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A case study of male tawny owl (*Strix aluco*) vocalizations in South Korea: call feature, individuality, and the potential use for census

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EVOLUTION & MOLECULAR ECOLOGY

ABSTRACT
Vocal individuality has been used as a monitoring tool, and two criteria are a prerequisite: high variation among individuals and low variation within individuals, and vocal consistency within and across seasons. We examined individual variation in the territorial hoot calls of the tawny owl (*Strix aluco*) to discriminate between males and to assess a possible conservation technique that would allow for monitoring individuals within a study area. The territorial calls were recorded from five males in the Naejang Mountain National Park in South Korea during the breeding season in 2015 and 2016 and analyzed both quantitatively and qualitatively to determine the amount of variation within and between individuals. Our results showed that the territorial calls were specific to individuals within a population and that the acoustic distances between males living in the same territory during the two years were the smallest for the four nesting sites. Our results suggest that territorial calls of the tawny owls are individually identifiable over two years and that this acoustic technique can be useful for monitoring individual site fidelity.

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Acoustic distance; *Strix aluco*; territorial call; tawny owl; vocal individuality

Introduction

Animal communication is the process of exchanging information between a sender and receiver and works to keep animal societies together (Smith 1977). Many birds and some mammals (bats, cetaceans, and primates) commonly use vocal signals in reproduction and providing individual identity, status, and behavioral intentions (Kroodsma and Miller 1996; Oda 2002; Mishima et al. 2015; Toth and Parsons 2018). In recent decades, the structure and function of the vocal signals have attracted research interest in the field of ornithology (Garcia and Favaro 2017).

Bird vocalizations play a key role in communication among breeding pairs, chicks, and neighbors. Their communication is based on the distinctiveness of each individual vocalization (vocal individuality), which is a prerequisite for individual recognition as it minimizes confusion during vocal interactions (Wiley and Wiley 1977; Falls 1982; Ydenberg et al. 1988; Price 1999). Vocal individuality has been used as a monitoring tool to investigate the distribution and abundance of bird populations over both time and space (Terry et al. 2005). This monitoring tool provides the benefits of saving a lot of time and effort in capturing, marking, and handling individuals while reducing disturbance, stress, and injury (Hartwig 2005). The invasive approaches of traditional marking techniques or radiotelemetry are capable of producing detrimental effects on reproductive success and survivorship by multiple captures or the transmitters imposed on the birds (Sockman and Schwabl 2001). Thus, it is effective for birds that are sensitive or nocturnal, as well as endangered or threatened birds (Sung and Miller 2007).

To use vocal individuality effectively as a monitoring tool, two criteria should be satisfied when identifying and tracking individuals within a population over several years: high variation among individuals and little variation within individuals, and vocal consistency within and across seasons (Falls 1982; McGregor and Byle 1992; Terry et al. 2005). In the last few decades, vocal individuality has been extensively investigated in raptors, and in nocturnal owls in particular. Owl vocalizations are simple compared with passerine vocalizations. However, in several species, owl vocalizations were still sufficient for individual identification and to use for population monitoring, including in the following species: tawny owl (*Strix aluco*; Galeotti and Pavan 1991, Redpath 1994), pygmy owl (*Glaucidium passerinum*; Galeotti et al. 1993), Queen Charlotte saw-whet owl

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(*Aegolius acadicus*; Otter 1996), barred owl (*Strix varia*; Freeman 2000), African wood owl (*Strix woodfordii*; Delport et al. 2002), saw-whet owl (*Aegolius acadicus brooksi*; Holschuh and Otter 2005), scops owl (*Otus scops*; Denac and Trilar 2006), great gray owl (*Strix nebulosa*; Rognan et al. 2009), Guatemalan pygmy owl (*Glaucidium cobanense*; Eisermann and Howell 2011), eastern screech owl (*Megascops asio*; Nagy and Rockwell 2012), and sunda scops owl (*Otus lempiji*; Yee et al. 2016).

