BIOACOUSTIC TECHNIQUES TO MONITOR GREAT GRAY OWLS 
(*STRIX NEBULOSA*) IN THE SIERRA NEVADA

HUMBOLDT STATE UNIVERSITY

By

Cameron B. Rognan

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

Of the Requirements for the Degree

Masters of Arts

In Biology

December 2007
BIOACOUSTIC TECHNIQUES TO MONITOR GREAT GRAY OWLS 
(*STRIX NEBULOSA*) IN THE SIERRA NEVADA

HUMBOLDT STATE UNIVERSITY

By

Cameron B. Rognan

Approved by the Master’s Thesis Committee:

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joseph M. Szewczak</td>
<td>Major Professor</td>
<td></td>
</tr>
<tr>
<td>Brian S. Arbogast</td>
<td>Committee Member</td>
<td></td>
</tr>
<tr>
<td>Michael R. Mesler</td>
<td>Committee Member</td>
<td></td>
</tr>
<tr>
<td>T. Luke George</td>
<td>Committee Member</td>
<td></td>
</tr>
<tr>
<td>Michael R. Mesler</td>
<td>Graduate Coordinator</td>
<td></td>
</tr>
<tr>
<td>Chris A. Hopper</td>
<td>Interim Dean</td>
<td></td>
</tr>
</tbody>
</table>

Research, Graduate Studies & International Programs
ABSTRACT

BIOACOUSTIC TECHNIQUES TO MONITOR GREAT GRAY OWLS (STRIX NEBULOSA) IN THE SIERRA NEVADA

HUMBOLDT STATE UNIVERSITY

Cameron B. Rognan

The Great Gray Owl (Strix nebulosa) is listed as a State of California endangered species due to their low population of approximately 100 individuals. Annual surveys and long-term monitoring efforts are frequently conducted to determine the status of this species within its very limited range in the Sierra Nevada. Great Gray Owls are difficult to study because they are rare, nocturnal, and secretive. I investigated two bioacoustic techniques that may be useful to incorporate into current survey protocols and monitoring efforts of Great Gray Owls: (1) vocal individuality, and (2) the use of autonomous recording units (ARUs).

To investigate the potential of individually distinct vocalizations for population monitoring, I recorded the territorial calls of 14 male and 11 female Great Gray Owls between March and July 2006 and 2007. Nineteen of these owls were recorded on multiple occasions within a season, and eight owls were recorded on separate occasions between seasons. Seventeen frequency and 15 temporal variables of the calls were analyzed from 312 sonograms. A stepwise discriminant analysis selected the nine best discriminator variables and correctly classified 92.8% of the calls to the correct individual within a season. Between seasons, 71.4% of the calls were classified to the
correct individual. My results indicate that territorial calls could be used to monitor
individual Great Gray Owls for both short and long-term studies.

To investigate the use of autonomous recording units (ARUs), I installed ARUs in
15 potential Great Gray Owl territories from March to July 2006 and 2007. Each unit
recorded 12 hours per night (from 1800 to 0600). Great Gray Owl vocalizations were
successfully recorded at 10 of the 15 territories. In locations where owls were detected,
audible calls were recorded during 49.5% of the nights sampled. Recorded chick calls
late in the breeding season were the loudest and may be the most useful indicator for owl
presence and nest success. Adult territorial calls recorded by ARUs could also be
analyzed for vocal individuality. A combination of ARUs and vocal individuality would
be useful as a relatively non-invasive procedure to improve census estimates and yield
information on distribution, site fidelity, turnover rates, reproductive success, and
behavioral traits of Great Gray Owls in the Sierra Nevada and in other parts of their
range.
ACKNOWLEDGEMENTS

This research would have been impossible without the help of many other people. I would first like to thank my advisor, Dr. Joe Szewczak, for his effort creating SonoBird acoustic analysis software, designing ARUs, and for allowing me to use other acoustic equipment to record owls. His expert knowledge of bioacoustics, computers, and analysis methods was instrumental in carrying out this project. Caltrans contributed funds through the research project “Bird Species Identification and Population Estimation by Computerized Sound Analysis.” I would also like to give a special thanks to Dr. Mike Morrison for his counsel in writing the proposal and thesis, and for always pointing me in the right direction when I had questions about my field methods. My committee members, Dr. Luke George, Dr. Brian Arbogast, and Dr. Mike Mesler all gave me useful feedback on my thesis and helped me avoid several potential problems that would have made this project even more difficult.

I am very appreciative for the time Eric Jepson, Lori Tierney, and Joe Medley spent helping me locate many of these elusive owls and for the recordings they contributed. Chris Stermer and Todd Stansbery allowed me to record their radio-tagged owls. Roy Bridgeman provided me with access to several sites on the Stanislaus National Forest and gave me a place to stay in Groveland. Eric Berlow also provided housing at the Wawona field station. Steve Thompson and Jeff Maurer granted me access to several sites in Yosemite and allowed me to work in one of the most beautiful places in the world.
Last but not least I would like to thank my family for their constant support. They have always encouraged me to pursue my interests in wildlife and higher education. My wonderful wife, Melody, served as a great field assistant and helped me install and re-locate recording units to very remote locations. She was supportive and strong throughout the many weeks I spent away in the field, and when I was home, she was very patient as I listened to countless hours of recordings. For anyone else who helped inspire or influence this project in any way, thank you.
TABLE OF CONTENTS

ABSTRACT........................................................................................................................................ iii

ACKNOWLEDGMENTS....................................................................................................................... v

LIST OF TABLES ................................................................................................................................. ix

LIST OF FIGURES ............................................................................................................................... x

INTRODUCTION..................................................................................................................................... 1

  Bioacoustics as a Conservation Tool................................................................................................. 1

  Vocal Individuality ........................................................................................................................... 3

  Autonomous Recording Units (ARUs).............................................................................................. 6

  Natural History of Great Gray Owls in California ....................................................................... 8

  Great Gray Owl vocalizations......................................................................................................... 9

STUDY AREA ......................................................................................................................................... 20

MATERIALS AND METHODS........................................................................................................... 22

  ARU Test Recordings....................................................................................................................... 22

  Locating Owls .............................................................................................................................. 23

  Recording Equipment and Methods ............................................................................................ 24

  Active recording techniques ........................................................................................................ 24

  Passive recording techniques ...................................................................................................... 25

  Sonogram Analysis ......................................................................................................................... 29

  Discriminant Analysis.................................................................................................................... 36

  Within-season discriminant analysis .......................................................................................... 36

vii
<table>
<thead>
<tr>
<th>Table</th>
<th>Description and codes for frequency and temporal call variables extracted from Great Gray Owl sonograms</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Description and codes for frequency and temporal call variables extracted from Great Gray Owl sonograms</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>Description, codes, and formulas for calculated call variables from Great Gray Owl sonograms</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>Great Gray Owl detections by ARUs located near nests in Stanislaus and Sierra National Forests, June-July 2006</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Times of Great Gray Owl calling activity recorded by ARUs at 2-hour intervals, June-July 2006. Calling activity was measured by number of territorial calls for males, a combination of territorial calls, whoops, barks, and chatter for females, and begging calls lasting for a minute or longer for juveniles</td>
<td>46</td>
</tr>
<tr>
<td>5</td>
<td>Great Gray Owl detections by ARUs in active territories, Stanislaus and Sierra National Forests, and Yosemite National Park, March-April 2007</td>
<td>49</td>
</tr>
<tr>
<td>6</td>
<td>Times of Great Gray Owl calling activity recorded by ARUs at 2-hour intervals, March-April 2007. Calling activity was measured by number of territorial calls for males and a combination of territorial calls and whoops for females</td>
<td>50</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sonogram of male and female territorial calls. The male call is at a slightly lower frequency with a shorter note duration and longer internote duration compared to the female call. Recordings collected in May 2006, Stanislaus National Forest.</td>
</tr>
<tr>
<td>2</td>
<td>Sonogram of Great Gray Owl “low double hoot” calls. This is a 3 second segment of the actual call which was about 15 seconds long. Recording collected in March 2007, Stanislaus National Forest.</td>
</tr>
<tr>
<td>7</td>
<td>Sonogram of female Great Gray Owl barks or contact hoots. Recording collected in July 2006, Stanislaus National Forest.</td>
</tr>
<tr>
<td>9</td>
<td>Study area in Central Sierra Nevada including Yosemite National Park, Stanislaus National Forest, and Sierra National Forest.</td>
</tr>
<tr>
<td>10</td>
<td>Autonomous recording unit (ARU) set up within Great Gray Owl territory, Stanislaus National Forest, March 2007.</td>
</tr>
<tr>
<td>11</td>
<td>Sonogram of male Great Gray Owl territorial call. Temporal variables measured and analyzed from this sonogram include total call duration (TCD) and total number of notes (TN). Recording collected at Stanislaus National Forest, June 2006.</td>
</tr>
</tbody>
</table>
Sonogram of notes 2-4 of male Great Gray Owl territorial call. Temporal variables measured and analyzed include note two duration (ND2), note three duration (ND3), note four duration (ND4), internote duration between notes two and three (INT1), internote duration between notes three and four (INT2), time to amplitude for note two (TA2), time to amplitude for note three (TA3), and time to amplitude for note four (TA4). Tail duration (TD) was calculated by subtracting TA from ND for notes 2-4 ..........................................................33

