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Territory monitoring of Tawny Owls *Strix aluco* using playback calls is a reliable population monitoring method

Al Vrezec[a] and Irena Bertoncelj[b]

[a]National Institute of Biology, Ljubljana, Slovenia; [b]Department of Agricultural Ecology and Natural Resources, Agricultural Institute of Slovenia, Ljubljana, Slovenia

ABSTRACT

Capsule: Territory monitoring using playback of calls is a reliable approach for assessing population trends of Tawny Owls *Strix aluco*, particularly when human resources are limited or survey areas are difficult to access.

Aims: To explore whether response calls of Tawny Owls towards broadcast conspecific and heterospecific male owl playback calls would provide similar estimates of population size and trends over time as nest-box monitoring.

Methods: Between 1998 and 2017, Tawny Owls were monitored in a predominantly forested area of central Slovenia. Throughout the year, territories were monitored using a playback protocol comprising silent listening during five minutes before and after ten minutes of broadcasting male Tawny Owl. Seasonal variation in response rate was examined and results from the playback method were compared to data on occupancy rate of nest-boxes.

Results: Territory monitoring using playback calls showed a similar direction of population trends as nest-box monitoring but a different population dynamics pattern. The overall response rate in occupied territories to conspecific playback calls at first visits was 70%. This was significantly higher than for heterospecific playback calls and the frequency of spontaneous vocalizations. The response rate to conspecific playback calls when including two visits rose to nearly 90%. There was no difference in response rate between seasons. The average time to respond to conspecific playback calls was five minutes.

Conclusions: Compared to nest-box monitoring of breeding pairs, territory monitoring of breeding and non-breeding Tawny Owls using playback provides a robust and cost-effective method for monitoring. We recommend conducting territory monitoring between January and May during the breeding season, with two visits to each site using conspecific playback of territorial male hoot calls using the 5 + 10 + 5 minutes protocol.

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A review of raptor monitoring schemes in Europe (Derlink *et al.* 2018) reported far fewer monitoring schemes for nocturnal raptors compared to diurnal raptors. Also, at the species level, differences are large, with 52 existing monitoring schemes per species reported for the Common Kestrel *Falco tinnunculus* and the Peregrine Falcon *Falco peregrinus*, as the two most widely monitored diurnal raptors, and only 26 existing monitoring schemes for the Tawny Owl *Strix aluco*, as the most widely monitored nocturnal raptor. These discrepancies can be explained by the elusiveness of owls due to their nocturnal activity and more labour-intensive monitoring methods. Owl monitoring was, in general, reported as one of the weaknesses of existing European raptor monitoring schemes, and the development of best practice methods and international standards were reported among the main priorities for future international collaborations (Vrezec *et al.* 2012). The Tawny Owl, as the most widespread and numerous owl species in Europe (Petty & Saurola 1997), and with the bulk of its population confined to Europe (Mikkola 2013), is a useful species for which to test standard survey approaches at pan-European level.

Several methodological approaches have been developed to survey and monitor Tawny Owl populations. These can be divided into two categories: territory and nest monitoring (Saurola 2009). According to a review of raptor monitoring schemes in Europe (Derlink *et al.* 2018), 81% of Tawny Owl monitoring schemes use territory monitoring, 71% use nest monitoring, but the majority of schemes (52%) use both methods (calculated from the dataset of Derlink *et al.* 2018). Hardey *et al.* (2013) proposed a combination of both approaches where the first step is to identify active territories followed by the location of

CONTACT Al Vrezec al.vrezec@nib.si National Institute of Biology, Večna pot 111, Ljubljana SI-1000, Slovenia

nests so that detailed monitoring of the breeding attempts can be achieved. In practice, nest monitoring is rarely conducted by searching for nests in natural nesting sites (Southern 1970, Zuberogoitia & Campos 1998, Avotinš 2004), although breeding activity could be assessed by counting begging young (Sunde & Markussen 2005). More frequently it is conducted by examination of installed artificial nest-boxes, which in most circumstances have low influence on overall breeding density in the Tawny Owl due to its high adaptability in selection of breeding sites (Southern 1970, Petty *et al.* 1994, Avotinš 2004). In addition to assessment of breeding success, nest-boxes provide an opportunity for monitoring other ecological aspects such as diet, survival, colour variation, as well as prevalence of diseases, parasites and environmental contaminants (Appleby *et al.* 1999a, Ahrens *et al.* 2011, Grašytė *et al.* 2016, 2017, Saurola & Francis 2018). On the other hand, nest monitoring is labour-intensive when conducted at a large scale, especially in remote and inaccessible areas. Monitoring of nest-box occupancy could also lead to biases in areas with high availability of suitable natural nesting sites with low usage of nest-boxes by owls or by using different types of nest-boxes (Sacchi *et al.* 2004, Lambrechts *et al.* 2012, Hardey *et al.* 2013).

