Tools and Technology Article

Vocal Individuality of Great Gray Owls in the Sierra Nevada

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ABSTRACT The cryptic plumage and nocturnal nature of the great gray owl (*Strix nebulosa*) make it difficult to study in its densely forested habitat. We investigated whether the vocalizations of individual great gray owls could be distinguished and used as a tool for population survey and monitoring. We recorded 312 territorial calls produced by 14 male and 11 female great gray owls between March and July 2006 and 2007 in the Sierra Nevada range of California, USA. We recorded 19 owls on multiple occasions within a season and 8 owls between seasons. We extracted 17 frequency and 15 temporal variables from the sonograms of each call. Discriminant analysis selected 9 variables and classified 92.8% of calls to the correct individual within a season; 71.4% of calls were classified to the correct individual between seasons. Our results indicate that territorial calls could be used to monitor individual great gray owls for both short- and long-term studies. Vocal individuality could be useful as a noninvasive method to improve census estimates and yield information on site fidelity, turnover rates, seasonal movements, and behavioral traits of great gray owls. (JOURNAL OF WILDLIFE MANAGEMENT 73(5):755–760; 2009)

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The great gray owl (*Strix nebulosa*) is an uncommon bird throughout most of its Holarctic range. The occurrence of this species in California, USA, is especially unique because it represents their most southern distribution in the world. Resident great gray owls occur in just a few areas of the Sierra Nevada, with the largest population near Yosemite National Park and the Stanislaus and Sierra National Forests (Winter 1986, Green 1995). The entire Sierra Nevada population of great gray owls does not likely exceed 200–300 individuals (California Department of Fish and Game [CDFG] 2006). Due to their limited range and declining population, the CDFG has listed the great gray owl as endangered (CDFG 1987). In addition to their sparse distribution, efforts to monitor great gray owls in California are further complicated by their secretive nature, cryptic coloration, and nocturnal activity within dense forests (Johnsgard 2002). The current United States Forest Service (USFS) survey protocol for great gray owls in the Sierra Nevada requires surveyors to broadcast great gray owl vocalizations at multiple calling stations within suitable habitat to increase probability of detection (Beck and Winter 2000). Playback is useful for presence–absence surveys (Takats et al. 2001); additionally, territorial calls can also be easily recorded when owls respond to playback. Analysis of these acoustic data could potentially be used to identify individuals within the population and increase our overall understanding of this elusive species.

Computer hardware and software have advanced sufficiently in recent years to enable complex quantitative analyses of bioacoustic signals. Such innovations in technology have also made bioacoustic equipment more affordable and readily accessible by personal computers. A basic and important function of bioacoustic software is to generate visual portrayals of the time, frequency, and amplitude information in sounds. These spectrograms, or sonograms, support species identification and individual call analysis by enabling the user to quantitatively discern nuances in the structure, timing, and frequency of vocalizations that would otherwise be nearly impossible to distinguish with only the human ear (Gaunt and McCallam 2004). In many instances, individuals of the same species can be discriminated from others by unique features in their calls (Eakle et al. 1989, Farquahar 1993, Galeotii et al. 1993, Gilbert et al. 1994).

Identifying individuals within a population can be used to improve census estimates and provide important information on demographics, life history, and behavioral traits that frequently influence management decisions (Terry et al. 2005). Traditional marking techniques used to monitor bird populations often include capturing and marking individuals with external devices such as colored or numbered leg-bands, pit-tags, or radiotransmitters (Bibby et al. 2000, McGregor et al. 2000). Although often successful, techniques that involve the capture and handling of individuals can have detrimental effects such as stress and injury (Leberman and Stern 1977, Sockman and Schwabl 2001). External marking devices can also affect reproductive success of marked individuals, increase predation rates, reduce survivorship, and cause behavioral changes that may produce biased data (Erikstad 1979, Massey et al. 1988, Foster et al. 1992, Alisauskas and Lindberg 2002). Distinguishing individuals by a noninvasive means, such as vocal traits, could be preferable when the species of concern is rare, sensitive to handling, difficult to catch, or when other techniques are too expensive or labor-intensive (Terry et al. 2005). Great gray owls fit many of these criteria, making

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them ideal candidates to potentially monitor through vocal individuality.

