Journal of Field Ornithology

J. Field Ornithol. 81(4):430–441, 2010 DOI: 10.1111/j.1557-9263.2010.00299.x

Comparison of survey methods for monitoring Clark's Nutcrackers and predicting dispersal of whitebark pine seeds

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Received 26 February 2010; accepted 20 August 2010

ABSTRACT. Clark's Nutcrackers (*Nucifraga columbiana*) disperse seeds of whitebark pines (*Pinus albicaulis*) in western North America by their scatter-hoarding behavior. Because of declines in whitebark pine, resource managers are seeking an effective means of monitoring nutcracker population trends and the probability of seed dispersal by nutcrackers. We tested the reliability of four survey techniques (standard point counts, playback point counts, line transects, and Breeding Bird Survey routes) for estimating population size by conducting surveys at sites where a portion of the nutcracker population was marked with radio transmitters. The efficacy of distance sampling, based on detection rates from our unadjusted surveys, was also assessed. We conducted counts of whitebark pine cones within stands and related the probability of seed dispersal within stands to cone production and nutcracker abundance. We conducted 70 h of surveys for Clark's Nutcrackers at eight sites from July through November in 2007 and 2009 and estimated cone densities at six of these sites. Detection rates for all survey techniques were low and variable and we detected an average of 5.6 nutcrackers per 30 min of survey time. We also found no difference in detection rates among survey types, although significantly more nutcrackers were detected during surveys conducted during the peak of whitebark pine cone harvest ($P < 0.0001$). Nutcracker abundance was not correlated with cone density ($P = 0.29$) and we observed nutcrackers pouching seeds at all sites. Thus, cone density did not provide reliable information on whether seed dispersal was likely to occur. We suggest that alternate methods be considered for monitoring populations and assessing seed dispersal probability because we did not reliably detect nutcrackers using conventional survey techniques and because nutcracker abundance was not correlated with cone density.

RESUMEN. **Una comparación de métodos de muestreo para monitorear a *Nucifraga columbiana* y para predecir la dispersión de semillas de *Pinus albicaulis***

Nucifraga columbiana dispersa las semillas de *Pinus albicaulis* en el oeste de Norteamérica mediante su comportamiento de dispersión-acoplamiento. Por la disminución en la abundancia de *P. albicaulis*, los encargados de manejar los recursos naturales están buscando una manera efectiva de monitorear las tendencias del tamaño poblacional y la probabilidad de dispersión de semillas por *N. columbiana*. Probamos la confiabilidad de cuatro técnicas de muestreo (conteos por punto, conteos por punto con playback, transectas en línea y rutas del Breeding Bird Survey) para estimar el tamaño poblacional mediante muestreos en sitios donde una porción de la población de *N. columbiana* estuvo marcado con radio transmisores. La eficacia del muestreo de distancia, basado en las tasas de detección de nuestros muestreos sin la corrección por distancia también fue evaluada. Realizamos conteos de los conos de *P. albicaulis* y relacionamos la probabilidad de la dispersión de semillas a la producción de conos y a la abundancia de *N. columbiana*. También realizamos 70 horas de muestreos para *N. columbiana* en ocho sitios desde Julio hasta Noviembre en el 2007 y el 2009 y estimamos las densidades de conos en seis de estos sitios. Tasas de detección para todos los métodos de muestreo fueron bajas y variables y detectamos un promedio de 5.6 *N. columbiana* por cada 30 min de muestreo. No encontramos una diferencia en las tasas de detección entre tipos de muestreo, aunque significativamente mas *N. columbiana* fueron detectados durante muestreos realizados durante el pico de la cosecha de conos de *P. albicaulis* ($P < 0.0001$). La abundancia de *N. columbiana* no fue correlacionada con la densidad de conos ($P = 0.29$) y observamos a *N. columbiana* colectando y guardando semillas en todos los sitios. Entonces, la densidad de conos no proveo información confiable sobre la probabilidad de la dispersión de semillas. Sugerimos que métodos alternativos para monitorear poblaciones y evaluar la probabilidad de la dispersión de semillas sean considerados porque no detectamos confiablemente a los *N. columbiana* usando métodos convencionales de muestreo y porque la abundancia de *N. columbiana* no fue correlacionada con la densidad de conos.

Key words: distance sampling, line transect surveys, mark-resight, *Nucifraga columbiana*, point count surveys, radio telemetry

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Reliable information about the status of populations is important for effective management. Monitoring programs for rare, elusive, or at-risk species require special consideration because detection rates may be low (Thompson 2004). Clark's Nutcrackers (*Nucifraga columbiana*) are songbirds potentially at risk because of widespread declines in critical habitat (Tomback 1998, Tomback et al. 2001). Nutcrackers rely on pine seed year-round and some large-seeded pines, including limber (*Pinus flexilis*), whitebark (*P. albicaulis*), and pinyon (*P. edulis* and *P. monophylla*) pines, are declining throughout western North America (Tomback et al. 2001, Breshears et al. 2005, Shaw et al. 2005). Despite concerns over habitat loss, reliable information about population trends of Clark's Nutcrackers is lacking (Tomback 1998). Monitoring programs, such as the North American Breeding Bird Survey (BBS) and Christmas Bird Count, have limitations for projecting population trends of nutcrackers because they do not dependably monitor resident populations (Tomback 1998). Many populations occupy remote, subalpine terrain that is difficult to access and breed in February and March when counts are not being conducted (Mewaldt 1956). In addition, nutcrackers are facultative migrants during most of the year, and regions with cone abundance may attract nonresident birds from distant regions (Mewaldt 1948, Vander Wall et al. 1981, Lorenz and Sullivan 2009). Moreover, counts that rely on auditory or visual cues to detect nutcrackers may be biased because nutcrackers are not territorial and do not reliably advertise their presence with characteristic songs, calls, or displays.