Sonogram of the second note of male Great Gray Owl territorial call. Frequency variables extracted and analyzed include start frequency (SF2), fundamental frequency (FF2), high frequency (HF2), and end frequency (EF2). The same measurements were taken for notes 3 and 4......34

Waveform of three Great Gray Owl calls collected by an ARU in April 2007, Stanislaus National Forest. Waveform generated and analyzed using Audacity audio-editing software. .................................................................39

Plot of first two canonical-variate scores representing the best discriminators of Great Gray Owl territorial calls. Male calls are on the left, represented by numbers 1-14; female calls are on the right represented by numbers 15-25. Notice smaller cluster size for males, indicating lower within-individual variation.................................42
INTRODUCTION

Bioacoustics as a Conservation Tool

Bioacoustics is the study of how animals produce sound and communicate through sound signals. Traditional surveys for birds commonly rely on bird vocalizations to help identify species presence, absence, or abundance (Ralph et al. 1995, Bibby et al. 2000). For nocturnal species, or in situations when vegetation is too thick to see birds, vocalizations may provide the only means of identification. In recent years, more advanced bioacoustic applications have been used as a conservation tool to monitor rare avian species (Hobson et al. 2002, Gaunt and McCallam 2004, Terry et al. 2005). Bioacoustics can be especially advantageous when dealing with species of concern since these birds are usually very rare and seldom seen and thus require more extensive survey efforts over longer time periods to produce observations.

Research on owls can particularly benefit from the use of bioacoustics since most owls occur in low densities, are typically very secretive, and their cryptic coloration makes them difficult to detect in the wild (Johnsgard 2002). In fact, most surveys of owls today rely heavily on playback and detections of response calls to determine owl presence or absence (Takats et al. 2001). In California, annual surveys using playback are conducted to monitor populations of Great Gray Owls (*Strix nebulosa*). Although it is not listed federally, this species is considered a “Sensitive Species” by the United States Forest Service (USFS) in the Pacific Southwest and listed as endangered in the state of
California due to its limited range and declining population. The current USDA Forest Service survey protocol for Great Gray Owls in the Sierra Nevada requires surveyors to broadcast Great Gray Owl calls at multiple calling stations along transects within suitable habitat (Beck and Winter 2000). Although playback produces higher detection rates, it can also cause disturbances at nests and unnecessary stress for the owls (Johnson et al. 1981, Baptista and Gaunt 1997, Legare et al. 1999). Even with the aid of playback, many owls may still go undetected due to their secretive nature. Vocal activity is often limited to short calling bouts usually peaking between 0100 and 0400 (Beck and Winter 2000). In areas supporting a single pair of birds, male Great Gray Owls are less territorial and often do not respond to playback (Beck and Winter 2000). Unpaired owls, sometimes known as floaters, may not call to avoid territorial conflict with other males (Rohner 1997). These elusive behaviors complicate Great Gray Owl surveys, making them a very difficult species to study.

The timing and structure of owl vocalizations also make them suitable candidates for bioacoustic research. Since most owls call at night, they avoid acoustic competition with other birds. Sonograms created from owl recordings often contain fewer distortions and interferences caused from simultaneously calling birds or ambient noise attributed to high daytime winds. Furthermore, owls produce very low frequency calls which carry for long distances. These low frequency sounds are more capable of penetrating acoustical obstructions such as trees, brush, and thick vegetation (Catchpole and Slater 1995). In optimal conditions, calls of Great Gray Owls can be heard from a distance of up to 800 m, although they are usually heard at a maximum distance of 300-500 m (Johnsgard
In this study I investigated two bioacoustic methods that may be useful to aid in surveys and monitoring efforts of Great Gray Owls:

1. The use of vocal individuality

2. The use of autonomous recording units (ARUs)

I approached these methods as two distinct bioacoustic techniques; however, I found that ARUs were extremely useful to collect recordings of owls that were needed for vocal individuality analysis. Therefore, I investigated the effectiveness of both of these bioacoustic methods separately and in combination.

Vocal Individuality

In recent years there have been significant improvements in computer software with advanced bioacoustic applications. One of the major advancements is the speed at which complex quantitative analyses can be performed. Innovations in technology have also allowed bioacoustic equipment to become more affordable and readily accessible by personal computers. A basic and important function of bioacoustic software is to generate visual portrayals of sounds called sonograms or spectrograms. Analysis of sonograms are useful in species identification because they allow the user to quantitatively discern nuances in the structure, timing, and frequency of bird 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

Identifying individuals within a population can be used to improve census estimates and provide important information on demographics, life history, and behavioral traits that might influence management decisions (Terry et al. 2005). Traditional marking techniques that have been used to monitor bird populations include capturing the individuals and marking them with external devices such as colored or numbered leg bands or radio-transmitters (Bibby et al. 2000, McGregor et al 2000). Although these techniques are often successful, there are several reasons why alternative-marking techniques may still be useful. For example, the above techniques involve capturing and handling of individuals, which can have detrimental effects such as stress (Leberman and Stern 1977, Sockman and Schwabl 2001). The external marking devices can also affect reproduction 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 unique characteristics, such as vocal traits, might be preferred when the species of concern is rare, sensitive to handling, difficult to catch, or when other techniques are too expensive or time consuming (Terry et al. 2005). Nonetheless, exclusive use of vocal individuality would limit the data availability for a species of concern. For example, monitoring long-term movements, condition, sex, or age of birds is usually more practical with traditional mark-recapture or radio-telemetry.
techniques. Application of bioacoustic methods would probably be most useful as a supplement to traditional monitoring techniques, rather than as a replacement.

Vocal individuality has been confirmed and used as a management tool for several species of owls including: Tawny Owls (*Strix aluca*) (Appleby and Repath 1997), African Wood Owls (*Strix woodfordii*) (Delport et al. 2002), Barred Owls (*Strix varia*) (Freeman 2000), Scops Owls (*Otus scops*) (Galeotti and Sacchi 2001), Pygmy Owls (*Glaucidium passerinum*) (Galeotti et al. 1993), Christmas Island Hawk Owls (*Ninox natalis*) (Hill and Lill 1998), Eagle Owls (*Bubo bubo*) (Lengagne 2001), Northern Saw-whet Owls (*Aegolius acadicus*) (Otter 1996), and Western Screech Owls (*Megasocps kennicottii*) (Tripp 2004). Overall, research on owls of the genus *Strix* has proven very successful. Calls of Tawny Owls and African Wood Owls have been shown to remain relatively stable over successive years; making their vocal identities useful for re-identification in long-term studies (Appleby and Redpath 1997, Delport et al. 2002). In the case of African Wood Owls, even the sex of individuals could be determined by their vocalizations. The accuracy for classifying individuals based on their calls has also been promising in African Wood Owls, Barred Owls, and Tawny Owls with success rates of 81%, 85%, and 98% respectively. My study is the first attempt to determine vocal individuality in Great Gray Owls.
Autonomous Recording Units (ARUs)

Autonomous recording units (ARUs) are automated digital recorders that can be used to collect and store vocalizations recorded in the field or in a lab. Equipped with a substantial hard drive and powerful batteries, these recording units can be deployed in remote locations and set to continuously record acoustic data for weeks at a time (Calupca et al. 2000). One of the challenges with data collected by ARUs is locating the sounds of interest produced by a target species (Clark and Fristrup 1999). Ambient noise such as wind, planes, insects, birds, or other animals may cloud these sounds and make them difficult to find among thousands of hours of data. Advancements in acoustic software have made this process more efficient by quickly scanning through waveforms, spectrums, or sonograms that search for pre-determined characteristics matching the sounds of interest (Clark and Fristrup 1999). High and low pass filters can also be applied to eliminate background noises that are not within the frequency range of the target species. With the aid of computer software, most, if not all, of the sounds of interest can be found without having to physically listen to each recording.