Territory monitoring could present a more cost-effective approach for application at European-wide scale to widen the geographical coverage of population monitoring (currently the Tawny Owl is monitored in only 32% of European countries in which it breeds; Derlink *et al.* 2018). Territory monitoring of the Tawny Owl can be conducted in various ways: by searching for remains (pellets, feathers); by listening for spontaneous owl vocalizations; or by recording territorial owl responses to broadcasting of playback calls – the so-called playback method (Southern 1970, Hirons 1985, Petty *et al.* 1994, Zuberogoitia & Campos 1998, Avotinš 2004). Among listed methods, the playback method has been shown to be the most efficient for surveying Tawny Owl territories and to require the lowest field effort (Zuberogoitia & Martínez Clement 2000), but has so far not been compared directly to the actual breeding population of the species obtained from nest-box monitoring.

Both male and female territorial Tawny Owls respond rapidly to playback calls (Appleby *et al.* 1999b). The playback method for this species was first proposed by Hirons (1985), and has since been used in many census and ecological studies across Europe (Sánchez-Zapata & Calvo 1999, Sergio *et al.* 2007, Silva *et al.* 2012, Żmihorski *et al.* 2012). For the survey protocol, most of the studies referred to Redpath (1994) and Jędrzejewski *et al.* (1996) who, however, proposed quite different survey protocols. Redpath (1994) proposed a 30-minute survey protocol, which included four consecutive one-minute playback sessions interrupted by five-minute periods of silent listening for owl response calls. Jędrzejewski *et al.* (1996) used a shorter period of three-minute playback broadcasting followed by five minutes of silent listening for a response. In addition, some studies used different playback broadcasting durations, ranging between 2 and 20 minutes (Redpath *et al.* 2000, Vrezec 2003, Bolboacă *et al.* 2015, Worthington-Hill & Conway 2017), but all included periods of silent listening for owl responses. Tawny Owls have been shown to respond to playback at relatively high rates with 48% of birds responding within the first 5 minutes and 94% within 30 minutes (Redpath 1994). However, at the northern distribution limit of the species, Sunde *et al.* (2001) estimated only a 28% response rate within 30 minutes. The most cited protocol, Redpath (1994), indeed demonstrated that 94% of territorial pairs can be detected within 30 minutes, but human-imitated owl calls were used and not a real recorded owl call. For playback calls, most studies used recordings of a male hoot, while female calls, male and female duets or owlet calls were rarely used (Jędrzejewski *et al.* 1996, Zuberogoitia & Campos 1998, Appleby *et al.* 1999b, Worthington-Hill & Conway 2017). Regarding seasonality, Redpath (1994) proposed that surveys should be conducted between September and April, taking into account both autumn/winter territorial periods and the beginning of the breeding period in spring. However, in most census studies, surveys were conducted between August and May (Jędrzejewski *et al.* 1996, Salvati & Ranazzi 2002, Vrezec 2003, Silva *et al.* 2012), while Zuberogoitia & Martínez Clement (2000) claimed no seasonal variability in Tawny Owl response to playback. Audibility range of the playback was estimated to be up to 200–600 m (Jędrzejewski *et al.* 1996, Appleby *et al.* 1999b, Silva *et al.* 2012), and in some studies vocalizing owls at the distance above 500 or 600 m were excluded from analysis, since the survey point was not within territory limits (Vrezec 2003, Silva *et al.* 2012, Bolboacă *et al.* 2015). All surveys were conducted on calm, dry nights, since Tawny Owl acoustic communication is significantly lower in wet weather (Lengagne & Slater 2002).

In general, owls have also been shown to respond to calls of other coexisting owl species (Enriquez & Salazar 1997, Bosakowski & Smith 1998, Boal & Bibles 2001, Vrh & Vrezec 2006). For example, Vrh & Vrezec (2006) showed that Ural Owls *Strix uralensis* responded to Tawny Owl playback calls at a similar rate compared to conspecific playback calls. Many long-term monitoring schemes include several owl species (Derlink *et al.* 2018), but to what extent data on heterospecific response can be used for monitoring purposes, and whether different owl species surveys could be combined for monitoring purposes, has yet to be evaluated.