Vocal individuality has been confirmed and used as a management tool for several genera of owls, including the tawny owl (*Strix aluco*; Appleby and Redpath 1997), Scops owl (*Otus scops*; Galeotti and Sacchi 2001), pygmy owl (*Glaucidium passerinum*; Galeotti et al. 1993), Christmas Island hawk owl (*Ninox natalis*; Hill and Lill 1998), eagle owl (*Bubo bubo*; Lengagne 2001), northern saw-whet owl (*Aegolius acadicus*; Otter 1996), and western screech owl (*Megascops kennicottii*; Tripp 2004). Calls of the tawny owl and African wood owl (*S. woodfordii*) were stable over successive years, making their vocal identities useful for re-identification in long-term studies (Appleby and Redpath 1997, Delport et al. 2002). Additionally, gender could be determined from individual African wood owl vocalizations (Delport et al. 2002). In our study we investigated whether the vocalizations of individual great gray owls could be distinguished and used for population monitoring.

STUDY AREA

We collected owl recordings on the western slopes of the Sierra Nevada in Yosemite National Park, Stanislaus, and Sierra National Forests in Madera, Mariposa, and Tuolumne counties, California. All recording sites were located at or adjacent to montane meadows ranging in elevation from 830 m to 2,400 m above sea level. The dominant vegetation was mixed evergreen forests consisting mostly of sugar pine (*Pinus lambertiana*), ponderosa pine (*P. ponderosa*), lodgepole pine (*P. contorta*), Jeffrey pine (*P. jeffreyi*), incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), and red fir (*A. magnifica*). At lower elevations, oak (*Quercus* spp.) and manzanita (*Arctostaphylos* spp.) were also common components of habitats.

The weather for this area varied considerably over the range of elevations, but summers were generally warm and dry, whereas winters were wet and cold. During our study from January to May 2006, precipitation was 89% above average with daily high temperatures 19% cooler than average (California Department of Water Resources [CDWR] 2006). Precipitation was 28% below average with daily high temperatures 4% warmer than average from January to May 2007 (CDWR 2007). Biologists from CDFG and USFS found several nests in both seasons of our study, indicating that breeding occurred regularly despite these differences in weather conditions.

METHODS

Locating and Recording Owls

We located and recorded great gray owls in cooperation with CDFG and USFS biologists (Institutional Animal Care and Use Protocol 05/06.B.52.E). We visited several locations with previous observations or historic nesting records (Winter 1986, Green 1995, Riper and Wagtendonk 2006). To maximize chances of finding owls, we followed guidelines outlined by Beck and Winter (2000), which consist of several visits to each site during which surveyors broadcasted great gray owl vocalizations and performed meadow searches. We collected recordings of great gray owls both with and without use of playback to ensure that vocalizations of owls that were prompted to call did not differ from vocalizations not initiated by playback.

During USFS broadcast surveys we recorded the territorial calls of responding owls using an iRiver H120 digital recorder (ReignCom, Seoul, South Korea) and a Sennheiser ME66 shotgun microphone with a K6 power module (Sennheiser, Wennebostel, Germany). We made recordings at a sampling frequency of 44.1 kHz and stored them as 16-bit wave files. We collected all recordings within approximately 50 m of the owl during calm nights (Beaufort scale 0–1) with no precipitation. We also recorded 4 radiotagged owls that were being monitored in a separate study conducted by CDFG.

We used 2 additional passive techniques to record great gray owls. Our first technique was to place a microphone and recorder near a nest or roost site set to record overnight. Our second technique was to install autonomous recording units (ARUs) within known great gray owl territories. In 2006 we placed ARUs within 100 m of 6 occupied or recently abandoned great gray owl nests. Each ARU contained a DMC Xclef digital recorder (Digital Mind Corporation, Carlsbad, CA) with a 100-gigabyte (GB) hard drive. We collected acoustic data at 320 kilobits/second with a sampling frequency of 44.1 kHz. We made recordings in stereo using 2 PA3 omni mini-microphones with built in preamps (Supercircuits, Austin, TX). Digital recorders and microphones received power from 2 12-V, 12-amp-hour batteries, and we recharged batteries with a 20-watt solar panel connected via a charge controller. We attached microphones to tree limbs with all remaining equipment housed in a weatherproof enclosure covered with leaves and bark for camouflage. We recorded data for 111 nights, with a mean of 18.5 nights/territory. The ARUs collected data at each site from 1 week to 4 weeks between 5 June and 14 July 2006.