The tawny owl (*Strix aluco*) is a nocturnal raptor, extensively distributed throughout the Eurasian continent, from Britain in Western Europe and northwest Africa to East and South Asia, where 10–15 subspecies subspecies of *S. aluco* are recognized in East and South Asia (Voous and Cameron 1988). Plumage coloration varies widely among the subspecies, without other apparent differences in appearance. However, owls in cold and dry climates tend to have darker gray plumage (Galeotti and Cesaris 1996). The predominant territorial calls of the owls consist of three notes or syllables that are mostly highly stereotypical. The calls have been used to monitor populations, and revealed micro- and macro-geographical variation among populations or subspecies (Redpath 1994; Galeotti et al. 1996; Appleby and Redpath 1997; Galeotti and Sacchi 2001; Shekhovtsov and Sharikov 2015). Although the calls have the same basic pattern with a very simple three-note structure (Galeotti and Pavan 1991), many of the detailed temporal and frequency measurements of the call differed between males according to geographic area or habitat type. The tawny owls in Korea are recognized as *S. aluco ma* and inhabit well-developed, mixed hardwood forests. Nests were not evenly distributed in the hardwood forests and local populations are often small. Twenty-four owls were recorded in the 3rd National Natural Environment Survey conducted by the Ministry of Environment from 2010 to 2016 (NIE 2017), with more than 50 in total when including the owls in the national park. The vocalizations of this subspecies have been used to monitor their presence in potential habitats (Park et al. 2012).

In the present study, we analyzed the structure of the territorial hoot calls, with three aims: (1) to examine individual variation within a population; (2) to evaluate the potential for vocal individuality as a management tool (e.g. for monitoring long-term changes in populations); and (3) to provide the call information for further study, such as on the effects of habitats.

Materials and methods

Study area and recordings

We recorded the territorial hoot calls of male tawny owls in two sites of woodlands, approximately 6 km apart within the Naejang Mountain National Park (NMNP; 35° 24′ ~ 35°32′ N, 126°48′ ~ 126°56′ E) from 1 March to 30 June 2015 and 2016 (Figure 1). The elevation ranged

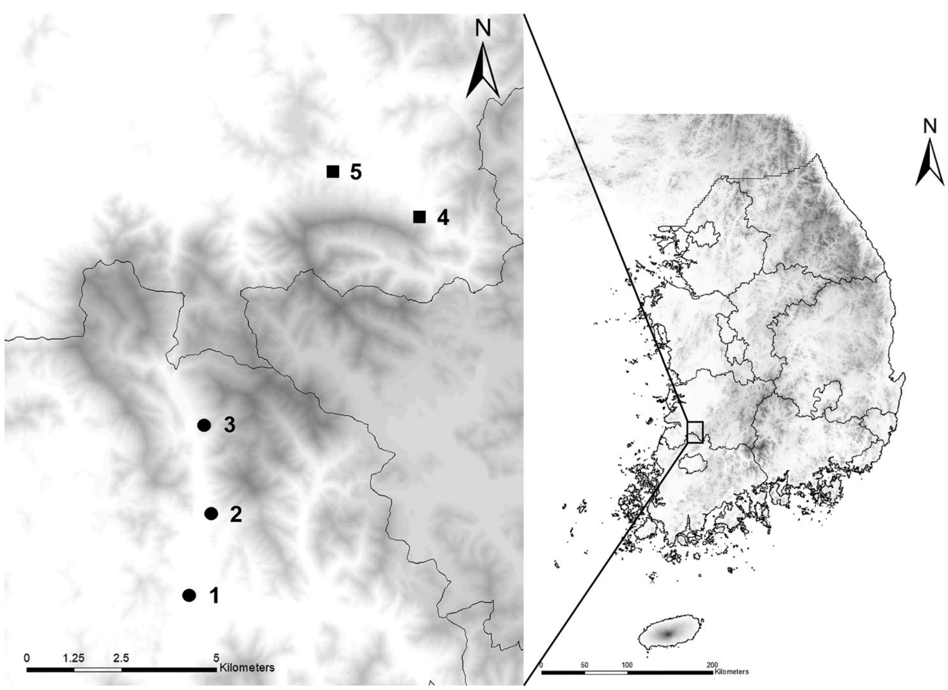

Figure 1. Localities of the five recording and nesting sites of male tawny owls in Naejang Mountain National Park during the breeding season in 2015 and 2016, where four out of five males remained in the same territory in both years except for a male of # 5 territory. The males of the two groups were located in separate mountainous areas 6 km apart.

