AUTONOMOUS RECORDING OF GREAT GRAY OWLS IN THE SIERRA NEVADA

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ABSTRACT—The Great Gray Owl (*Strix nebulosa*) is a difficult species to detect because of its remote breeding locations and secretive nature. We used autonomous recording units (ARUs) to monitor nest activity at 6 Great Gray Owl territories from June–July 2006 in the Sierra Nevada, California. We also used ARUs to survey for Great Gray Owl presence–absence status at 15 potential territories from March–April 2007. Each unit recorded 12 h/night (18:00–06:00). In 2006, we recorded juvenile begging calls at 3 sites. In 2007, we recorded adult Great Gray Owl vocalizations at 10 sites. We recorded audible calls during approximately 40% of the nights sampled at locations with owl detections. We concluded that a combination of ARUs and acoustic analysis provides an effective non-invasive method to detect and monitor Great Gray Owls as well as other secretive and nocturnal species.

Key words: ARU, autonomous recording unit, bioacoustics, Great Gray Owl, nest monitoring, non-invasive methods, presence-absence survey, Sierra Nevada, *Strix nebulosa*

Bioacoustic techniques are increasingly used as a conservation tool to aid in presence-absence surveys and to monitor rare or endangered species (Calupca and others 2000; Hobson and others 2002; Gaunt and McCallam 2004). Acoustic monitoring can be particularly beneficial for monitoring owls because most species occur at low densities, are secretive, and their cryptic coloration makes them difficult to detect (Johnsgard 2002). In California, Great Gray Owls (*Strix nebulosa*) 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). Regular monitoring of Great Gray Owl activity is challenging because they breed in remote areas. Although playback is often used during surveys to increase the probability of detection, many owls may go undetected because of environmental factors (O'Donnell 2004), or for various other reasons. For example, in areas supporting a single pair of birds, male Great Gray Owls often do not respond to playback (Beck and Winter 2000). In addition, unpaired individuals may remain quiet during playback to avoid territorial conflict with other males (Rohner 1997).

Advancements in acoustic technologies have improved our ability to address these survey challenges. Autonomous recording units (ARUs) record and store vocalizations collected from microphones deployed in the field. With sufficient digital memory and power, these recording units can be deployed in remote locations and continuously record acoustic data for weeks at a time (Calupca and others 2000).

Owls make ideal subjects for ARU monitoring because they produce low frequency vocalizations that carry long distances. In optimal conditions with no wind or precipitation, calls of Great Gray Owls can be heard at distances up to about 400 m (Beck and Winter 2000). We investigated whether the use of autonomous recording units (ARUs) could be used as a viable detection method to aid in presence–absence surveys. When nests were located, we also investigated how ARUs could be used to monitor nest activity.

METHODS

Study Area

We installed ARUs on the western slope of the Sierra Nevada in Yosemite National Park,

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and Stanislaus and Sierra National Forests in Madera, Mariposa, and Tuolumne counties. All recording stations were located at or adjacent to montane meadows ranging in elevation from 830 to 1800 m. The dominant vegetation was mixed evergreen forests consisting mostly of Sugar Pine (*Pinus lambertiana*), Ponderosa Pine (*Pinus ponderosa*), Lodgepole Pine (*Pinus contorta*), Jeffrey Pine (*Pinus 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.

Autonomous Recording Units for Monitoring Nest Activity

In 2006, we placed ARUs between 50 to 80 m away from 6 active or recently active 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 in mp3 format at 320 kbps with a sampling rate of 44.1 kHz. We made stereo recordings using 2 PA3 omni-directional mini-microphones with built-in preamps (Supercircuits, Austin, TX). Digital recorders and microphones received power from two 12-volt, 12 amp-hour batteries kept charged 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. At the 6 nest sites we recorded data for a combined total of 111 nights, with a mean of 18.5 nights/territory. The ARUs collected data at each site from 1 to 4 wk between 5 June and 14 July 2006. This sampling period coincided with the Great Gray Owl nesting and fledging stage. Acoustic data was downloaded and analyzed after ARUs were removed from the field in late July.