Application of ARUs in Great Gray Owl territories may offer an alternative approach to reduce excessive disturbances caused by researchers and broadcast surveys. ARUs could be used for presence/absence surveys at specific localities or during time periods of special concern. In this way they could reduce the number of visits necessary to adequately survey for Great Gray Owls, thus decreasing disturbances to the owls and their fragile habitat. ARUs could also be useful in situations where access is limited such
as in steep terrain or remote areas that are difficult to visit regularly. In addition, recording devices like ARUs can be beneficial when there is a shortage of trained field technicians that are qualified to collect the required data (Hobson et al. 2002).

Another advantage of data collected by ARUs is the ability to control for observer variability. Observations among different field technicians can vary based on skill, age, and hearing acuity (Sauer et al. 1994, Hobson et al. 2002). For example, experienced observers can often distinguish the territorial call of male or female Great Gray Owls. However, new or inexperienced researchers may struggle to correctly identify the sex of an owl, or sometimes even the species of an owl. Recordings stored in an ARU can be retrieved at any time and examined by trained individuals, ensuring that all the data is analyzed correctly. These recordings can also be archived as legacy data for future research purposes.

Considering the vocal behavior of Great Gray Owls, passive-recording techniques such as ARUs, may be one of the most effective means to collect recordings. Many Great Gray Owls are not particularly vocal and often do not respond to broadcasts (Beck and Winter 2000). Territorial calling usually peaks early in the season between 0100 and 0400 when surveys are typically not being conducted (Winter 1986). The application of ARUs could increase our overall understanding of Great Gray Owl vocal behaviors and life history traits. In addition, high quality recordings collected by ARUs could be used for further analysis such as vocal individuality. A combination of these bioacoustic methods would be useful to improve the accuracy of census estimates and provide valuable information such as turnover rates, site fidelity, and survival estimates.
Natural History of Great Gray Owls in California

Although Great Gray Owls have a Holarctic distribution, the population in California is unique because it is the most southern in the world. Great Gray Owls are uncommon residents in California, with scattered populations occurring in the central and northern Sierra Nevada range. The largest population is in the central Sierras where more than 75 percent of the records are from Yosemite National Park and Stanislaus National Forest (Winter 1986). In the northern Sierra Nevada, a small population persists near Lake Davis in Plumas National Forest. The entire Sierra Nevada population of Great Gray Owls has been estimated at approximately 100 individuals (Winter 1986, Green 1995).

Great Gray Owls normally breed in mixed coniferous forests ranging in elevation from 750 to 2,700 m (Green 1995). They favor areas with large stands of coniferous trees for roosting and broken-topped conifer snags for nesting. Nests are almost always located in close proximity to meadows, which provide habitat for their primary prey, voles (Microtus sp) and pocket gophers (Thomomys sp) (Winter 1986). Nests found in California had an average distance of 152 m from a meadow (Beck and Winter 2000). In the Yosemite area, Great Gray Owls require meadows of at least 10.1 ha in size for persistent occupancy and reproduction (Winter 1986).

Depending on the elevation, and the amount of snow, breeding usually commences between February and April. Fledglings leave the nest from May to July and may remain on the breeding grounds until November (Beck and Winter 2000). In the northern boreal
forests, Great Gray Owls often migrate long distances to avoid harsh weather and low prey availability (Johnsgard 2002). However, in the Sierra Nevada owls migrate only short distances, moving to similar habitats at lower elevations. Some individuals even remain on their breeding grounds year round (Riper and Wagendonk 2006).

Great Gray Owl vocalizations

Compared to other nocturnal owls, the vocal repertoire of the Great Gray Owl has been considered rather sparse (Johnsgard 2002). This view may be due, in part, to the lack of vocal studies that have been conducted on this species, especially for the race in North America. Unlike most species of owls, Great Gray Owls are not considered highly territorial, and are thought to defend only the immediate nest area (Bull and Henjum 1990). Great Gray Owls in California can be vocal at any time of the year, however, calling activity usually peaks during the early breeding stages from late January to mid-May (Beck and Winter 2000). In North America, territorial calling often increases again in the autumn (Bull and Duncan 1993).

The primary territorial call is a series of 4-12 low pitched hoots that are evenly spaced lasting between 5-10 seconds. This call is mainly given by males from February to April, but can be heard at any time of the year. It is most often used to attract mates and to defend territories. The first and last notes of the call are generally softer and lower pitched, sometimes becoming slurred at the end. Calls may range between 200-500 Hz but are most often around 300 Hz. Typically, just a few calls are given, however, some owls may continue calling for several hours with an average interval of 33 seconds
between calls (Winter 1980). The territorial call is less frequent in females, occurring mostly prior to the egg-laying period (Johnsgard 2002). The female territorial call can usually be distinguished from the male call by its higher pitch, longer note duration, and shorter internote duration (Figure 1). Despite its softness, the territorial call can be heard at distances over 500 m under the right conditions (Johnsgard 2002).

The “low double hoot” is another vocalization that is used for defending the territory (Figure 2). This is an aggressive call, typical of an agitated owl defending against intruders (Beck and Winter 2000). It is much lower in pitch, usually around 200 Hz consisting of several low double hoots given at the rate of 2-3 per second and lasting up to 20 seconds. This call sometimes precedes or follows the primary territorial series call. It is usually heard at distances of less than 50 m (Beck and Winter 2000). Males and females are capable of producing this call, however, it is much more common in males.

The most frequently used call by females is often described as the “whoop” call (Nero 1980) (Figure 3). Whoops are higher pitched than the territorial calls, usually between 500 and 700 Hz and can be heard at distance of a few hundred meters. This call is regularly used to beg for food, maintain contact with the male or chicks, or in response to intruders. Males will also produce a similar call near the nest, although it is very uncommon (Johnsgard 2002). During prey deliveries, females produce these calls in rapid sequence getting louder and higher pitched as the male arrives to the nest. Similar female begging calls described as “ooh-uh” or “eeWheet” (Johnsgard 2002, Beck and Winter 2000) are often made while waiting for the male to arrive with prey (Figure 4). Like the whoop calls, they get louder and higher pitched prior to the male delivering
prey. The pitch of these calls often rises to above 1 kHz before dropping back down to about 600 Hz at the end of the call. Just after prey is delivered, excited “chatter” calls are often produced (Figure 5). These rapid calls usually range from 1-2 kHz and last a few seconds.

Great Gray Owls produce several other vocalizations including various types of hoots, wails, screeches and bill snaps. Long deep hoots are sometimes given preceding a primary territorial call or when stressed (Figure 6). These calls may consist of one to three or more hoots with each hoot lasting a second or longer. After the chicks have fledged, adults will sometimes produce short bark-like hoots consisting of 2-4 notes (Figure 7). These hoots are probably used to keep in contact with the juveniles and could serve as an alarm-warning (Beck and Winter 2000). Juvenile begging calls are described as a harsh “sher-rich” or “err REEK” (Figure 8) (Johnsgard 2002, Beck and Winter 2000). Ranging from 2.5-3.5 kHz, these calls are much higher in frequency than the female begging calls. Prior to a prey delivery, juvenile begging calls are more frequent and much louder. They can often be heard over 500 m away.
Figure 1. Sonogram of male and female territorial calls. The male call is at a slightly lower frequency with a shorter note duration and longer internote duration compared to the female call. Recordings collected in May 2006, Stanislaus National Forest.
Figure 2. Sonogram of Great Gray Owl “low double hoot” calls. This is a 3 second segment of the actual call which was about 15 seconds long. Recording collected in March 2007, Stanislaus National Forest.
Figure 3. Sonogram of a female Great Gray Owl “whoop” call. Recording collected in July 2006, Yosemite National Park.
Figure 4. Sonogram of female Great Gray Owl begging call. Recording collected in June 2006, Stanislaus National Forest.
Figure 5. Sonogram of Great Gray Owl “chatter” vocalizations. Recording collected in June 2006, Stanislaus National Forest
Figure 6. Sonogram of Great Gray Owl long deep hoots. Recording collected in July 2006, Stanislaus National Forest.
Figure 7. Sonogram of female Great Gray Owl barks or contact hoots. Recording collected in July 2006, Stanislaus National Forest.
Figure 8. Sonogram of juvenile Great Gray Owl begging calls. Recording collected in June 2006, Stanislaus National Forest.
STUDY AREA

My study area was located in the central Sierra Nevada Mountains in California (Figure 9). I collected owl recordings on the western slopes of the Sierra Nevada in Yosemite National Park and adjacent Stanislaus and Sierra National Forests. Elevations ranged from 830 m by Groveland to 2,400 m near Glacier Point in Yosemite. The dominant vegetation was mixed evergreen forests consisting mostly of sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), Jeffery pine (*Pinus jeffreyi*), incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), and red fir (*Abies magnifica*). At lower elevations, oak (*Quercus sp*) and manzanita (*Arctostaphylos sp*) were also common components of habitats. All sites were adjacent to montane meadows.