Clark's Nutcrackers are scatter-hoarders that act as seed dispersers for large-seeded pines in western North America. They are considered obligate mutualists of one species, whitebark pine, because they enable population-wide regeneration through their scatter-hoarding of seeds (Hutchins and Lanner 1982, Tomback 1982). Whitebark pine is a keystone species in subalpine ecosystems, but is declining throughout its range (Tomback et al. 2001). Resource managers are seeking a reliable method to monitor nutcrackers because of concerns over their populations and because the presence of nutcrackers in autumn could be useful in assessing the likelihood of whitebark pine seed dispersal (McKinney et al. 2009). However, no one to date has examined the efficacy of songbird survey techniques for estimating the size of nutcracker populations and the probability of seed dispersal.

Our objective was to compare the accuracy of four standard songbird survey techniques for estimating population size, where population size was obtained from mark-resighting data of Clark's Nutcrackers fitted with transmitters. Our intent was to test four easily implemented and widely used methods that could be used by whitebark pine managers with limited resources: standard point counts, playback point counts, line transects, and BBS routes. Thus, we compared accuracy and detection rates among four survey techniques: standard point counts, playback point counts, line transects, and BBS routes. We used detection rates from our unadjusted counts to assess the cost-effectiveness of a fifth survey method, distance sampling. Last, we used radio telemetry to determine if detection rates during surveys provided a reliable predictor of seed dispersal probability.

METHODS

Our study was conducted from July 2007 through November 2009 at two locations in the state of Washington: (1) the northeast corner of the Olympic Mountains approximately 30 km southwest of Sequim, Washington (approximately 123°08′W, 47°49′N) and (2) the eastern slopes of the Cascade Range, approximately 40 km west of Yakima, Washington (approximately 120°58′W, 46°45′N). Dominant cover types in the Olympic lowlands included western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*). High-elevation forests were dominated by subalpine fir (*Abies lasiocarpa*) and whitebark pine. For the Cascade Range, vegetation varied along an east-west and elevational gradient. Locations close to the Cascade Crest were dominated by closed-canopy hemlock and Douglas-fir forests; locations 40 km to the east and near the shrub-steppe zone of the Columbia Basin were dominated by open-canopy ponderosa pine (*Pinus ponderosa*) forests. For both the Olympic and Cascade Mountain study sites, whitebark pine occurred at elevations from 1400 to 2300 m.

Estimating cone production. We counted whitebark pine cones at one site in the Olympic Mountains and at five sites in the Cascade Range in 2007 and 2009. We arbitrarily selected 5 (one site), 10 (four sites), or 15 (one site) mature trees for cone counts at each site. Cones were not counted at the Cash Prairie site in 2009 or at the Darland site in 2007. Because cone production did not exhibit much variation in the Cascades within years (2007 SE = 1.62, 2009 SE = 0.52), we extrapolated an estimate of cone production for these two year-site combinations that lacked cone counts based on the mean number of cones across all sites in the Cascades. Across all sites and years, six cone-count trees were killed by mountain pine beetles (*Dendroctonus ponderosae*) and one was uprooted and killed. These trees were replaced with trees of comparable size. Observers counted all cones visible from the north and south aspects of each tree using 8 × 42 binoculars. Cone counts were conducted from 15 July to 16 August.

In 2009, we revisited each site and estimated the density of cone-bearing trees along transects following McKinney et al. (2009). For each site, we established either four (two sites) or eight (four sites) 10 m × 50 m belt transects. We used a Geographic Information System to model the distribution of whitebark pine at each site and generate a list of coordinates of random points within whitebark pine habitat at each site. We then used these random points to select start points for transects; we visited each random point and selected the nearest mature whitebark pine tree within 50 m as the start of the transect. If no whitebark pine tree was located within 50 m of the random point, we omitted the random point and selected the next random point available on our list. We spun a compass rosette to obtain a random bearing for the layout of each transect. We summed all mature cone-bearing trees within each transect. For trees within clumps, we considered a tree to be "any single stem or multiple stem clump where two or more stems were joined below 1.4 m height" (McKinney et al. 2009). Cone production for each site was calculated as the product of the mean number of cones per tree and the mean number of trees per hectare (McKinney et al. 2009).