The great diversity of Tawny Owl survey protocols indicates a lack of consensus on the use of playback and its cost-efficiency. Survey protocols using playback have not yet been systematically optimized in the field. Our aim was to test and optimize the cost-efficiency of this monitoring method. In order to show its application in a long-term monitoring program, we compared its results with simultaneous nest-box occupancy monitoring of the same Tawny Owl population. To evaluate and optimize playback, we examined several parameters: the effects of season on Tawny Owl vocal response; the duration of playback and the number of required visits to the same survey site to allow reliable abundance estimation; and the potential to use heterospecific responses of territorial Tawny Owls to playback calls of coexisting owl species (in our study to Ural Owl and Tengmalm's Owl *Aegolius funereus*) in the monitoring survey protocols.

Methods

Study area

We carried out our study on Mount Krim (14°25′E 45°58′N), 10 km south of Ljubljana city, central Slovenia. The area is 140 km^2, of which 77% is covered by forest, 20% by agriculture and forest clearings and 3% by human settlements, with the latter mainly situated in the lowlands (Figure 1). Mount Krim is a mountain of modest height in the North Dinaric Alps, ranging from 290 to 1108 m above sea level. The slopes of Mount Krim are covered predominantly with mixed temperate beech forest (*Omphalodo-Fagetum*) with Beech *Fagus sylvatica* and Silver Fir *Abies alba* as dominant tree species (Vrezec 2003). Most of the forest was in an old growth phase, with trees with trunks of diameter greater than 30 cm at breast height, and therefore provided enough suitable natural tree cavities that could be used as nest sites by Tawny Owls. Coniferous plantations of Norway Spruce *Picea abies* were located mainly on the lower parts of the mountain and around settlements, where forestry was most intensive. Clearings were small and dispersed, mostly around the settlements. The area was populated by many raptor species and, among nocturnal forest raptors, the most abundant were Tawny, Ural and Tengmalm's Owls (Vrezec & Tome 2004).

Playback survey of Tawny Owl territories

Surveys were conducted over a network of survey points selected randomly from the bottom of Mount Krim to the top, and stratified according to the area of altitudinal belts (Figure 1). Survey points were spaced 700–2150 m apart and were surveyed annually (Vrezec & Tome 2004). For monitoring of Tawny Owl territories we used a playback method comprising five minutes of silent listening for spontaneous vocalization, followed by ten minutes of broadcasting a male territorial call and concluded by five minutes of silent listening for any delayed response calls (Vrezec 2003). If the owl responded before playback broadcast had ended, we stopped the playback. For playback we used different available recordings of male territorial calls (Roché & Mebs 1989, Trilar 2002, Pelz 2003, own recordings) with the frequency of 4–5 hoots per minute in Tawny Owl, 4–6 hoots per minute in Ural Owl and with continuous call in Tengmalm's Owl. Playback was broadcast using different kinds of equipment: cassette player or MP3 player combined with a wired or wireless loudspeaker with loudness of the playback broadcast set at around 80–90 dB. We broadcast playback calls of only one owl species per territory on each visit to avoid side effects of different playback calls on the responsiveness of owls (Crozier *et al.* 2005, 2006, Lourenço *et al.* 2013). 'Territory' was defined as an exclusive area defended by an owl pair, or occasionally by a single owl, against intra- and interspecific competitors during the breeding season (Brown 1969, Murray 1971). We considered a territory occupied if at any of the visits we recorded the Tawny Owl response in the current breeding season within a radius of 500 m from the survey point.