In 2007 we improved the hardware used in ARUs by replacing the DMC Xclef digital recorders with iRiver H320 units (ReignCom). We installed Rockbox firmware (Rockbox Firmware 2007) on each H320 to enhance recording functions. These recorders had internal 20-GB hard drives and we programmed them to save recordings as lossless 16-bit WavPack files at a sampling frequency of 44.1 kHz. Each recorder had an integral real-time clock that labeled the recordings with a date and time stamp. We programmed each unit to record 12 hours every night from 1800 hours to 0600 hours using a countdown timer function. In total, we installed ARUs in 15 potential owl territories between 2 March and 15 April 2007. We set up 6 of these ARUs in the same locations as 2006. The ARUs collected acoustic data for 274 nights with a mean of 18.3 nights/territory.

We recorded 25 individual owls, 19 of which were recorded on separate occasions within a season to determine within-season variation of territorial calls. Additionally, to

determine between-season variation of calls, in 2007 we returned to all territories visited in 2006. We used radio-telemetry data from the CDFG study to verify the correct identity of 4 owls (2 M and 2 F) recorded within a season and 2 owls between seasons (1 M and 1 F). We also used leg-bands to confirm the identity of 2 owls (1 M and 1 F) between seasons. We assumed that owls without distinctive radiotags or leg-bands for identification were distinct individuals if we collected recordings at a different nest or territory. Average home range size of great gray owls in the Sierra Nevada is <20 ha during the breeding season for males and approximately 60 ha for females (Riper and Wagtendonk 2006). We collected most of our recordings in isolated areas where the nearest neighboring great gray owl territory was >3 km away. Although it is possible a non-breeding floater could have entered our study population, great gray owls normally only perform territorial calling near their immediate nest site (Bull and Henjum 1990). We feel confident that the 25 owls we recorded and included in our analysis were different individuals.

Sonogram Analysis

We generated sonograms of 312 territorial calls from 25 individual owls and analyzed them on a Macintosh OS X computer (Apple Inc., Cupertino, CA) using acoustic analysis software SonoBird beta Version 2.5.8 (2007; DNDesign, Arcata, CA). We plotted each sonogram with an upper frequency scale of 1 kHz and selected 5–12-second segments depending on duration of the call. Quality of sonograms was influenced by several factors such as ambient noise levels, distance to the owl, and overall intensity of owl calling. To minimize measurement errors, we only analyzed high-quality sonograms that were free from substantial distortions. As an additional precaution, we did not analyze the introductory note of the calls because it was often of lower amplitude than subsequent notes and thus difficult to obtain accurate measurements.

We extracted 12 frequency and 10 temporal variables from each territorial call (Fig. 1). The first temporal variables that we measured were the total number of notes and total call duration. We then took measurements from the second, third, and fourth notes of each call. We did not include territorial calls consisting of <4 notes in the analysis. We extracted the note duration for notes 2–4 and the internote duration between notes 2–3 and 3–4. We also measured time from the beginning of each note to the amplitude of the respective note. Lastly, we collected 4 frequency variables for notes 2–4. For each of these notes we measured the frequency at the start and end of the note and then measured the dominant frequency and the highest frequency.

From the extracted variables we calculated an additional 5 temporal and 5 frequency variables. First, we calculated calling rate in notes per second by dividing total number of notes by total call duration. Second, we calculated tail duration of each note or time from maximum amplitude to end of the note; we repeated this step for notes 2–4 and then averaged the result to produce mean tail duration. We also