The weather for this area varies considerably over the range of elevations, but summers are generally warm and dry, while the winters are wet and cold. Temperatures in Yosemite range from a mean minimum of \(-3{\degree}C\) in January to a mean maximum of \(32{\degree}C\) in July (Table 1). Mean annual precipitation is 94.7 cm, with most of this occurring from November through March. During the time of my study from January to May 2006, precipitation was 89% above average with daily high temperatures 19% cooler than average (CDWR 2006). From January to May 2007, precipitation was 28% below average with daily high temperatures 4% warmer than average (CDWR 2007). Several nests were found in both seasons of my study, indicating that breeding occurred regularly despite these differences in the weather conditions.
Figure 9. Study area in Central Sierra Nevada including Yosemite National Park, Stanislaus National Forest, and Sierra National Forest.
MATERIALS AND METHODS

ARU Test Recordings

To determine the recording capabilities and limitations of ARUs, I tested the equipment in a controlled setting and in the presence of a Great Gray Owl calling in a natural setting. For the controlled test I set up an ARU in an open area resembling a meadow where no Great Gray Owls were present. Then I broadcasted pre-recorded vocalizations of Great Gray Owls and adjusted the output volume so that it could be heard at a maximum distance of 400 m. This is approximately the maximum distance at which I could hear owls calling in the wild under similar conditions. I repeated the broadcasts while moving further away from the ARU at intervals of 10, 25, 50, 100, 150, 200, and 300 m. I recorded the broadcasts at each distance. Then I repeated this procedure in a forested area to determine how much degradation in recording quality could be attributed to trees and other vegetation. To establish what effect orientation from the ARU would have on the quality of recordings I broadcasted owl calls at 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, and 330 degrees from the ARU. Each broadcast was 50 m away from the ARU.

In addition to controlled tests, I was also able to identify the approximate recording capabilities of ARUs from personal observations of Great Gray Owls calling near ARUs stationed in the field. Prior to a broadcast survey performed by the forest service, I set up an ARU at the calling station most likely to get a response from a Great
Gray Owl. During the broadcast survey a male Great Gray Owl moved to within approximately 40 m of the ARU and continuously called for 20 minutes. On three other occasions I observed owls calling within approximate distances of 25, 70 and 160 m from ARUs. From these events and the controlled tests above, I determined approximate recording capabilities of ARUs by evaluating the quality of sonograms and waveforms produced during each recording event.

Locating Owls

I located Great Gray Owls in cooperation with biologists from California Department Fish and Game (CDFG) and the Stanislaus National Forest Service. I also visited locations with previous observations or historic nesting records (Winter 1986, Green 1995, Riper and Wagendonk 2006). To maximize the chances of finding owls, I followed the guidelines outlined by (Beck and Winter 2000). This protocol consists of several visits to each site during which surveyors broadcast Great Gray Owl vocalizations and perform meadow searches both day and night. However, many locations that were surveyed by the forest service and myself produced Great Gray Owl observations and recording opportunities in the first few visits. Therefore I did not continue surveys with the forest service for follow-up visits after sufficient recordings were collected or when suitable locations were identified for installing ARUs. I was able to find and record four radio-tagged owls that were being monitored in a separate study conducted by CDFG.
Active recording techniques

I attempted to record Great Gray Owls by both active and passive means to ensure that vocalizations of owls that were prompted to call did not differ from vocalizations not initiated by playback. Active recording methods consisted of recording the territorial calls from individuals that responded to broadcast surveys conducted by the forest service. These owls were recorded with an IRiver™ H120 digital recorder (ReignCom, Seoul, South Korea) and a Sennheiser™ ME66 shotgun microphone with a K6 power module (Sennheiser, Wennebostel, Germany). Recordings were made at a sampling frequency of 44.1 kHz and stored as 16-bit PCM wave files. All recordings were collected within approximately 50 m of the owl during calm nights with no precipitation.

To accurately determine within-season variation of territorial calls, I collected multiple recordings of 19 individual owls on separate nights within a season. Additionally, all of the territories visited in 2006 were revisited in 2007 in an attempt to re-record any owls that returned to the same location. Radio-telemetry was used to verify the correct identity of four owls (2 males and 2 females) recorded within a season and two owls between seasons (1 male and 1 female). Leg-bands were also used to confirm the identity of two owls (1 male and 1 female) between seasons. Owls that did not have distinctive radio-tags or leg-bands for identification were assumed to be a different individual if recordings were collected at a different nest or territory. The average home range size of Great Gray Owls is less than 20 ha during the breeding season (Riper and
Wagtendonk 2006). Most of my recordings were collected in isolated areas where the nearest neighboring Great Gray Owl territory was more than 3 km away. Additionally, territorial calling in Great Gray Owls normally only occurs near the immediate nest site (Bull and Henjum 1990). Assuming this territorial behavior held true, and considering my efforts to collect recordings on multiple occasions at the same sites, I am confident that the identity of individual owls was accurately determined.

**Passive recording techniques**

I used two passive recording techniques to record Great Gray Owls that would not respond to broadcasts or otherwise remained silent while being observed. The first technique I attempted was to simply place the microphone and recorder near a nest or roost site and allow it to record overnight. The second passive recording technique I engaged was installing ARUs within known Great Gray Owl territories. To ensure that calls collected by different means did not vary, I compared the calls of four owls that were recorded during broadcast surveys and via passive techniques.

In 2006 I placed eight ARUs within 100 m of six active or recently abandoned Great Gray Owl nests. Data was recorded for 111 nights, with a mean of 18.5 nights per territory. ARUs collected data at each site from one to four weeks between June 5 and July 14, 2006. During this time, most of the chicks were at the fledging stage. Each ARU contained a DMC Xcelf™ digital recorder (Digital Mind Corporation, Carlsbad, California, USA) with a 100 GB hard drive that recorded in mp3 format at a sampling frequency of 44.1 kHz. I set the bit rate to the highest quality (320 kbps). Recordings
were done in stereo using two PA3 omni mini-microphones with built in preamps. Digital recorders and microphones were powered by two twelve-volt batteries, which maintained a charge from a 20-watt solar panel. The microphones were attached to tree limbs while all the remaining equipment was enclosed in weatherproof housing and covered with leaves and bark for camouflage (Figure 10). I set each ARU to continuously record after noting the date and time at the beginning of the recording. Many of the recorders stopped unexpectedly after a few days of recording due to unstable firmware. As a result, I checked each ARU on a weekly basis and reset them when necessary.

In 2007 the hardware used in ARUs was improved by replacing the DMC Xclef digital recorders with IRiver™ H320 units (ReignCom, Seoul, South Korea). I installed Rockbox™ firmware (Rockbox Version 5, 2007) on each IRiver to improve recording functions and overcome the problem of unstable firmware. These recorders supported 20 GB hard drives and stored recordings as lossless 16-bit WavPack files at a sampling frequency of 44.1 kHz. Each recorder possessed an internal real time clock that labeled the recordings with a date and time stamp. Using a countdown timer function, I set each unit to record 12 hours every night from 1800-0600.