To explore seasonal variability in the vocal activity of territorial Tawny Owls we used data on spontaneous vocalization and the number of positive responses to playback calls of three owl species from 30 occupied Tawny Owl territories that were visited at least 10 times in at least two different survey years (the survey was conducted between 1998 and 2005 and in 2011). We pooled the number of responses within season: spring (March to May), summer (June to August), autumn (September to November) and winter (December to February). We compared the number of positive responses (spontaneous calling or response to playback calls of three owl species) in different seasons by fitting a Poisson generalized linear mixed model (GLMM) using the *lme4* package in R (Bates *et al.* 2015). The species of the playback call and survey year were included as fixed factors and we specified territory as a random factor. The number of visits to the territory

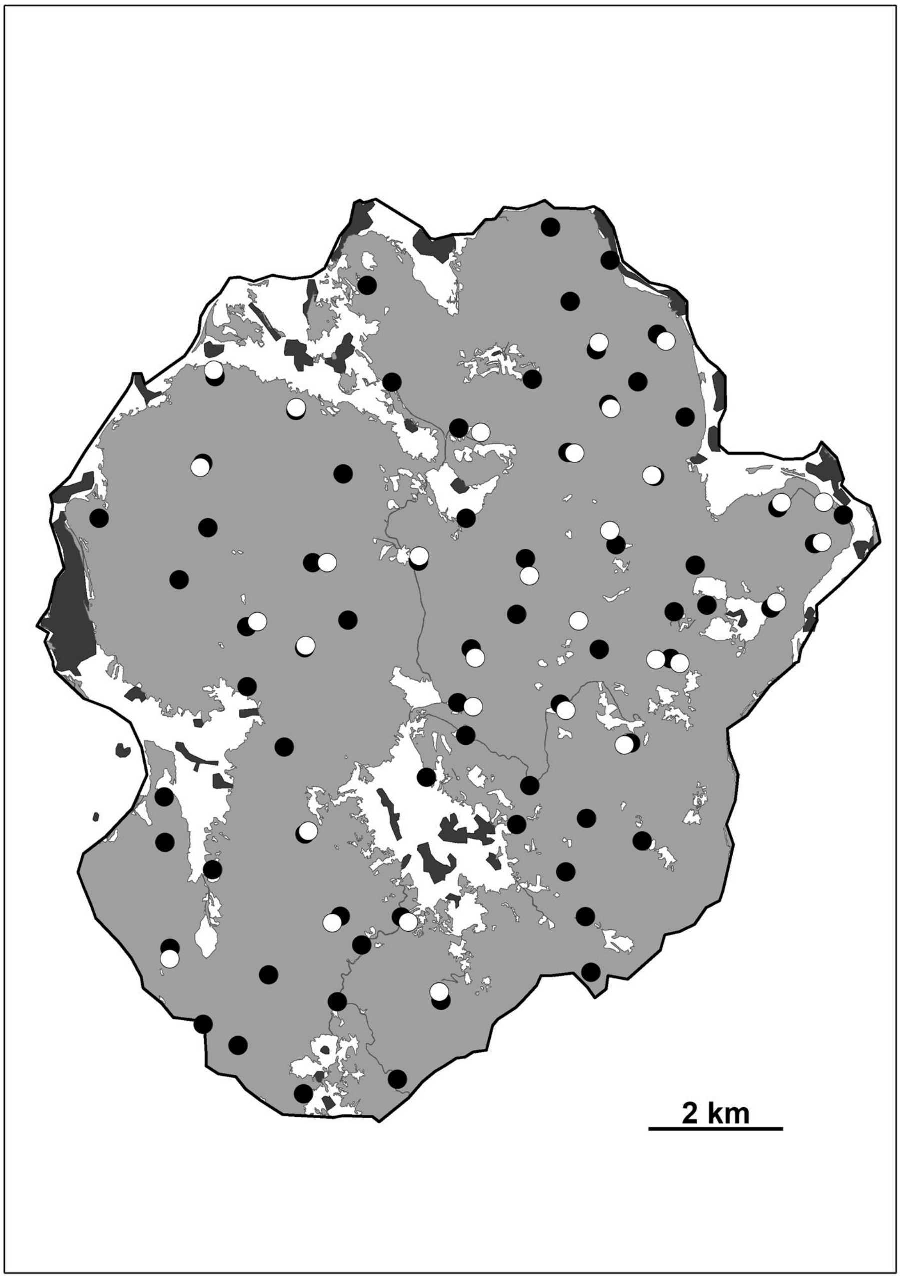

Figure 1. The study area of Mount Krim (140 km^2) with the distribution of survey points (black dots) and nest-boxes (white dots) for monitoring of the Tawny Owl population. The light grey denotes the area covered with forest, dark grey areas are settlements, and white areas are clearings. Note that not all survey points and nest-boxes were surveyed in the whole period 1998–2017 (see text for details).