from 165 up to 320 m. Coniferous and deciduous woods are dense over the breeding areas along small streams. A total of five owls were recorded in 2015, four of which were recorded again in 2016. We started recordings 1 h before sunset and continued recording for about three hours on calm and dry nights. In 2015, we repeatedly recorded the territorial calls of five males over the four months. The time interval between recordings in the same territory was on average 17.8 days (±14.1, range 1–46). We did not band or mark the subject birds, but we assumed we recorded the territorial calls from the same males because of the following reasons: 1) the males in the same territory during the breeding season remained the same, 2) we frequently observed males calling at the same time in distance during the two-year study period, and 3) even though we do not have the exact information on home ranges, we found that the calling point (or tree) was different from each territorial male. This assumption was also made in previous studies (Galeotti and Sacchi 2001; Yee et al. 2016). We recorded calls using a Marantz PMD 660 digital recorder and a Telinga Pro-8 DAT parabolic microphone with a flexible parabolic reflector (Telinga Microphones, Tobo, Sweden). Recordings were made as close to the vocal birds as possible, at approximately 5–50 m.

Sound analysis

We selected a total of 202 good quality calls (i.e. with low background noise; 5 males in 2015; 4 males in 2016, mean = 22.4 calls, range 5–54 calls) to minimize measurement errors. Each call was measured for temporal (duration of call, call parts, and interval) and frequency (high, low, and max frequency) variables (Figure 2). Spectrograms were produced using Raven Pro 1.4 with a 512 sample Fast Fourier Transform and a Hann smoothing window, resulting in a temporal resolution of 2 ms and a frequency resolution of 15 Hz. The temporal and frequency measurements used were similar to those of this species' calls, as described by Galeotti and Pavan (1991). Specifically, we measured the duration of the notes (D1, D2), inter-note intervals measured between the notes (DI1, DI2), total duration of the call (DT), duration of the frequency modulated initial portion of note 3 (first part of note 3, D3_1), tail duration (second part of note 3, D3_2), low, high, range, and max frequency of the call (FL, FH, FR, FM), low, high, range, and max frequency of the note 1 (FL1, FH1, FR1, FM1), max frequency of the note 2 (FM2), low, high, range, and max frequency of the first part of note 3 (FL3_1, FH3_1, FR3_1, FM3_1), low, high, range, and max frequency of the second part of note 3 (FL3_2, FH3_2, FR3_2, FM3_2).

Data analysis

We analyzed 128 calls from five territorial males recorded in 2015 to examine call variation within individuals and within a year. Prior to analysis, we reduced the 24 call variables to a smaller number of 12 variables by eliminating the variables with strong collinearity (Spearman's $r^2 > 0.70$; Zar 1999). We calculated the coefficient of variation (CV) for each variable within individuals, and an average within-individual coefficient of variation (CV_w) was computed. An among-individual coefficient of variation (CV_a) was calculated from those means. The ratio CV_a / mean CV_w provides a measure of individuality (Jouventin 1982; Bretagnolle 1989). Call measurement differences among males on the variables were estimated using one-way ANOVA, and then stepwise discriminant function analysis (DFA) was performed to determine the level of correct classification of the calls using the leave-one-out-cross-validation option in SPSS (v. 23.0; SPSS, Chicago, IL, USA) and to investigate the most important variable for correctly predicting individual owls.