In total, I installed ARUs in 15 potential owl territories between March 2 and April 15, 2007. This is the approximate time when most owls were establishing and defending territories. Six of these ARUs were set up in the same locations as 2006 where active nests were found. Two ARUs were set up in other locations of known Great Gray Owl occupancy, and seven were set up in areas of possible occupancy. In areas of possible occupancy, I rotated ARUs along the edge of the meadow approximately 150 m
at a time to cover a larger area and increase the chances of collecting owl vocalizations. ARUs were rotated after five or more nights passed without recording a Great Gray Owl. I covered a total of 28 locations within the 15 potential owl territories. Acoustic data for 274 nights was collected with a mean of 18.3 nights per territory. I checked ARUs on a weekly or bi-weekly basis and moved them to new locations when a minimum of 12 territorial owl calls was collected. Depending on their location, and activity of the owls, ARUs remained within each territory for a minimum of 8 nights and a maximum of 42.
Figure 10. Autonomous recording unit (ARU) set up within Great Gray Owl territory, Stanislaus National Forest, March 2007.
Sonogram Analysis

Sonograms of 312 territorial calls from 25 individual owls were generated and analyzed on a Macintosh OS X computer using acoustic analysis software SonoBird™ beta Version 2.5.8 ™ (DNDesign 2007). Each sonogram was plotted at a frequency scale of 1 kHz and 5-12 seconds depending on the duration of the call. The quality of sonograms was influenced by several factors such as ambient noise levels, distance to the owl, and overall intensity of the owl calling. To keep measurement errors at a minimum, I only analyzed high quality sonograms that were free of significant distortions.

In total, I extracted 12 frequency and 10 temporal variables from each territorial call (Table 2). The first temporal variables that I measured were the total number of notes and total call duration (Figure 11). Then I took measurements from the second, third and fourth notes of each call (Figure 12). I did not analyze the introductory note because it was often of lower amplitude than subsequent notes and thus difficult to obtain accurate measurements. I also chose not to analyze the final notes because some owl calls consisted of only four notes. Additional temporal variables I extracted included note duration for notes two through four, and the internote duration between notes two to three and three to four. I also measured the time from the beginning of each note to the amplitude of the respective note. Lastly I collected four frequency variables for notes two through four (Figure 13). For each of these notes I measured the frequency at the start and end of the note. Then I measured the fundamental frequency and the highest frequency of each note.
From the extracted variables I calculated an additional five temporal and five frequency variables (Table 3). First I calculated the calling rate in notes per second by dividing the total number of notes by the total call duration. Second, I calculated the tail duration of each note by subtracting the start time to amplitude from the note duration (Figure 12). This step was done for notes two through four and then averaged to produce the mean tail duration. I also averaged the note duration, time to the amplitude, internote duration and frequency measurements taken from notes two through four, producing mean temporal and frequency values for a typical note in the territorial call. The averaged variables were more robust for analysis, reducing the influence of potential errors caused by inaccurate sonogram measurements. Lastly, I calculated the mean frequency range of each call by subtracting the lowest mean frequency of the call from the highest.
Table 1. Description and codes for frequency and temporal call variables extracted from Great Gray Owl sonograms.

<table>
<thead>
<tr>
<th>Call Variables</th>
<th>Frequency variables</th>
<th>Temporal variables</th>
<th>Code</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start frequency note 2</td>
<td>SF2</td>
<td>Total notes</td>
<td>SF2</td>
</tr>
<tr>
<td></td>
<td>End frequency note 2</td>
<td>EF2</td>
<td>Total call duration</td>
<td>EF2</td>
</tr>
<tr>
<td></td>
<td>Fund. frequency note 2</td>
<td>FF2</td>
<td>Note 2 duration</td>
<td>FF2</td>
</tr>
<tr>
<td></td>
<td>High frequency note 2</td>
<td>HF2</td>
<td>Note 2 time to amplitude</td>
<td>HF2</td>
</tr>
<tr>
<td></td>
<td>Start frequency note 3</td>
<td>SF3</td>
<td>Internote duration notes 2-3</td>
<td>SF3</td>
</tr>
<tr>
<td></td>
<td>End frequency note 3</td>
<td>EF3</td>
<td>Note 3 duration</td>
<td>EF3</td>
</tr>
<tr>
<td></td>
<td>Fund. frequency note 3</td>
<td>FF3</td>
<td>Note 3 time to amplitude</td>
<td>FF3</td>
</tr>
<tr>
<td></td>
<td>High frequency note 3</td>
<td>HF3</td>
<td>Internote duration notes 3-4</td>
<td>HF3</td>
</tr>
<tr>
<td></td>
<td>Start frequency note 4</td>
<td>SF4</td>
<td>Note 4 duration</td>
<td>SF4</td>
</tr>
<tr>
<td></td>
<td>End frequency note 4</td>
<td>EF4</td>
<td>Note 4 time to amplitude</td>
<td>EF4</td>
</tr>
<tr>
<td></td>
<td>Fund. frequency note 4</td>
<td>FF4</td>
<td></td>
<td>FF4</td>
</tr>
<tr>
<td></td>
<td>High frequency note 4</td>
<td>HF4</td>
<td></td>
<td>HF4</td>
</tr>
</tbody>
</table>
Figure 11. Sonogram of male Great Gray Owl territorial call. Temporal variables measured and analyzed from this sonogram include total call duration (TCD) and total number of notes (TN). Recording collected at Stanislaus National Forest, June 2006.
Figure 12. Sonogram of notes 2-4 of male Great Gray Owl territorial call. Temporal variables measured and analyzed include note two duration (ND2), note three duration (ND3), note four duration (ND4), internote duration between notes two and three (INT1), internote duration between notes three and four (INT2), time to amplitude for note two (TA2), time to amplitude for note three (TA3), and time to amplitude for note four (TA4). Tail duration (TD) was calculated by subtracting TA from ND for notes 2-4.
Figure 13. Sonogram of the second note of male Great Gray Owl territorial call. Frequency variables extracted and analyzed include start frequency (SF2), fundamental frequency (FF2), high frequency (HF2), and end frequency (EF2). The same measurements were taken for notes 3 and 4.
Table 2. Description, codes, and formulas for calculated call variables from Great Gray Owl sonograms.

<table>
<thead>
<tr>
<th>Description of calculated variables</th>
<th>Variable code</th>
<th>Formula for new variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calling rate</td>
<td>CR</td>
<td>TN/TCD</td>
</tr>
<tr>
<td>Tail duration notes 2-4</td>
<td>TD (2-4)</td>
<td>ND-TA</td>
</tr>
<tr>
<td>Mean tail duration</td>
<td>MTD</td>
<td>((\text{TD2}+\text{TD3}+\text{TD4})/3)</td>
</tr>
<tr>
<td>Mean note duration</td>
<td>MND</td>
<td>((\text{ND2}+\text{ND3}+\text{ND4})/3)</td>
</tr>
<tr>
<td>Mean internote duration</td>
<td>MINT</td>
<td>((\text{INT1}+\text{INT2})/2)</td>
</tr>
<tr>
<td>Mean start frequency</td>
<td>MSF</td>
<td>((\text{SF2}+\text{SF3}+\text{SF4})/3)</td>
</tr>
<tr>
<td>Mean end frequency</td>
<td>MEF</td>
<td>((\text{EF2}+\text{EF3}+\text{EF4})/3)</td>
</tr>
<tr>
<td>Mean fundamental frequency</td>
<td>MFF</td>
<td>((\text{FF2}+\text{FF3}+\text{FF4})/3)</td>
</tr>
<tr>
<td>Mean high frequency</td>
<td>MHF</td>
<td>((\text{HF2}+\text{HF3}+\text{HF4})/3)</td>
</tr>
<tr>
<td>Mean frequency range</td>
<td>MFR</td>
<td>MHF-MEF</td>
</tr>
</tbody>
</table>
Discriminant Analysis

A forward stepwise discriminant analysis (DA) was performed to investigate vocal individuality of the territorial call using SPSS™ statistical software (SPSS Version 15.0, 2006). The most significant call variables were entered into the model (P < 0.05) sequentially or until extra variables no longer improved the discrimination.