(log transformed) was included as an offset thus making the dependant variable effectively a proportion. Estimated marginal means of the number of positive responses derived from the model were calculated using R software package *emmeans* (Lenth 2016).

In the spring months (March, April, May) of 2004, 2005 and 2011 we recorded the time to response (in seconds) from the start of the broadcasting of playback calls of territorial Tawny Owls in order to determine optimal duration of the survey. We analysed 55 responses obtained at 28 territories. If two territorial males/pairs responded at the same site, only the response of the first was considered. To compare the time to response of Tawny Owls to playback calls of conspecific Ural and Tengmalm's Owls, and to compare the time to respond among different years, we fitted a linear mixed model (LMM) with time to response as the dependent variable, and with year and broadcast owl species as fixed factors and territory as a random factor. Estimated marginal means of the time to respond to playback calls of the three different owl species derived from the model were calculated using R software package *emmeans* (Lenth 2016).

In order to estimate how many survey visits to the same territory were needed to obtain a response of a territorial Tawny Owl we used a subset of playback monitoring data collected between 1998 and 2005 and for 2011 at territories that were visited in the winter and spring months between January and May. We stopped visiting a territory when the first response was obtained and only occupied territories were included in the analysis. We conducted 90 survey sessions using the 5 + 10 + 5 minute playback method broadcasting Tawny Owl calls. A maximum of five visits to the same territory were conducted and a cumulative percentage of detected Tawny Owl territories at each consecutive visit was calculated for each of the eight survey years. We calculated the mean (±1 standard error) of the cumulative percentage of detected territories per year at each of consecutive visits.

Comparison of population trend between playback and nest-box monitoring

Between 2004 and 2017 we set up a total of 32 nest-boxes (for details see Vrezec *et al.* 2018) with neighbouring nest-boxes spaced at least 900 m apart to ensure independence (Figure 1). We checked between 23 and 29 nest-boxes in the spring of each year in the period between 2004 and 2017 for the presence of breeding owls. Simultaneously, each year we checked the presence of territorial pairs of Tawny Owls at between 25 and 64 territories in the Krim area including territories with the nest-boxes. We also visited each territory twice per season to undertake the 5 + 10 + 5 minute playback method using Tawny Owl calls. This study design enables a comparison of long-term occupancy trends in the population of Tawny Owl revealed by each of the two monitoring methods.

To estimate population trends obtained in the period between 2004 and 2017 in both simultaneously conducted monitoring methods we used log-linear trend models based on the assumption of independent Poisson distributions calculated using TRIM3 (Pannekoek & Van Strien 2001, van der Meij 2013). We used the linear trend option with overdispersion and serial correlation, and missing data were taken into account since not all survey points were checked in each year. To further compare the occupancy rate over the 14 years, recorded by the two monitoring methods, we fitted several general additive models (GAM) with Poisson distribution using the number of territorial pairs (identified from playback call responses) or the number of occupied nest-boxes as the response variable and the log transformed number of visited territories/examined nest-boxes as offsets. In the first GAM we fitted a smoother for time (years) and included the monitoring method as a fixed covariate. In the second GAM we fitted two separate smoothers for time; one for each monitoring method. In the third GAM we included a common smoother for time (combining all data regardless of the monitoring method), a separate smoother for time for playback territory monitoring data only and the monitoring method as a fixed factor, thus effectively including an interaction term for the effect of time and monitoring method (Zuur *et al.* 2009). The second smoother represents the deviation of temporal variation of owl occupancy rate estimated using playback monitoring from the overall temporal variation of owl occupancy rate. All GAM models were executed in the *mgcv* R software package (Wood 2017).

Results

Seasonal dynamics in vocal activity

We compared seasonal variability in the vocal activity of Tawny Owls at 30 territories, which were in total visited on 1682 occasions in different months with spontaneous calling or positive response to conspecific/heterospecific playback obtained on 296 occasions (17.6%). Overall, the vocal response of territorial Tawny Owls was significantly higher to conspecific playback calls compared with spontaneous vocalization or response to heterospecific calls of two sympatric owl species (Table 1, Figure 2). Tawny Owls responded more readily to playback calls of Tengmalm's Owl than calls of Ural Owl and the rate of spontaneous vocalization was significantly lower than the response to any of the playback calls (Figure 2).

Some non-significant differences in the vocal activity of Tawny Owls among seasons were present, with the highest vocal activity in autumn (Table 1, Figure 3). The standard errors of the mean number of positive responses were smaller in spring compared to other seasons (Figure 3).