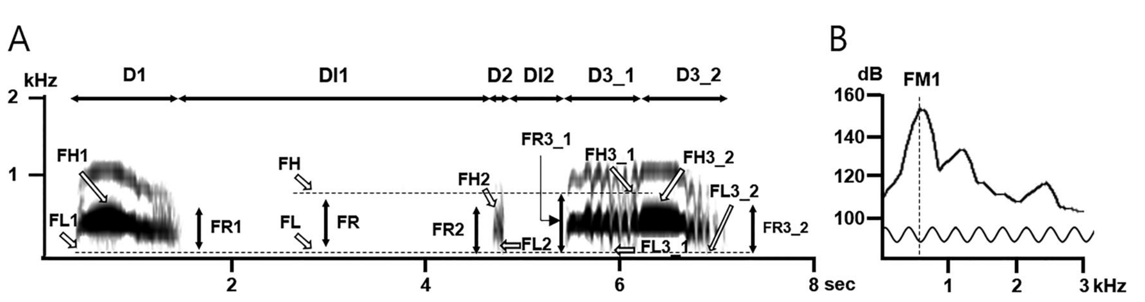

Figure 2. Examples of variables of male tawny owl calls used in the study. A – Duration of the notes (D1, D2), inter-note intervals measured between the notes (DI1, DI2), duration of first part of note 3 (D3_1), second part of note 3 (D3_2), low, high, and frequency range of the call (FL, FH, FR), low, high, and frequency range in note 1 (FL1, FH1, FR1), low, high, and frequency range in the first part of note 3 (FL3_1, FH3_1, FR3_1), low, high, and frequency range in the second part of note 3 (FL3_2, FH3_2, FR3_2); B – max frequency in note 1 (FM1).

Stepwise DFA was performed twice: first, on 128 calls collected in 2015 to identify territorial males; and second, on 202 calls from five males recorded in 2015 and from four recorded in 2016 that were in the same locations as in 2015 to assess the similarity between years among them. To compare the calls from the two years, all DF scores were standardized across both years; Euclidean distances (also termed 'acoustic distance' after Nelson 1992) were measured for each bird following Gilbert et al. (2002). Thus, the degree of similarity between each pair of birds across the two years was obtained by comparing the Euclidean distances among them.

Data were analyzed using SPSS Statistics software package. $\alpha = 0.05$ was used to determine the significance of the results. Numerical data are presented as mean ± SD.

Results

A total of 128 calls from five males in 2015 were analyzed, and the means (±SD) and CVs of 12 variables are summarized in Table 1. All 12 variables significantly differed among individual owls. The ratio CV_a / mean CV_w of all variables showed a value > 1, implying there was greater variation among individuals than within individuals. Thus, all variables were considered to be useful for individual identification. In particular, individual features were apparent in the duration and high frequency of the third note (D3_1, D3_2, FM3_1, FH3_1), where the high CV-ratios corresponded to the high F values obtained by one-way ANOVAs. The DFA on the data collected in 2015 correctly classified 96.9% of the calls within a season. Of the 128 calls, 122 (95.3%) were attributed to the correct individual using the leave-one-out-cross-validation method. Of the six calls misclassified, two calls were assigned to #3 individual, and the remaining four calls were assigned to each four individual (Figure 3). All four discriminant functions generated were highly significant, with the first two accounting for 72.4% of the variance (Table 2). Stepwise discrimination selected eight of the 12 variables, where the variables that contributed the most to the discrimination (F-value) were selected in the following order: D3_2 ($F =$ 44.5), FM3_1 ($F = 39.9$), D3_1 ($F = 38.8$), DI1 ($F = 21.3$), D1 ($F = 17.2$), FH3_1 ($F = 12.7$), D2 ($F = 6.0$), FL1 ($F = 5.7$). D1 and D2 contributed to the first discriminant function, while FH3_1, FM3_1, and FL1 were of importance for the second, D3_1 and D3_2 for the third function, and DI1 for the fourth function.

The acoustic distance of the males studied in 2016 in the same territory from the ones studied in 2015 was the smallest among all possible matching pairs (Table 3). The acoustic distances of males within the same territory were significantly shorter than those of males with different territories ($F = 11.36$, df = 1, 18, $p = 0.003$), where the mean acoustic distance of males within the same territory was 1.60 (±0.75, ranged 0.63 ∼ 2.45) and males with different territories was 3.09 (±0.80, ranged 1.86 ∼ 4.77).

Table 1. Summary of territorial call variables from 128 calls among five male owls in 2015.