Clark's Nutcracker surveys. We established routes for surveying nutcrackers at one site in the Olympic Mountains and at seven sites in the Cascade Range. We conducted four different types of surveys: standard point counts, playback point counts, line transects, and BBS routes. However, BBS were only conducted at four sites because they required a large area and could only be established at sites where large tracts of continuous pine habitat were available. All surveys were conducted on roads and trails for ease of access. Although we acknowledge that we incurred bias by surveying along roads and trails, we believe this bias was minimal because roads in our study were either Forest Service tertiary roads (light-duty, unimproved dirt tracks) or footpaths that had minimal impact on natural vegetation and were lightly traveled (Ralph et al. 1993, Hutto and Young 2002, 2003). In addition, the benefits of road and trail surveys include ease-of-access and an ability to focus on surveys (rather than footing) and may outweigh the disadvantages in uneven, mountainous terrain like that on our study sites (Ralph et al. 1993).

We designed each survey to last 30 min to enable direct comparisons across survey types. We pooled data from the 5-min point-count stations at each site for each visit. Surveys were conducted three times in 2007 (July, August–September, and October) and twice in 2009 (August–September and October), corresponding to a preseed harvest, seed harvest, and post-seed harvest nutcracker count. During each visit to a site, we conducted all four surveys during the same morning. We noted observations of nutcrackers as we traveled between point-count stations, but did not include these individuals in the analysis.

For standard point-count surveys, we counted all nutcrackers heard and seen for 5 min within and outside of a 50-m radius circle centered on the point count. Flyovers were recorded separately, but were included in our analyses. Playback point counts immediately followed standard point counts and were conducted at the same points. We broadcast the regular calls and shrill calls of Clark's Nutcrackers (Mewaldt 1956) in the following sequence: (1) 10 sec of regular call, (2) 50 sec of silence, (3) 10 sec of shrill call, (4) 2 min 50 sec of silence, (5) 5 sec of regular call followed by 5 sec of shrill call, and (6) 50 sec of silence. We established six standard point counts (and their paired playback point counts) separated by 250 m at each site. We chose 250 m as the distance between point-count stations because this is a standard distance used to minimize double counting when surveying for songbirds in general, and has been used successfully with corvids in the past (Ralph et al. 1993, Luginbuhl et al. 2001). We recognize that 5 min is a relatively short period of time for a point count. However, our objective was to test the efficiency of songbird methods for managers with limited resources and thus we faced a tradeoff between the duration of each point count and the number of point counts that could be included in 30 min. We chose 5 min as a compromise in efficiency between a few long-duration point counts (i.e., three 10-min point counts) and many short-duration point counts (i.e., 10 3-min point counts; Ralph et al. 1993).

Walking transects were 2-km long and observers walked 2 km in 30 min and recorded all nutcrackers heard and seen within and outside of a 100-m band centered on the transect. BBS routes were modeled after the North American BBS protocol (Patuxent Wildlife Research Center, Laurel, MD) and partially overlapped both transects and point-count routes. Routes were approximately 8-km long. Observers drove the route in a vehicle and stopped every 0.8 km (0.5 mile) to conduct a 3-min point count. Observers counted all nutcrackers heard and seen for 3 min within and outside of a 50-m radius circle centered on the point count and flyovers. Minimum distance between the individual transects and BBS routes was about 20 km.

In total, we surveyed for Clark's Nutcrackers at 42 point count stations, 7 line-transect routes, and 4 BBS routes. BBS routes were longer than walking-transect routes (8 km vs. 2 km per site, respectively), which were longer than point-count routes (6 points along a 1.25-km transect per site). Because our objective was to compare detection rates among survey types, we purposely set point-count stations along walking transect routes and BBS routes wherever possible and, similarly, placed walking transects along BBS routes. However, BBS routes extended 6 km beyond walking transects and 6.75 km beyond point-count transects.

During all surveys, we noted whether nutcrackers were simply present or actively pouching seeds. To minimize double counting of birds, we sketched locations of detected nutcrackers on a map when multiple birds were detected during a survey. We used a team of four experienced observers and conducted surveys only when rain, snow, fog, or wind did not obstruct visibility to less than 2 km or interfere with our ability to detect calls.

In 2007 and 2008, we set up trap stations baited with raw beef suet to capture nutcrackers at 12 sites along five survey routes. During a pilot study in 2006, we found that nutcrackers could only be effectively captured during winter-spring (November–May) and when there was substantial snowpack on our study sites. We were therefore logistically constrained to setting up feeding stations that were reasonably accessible on foot during winter and spring (i.e., within 15 km and 1050 m elevation of a plowed road) and some survey routes were logistically inaccessible. Captured adult nutcrackers were fitted with 3.9-g (3% of body weight) radio transmitters (Advanced Telemetry Systems, Isanti, MN) secured to the back with a harness. Transmitter battery life was approximately 450 days.

