estimation (Kepler and Scott 1981, Ramsey and Scott 1981). A technique such as proposed by Buckland and Turnock that provides precise density estimates without having to train observers to estimate survey distances is valuable. More time could be spent on identification of birds by sound, another difficult component of point-count sampling. Additionally, the method could be used to calculate density for survey indices such as Christmas bird counts.

Because we had previously radiotagged birds around the island to find nests and to determine survival as part of another study, the effort required to obtain the movement data for this project was not substantial. We suggest limiting birds to one test per 3-mo interval to avoid excessive disturbance and possible habituation to the taped calls. Movement tests can also be performed on unmarked birds, saving capture time and effort, but more search time will be required to locate them compared to radio-tagged birds.

Our findings suggest movement during surveys can be corrected *post hoc* with several methods to give reliable, yet conservative estimates of density that can be used to calculate abundance. Future Hawaiian Hawk surveys should continue to use playbacks during surveys to increase hawk detections. However, data should be corrected for attraction, so reliable and conservative density estimates are made. The method of correction can be improved by resampling detection distances prior to correction for each successive simulation and by increasing the number of correction simulations from 100 to 1000 so that more robust variance estimates are produced. Researchers interested in applying this technique to their study should customize the correction to their unique setting and attempt to validate their correction by comparing calculated densities to areas of known density or by comparing results produced by several techniques (Fancy 1997, Buckland et al. 2006). The technique could be used to estimate density accurately for other woodland raptors such as Red-shouldered Hawks which are difficult to survey without the use of playback recordings (Dykstra et al. 2001).

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