Variable[a]	Mean ± SD	CV_a	CV_w	CV-ratio[b]	F values[c]
D1	0.72 ± 0.09	0.13	0.08	1.56	32.04
D2	0.09 ± 0.03	0.27	0.20	1.31	9.83
D3_1	0.68 ± 0.11	0.17	0.07	2.22	77.38
D3_2	0.70 ± 0.21	0.30	0.15	2.02	80.61
DI1	3.87 ± 0.42	0.11	0.07	1.45	49.60
DI2	0.58 ± 0.05	0.09	0.07	1.35	23.75
FH1	804.8 ± 38.3	0.05	0.04	1.36	31.37
FH3_1	816.5 ± 38.1	0.05	0.03	1.57	44.59
FL1	320.7 ± 48.0	0.15	0.11	1.31	17.68
FM1	591.8 ± 43.6	0.07	0.05	1.64	15.18
FM3_1	575.7 ± 32.7	0.06	0.02	3.48	44.74
FR3_1	502.2 ± 65.2	0.13	0.11	1.22	13.39

Note: A total of 24 measured call variables were reduced to 12 variables by eliminating the variables with strong collinearity (Spearman's $r^2 > 0.70$; Zar 1999).
[a]Frequency variables (*F*-) in Hz and temporal variables (*D*-) in msec.
[b]CV is reported as a percentage and CV − ratio = (CVa/CVw) (see methods).
[c]All *F* values were highly significant ($p < 0.001$; df = 4, 123).

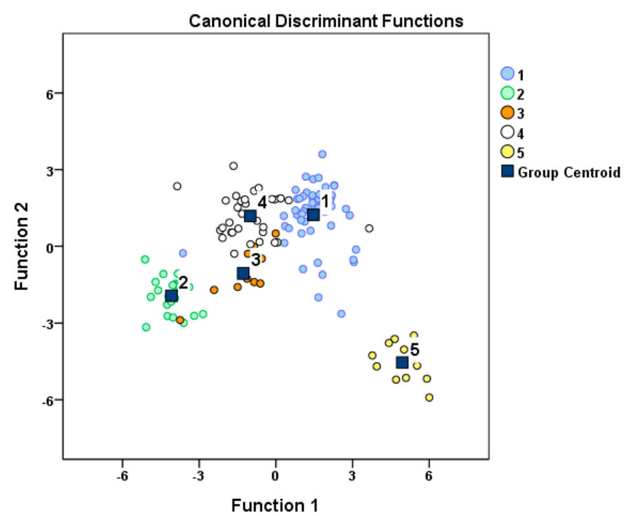

Figure 3. Scatterplot of the first two discriminant function scores, with group centroids from territorial hoot calls of the five tawny owl males in 2015. Each mark is a separate call.

Table 2. Eigenvalues of the four discriminant functions, % variance, and canonical correlations performed on 128 calls from five male owls.

Function	Eigenvalue	% of variance	Cumulative %	Canonical correlation
1	6.503	46.5	46.5	0.931
2	3.619	25.9	72.4	0.885
3	2.712	19.4	91.8	0.855
4	1.140	8.2	100.0	0.730

Table 3. Call similarity between five males in 2015 and four males in 2016, obtained by Euclidian distance measurement.

		2016			
	A	B	C	D	
2015	A	**0.63**	2.08	2.98	2.75
	B	2.69	**2.45**	3.02	4.01
	C	3.37	2.49	**1.61**	2.75
	D	1.86	2.89	2.30	**1.70**
	E	4.07	4.01	3.39	4.77

Note: Letters represent males in nesting sites and the same sites have the lowest distance for all four sites (in bold).

In addition to quantitative analysis, male calls help with individual identification through visual analysis on the sonograms, even though a certain degree of intra-individual variation exists (Figure 4).