Table 1. Results of a GLMM examining effects of owl species playback call, season and year on the number of positive responses of territorial Tawny Owls in the Mount Krim area. Tawny Owl is the reference species for comparison of effects of owl species

	B ± se	*P* value (df)
Owl species		<0.001 (3)
Tawny Owl	–	
Tengmalm's Owl	−0.46 ± 0.17	
Ural Owl	−1.01 ± 0.19	
Spontaneous vocalization	−1.85 ± 0.16	
Season		0.096
Year		0.475

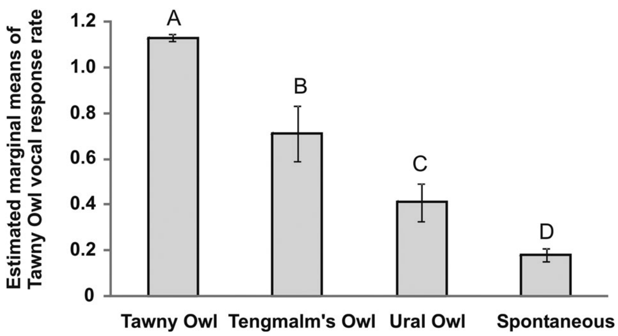

Figure 2. Estimated marginal means (± se) of the number of positive responses of territorial Tawny Owls to conspecific and heterospecific playback calls (Ural Owl and Tengmalm's Owl) and for spontaneous vocalization. Means were obtained from a GLMM taking the effects of survey year and territory into account. Columns marked with different letters differ significantly according to the GLMM.

Our data did not show any differences in the vocal activity of Tawny Owls among years (Table 1).

Duration of the playback to evoke a response

The time to response of the territorial Tawny Owl pairs to conspecific, Ural and Tengmalm's Owl playback calls was on average 5 minutes (300 seconds) and did not differ significantly between the playback calls of different owl species (LMM, df = 2, $\chi^2 = 0.5$, $P = 0.78$; Figure 4). Of 55 measured responses, the majority ($n = 30$) were evoked by conspecific playbacks where the time to respond was between 1.0 and 13.5 minutes, with only

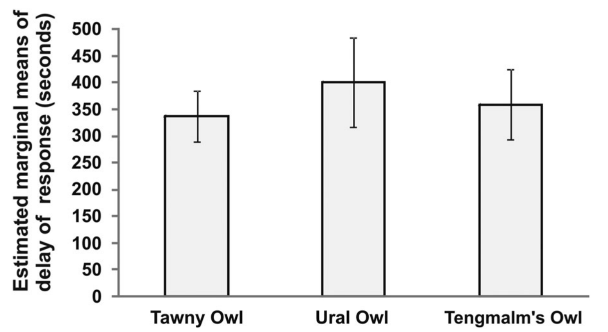

Figure 4. Estimated marginal means (± se) of the time to response (in seconds) of territorial Tawny Owls following the start of broadcasting of the playback calls of three different owl species. Means were obtained from a LMM taking the effects of survey year and territory into account.

20% of the responses recorded after 10 minutes. There was no significant difference in response times between years (LMM, df = 2, $\chi^2 = 0.7$, $P = 0.70$).

How many survey repeats are needed?

During winter and spring months, the highest proportion of Tawny Owl territorial individuals responded to playback broadcast at the first visit to their territory with an annual average of 70.6% of pairs detected (Figure 5). The annual average cumulative percentage of detected pairs on the second, third and fourth visits was 86.3%, 94.8% and 96.8%, respectively (Figure 5). The latter was the highest value reached after four visits and the fifth visit did not increase it.