We tracked radio-tagged nutcrackers year round to determine migratory status, home range boundaries, and the proportion of telemetry locations within 100 m, 200 m, and 1 km of all survey routes. We obtained point locations on nutcrackers by homing and recorded the locations (location error ranged from 1–6 m) on portable Global Positioning System units (Garmin International, Inc., Olathe, KS). During the survey period (15 July–1 November), we tracked nutcrackers intensively for at least one 2–6-h behavioral observation session each week. Individual nutcrackers were tracked as continuously as possible by one to four observers during these sessions to monitor whitebark pine seed harvest and cache sites. We used this information to determine if seed dispersal occurred within our survey routes. Seed dispersal is a complex, multistage process, but, for comparative purposes, we defined seed dispersal as observing a nutcracker place seeds in its sublingual pouch or observing a nutcracker with seeds in a sublingual pouch (McKinney et al. 2009).

While surveys were being conducted and while traveling between point-count stations, we used a receiver to determine if detected nutcrackers had a radio transmitter. On days that surveys were conducted within the home ranges of radio-marked nutcrackers, additional observers monitored the movements of radio-tagged nutcrackers during the survey period to estimate the proportion of time that radio-marked nutcrackers could have been detected during the surveys. We estimated that nutcrackers could be reliably detected up to 200 m from survey routes if they were calling and up to 100 m from survey routes visually. We therefore determined the number of telemetry points that occurred within 100 m and 200 m of survey routes to assess whether nutcrackers were within the range of detection of surveyors.

Data analysis. We anticipated using the number of marked nutcrackers detected during surveys to estimate population size using the joint hypergeometric estimator. However, radio-marked nutcrackers were never detected during surveys. We therefore estimated the probability of a marked nutcracker being on a survey route (p_i; White and Shenk 2001). We used this information to determine if our failure to detect marked nutcrackers was likely a factor of nutcracker detectability or our failure to establish survey routes in areas frequented by marked nutcrackers.

We did not conduct distance sampling, but rather considered distance sampling as an ad hoc alternative and treated our survey results as pilot season data for estimating a required sample size to calculate a detectability function (Buckland et al. 2001). For line transects, we estimated the minimum length of transect required for a coefficient of variation of 10% as

$$n = \left(\frac{b}{\{cv_t(\hat{D})\}^2}\right)\left(\frac{L_0}{n_0}\right)$$

where $b = 3$ (Burnham et al. 1980, Buckland et al. 2001), $cv_t(\hat{D}) = 0.10$, $L_0 =$ kilometers of transect surveyed, and $n_0 =$ number of nutcrackers detected along transects. For point counts, we estimated the minimum number of point counts required by substituting k_0 (number of point counts surveyed) for L_0 (Buckland et al. 2001).

Because we failed to detect marked nutcrackers during surveys, we were unable to assess the accuracy of different survey types for estimating population size. We instead compared detection rates among survey types and among survey periods (July, August–September, and October) using one-way-blocked ANOVA. For our among-survey type comparison, we summed all nutcracker detections (<50 m, >50 m, and fly-overs) across periods and computed a survey type index of abundance (mean number of detections per visit). For among period comparisons, we summed all nutcracker detections across survey types (walking transect, standard point count, and BBS) and computed a period index of abundance (mean number of detections per visit). When estimating the period abundance index, we excluded counts of nutcrackers from playback surveys because of the potential for artificially inflated abundance estimates caused by the attraction of nutcrackers to playback calls. For comparisons of detection rates among survey periods and types, we used a repeated-measures design, with site as a block. If differences among treatments were statistically significant, we used post hoc Tukey tests to assess significant differences among treatment levels.

We compared detection rates of standard versus playback point counts for each survey period using paired-sample *t*-tests. We investigated relationships between nutcracker relative abundance and cone production and survey effort using standard correlation methods and simple linear regression. All data were analyzed for violations of assumption of normality and heteroscedasicity. Our count data were positively skewed and we used square and cube root transformations as appropriate.

We used SAS statistical software (SAS Institute 2007) for all statistical analyses. We report values as means ± 1 SD unless otherwise noted. We considered statistical results significant at $\alpha = 0.05$.

RESULTS

Surveys. We completed 70 h of surveys for Clark's Nutcrackers across all years, periods, and sites. Overall detection rates were low and variable (5.6 ± 9.8 per 30 min of survey time; $N =$ 140 surveys). We found differences in detection rates among blocks ($F_{7,127} = 3.0$, $P = 0.007$), but not among survey types ($F_{3,127} = 1.0$, $P =$ 0.40; Table 1). We detected more nutcrackers during the second survey period ($F_{2,127} = 10.0$, $P < 0.0001$) that corresponded to the middle of the cone harvest season for whitebark pine (Table 1). We detected nutcrackers pouching whitebark pine seeds at every site except the Cleman site that contained no whitebark pine. However, we did observe nutcrackers caching whitebark pine seeds at this site.

Detection rates for standard and playback point-count surveys were comparable for the first ($t = 0$, $P = 1.0$, $N = 8$) and second ($t =$ 1.0, $P = 0.35$, $N = 8$; early and midseed harvest season) survey periods. During the third survey

Table 1. Mean (±SD), minimum, and maximum numbers of Clark's Nutcrackers detected during four different types of surveys and during three survey periods in the Olympic and Cascade Mountains, Washington, in 2007 and 2009.