Discussion

Our results revealed that territorial calls of male tawny owls were individually identifiable from quantitative and qualitative analyses and that individuals could be traced within a population over two years. All 12 variables from the calls significantly differed among the five males, and the CV-ratios (CV_a / mean CV_w) were higher than 1.0, ranging from 1.3 to 3.5, indicating that all 12 variables can be used as information to identify individuals. The CV-ratios were similar to those reported in various subspecies; 1.9–4.1 in the eastern European subspecies (*S. a. aluco*) and 0.9–4.8 in the Caucasian subspecies (*S. a. wilkonskii*; Shekhovtsov and Sharikov 2015). DFA produced a high classification rate (96.9%) from a set of nine variables. The high success rate of classification appeared to be similar to that in European populations of tawny owls (98%–100%) (Galeotti and Pavan 1991; Galeotti et al. 1996; Appleby and Redpath 1997). Thus, these results indicate that the calls of tawny owls have sufficient specific characteristics to allow for tracking individuals within the population over several years.

The CV-ratio, ANOVA, and DFA analyses in this study revealed that many of the temporal and frequency measures in the calls play a role in discriminating individuals. In particular, the third note of the calls

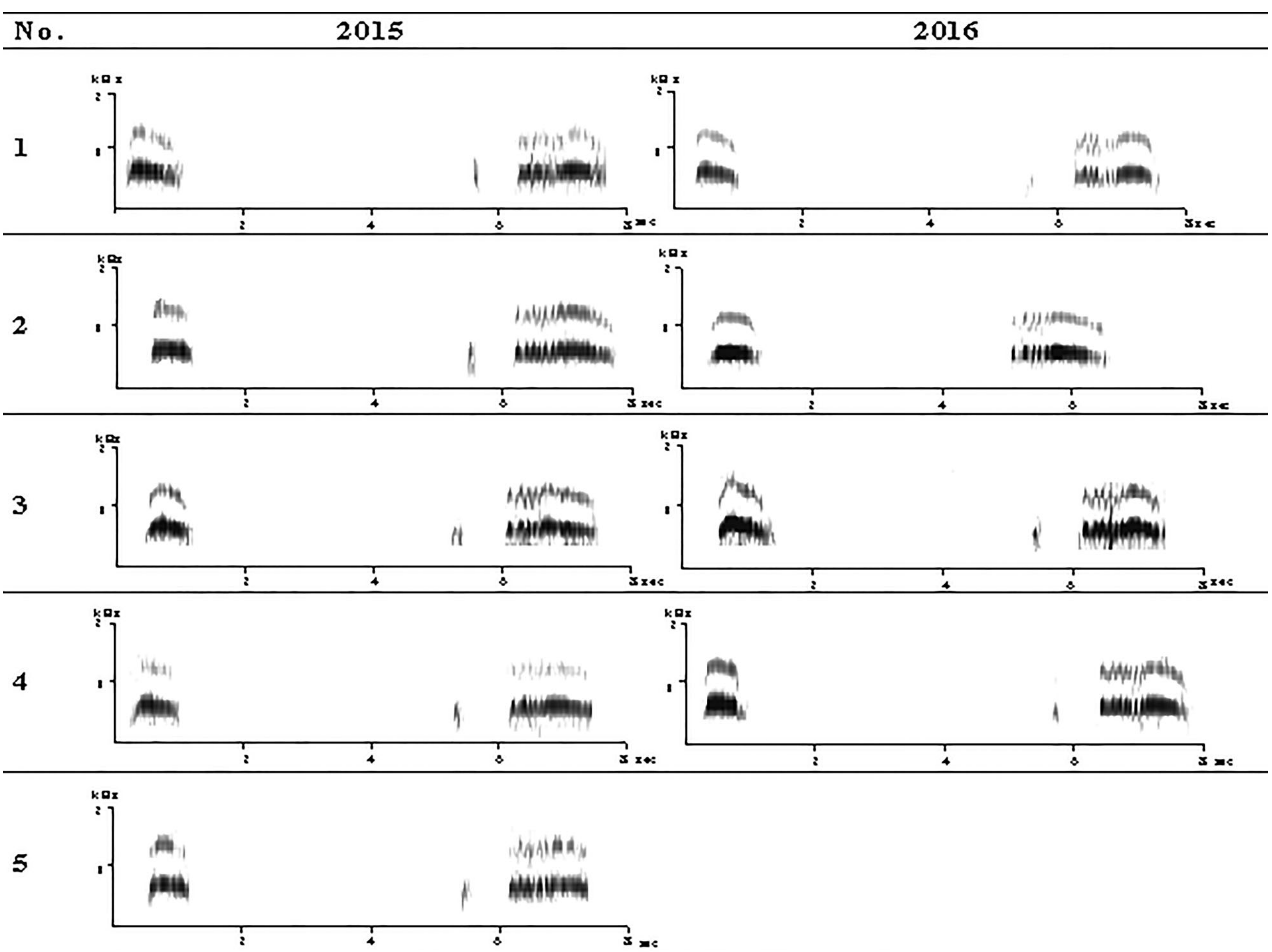

Figure 4. Sonograms of territorial hoot calls recorded within the same territory for two years, 2015 and 2016. Each pair shows similarities in note 1 and note 3 by visual analysis.

(D3_2, FM3_1, and D3_1) is very important for individual discrimination. In tawny owl populations in Europe, the duration of the first part of note 3 (D3_1) served to discriminate individuals in the northern Italian populations (Galeotti and Pavan 1991) and in the Italian and English populations (Galeotti et al. 1996). However, Appleby and Redpath (1997) demonstrated that the duration of the first part of the third note (D3_1) was only important as an individual 'identifier' in males of woodland habitats, not in males from farmlands. Thus, the third note in the calls was best at differentiating these individuals, consistent with both our findings and other population studies. There have also been reports that the first note is stereotypic (Galeotti and Pavan 1991) and played a role in differences among three English populations (Appleby and Redpath 1997).

In addition, call similarity (mean acoustic distance) showed that calls from males that shared a territory between years were more similar compared to those from different territories. The method of acoustic distance is useful for comparing calls of new individuals while DFA may only be applicable for particular individuals that are already known (Terry et al. 2005). Several studies have used this method to test nest fidelity between years in corncrake (*Crex crex*, Peake et al. 1998), great bitterns (*Botaurus stellaris*, Gilbert et al. 2002), and eagle-owls (*Bubo bubo*, Grava et al. 2008). However, a recent study by Peri (2018) instead suggested the use of the visual spectrogram comparison method with field information for a census of tawny owl populations at high densities.