Autonomous Recording Units for Presence–Absence Surveys

In 2007, we monitored owls and evaluated presence–absence status by collecting vocalizations during the courtship and early nesting period between 2 March and 15 April. We also improved the hardware used in ARUs by replacing the DMC Xclef digital recorders with iRiver H320 units (ReignCom, Seoul, South Korea) on which we installed Rockbox Firmware (2007) to enhance recording functions. These recorders had internal 20-Gb hard drives and we programmed them to save recordings as lossless 16-bit WavPack (Bryant 2006) files at a sampling rate of 44.1 kHz. Each recorder had an integral real-time clock that labeled the recordings with a date and time stamp. Using a countdown timer function, we set each unit to record 12 h every night from 18:00 to 06:00.

During 2007, we installed ARUs at the same 6 territories as 2006 where nests were located and monitored. We set up 2 additional ARUs in other occupied owl territories, and 7 more in undocumented but potential owl territories. In the latter, we moved ARUs to multiple locations within the same habitat to increase the likelihood of detection. In these areas of suitable habitat where owl presence was still unknown, we downloaded and analyzed acoustic data every few days and relocated ARUs 200 to 300 m away if 5 or more nights passed without recording a Great Gray Owl. We sampled a total of 28 subset locations within the 15 potential owl territories. ARUs recorded data at each territory or potential territory for a minimum of 8 and a maximum of 42 nights. The ARUs collected acoustic data for a combined total of 274 sampling nights (12 h/night) with a mean of 18.3 nights/territory.

Data Analysis

Although our recording goals were different in 2006 and 2007 (nest monitoring vs. presence–absence survey), our methods to analyze acoustic data were similar in both seasons. We analyzed ARU recordings collected between 18:00 to 06:00 on a Macintosh^{TM} OS X computer using audio-editing software Audacity^{TM} (Audacity, beta Version 1.32, 2007). We converted all mp3 and WavPack audio files to 32-bit floating wave format at a sampling frequency of 44.1 kHz for analysis. We applied a band pass filter to isolate sounds within the primary frequency range of the Great Gray Owl (20 to 650 kHz). Then we reviewed each 12-h recording by manually scrolling through the waveform and highlighting all patterns that looked like possible Great Gray Owl territorial calls (Fig. 1), whoop calls, contact calls, chitter, and begging calls (Collins 1980; Beck and Winter 2000; Rognan 2007). Lastly, we listened to all the candidate sounds amplified by 10 to 25 decibels

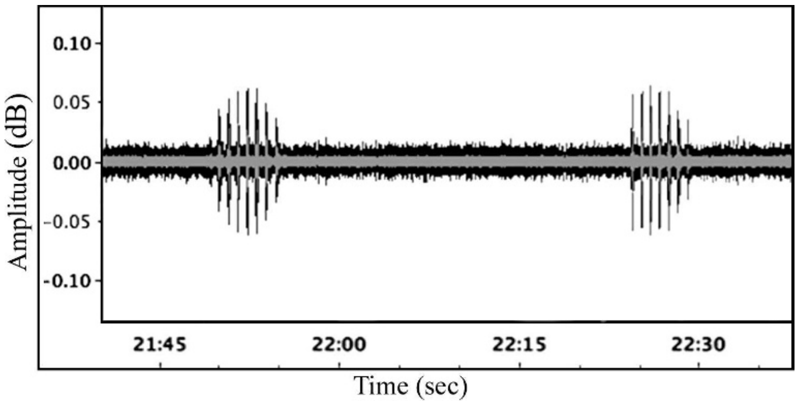

FIGURE 1. Sample waveform of Great Gray Owl territorial call collected by an autonomous recording unit in Stanislaus National Forest, California, 18 March 2007.

and inspected their sonograms in SonoBird™ beta Version 2.58 (DNDesign, Arcata, CA, 2007) to confirm whether they were produced by a Great Gray Owl. During our analysis, we compiled detailed notes of Great Gray Owl vocalizations to calculate the times when owls were vocalizing and to quantify their vocal activity patterns. Territorial calls, often described as a series of 4 to 12 hoots (Beck and Winter 2000), were recorded as a single event, while whoop calls, contact calls, chitter, and begging calls were combined and counted as a single calling event, or bout, when there were several consecutive calls (<15 s between them).