	Mean	Minimum	Maximum
Survey type			
BBS	6.3 (8.1)	0	27
Playback point count	5.8 (9.3)	0	23
Standard point count	4.3 (8.6)	0	49
Transect	6.5 (12.0)	0	64
Survey period			
1 (July)	3.3 (3.4)	0	10
2 (August–September)	9.5 (13.8)	0	64
3 (October)	2.9 (4.3)	0	19

period, the difference in detections approached significance ($t = 2.0$, $P = 0.08$, $N = 8$) and detection rates were higher for playback point counts than standard point counts (Fig. 1). Although we had no responses to playback calls during the early and midseasons, nutcrackers responded at 17% of the points during the late season ($N = 126$ playback point counts). Although we did not distinguish between responses to regular versus shrill calls, most responses appeared to be in response to playback of regular calls.

Because of low detection rates, the amount of survey effort required to estimate nutcracker detectability for distance sampling was prohibitively high. During the peak of nutcracker abundance in August and September, a minimum of 45 km of transects or 249 point counts would need to be surveyed annually per site to reliably assess nutcracker population size using distance sampling (Table 2). For surveys conducted in July or October, we estimated that up to 300 km of transects would need to be surveyed or 993 point counts conducted for a similar level of accuracy.

Telemetry. We attempted to trap nutcrackers along 12 survey routes in 2007 and 2009, but only captured nutcrackers along two routes in 2007 and four routes in 2009. We radio-tagged 31 nutcrackers and obtained 2912 locations. Across the four survey routes where nutcrackers were captured, between 12% and 82% of all locations were within 1 km of survey routes (Fig. 2).

Of 31 nutcrackers captured within 2 km of survey routes, three were present in the

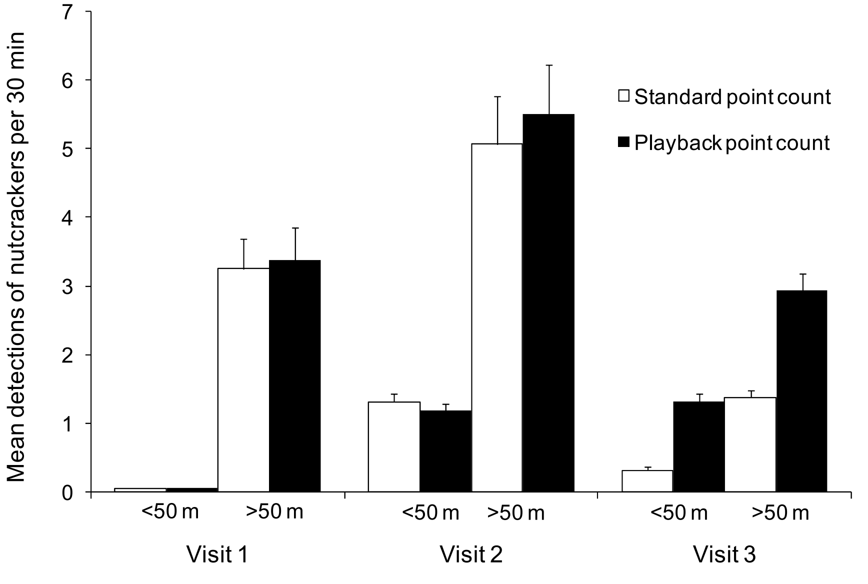

Fig. 1. Comparison of mean number of Clark's Nutcrackers detected during six 5-min standard and playback point count surveys for early, mid-, and late season visits during surveys conducted in the Olympic and Cascade Mountains, Washington, in 2007 and 2009.

Table 2. Minimum required sample size for kilometers of transects and numbers of point counts needed to estimate a detectability function for distance sampling of Clark's Nutcrackers in the Cascade and Olympic Mountains, Washington, with a desired coefficient of variation of 0.10. Estimates are based on number of nutcrackers detected during transects and point counts (n_0), lengths of transects surveyed (L_0), and number of point counts surveyed (k_0) in 2007 and 2009.

Transects:				
Month	L_0	n_0	L_0/n_0	Estimated number of kilometers required for distance sampling
July	16	27	0.59	177
August–September	32	201	0.15	45
October	32	32	1.00	300
Average across all months	80	260	0.30	92
Point counts:				
Month	k_0	n_0	k_0/n_0	Estimated number of points required for distance sampling
July	48	28	1.71	513
August–September	96	115	0.83	249
October	96	29	3.31	993
Average across all months	240	172	1.39	419

area when surveys were conducted in summer and fall. Two radio-tagged nutcrackers occupied home ranges that overlapped the Cash Prairie survey route in 2007 and one occupied a home range along the Cleman survey route in 2007. During the entire survey period (21 July–1 November), we obtained 1233 locations for these three resident nutcrackers, but never