Within-season discriminant analysis

I analyzed 277 calls produced from 14 male and 11 female Great Gray Owls for within-season vocal individuality. Depending on the quality and quantity of recordings, a maximum of 12 calls and a minimum of 6 were analyzed for each individual ($\bar{x} = 11.1$) (SD = 1.85). Within-season classifications were cross-validated with the leave-one-out method which randomly removed each observation and re-classified it using the remaining observations. Traditional DA uses the same observations to build the model as it does to produce classifications. Therefore cross-validation is an important step because it produces more accurate classification predictions when the true group membership is unknown (Afifi et al. 2004).

Between-season discriminant analysis

Using the same variables selected for the within-season analysis, I performed a discriminant analysis to determine between-season vocal individuality. In 2006 and 2007 I collected 151 calls that were produced by 10 Great Gray Owls occupying the same nesting territories between seasons. The correct identity of one male and one female owl
that had returned to their respective territories was confirmed by radio-telemetry. Two additional radio-tagged owls were recorded in 2006 but died during the winter between seasons. Therefore the owls that were recorded in these territories in 2007 were known to be new individuals and I did not include them in my between-season analysis. As a result, I analyzed 127 calls from 4 male and 4 female owls that were assumed to be the same individuals at their respective territories during both seasons. Of these, 35 of the calls were collected in 2006 and 92 were collected in 2007. A maximum of 24 and a minimum of 13 calls were analyzed for each individual ($\bar{x} = 15.9$) (SD = 3.39). I 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. These calls were also pooled with my remaining data set, which consisted of 185 calls representing 17 different individual owls.

ARU Analysis

ARU recordings were analyzed on a Macintosh™ OS X computer using audio-editing software Audacity™ (Audacity, beta Version 1.32, 2007). During analysis, all mp3 and WavPack files were converted to 32-bit floating wave format with a sampling frequency of 44.1 kHz. I analyzed all data recorded between 1800-0600 hours. I took detailed notes during the analysis of each file including the times of owl observations, calls of males, females, chicks, and different calling behaviors. I also noted the times and frequency of other birds or animals recorded.
To locate owl vocalizations recorded by ARUs I first used a band pass filter to eliminate noises below 100 Hz and above 700 Hz (most Great Gray Owl vocalizations are between 200-500 Hz). I reviewed each 12 hour recording by manually scrolling through the waveforms at four-minute intervals and searching for low frequency sounds approximately two or more decibels above ambient noise levels. When present, owl vocalizations could be identified by their evenly spaced hoots that created a recognizable pattern in the waveform (Figure 14). I selected these sounds and amplified them by 25 decibels. Lastly, I listened to all candidate sounds and inspected the signal’s sonogram to determine if it was a Great Gray Owl.
Figure 14. Waveform of three Great Gray Owl calls collected by an ARU in April 2007, Stanislaus National Forest. Waveform generated and analyzed using Audacity audio-editing software.
RESULTS

ARU Recording Capabilities

Under controlled settings with no rain, wind or thick vegetation, I was able to adequately record the Great Gray Owl broadcasts at all distances up to 150 m. These recordings were discernable enough to be detected using my normal ARU analysis methods. When trees were present, the effective recording range was reduced to 75 m or less. Orientation from the ARU only slightly affected the quality of recordings, with calls recorded at 90 and 270 degrees quieter than calls recorded at other orientations.

When Great Gray Owls were observed calling near ARUs, I successfully collected recordings of their territorial calls at distances of 25, 40, 70 and 160 m. In these situations, the only calls that were recorded at a quality level acceptable for vocal individuality analysis were collected at approximately 25 and 40 m.

Within-Season Vocal Individuality

Discriminant analysis using leave-one-out cross-validation successfully classified 92.8% of the calls to the correct individual (Figure 15). Among males, 92.3% of the calls were correctly classified, while among females 93.6% of the calls were correctly classified. I found no significant difference in the classification of calls collected by passive means verses those collected by prompting the owl to call. I also found no significant difference in the classification of calls recorded on different nights within a
season. Misclassified calls were distributed among 11 individuals, with no more than 2 per individual.

Stepwise discrimination selected only 9 of the original 32 variables in the analysis. The variables that contributed the most to the discrimination were selected in this order: mean note duration \( (f = 407.18) \), mean internote duration \( (f = 380.51) \), mean end frequency \( (f = 232.52) \), mean fundamental frequency \( (143.25) \), mean tail duration \( (103.66) \), calling rate \( (80.02) \), mean start frequency \( (f = 64.64) \), total call notes \( (f = 54.21) \), and total call duration \( (f = 45.93) \).
Figure 15. Plot of first two canonical-variate scores representing the best discriminators of Great Gray Owl territorial calls. Male calls are on the left, represented by numbers 1-14; female calls are on the right represented by numbers 15-25. Notice smaller cluster size for males, indicating lower within-individual variation.
Between-Season Vocal Individuality

Discriminant analysis for data collected between-seasons classified 71.4% of the calls from 2006 to its respective territory in 2007. Among males 90.9% of the calls were correctly classified, while 38.5% of the female calls were correctly classified. With the exception of one female owl, at least one call for each individual was classified to the correct individual.

The same variables selected in the within-season analysis were used for the between-seasons analysis. The variables were selected in the same order: mean note duration ($f = 403.28$), mean internote duration ($f = 383.76$), mean end frequency ($f = 232.73$), mean fundamental frequency (142.82), mean tail duration (101.98), calling rate (78.22), mean start frequency ($f = 63.41$), total call notes ($f = 53.20$), and total call duration ($f = 44.96$).

ARU Detections in 2006 (Mid-Late Breeding Stage)

In 2006, Great Gray Owls were successfully detected by ARUs at all six territories, with recordings occurring on 74 of the 111 nights or 66.7% (Table 4). Females were detected more frequently than males, but both sexes were recorded at least once in each of the six territories. Depending on the territory, the probability of an ARU recording an owl on a given night ranged from 16.7% to 100%.

At locations where chicks were present ($n = 4$), they were detected by their loud begging calls on 52 out of 90 nights or 57.8%. Calls were consistently detected
throughout the night, but most frequently occurring between 2000–2200 hours (Table 5). Begging calls were often repeated more rapidly and loudly when an adult was vocalizing in the area or prior to receiving prey.

The most commonly recorded vocalization by females was the “whoop” call. In total, whoop calls were detected on 49 out of 111 nights or 44.1%. These calls were regularly detected at all times during the night, but most frequently in the morning from 0400-0600 hours (Table 5). Females at two locations also produced 2-4 note contact hoots or barks after chicks had fledged. These calls were usually made from 0200-0400 hours. Female territorial calls were detected at three sites on just eight occasions. Each time the territorial call was recorded in the early morning before sunrise.

Male territorial calls were recorded on 25 out of 111 nights or 22.5%. Calls were most frequently detected between 0200 and 0400 hours (Table 5). Calling was usually limited to just one or two calls, with 73.3% (33/45) of the calling events consisting of fewer than three territorial calls. Extended calling activity was detected at only two locations. An increase in calls at one territory seemed to be triggered by a nest failure when the female stopped incubating. This male called for several consecutive nights with bouts starting as early as 1830 and lasting until 0500 hours. Another event associated with increased territorial calling was a long-distance movement. In early July a radio-tagged owl had moved approximately eight miles away from its breeding territory for at least two days before returning. The night when it returned calling bouts began around 2400 and continued until approximately 0430. Prior to this event, a male territorial call was only detected once at this site, despite the male frequently roosting near the ARU.
Table 3. Great Gray Owl detections by ARUs located near nests in Stanislaus and Sierra National Forests, June-July 2006.

<table>
<thead>
<tr>
<th>Territory</th>
<th>Nights sampled</th>
<th>Nights chicks detected</th>
<th>Nights female detected</th>
<th>Nights male detected</th>
<th>Nights GGOW detected</th>
<th>% Nights GGOW detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>0 *</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>16.7 %</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td>75.0 %</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>18.2 %</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>10</td>
<td>71.4 %</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>0 *</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>100 %</td>
</tr>
<tr>
<td>6</td>
<td>42</td>
<td>34</td>
<td>36</td>
<td>11</td>
<td>40</td>
<td>95.2 %</td>
</tr>
<tr>
<td>Total</td>
<td>111</td>
<td>52</td>
<td>52</td>
<td>25</td>
<td>74</td>
<td>66.7 %</td>
</tr>
</tbody>
</table>

* Nests were predated or abandoned before chicks hatched.
Table 4. Times of Great Gray Owl calling activity recorded by ARUs at 2-hour intervals, June-July 2006. Calling activity was measured by number of territorial calls for males, a combination of territorial calls, whoops, barks, and chatter for females, and begging calls lasting for a minute or longer for juveniles.