We used NCSS™ statistical package (Hintze 2008) to analyze the temporal occurrence of Great Gray Owl vocalizations. For this analysis, we grouped the calls into six 2-h time periods starting at 18:00 and ending at 06:00. We used repeated measures analysis of variance (ANOVA) to determine if more or less calls than expected were collected during any of the 2-h time periods.

RESULTS

During the nesting and fledging stage in 2006, we recorded adult vocalizations at all 6 occupied owl territories and juvenile begging calls at 3 of the 4 active nests (Table 1). Whoop calls were recorded by ARUs 197 times, territorial calls were recorded 170 times, and juvenile calling bouts, often lasting for several minutes or longer, were recorded 205 times. We detected owls on 74 of 111 (66.7%) sampling nights. The average nightly detection rates in the 6 occupied territories ranged from 16.7 to 100%.

Begging calls of Great Gray Owl nestlings and fledglings were detected on 52 of 90 (57.8%) nights sampled. These calls were especially frequent and intense during presumed prey deliveries. Although more begging calls were recorded in the evening, this observation was not statistically significant from other times during the sampling period ($P = 0.15$).

The most commonly recorded vocalization by adult Great Gray Owls was the whoop call. In total, we detected whoop calls on 49 of 111

TABLE 1. Great Gray Owl (GGOW) nest monitoring by autonomous recording units (ARUs) in Stanislaus and Sierra National Forests, California, 5 June–14 July 2006.

Territory	Nights sampled	Nights juvenile detected	Nights GGOW detected	% Nights GGOW detected
A	12	0 *	2	16.7
B	12	9	9	75.0
C	22	0 **	4	18.2
D	14	9	10	71.4
E	9	0 *	9	100
F	42	34	40	95.2
Total	111	52	74	66.7

* Nests were predated or abandoned before chicks hatched.
** Due to technical problems, ARU recorded less than 20 h before fledgling dispersed.

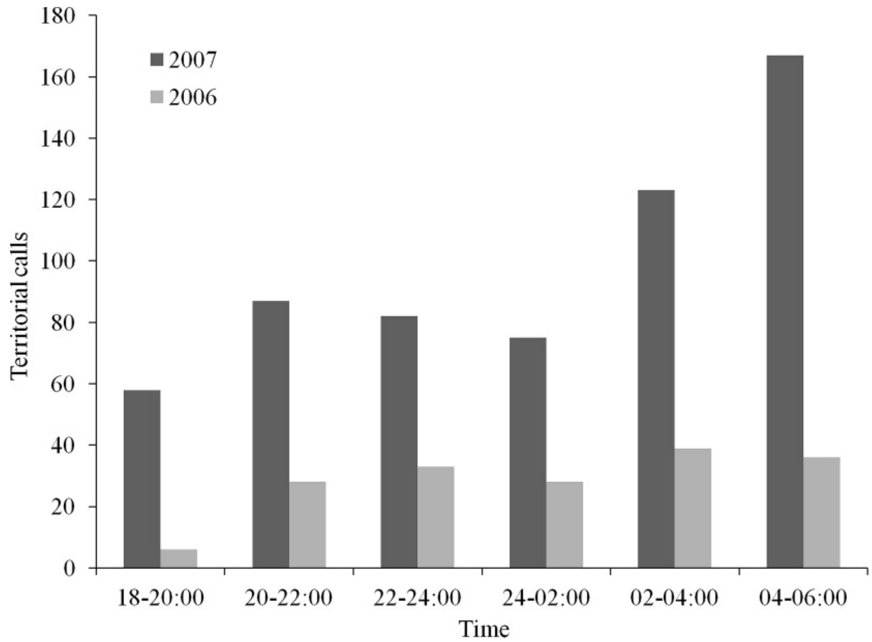

FIGURE 2. Timing of Great Gray Owl territorial calls in 2-h intervals between 18:00 and 06:00 in Stanislaus and Sierra National Forests, California, 5 June–14 July 2006 and 2 March–15 April 2007.

(44.1%) nights and at 5 of 6 territories. We recorded territorial calls on 28 of 111 (25.2%) nights and at all 6 occupied territories. We recorded 41.7% of the calls between 02:00 and 06:00 (Fig. 2), but this was not significantly different from other time periods ($P = 0.31$). At 2 locations, Great Gray Owls also produced 2 to 4 note contact hoots or barks (Beck and Winter 2000) shortly after chicks had fledged.