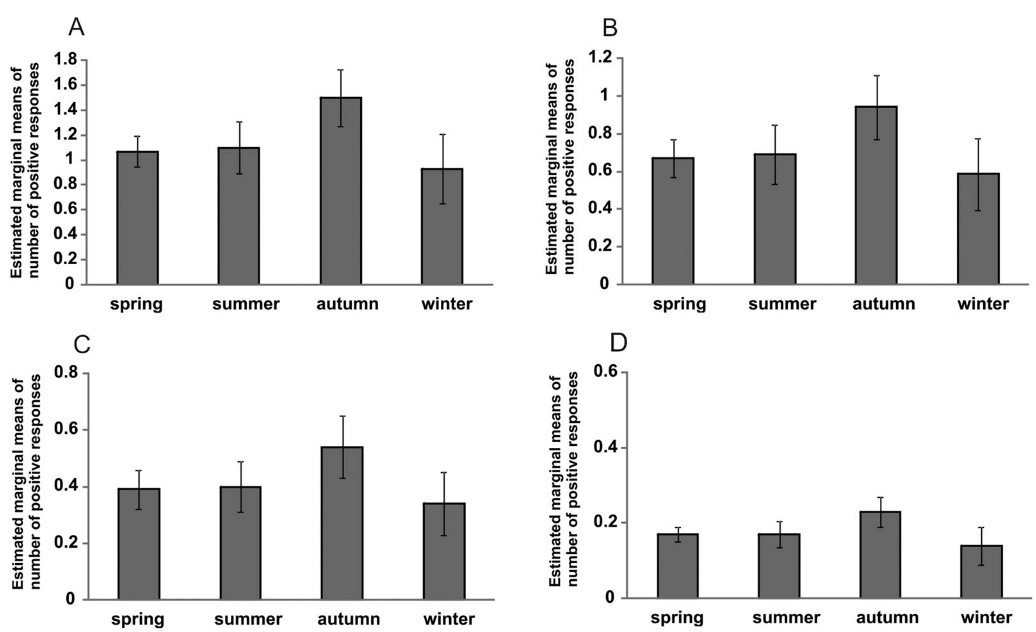

Figure 3. Estimated marginal means (± se) of seasonal fluctuation in the number of positive responses of territorial Tawny Owls to the playback of conspecific (A) and heterospecific territorial calls, Tengmalm's Owl (B) and Ural Owl (C), compared to spontaneous unprovoked vocalization (D). Means were obtained from a GLMM taking the effects of survey year and territory into account.

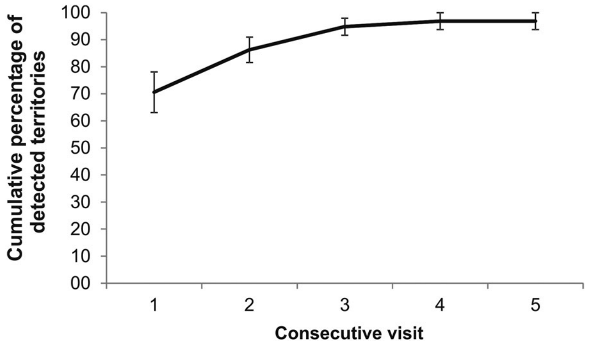

Figure 5. Mean (± se) of cumulative percentage of detected Tawny Owl territories in different years at each consecutive visit using a monitoring method with playback of conspecific male calls.

Playback territory monitoring versus nest-box monitoring

A total of 71 simultaneous checks of the presence of a Tawny Owl territorial pair (using playback) and of occupancy of the nest-boxes were carried out on 15 sites where owls bred in the nest-box at least once between 2004 and 2017. In this 14-year period, some sites with nest-boxes were used in multiple years, 1 to 13 times per site, depending on the territorial and breeding activity of owls (sites were excluded for years, when no owls were present). Out of 33 pairs with confirmed breeding in the nest-boxes, 98.3 ± 5.8% (mean ± se) responded to the playback call. On the other hand, out of 70 territorial pairs with a confirmed response to the playback call, only 45.3 ± 28.0% (mean ± se) bred in a nest-box.

During the period between 2004 and 2017, playback monitoring of the Tawny Owl population showed considerable fluctuation in the percentage of occupied territories, with a minimum of 28.0% (in 2006 and 2007) and a maximum of 56.3% (in 2011), and overall mean (± se) of 42.1 ± 2.9%. The nest-box monitoring in the same period showed a minimum of 3.8% (in 2013) and a maximum of 35.7% (in 2017) of the nest-boxes were occupied, with an overall mean (± se) of 17.4 ± 2.3%. Log-linear trend models in TRIM estimated for both survey methods were not rejected (goodness-of-fit for playback territory monitoring LR = 169.8, df = 283, $P = 1.00$; Goodness-of-fit for nest-box monitoring LR = 115.9, df = 171, $P = 1.00$). However, the overall slope model for playback monitoring indicated a significant trend, showing a moderate increase in the population (+4.5 ± 1.9% annually, $P < 0.05$), while the trend estimate for nest-box monitoring was uncertain (+2.7 ± 4.4% annually).