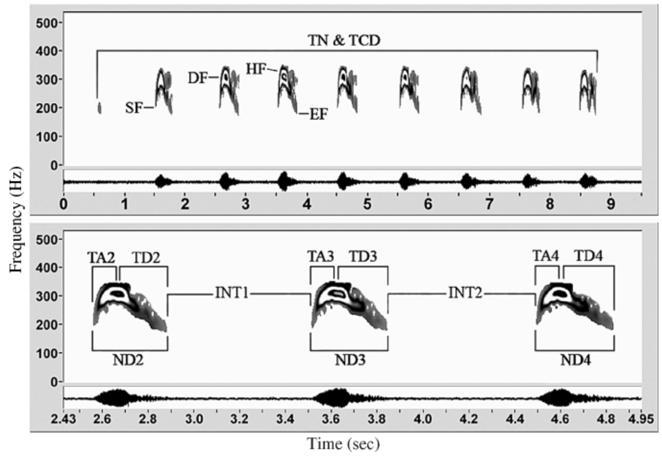

Figure 1. Sonogram of male great gray owl territorial call collected in June 2006, Tuolumne County, California, USA. Temporal variables measured and analyzed from the entire call included total number of notes (TN) and total call duration (TCD). From note 2 through note 4, frequency and temporal variables analyzed included start frequency (SF), dominant frequency (DF), high frequency (HF), end frequency (EF), note duration (ND), time to amplitude (TA), tail duration (TD), and internote duration (INT).

averaged note duration, time to amplitude, internote duration, and frequency measurements taken from notes 2–4, to produce mean temporal and frequency values for a typical note in the territorial call. The averaged variables were more robust, reducing the influence of potential errors caused by variability in sonogram measurements. Nonetheless we included both the averaged and original variables in the analysis to ensure that no individual variation was lost. Lastly, we calculated the mean frequency range for each call by subtracting the lowest mean frequency of the call from the highest.

Discriminant Analysis

We performed discriminant analysis (DA) with forward stepwise inclusion of variables to investigate vocal individuality of the territorial call using Statistical Package for the Social Sciences (Version 15.0 [2006]; SPSS, Inc., Chicago, IL). We entered the most significant call variables into the model ($P < 0.05$) sequentially or until extra variables no longer improved discrimination.

We analyzed 277 calls from 14 male and 11 female great gray owls for within-season vocal individuality. Depending on quality and quantity of recordings, we analyzed 6–12 calls for each individual ($\bar{x} = 11.1$; SD = 1.85). We cross-validated within-season classifications with the leave-one-out method, which randomly removed each observation and reclassified it using the remaining observations.

We also used DA to determine between-season vocal individuality using the same variables selected for the within-season analysis. We analyzed 127 calls from 4 male and 4 female owls, of which 35 of the calls were collected in 2006 and 92 were collected in 2007. We analyzed 13 to 24 calls for each individual ($\bar{x} = 15.9$; SD = 3.39). We treated the 35 calls collected in 2006 as unknowns and cross-validated them against the 92 calls produced by presumably

the same owls in 2007. We pooled these calls with the remaining data set, which consisted of 185 calls representing 17 individual owls.

RESULTS

Discriminant analysis classified 92.8% of calls within a season to the correct individual. Among males, 92.3% of calls were correctly classified, whereas among females 93.6% of calls were correctly classified. Successful classifications ranged from 83.3% to 100% among males and 62.5% to 100% among females. Misclassified calls were distributed among 11 individuals with $\leq$2/individual. Misclassified calls were also evenly distributed among owls that we prompted to call versus those that we recorded passively and among individuals that we recorded on different nights within a season.

Stepwise discrimination selected 9 of the original 32 variables for the within-season analysis. Variables that contributed the most to the discrimination (F-value) were selected in this order: mean note duration ($F = 407.18$), mean internote duration ($F = 380.51$), mean end frequency ($F = 232.52$), mean dominant frequency ($F = 143.25$), mean tail duration ($F = 103.66$), calling rate ($F = 80.02$), mean start frequency ($F = 64.64$), total call notes ($F = 54.21$), and total call duration ($F = 45.93$).

Discriminant analysis for data collected between seasons classified 71.4% of calls from 2006 to their respective territories in 2007. Among males 90.9% of calls were correctly classified, whereas 38.5% of female calls were correctly classified. With the exception of one female, $\geq$1 call for each owl was classified to the correct individual.

The same variables used in the within-season analysis were also selected by stepwise discrimination for the between-seasons analysis. These variables were selected as follows: mean note duration ($F = 403.28$), mean internote duration ($F = 383.76$), mean end frequency ($F = 232.73$), mean dominant frequency ($F = 142.82$), mean tail duration ($F = 101.98$), calling rate ($F = 78.22$), mean start frequency ($F = 63.41$), total call notes ($F = 53.20$), and total call duration ($F = 44.96$).