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>18-2000</th>
<th>20-2200</th>
<th>22-2400</th>
<th>00-0200</th>
<th>02-0400</th>
<th>04-0600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male calls (N=162)</td>
<td>3.7 %</td>
<td>17.3 %</td>
<td>20.4 %</td>
<td>16.0 %</td>
<td>21.6 %</td>
<td>21.0 %</td>
</tr>
<tr>
<td>Female calls (N=205)</td>
<td>14.1 %</td>
<td>19.0 %</td>
<td>19.1 %</td>
<td>14.1 %</td>
<td>16.1 %</td>
<td>21.5 %</td>
</tr>
<tr>
<td>Juvenile calls (N=413)</td>
<td>8.5 %</td>
<td>20.3 %</td>
<td>16.5 %</td>
<td>14.8 %</td>
<td>15.5 %</td>
<td>16.9 %</td>
</tr>
<tr>
<td>Mean calling activity</td>
<td>8.8 %</td>
<td>18.9 %</td>
<td>18.7 %</td>
<td>14.9 %</td>
<td>17.7 %</td>
<td>19.8 %</td>
</tr>
</tbody>
</table>
ARU Detections in 2007 (Early Breeding Stage)

In 2007, Great Gray Owls were successfully recorded at 10 out of the 15 territories. In these locations, they were recorded during 79 out of 198 nights or 39.9% (Table 6). Combined with the data in 2006, ARUs detected Great Gray Owls on 153 out of 309 nights or 49.5%. Depending on the territory, the probability of an ARU recording an owl on a given night in 2007 ranged from 11.1% to 60%. Female owls were recorded in all active territories, whereas males were recorded in seven out of the ten active territories. Female owls were also detected on more nights (n = 65) than males (n = 53). Although female owls were detected more frequently, male territorial calls (n = 318) were recorded more often than females (n = 274).

The regularity at which ARUs recorded owls varied substantially depending on the location where it was placed. For example, in all of the previously known nesting sites (n = 8), ARUs recorded owls consistently. In meadows where their presence was unknown (n = 7), ARUs recorded Great Gray Owls at two locations. Of the five meadows where Great Gray Owls were not recorded by ARUs only one was known to have them present from other surveys or observations.

Although recordings of Great Gray Owls were collected at all times of the night, the most common time of detections was between 0200-0600 hours (Table 7.) These hours accounted for 48.2% of the nightly activity. Females were especially active during this time period, with over 80% of the territorial calls that were collected being recorded in the few hours before sunrise. Calling activity of both males and females also showed a
small increase during the evening hours from 2000-2400, which accounted for 28.7% of the nightly detections.

It was not unusual for male and female calls to be recorded together, with one owl responding to the other. However, males were never heard calling to each other or competing with one another to defend a territory. Overall, I found that territorial calling decreased as the breeding season progressed. For example, female territorial calls were recorded just eight times by ARUs in June and July of 2006. Whereas ARUs placed at the same six locations in March and April of 2007 collected 198 territorial calls. Although not as extensive, a similar trend held true for male owls with 106 calls collected in June and July of 2006, while 157 calls were collected at the same four locations in March and April of 2007.
Table 5. Great Gray Owl detections by ARUs in active territories, Stanislaus and Sierra National Forests, and Yosemite National Park, March-April 2007.

<table>
<thead>
<tr>
<th>Territory</th>
<th>Nights sampled</th>
<th>Nights female detected</th>
<th>Nights male detected</th>
<th>Nights GGOW detected</th>
<th>% Nights GGOW detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>12.5 %</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>50.0 %</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>29.4 %</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td>60.0 %</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td>52.4 %</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>11.1 %</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>56.3 %</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>37.5 %</td>
</tr>
<tr>
<td>9</td>
<td>38</td>
<td>11</td>
<td>6</td>
<td>13</td>
<td>34.2 %</td>
</tr>
<tr>
<td>10</td>
<td>37</td>
<td>11</td>
<td>9</td>
<td>13</td>
<td>35.1 %</td>
</tr>
<tr>
<td>Total</td>
<td>198</td>
<td>65</td>
<td>53</td>
<td>79</td>
<td>39.9 %</td>
</tr>
</tbody>
</table>
Table 6. Times of Great Gray Owl calling activity recorded by ARUs at 2-hour intervals, March-April 2007. Calling activity was measured by number of territorial calls for males and a combination of territorial calls and whoops for females.

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>18-2000</th>
<th>20-2200</th>
<th>22-2400</th>
<th>00-0200</th>
<th>02-0400</th>
<th>04-0600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male calls (N= 318)</td>
<td>9.4 %</td>
<td>11.6 %</td>
<td>21.1 %</td>
<td>11.9 %</td>
<td>20.1 %</td>
<td>25.8 %</td>
</tr>
<tr>
<td>Female calls (N=309)</td>
<td>11.0 %</td>
<td>18.1 %</td>
<td>6.5 %</td>
<td>13.9 %</td>
<td>21.0 %</td>
<td>29.4 %</td>
</tr>
<tr>
<td>Mean calling activity</td>
<td>10.2 %</td>
<td>14.8 %</td>
<td>13.9 %</td>
<td>12.9 %</td>
<td>20.6 %</td>
<td>27.6 %</td>
</tr>
</tbody>
</table>
DISCUSSION

Vocal Individuality as a Conservation Tool

My results indicate that the territorial calls of Great Gray Owls could be used to distinguish individuals within a season, and to a lesser extent, between seasons. This finding suggests that vocal individuality could be used as an alternative marking technique to monitor individual owls. Male owls in particular could be reliably identified by this method considering their low within-individual variation and high between-individual variation (Figure 14). Calls of male owls were classified to the correct individual more than 90% of the time within and between-seasons.

Female Great Gray Owls also demonstrated high between-individual variation, however, individuals would be more difficult to consistently distinguish because some demonstrated high within-individual variation. This variation was especially evident between-seasons where only 38% of the calls were classified to the correct individual. These results, however, may be have been slightly skewed by my 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 not similar to those collected in 2006. Recordings of this owl were collected by ARUs just three weeks after her mate had died. All of the calls sounded very atypical, and observations from the ARU data indicated that she called extremely frequently. Stress and sickness may have contributed to irregular
calling behaviors, as she died a few weeks later. After omitting this unusual case, the number of female calls correctly classified between-seasons increased to 50%. Less than ideal classification percentages, such as these, do not necessarily indicate that DA will be ineffective at distinguishing individuals. By increasing the sample size of individuals and calls per individual in the analysis, researchers can greatly increase the probability of correctly identifying individuals, even if DA misclassifies some calls.

My original design for testing vocal individuality included a larger sample of radio-tagged birds in the data set. I recorded just four owls that were being monitored by radio-telemetry, and two of these birds died between seasons. As a result of these, and potentially other deaths related to the radio-tags, CDFG temporarily stopped their trapping. In turn, my between-season analysis only included two radio-tagged owls, thus reducing the control individuals designated to confirm the true identity of owls. Future studies investigating vocal individuality might want to ensure that a larger portion of their sample can be reliably identified by other means such as radio-telemetry, pit tags, or colored leg bands.

Since Great Gray Owls frequently occupy the same territory or even 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. Vocal identification was used to calculate residency and turnover rates of African Wood Owls (Delport et. al. 2002). Similarly, site use and fidelity were also monitored by vocal individuality in Western Screech Owls and Queen Charlotte Saw-whet Owls (Aegolius acadicus brooksi) (Holschuh 2004, Tripp 2004). Perhaps the
most significant advantage of using vocal individuality to monitor individuals is that it is less invasive than conventional methods that require capture and handling. This may be especially advantageous for Great Gray Owls considering that they can be rather sensitive to handling and marking techniques.

Knowing the identity of individual Great Gray Owls could also be used to improve the accuracy of census estimates. Floaters or other territorial birds covering a large range can often be counted twice, causing inflated population estimates. Vocal individuality applied on a study of Cornrake (Crex crex) improved census estimates by 20-30% and revealed bias in traditional acoustic surveys caused by extremely vocal individuals (Peake and McGregor 2001). With a limited number of ARUs I was not able to effectively track the movements of owls through vocal individuality. However, my results did show that owls in some locations called significantly more than others. In areas with high densities of owls or with highly vocal individuals, applying vocal individuality could be useful to ensure more accurate census or density estimates. This approach may be beneficial, especially in parts of California where high densities of owls (0.66 pair/km²) have been reported in certain areas (Winter 1986).