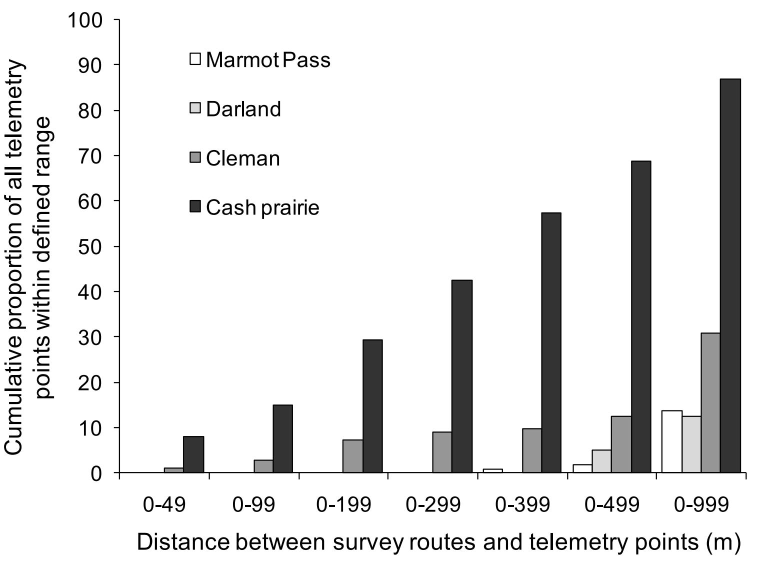

Fig. 2. Proportion of all telemetry points within 1 km of four survey routes in the Olympic and Cascade Mountains, Washington, for all radio-tagged Clark's Nutcrackers captured in 2007 and 2008.

Table 3. Number (proportion) of minutes spent by radio-tagged Clark's Nutcrackers within 100 m (visual detection distance), 200 m (auditory detection distance), and 500 m of surveyors while surveys were being conducted.

Site	Survey period	Bird ID	Number (proportion) of min within 100 m	Number (proportion) of min within 200 m	Number (proportion) of min within 500 m	Number of total min tracked during surveys
Cleman	July	211	0	5 (0.07)	12 (0.18)	67
	Aug.–Sept.	211	0	0	0	16
	October	211	0	0	0	56
Cash Prairie	July	043	50 (0.75)	67 (1.0)	67 (1.0)	67
	Aug.–Sept.	043	0	4 (0.27)	15 (1.0)	15
	October	043	0	0	25 (0.20)	128
	July	893	14 (0.35)	20 (0.50)	40 (1.0)	40
	Aug.–Sept.	893	7 (0.14)	17 (0.35)	49 (1.0)	49
	October	893	0	25 (0.71)	35 (1.0)	35

detected them during 12 survey hours at the Cash Prairie and Cleman sites. We also did not detect radio-tagged nutcrackers while traveling between point-count stations during surveys. By radio-tracking nutcrackers during surveys, we found that marked nutcrackers were commonly within detection distance during surveys. Overall, we obtained 132 telemetry points during 7.9 h of tracking of the three resident nutcrackers while surveys were being conducted. From these tracking sessions, we found that Cash Prairie residents spent 21% of their time within visual detection distance and 40% of their time within auditory detection distance of surveyors during surveys (Table 3). The single Cleman resident was within auditory and visual detection distance 4% of the time. The probability of a nutcracker being within detection distance of a surveyor during surveys (p_i) ranged from 0.23–0.53 for Cash Prairie nutcrackers and was 0.03 for the single Cleman nutcracker.

Of 218 whitebark pine seed pouching events observed at the Cash Prairie site, 215 were by radio-tagged Clark's Nutcrackers, and all 108 caching events observed were by radio-tagged nutcrackers at the Cash Prairie and Cleman sites. While observers were conducting the surveys, other observers recorded 12 seed-pouching events by radio-tagged nutcrackers and seven seed caching events by tagged nutcrackers within 100 m of the surveyors. Thus, although seed-dispersing radio-tagged nutcrackers were within detection distance of observers during surveys, observers failed to detect their presence using standard songbird survey techniques.

Cone production and nutcracker abundance. Cone production within whitebark pine stands ranged between 101 and 4584 cones/ha across all years and sites (Table 4). Nutcracker abundance across all survey types combined was not correlated with cone production ($r^2 = 0.09$, $P = 0.29$, $N = 14$; Fig. 3), and we observed nutcrackers pouching seeds at all whitebark pine sites during both years. Combining all sites, cumulative nutcracker abundance was correlated with the number of minutes of survey time ($r^2 = 0.96$, $P < 0.0001$, $N = 11$; Fig. 4).

DISCUSSION

We found that detection rates of Clark's Nutcrackers were low for all survey types. Nearly a third of all surveys had zero detections and all survey types failed to detect radio-marked nutcrackers that were within detection distance during surveys. Consequently, we were unable to either estimate population size or assess the accuracy of survey methods. Detection rates of nutcrackers were also highly variable. For example, during surveys conducted in July at our Darland site, we detected no nutcrackers after 90 min of surveys, but one month later we detected 42 nutcrackers during the first 90 min of surveys. Given these low and variable detection rates, we conclude that the survey techniques used in our study are not the best approaches for monitoring nutcrackers.

The low and variable detection rates in our study are not surprising given our understanding

Table 4. Whitebark pine cone production estimates and white pine blister rust infection at seven survey sites in the Olympic and Cascade Mountains, Washington, 2007 and 2009.