Tawny owl calls have two useful attributes that allow for monitoring. First, the use of territorial calls has many benefits for identifying individual birds. For example, it requires no time and energy for capturing and handling compared to band and radio-telemetry. In addition, it can be used to monitor shy or nocturnal birds, such as owls (McGregor et al. 2000). Tawny owl males are highly territorial through the year, with maximum vocal activity from February to May and August to October (Southern 1970). Furthermore, the calls are loud and are given in bouts lasting from a few minutes to several hours. Thus, the calls can easily be recorded anytime over the breeding season and used to determine whether the calls are from the same territorial males.

The second useful attribute of tawny owl calls is that selected call parameters make individuals traceable over years. We showed possible nest site fidelity in breeding males from year to year using eight variables selected through stepwise DFA. Until now, the territorial calls of male tawny owls showed call stability only over 6-month intervals for some variables (Galeotti and Pavan 1991). Long-term call consistency had not been previously reported in this species. However, wood owl (*Strix woodfordii*) calls show long-term stability for at least 12 years for certain call variables, though individual calls in different sampling periods did not always overlap exactly due to measurement effects (e.g. distance) and environmental effects (e.g. perch site; Delport et al. 2002). These limitations require 1) banded individuals, 2) recording high-quality calls in an appropriate environment (e.g. quiet nights with little wind) and within a certain distance, and 3) using call variables with little variation within males to allow for quantitative analysis.

Conclusions

This study showed that the territorial hoot calls of the tawny owl are individually specific, and we could potentially use them as a monitoring tool, as expected for a nocturnal species. The calls were easily obtained over the breeding season and the call identity can be traced using visual and statistical analyses. In particular, the third note of the calls commonly plays a role in individual discrimination. The acoustic distance of each male living in the same territory during the two years was the smallest for the four nesting sites, which suggest that the same males occupy the same territories between the two years. Long-term studies with more territorial owners are needed to make tools useful for acoustic monitoring of the tawny owl. In addition, making a catalog of sonograms for the territorial call of the tawny owl would help in conservation efforts for this endangered species in South Korea.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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