One of the limitations of vocal individuality is that identification of individual birds cannot be easily determined while in the field. Post-processing the data, analyzing sonograms, and performing statistical analyses are necessary to achieve accurate identifications. Moreover, determining the age and condition of individuals would also be difficult. Despite these drawbacks, vocal individuality is gaining popularity in
conservation biology as a supplemental, non-invasive research tool and could be very useful for studies on Great Gray Owls.

ARU Advantages and Limitations

My results suggest that ARUs could be useful to collect vocalizations of Great Gray Owls and thus aid in determining presence/absence status. Great Gray Owls were successfully detected by ARUs at eight known nesting sites and two additional sites where their presence was previously undetermined. However, of the five sites where ARUs did not record Great Gray Owls, their presence was confirmed in at least one. While setting up an ARU at this meadow, I observed a Great Gray Owl foraging within 50 m. This meadow is only a few miles from another meadow that supported a nesting pair of Great Gray Owls. It is possible the nesting pair from a few miles away foraged at this meadow, and did not defend the area through territorial calling. ARUs at this location regularly recorded Great Horned Owls (*Bubo virginianus*), which may have also limited calling activity of Great Gray Owls. At the other four sites where ARUs did not record Great Gray Owls I never observed an owl during my evening ground surveys nor did forest service biologists during broadcast surveys.

In addition to determining occupancy, ARUs could be useful for a variety of other purposes. If high quality recordings are collected, they could be used for vocal individuality analysis. For example, 18 of the 25 individual owls in my data set were either partially or entirely represented by recordings collected via ARUs. The frequency
of prey deliveries to nests could potentially be calculated using ARUs. These events are often very loud and easily recorded by ARUs within 50 m of nests. During prey deliveries, it is also possible to determine if one or multiple chicks are calling. Acoustic data could be useful to gather chick survival estimates or to determine the time of fledging. Behavioral observations could also be generated from the use of ARUs. For example, in some instances I could hear a Great Horned Owl, howling coyotes (*Canis latrans*), snorting deer (*Odocoileus hemionus*), or other stimulus that may have triggered a calling response by Great Gray Owls.

As with any method, there are limitations that need to be considered when using an ARU. One of the limitations is the range at which an ARU can effectively record an owl. This range depends on several factors. Ambient noise such as wind, rain, planes, automobiles or other background noises can mask the target sound of interest. The immediate environment such as trees or thick vegetation also impacts how far the sound will carry. Even the volume of calls produced by an owl can vary considerably. With all these factors in mind, and judging from my ARU recording tests and field observations, I believe that my set up could typically record Great Gray Owl territorial calls at a range of 100-200 m. The begging calls of fledglings are much louder and could probably be recorded from 200-300 m away. However, for high quality recordings of adult owls that are intended for vocal individuality analysis, the recording range would probably need to be within 50 m.

The direction of the microphone can also influence recording capability. Although the microphones I used are omni-directional, they tend to produce slightly better results
when the sound is directly in front of the microphone. I arranged two microphones facing opposite directions in my ARU setup. During the controlled tests, this positioning would explain why I recorded slightly attenuated signals at 90 and 270 degrees. Although I don’t believe orientation of microphones in my ARUs largely affected the recording capability, if only one microphone was used there would likely be a more significant reduction in recording quality for sounds produced behind or to either side of the microphone.

One way to improve the recording capabilities would be to use higher quality microphones with better sensitivity in the low frequency range. Parabolic dishes could also be used to improve recording quality, however they would need to be extremely large to amplify the low frequency sounds typical of Great Gray Owls. Dishes would also increase the directionality of the microphone, thus reducing the signal for owls calling outside the line of sensitivity. Therefore, dishes would be most useful in situations where the location of the owl is known or when multiple dishes are arranged in several directions. Prior to deploying ARUs I attempted to determine areas with high calling activity to maximize my chances of recording owls with a limited number of ARUs. However, without prior knowledge of where calling activity is concentrated, several more ARUs may be needed to adequately sample a large area for Great Gray Owls.

Another limitation of using an ARU is that it is difficult to determine the exact location from where the sound was produced. Vocalizations given at a nest would only let researchers know that they are within a few hundred meters of the nest. With several birds calling simultaneously, it would also be difficult to estimate the number of
individuals calling within recording range of the ARU. One way to overcome these limitations would be to use multiple ARUs at each site. This approach would allow the location of nests and number of owls calling to be determined via triangulation. Despite the limitations and added expenses of ARUs, the overall costs could easily be offset from the savings of time and money required by additional field technicians.

In addition to monitoring Great Gray Owls, the use of ARUs could be useful for recording a variety of rare birds. For example, while reviewing the data collected by ARUs, I detected calls of several other species of owls. Great Horned Owls were detected by ARUs at nine sites, Northern Pygmy Owls (*Glaucidium gnoma*) were detected at five sites, Northern Saw Whet Owls were detected at three sites, California Spotted Owls (*Strix occidentalis occidentalis*) were detected at two sites, and Flammulated Owls (*Otus flammeolus*) were detected at one site. Due to the bandpass filter I applied prior to ARU analysis, I may have filtered out several of the vocalizations produced by these and potentially other species of owls. Therefore these numbers are probably underestimates of the total number of owls and species recorded by ARUs. Considering that Great Gray Owls are not as vocal as most species of owls, bioacoustic applications such as ARUs could probably be even more successful if efforts focused on louder or more vocally active birds.
Application to Current Survey Protocol

The most practical time period to deploy ARUs would be early in the breeding season from March to May when most adult owls are establishing and defending territories and thus regularly vocalizing (Johnsgard 2002). My results indicated that territorial calls from both males and females would be collected more frequently at this time than during any other time of the year. As the breeding season progressed, I found a significant decrease in territorial calling, especially among females. This behavior is consistent with owls in Oregon where the best response from playback occurred from late February through the end of April (Bryan and Forsman 1987). A disadvantage of placing ARUs this early in the season is that the weather is often very cold and wet. Rain and snow can increase ambient noise, thereby degrading the recording quality and making it more difficult to detect owl vocalizations. Furthermore, high snow levels often cause many roads to remain closed until later in the season, restricting access to several Great Gray Owl sites. An additional problem is that solar panels receive less light, potentially causing increased battery failures in ARUs.

Later in the breeding season from June to August would be another useful time period to deploy ARUs. This time would be beneficial because juvenile owls produce begging calls that are much louder and used more frequently than the adult territorial calls. These calls could be more easily recorded and they would be an excellent indicator of Great Gray Owl presence and nest success. After fledging, juveniles usually remain close to the nest in dense stands of trees (Bull and Henjum 1990). Placing ARUs after
chicks have fledged would allow managers to reduce disturbances during the nesting period and still provide a good indication if owls successfully reproduced in a given season. In the fall, vocal activity often increases again (Bull and Duncan 1993), offering another time to record both adult and juvenile owls. However, by this time many of the juveniles may have dispersed further away from the nest, making it difficult to determine where nesting occurred. Winter habitat usage could potentially be monitored through the use of ARUs. However, this may be less successful considering that most owls are not as vocal on wintering grounds or during the non-breeding season (Johnsgard 2002).

During the course of my study several nests were found and Great Gray Owls were apparently breeding in higher numbers than usual. This reproductive success may have benefited my study by facilitating the collection of recordings. In times of low food availability and or reduced breeding activity, it is possible that many owls will be less vocal and responsive to broadcasts. Nonetheless, due to the secretive nature of Great Gray Owls, the use of multiple research methods including bioacoustics would still be appealing to increase the probability of detection. In recent years, disturbances caused by human activity have been attributed to declines in Great Gray Owls at several historic sites in Yosemite (Wildman 1992, Maurer 1999) cited by (Riper and Wagtedonk 2006). In areas of concern such as these, or where access is limited, non-invasive bioacoustic approaches such as vocal individuality and ARUs could be a useful addition to current survey protocols and monitoring efforts.
REFERENCES CITED


DNDesign 2007. SonoBird Version 2.5.8. Arcata, California, USA.