DISCUSSION

Our results indicate that territorial calls of great gray owls can be used to distinguish individuals within a season, and to a lesser extent, between seasons. Analysis of unique vocal traits could be used as an alternative or supplemental technique to monitor individual owls or for scientific study. Male owls in particular could be reliably identified by this method considering their low within-individual variation and high between-individual variation. Additionally, male great gray owls produce the territorial call much more frequently than females (Johnsgard 2002), facilitating potential monitoring efforts.

Female great gray owls also demonstrated high between-individual variation; however, individuals were more difficult to consistently distinguish because some demonstrated high within-individual variation, especially between seasons. Our results, however, may have been slightly skewed by the small sample size and an unusual circumstance. In one location, a female great gray owl's vocalizations changed dramatically between seasons. Although leg-bands confirmed it was the same owl between seasons, sonograms from 2007 were markedly dissimilar to those from 2006. We acquired recordings of this owl by ARUs just 3 weeks after her mate died. All calls sounded noticeably atypical, and temporal observations from the ARU data indicated that she called extremely frequently. Stress and sickness may have contributed to irregular calling behaviors, because she died a few weeks later.

The lower classification rates for females in our study may have also been influenced by the seasonality of when we recorded calls. In 2006 we collected recordings later in the breeding season when owls were incubating or feeding chicks. In 2007 we recorded owls during prenesting and early nesting stages. Great gray owls, especially females, reduce their calling activity when nesting begins (Johnsgard 2002) and experience weight declines during the breeding season (J. R. Duncan, Manitoba Conservation, personal communication). Additionally, we only analyzed 57 calls from 4 female owls between seasons, increasing the influence of any unusual calls or behaviors related to seasonality. For vocal individuality to be useful as a monitoring tool for female owls, emphasis should be placed on consistently recording early in the season and in collecting a larger sample of calls for each individual.

Classification rates for individual great gray owls in our study are comparable to what has been found in other species of owls using similar techniques and analysis methods. Within the genus *Strix*, calls of individuals were correctly classified 84.5% in barred owls (*S. varia*; Freeman 2000) and 98.6% in tawny owls (Appleby and Redpath 1997) using DAs. During a 12-year study on African wood owls (Delport et al. 2002), 80.9% of male and 96.3% of female individuals were correctly identified using a combination of principal components analysis, multiple analyses of variance, and discriminant function analysis. Delport et al. (2002) also determined residency and turnover rates through analysis of unique vocal signatures. Other studies on owls have demonstrated additional benefits of vocal individuality to monitor habitat quality, site fidelity, and population demographics (Holschuh 2004, Tripp 2004).

Our original design for testing vocal individuality included a larger sample of radiotagged birds. We recorded just 4 radiotelemetered owls, and unfortunately 2 of these birds died between seasons. As a precaution, CDFG temporarily ceased trapping and tagging activity until the cause of death could be determined. Future investigators of vocal individuality may want to ensure that a larger portion of their sample can be reliably identified by other means such as radiotelemetry, pit tags, or colored leg-bands.

One of the limitations of vocal individuality is that identification of individual birds cannot be readily determined in the field, because it requires statistical analysis of sonograms to achieve accurate identifications. Moreover,

vocal data cannot provide age and condition of individuals to the extent of traditional capture methods. Despite these limitations, monitoring individuals through unique vocal signatures is growing as a supplemental, noninvasive research tool in conservation biology, and our results demonstrate that it can be used for studies on great gray owls.

MANAGEMENT IMPLICATIONS

Because great gray owls in montane habitats frequently occupy the same territory and often use the same nests each year (Bull and Henjum 1990), long-term demographic data such as reproductive success, site fidelity, turnover, and mortality rates could be estimated using vocal individuality. Monitoring individual great gray owls using this method and other bioacoustic techniques such as ARUs could be advantageous for their noninvasive nature compared to conventional techniques requiring capture and handling. These approaches may be especially advantageous in California considering that human activity and disturbances have contributed to declines in great gray owls at several historic breeding sites (Wildman 1992, Maurer 1999). Furthermore, recent deaths of radiotagged great gray owls in the Sierra Nevada have initiated investigations to determine if poor-fitting radiotransmitters or other factors contributed to the birds' deaths (Woods 2008). As a supplemental monitoring technique, vocal data can be acquired automatically and over much longer sampling periods than conventional survey protocols. This provides a much greater opportunity to detect and study these rare and secretive birds.

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