Site	Year	Cones/ha	ln(cones/ha)^2	Site-level average blister rust infection[a]
Cash Prairie	2007	123	23	no data
	2009	101	21	
Cleman	2007	0	0	0
	2009	0	0	
Clover Spring	2007	2070	58	18.2
	2009	2676	62	
Darland	2007	4584	71	16.2
	2009	3434	66	
Marmot Pass	2007	1272	51	19.6
	2009	329	34	
Timberwolf	2007	1309	52	26.3
	2009	1003	48	
Upper Nile	2007	849	45	55.7
	2009	552	40	

[a]Estimates of blister rust infection are proportion of trees with some sign of infection and data are from Shoal and Aubry (2004) for Clover Spring, Marmot Pass, Timberwolf, and Upper Nile.

corvid behavior. Many species occupy large home ranges relative to the range of detection measured by conventional songbird-survey plots. Thus, detection rates are often low (Tarvin et al. 1998, Luginbuhl et al. 2001). Also, many corvids do not regularly sing or call to maintain territory boundaries, making detectability when present problematic. Corvids, such as Pinyon Jays (*Gymnorhinus cyanocephalus*) and Clark's Nutcrackers, present additional challenges for

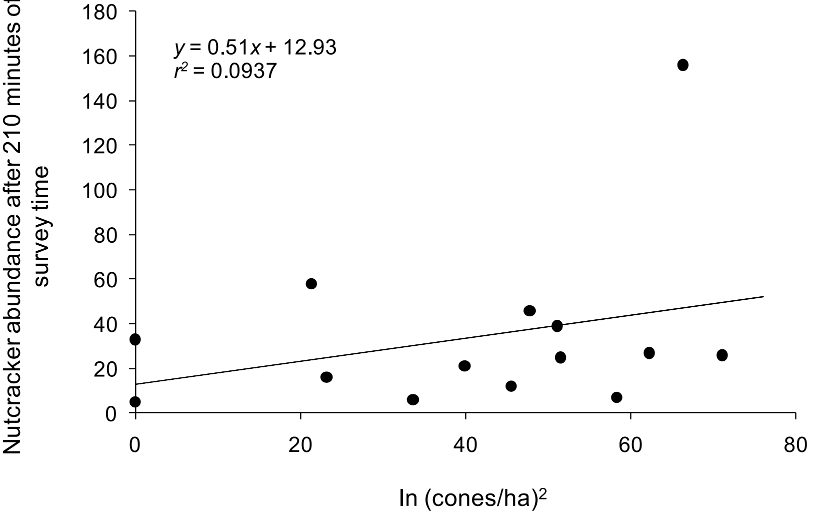

Fig. 3. Simple linear regression of Clark's Nutcracker abundance (survey periods combined) and transformed whitebark pine cone production (ln[number of cones per hectare])^2) for 14 year-site combinations in the Olympic and Cascade Mountains, Washington, 2007 and 2009.

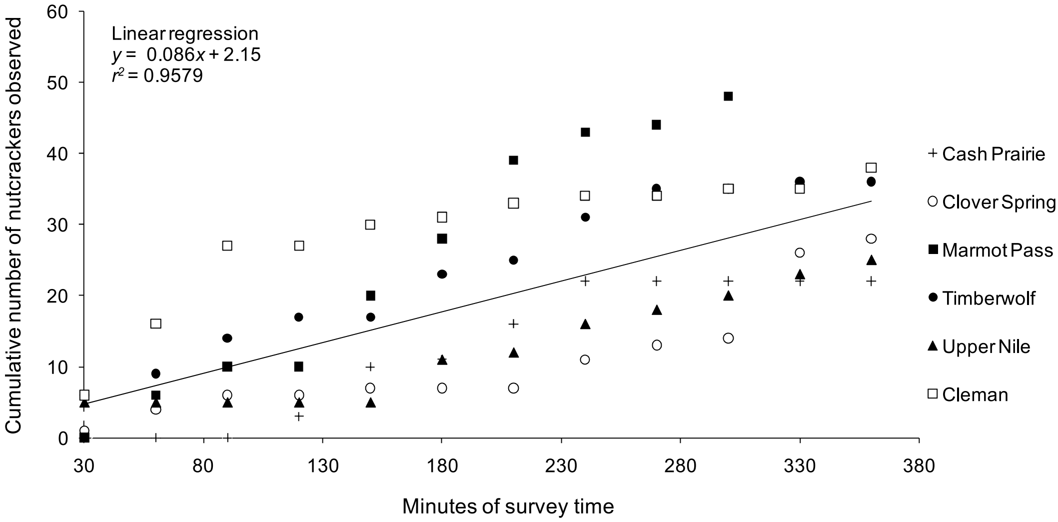

Fig. 4. Simple linear regression of number of Clark's Nutcrackers observed as a function of minutes of survey time and the natural log of minutes of survey time on six survey routes in the Olympic and Cascade Mountains, Washington, in 2007.

monitoring programs because they are social foragers and readily congregate in and move quickly between regions of high cone production (Balda 2002). Cone production varies widely both spatially and temporally and cannot be reliability predicted. Therefore, the timing, extent, and direction of nutcracker migration is unpredictable and complex compared to that of many songbirds (Vander Wall et al. 1981) that migrate in response to predictable, seasonal fluctuations in food availability. Even nonmigratory, resident nutcrackers will leave home ranges in autumn to harvest seeds from distance sources, and emigrants and residents congregate in large flocks during these times (Vander Wall et al. 1981, Lorenz and Sullivan 2009). Thus, the variation in detection rates that we observed could have been due to an influx of birds from other areas rather than actual changes in the size of the resident population.