Territorial calling this late in the season was usually limited to just 1 or 2 calls, with 73.3% (33 of 45) of the calling events consisting of fewer than 3 territorial calls. Extended calling activity was detected at only 2 locations. An increase in calls at 1 territory was apparently triggered by a nest failure when visual monitoring confirmed that the female stopped incubating. At this territory, calling was recorded for several consecutive nights with bouts starting as early as 18:30 and lasting until 05:00. Another event associated with increased territorial calling was a long-distance movement. In early July, a radio-tagged adult male owl moved approximately 15 km away from its breeding territory for at least 2 d before returning (T Stansbery, pers. comm., July 2006). The night when it returned, calling bouts began around 24:00 and continued until approximately 04:30. Prior to this event, a territorial call was only detected once at this site, despite this male frequently roosting near the ARU.

We experienced various ARU stoppages and recorder malfunctions in 2006. One ARU was over turned and the microphones broken. At another location, an animal chewed through a pair of microphone wires. Three DMC recorders stopped or turned off on 10 different occasions. In most of these situations we simply restarted the units and collected as much data as we could from that point forward. Recorders operated successfully during approximately 70% of the survey nights. Despite the loss of data, we collected sufficient data in all of the territories to detect owls and monitor nest activity, except for at 1 remote location where we could not restart the unit for nearly 2 wk. By this time, the nest had already fledged and we failed to record any juvenile calls.

In 2007 we recorded Great Gray Owls at 10 of 15 territories sampled early in the courtship and breeding season (Table 2). At these locations owls were recorded on 79 of 198 (39.9%) sampling nights. A total of 592 territorial calls were recorded, and 35 whoop calls or bouts were also recorded. ARUs detected the owls at all of their known occupied territories ($n = 8$).

TABLE 2. Great Gray Owl (GGOW) detections by autonomous recording units (ARUs) in Stanislaus and Sierra National Forests, California, 2 March–15 April 2007. Note that 5 additional territories sampled for 88 nights yielded no Great Gray Owl ARU detections.

Territory	Nights sampled	Nights GGOW detected	% Nights GGOW detected
A	8	1	12.5
B	16	8	50.0
C	17	5	29.4
D	20	12	60.0
E	21	11	52.4
F	9	1	11.1
G	16	9	56.3
H	16	6	37.5
I	38	13	34.2
J	37	13	35.1
Total	198	79	39.9

We recorded Great Gray Owl vocalizations in 2 of the 7 meadows sampled for the possibility of their presence.

Although Great Gray Owls were recorded at all times of the night, the most frequent time of detection was between 02:00 and 06:00, which accounted for 48.2% of the nightly vocal activity. Calling activity also showed a small increase during the evening hours from 20:00 to 24:00, which accounted for 28.7% of the nightly detections. These results were not statistically significant ($P = 0.18$).

In 2007, we experienced fewer problems with ARU malfunctions than in 2006. Three ARUs required battery recharging after their solar panels received insufficient light to keep the units fully charged. Two iRiver recorders stopped unexpectedly and were re-started. We discovered and corrected all of these issues with only minor delays and recorders operated successfully during 94% of the survey nights.

Discussion

We found that ARUs placed near nests effectively monitored nesting behaviors and activity. During June to August, juvenile owls call loudly and frequently for food, more so than adults uttering calls. For the first few weeks after fledging, juveniles usually remain close to the nest in dense stands of trees (Bull and Henjum 1990). Placing ARUs during this time period would inform researchers of nest success and could also indicate presence–absence status to a lesser extent. The main advantage of this strategy would be to reduce disturbances during the critical nesting stage. However, this method, if used exclusively, would underestimate territory occupancy because of nest failure and because Great Gray Owls do not breed every season (Duncan 1992).

Our results also indicate that ARUs can successfully record Great Gray Owl vocalizations to help determine presence. We recorded more vocalizations between 02:00 and 06:00 than during other time periods; however, these results were not statistically significant, likely because of our small sample size and high individual variation. A study conducted in the same area as ours (Winter 1986) revealed that 56% of calling activity occurred between 01:00 and 0:400. Our results support this finding, but also show that calling continued until dawn, and sometimes even after. We also found that owls were more vocal in March and April than during other times of the breeding season. This is consistent with Great Gray Owls in Oregon where the best response from playback occurred from late February through the end of April (Bryan and Forsman 1987). In some locations, owls that were recorded during this period later nested in the same area. In 2 of these locations where nesting occurred, owl vocalizations were recorded on just a single night during our sampling period. Therefore, it would be difficult to determine the level of occupancy or predict future nesting sites based on recorded vocalizations.