We found that distance sampling would likely be cost prohibitive, except in the most highly populated areas. Distance sampling requires large numbers of individual detections for estimating detection probabilities (Buckland et al. 2001, Rosenstock et al. 2002). For Clark's Nutcracker surveys, we estimated that up to 1000 point counts per season per site would be desirable to estimate the detectability function. Unfortunately, the most information is needed in regions with low populations of nutcrackers, and detection rates of nutcrackers may be too low in such regions for reliable estimates of population size. It is possible to increase detection rates by surveying for nutcrackers in autumn when flocks congregate in seed harvest stands. However, as indicated above, autumn surveys should not be used by managers interested in measuring population size because of bias associated with counting large numbers of emigrants from other regions (Bart et al. 2004). Emigrant nutcrackers may be attracted to cone-producing stands beginning in August and may overwinter and breed in these regions until the following June (Vander Wall et al. 1981, Lorenz and Sullivan 2009).

Although autumn surveys may not provide reliable information on the size of local breeding populations, they have been used to determine if seed dispersal is occurring in whitebark pine stands. For example, McKinney et al. (2009) used nutcracker presence or absence from July through early September to assess the likelihood of seed dispersal in whitebark pine stands in the northern Rocky Mountains. Our results suggest that such survey results should be interpreted with caution because nutcrackers are not easily detected, even during autumn, without lengthy surveys or multiple visits that extend well into October. In our study, seed-dispersing nutcrackers were not reliability detected by surveyors because they were often inconspicuous; we only were able to confirm seed pouching at some sites using radio telemetry. Moreover, by terminating surveys in early September, many seed-dispersal events may be missed because seed harvest occurs throughout September and October. In support of this, McKinney et al. (2009) predicted that the probability of whitebark pine seeds being pouched by nutcrackers at our Cash Prairie site would be at or near zero because this site lacked high densities of whitebark pine cones. Although nutcracker detection rates were low at the Cash Prairie site, by using radio telemetry, we were able to observe 215 seed pouching events by three residents (98% of all seed pouching events by these residents) during the survey period alone. Overall, our results suggest that nutcrackers may visit whitebark pine stands with few cones, but these visits are difficult to detect using conventional survey methods. We recommend that managers rely on cues of nutcracker seed harvest, such as the presence of nutcracker-harvested cones, rather than observations of nutcrackers when estimating the likelihood of seed dispersal.

Given the limitations of standard survey techniques for detecting nutcrackers, we suggest that alternate methods be considered for monitoring. Occupancy modeling is a promising alternative that could be used to evaluate the proportion of the landscape used by nutcrackers based on presence/absence data (MacKenzie et al. 2002). For managers who would like information about relative abundance, we suggest that time-of-detection methods (Farnsworth et al. 2002) in conjunction with longer surveys (i.e., 20–30 min per point count) may provide a promising alterative where populations are reasonably robust. These methods allow for the estimation of the availability of birds, thereby enabling more reliable estimates of population size. Calculating the availability of nutcrackers is important given their unreliable and variable detectability. For managers needing information about the status of local nutcracker populations, we further suggest that surveys be conducted during July when, as mentioned above, emigrants are least likely to inflate population estimates.

Collectively, our results suggest that conventional methods for monitoring Clark's Nutcrackers may not produce meaningful estimates of either population size or seed dispersal probability during the summer and autumn because nutcrackers are difficult to reliably detect. Future studies should explore the use of either time-of-detection methods or occupancy modeling. We do not recommend any of the standard survey techniques used in our study for monitoring nutcracker populations.

ACKNOWLEDGMENTS

We are grateful to the following individuals who provided support during this study: C. A. Aubry, A. V. Bakian, T. D. Bloxton, M. G. Raphael, and R. Shoal. T. Ohlson granted permission to use cone count data for the Darland survey site. Employees of the Okanogan-Wenatchee National Forest (Naches Ranger District) and Washington Department of Fish and Wildlife (Oak Creek Wildlife Area) provided logistical support. We thank D. F. Tomback and M. B. Wunder for their insightful comments on earlier versions of this manuscript. We also thank D. R. Archer and N. T. Ernst for assisting with surveys. T. D. Bloxton, B. Davies, E. M. Gese, J. Hanson, M. M. Jaeger, C. G. Leingang, C. Raley, and S. G. Sovern loaned us trapping and telemetry equipment. This study was funded by the Seattle City Light Wildlife Research Program, the U.S. Department of Agriculture, Forest Service, Utah State University Biology Department, and Utah State University Ecology Center.

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