There are other important factors to consider in order for this monitoring technique to be effective. Researchers using ARUs this early in the season should prepare for cold and wet conditions. Rain and snow can increase ambient noise, thereby degrading recording quality and making it more difficult to detect owl vocalizations. In 2007, we lost about 1 night worth of data from sound degradation due to a rain storm; however, no storms occurred during our sampling in 2006. Solar panels receive less light during shorter winter days with the potential for long periods of cloud cover, and should be sized accordingly. Colder temperatures can also increase the likelihood of battery or hardware failures. Lastly, we recommend that all ARU equipment be carefully tested at the intended sites or under similar weather conditions to ensure the units are capable of recording for long periods without stopping.

Although outside the scope of our study, additional research should focus on comparing presence–absence results derived from ARUs to existing traditional survey protocols to determine the cost effectiveness and appropriate application of each method. If resources permit, it is likely that a combination of survey and monitoring methods would be the most successful to maximize the probability of detection while minimizing disturbance. For example, we verified Great Gray Owl presence at 2 undocumented locations with ARUs, but we failed to do so at a location where visual observations confirmed their presence. While setting up an ARU at this meadow, we observed a Great Gray Owl foraging within 50 m. This meadow is only about 3 km from another meadow that supported a nesting pair of Great Gray Owls.

There are several advantages and disadvantages to using acoustic monitoring. For example, field observations collected by different technicians can vary based on the technicians' skill, age, and hearing acuity (Sauer and others 1994; Hobson and others 2002). Audio files can be retrieved at any time and examined by trained individuals, ensuring that all data is analyzed consistently and accurately. These data can also be archived and re-used for future research purposes. Acoustic data can also undergo third party verification. Single ARUs provide limited information as to where the sound originated; however, multiple ARUs with separate microphones that are synchronized and connected to a central recording station (Mennill and others 2006) can be used to triangulate precise locations. This would allow researchers to locate nests and calling roosts of owls without disturbance from personnel. Even though recent improvements to recording equipment have reduced the frequency of failures, loss of data can still occur from dead batteries, recorder malfunctions, or animals destroying equipment. Despite these limitations and the initial expenses of acquiring ARU equipment and training, the overall cost may be offset by the increased data richness and spatial coverage possible with the same personnel resources, particularly when working in remote areas.

Advances in computer technologies have improved the speed and accuracy for locating target sounds of interest. Acoustic analysis software such as SonoBird (DNDesign, Arcata, CA) or XBAT (Cornell Lab of Ornithology, Ithaca, NY) can automatically scan through waveforms, sonograms, and power spectrums of acoustic data. Frequency filters can also be applied to eliminate background noises that are not within the frequency range of the species being monitored. These programs highlight all sounds matching pre-determined temporal and frequency characteristics of the target sound(s), thus enabling rapid identification of species of interest (Clark and Fristrup 1999).

Future attempts to monitor Great Gray Owls using ARUs will increase our understanding of this elusive bird. Application of ARUs could also benefit the monitoring and research initiatives of many other nocturnal species which share traits with Great Gray Owls. During our analysis, we noted 5 other species of owls including Great Horned Owl (*Bubo virginianus*), California Spotted Owl (*Strix occidentalis occidentalis*), Northern Saw-whet Owl (*Aegolius acadicus*), Northern Pygmy Owl (*Glaucidium gnoma*), and Flammulated Owl (*Otus flammeolus*). We also recorded other nocturnal animals such as Coyote (*Canis latrans*), Gray Fox (*Urocyon cinereoargenteus*), chiropterans, and anurans. High quality recordings collected by ARUs can also provide useful data for other analyses such as vocal individuality (Terry and others 2005; Rognan and others 2009). A combination of bioacoustic methods and other techniques could be a cost effective way to highlight behavioral traits, confirm breeding status, and improve the accuracy of Great Gray Owl and other nocturnal surveys.

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