A GAM including a common smoother for temporal changes and the monitoring method (playback or nest-box) as a fixed factor explained 77.1% of deviance and showed a significant effect of time (edf = 8.7, $\chi^2 = 46.9$, $P < 0.001$) and monitoring method (df = 1, $\chi^2 = 136.1$, $P < 0.001$) on owl occupancy rates. The second GAM including two separate smoothers for temporal changes (one for each monitoring method) explained 87.4% of deviance and showed significant temporal changes in owl occupancy rates for both playback (edf = 9.3, $\chi^2 = 52.2$, $P < 0.001$) and nest-box (edf = 3.3, $\chi^2 = 27.11$, $P < 0.001$) monitoring methods (Figure 6).

The third GAM examined differences in temporal variation of owl occupancy rates shown by the two monitoring methods and explained 91.5% of deviance. A highly significant second (playback method only) smoother (edf = 8.7, $\chi^2 = 150.6.2$, $P < 0.001$) indicated that temporal variation in owl occupancy rates

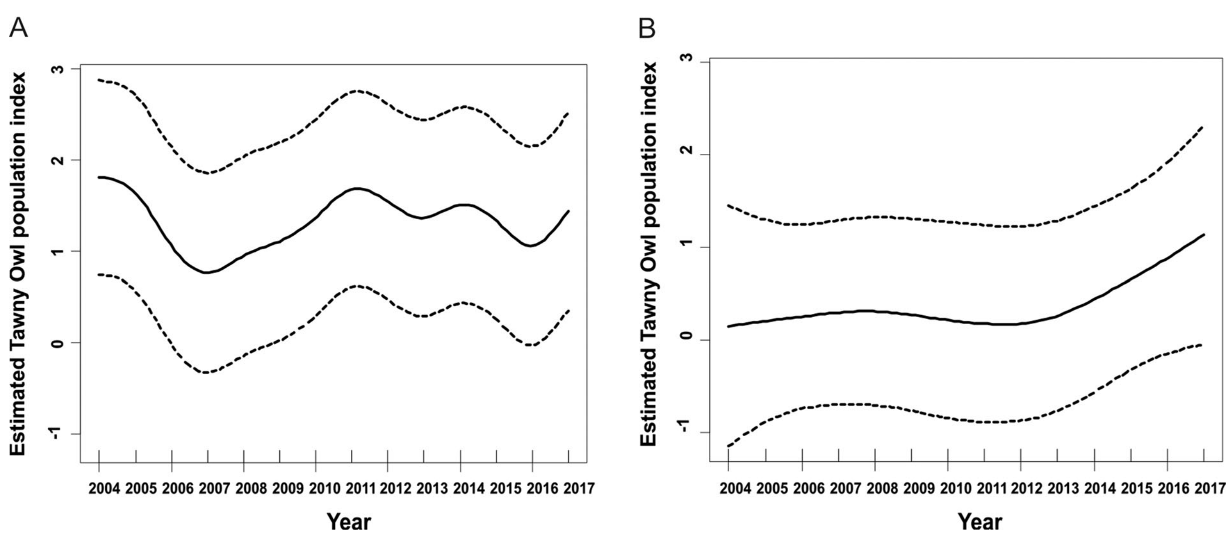

Figure 6. Estimated smoothing curves with 95% confidence intervals (dashed lines) of Tawny Owl population indices through time (between 2004 and 2017) estimated using (A) playback and (B) nest-box monitoring methods.

estimated using the playback method differs from overall temporal variation estimated using a common smoother combining data from both monitoring methods.

Discussion

Our comparison of long-term linear trends of Tawny Owl population estimated using playback and nest-box monitoring methods showed the same direction of the trend which is in accordance with the previous conclusions of Saurola (2009). However, according to our analysis the two monitoring methods showed different population dynamics patterns in time. Almost all breeding pairs were highly responsive to playback, indicating high detection probability of breeding Tawny Owls. On the other hand, a low proportion of territorial birds actually bred in the nest-boxes. Territory monitoring using playback thus also included a high proportion (55%) of territorial pairs with uncertain breeding status (presumably comprising both non-breeders and undetected breeders) which nevertheless represent at least potential breeding birds, which might breed in good years with high prey availability. Therefore, we conclude that the population dynamics patterns in time showed by the two monitoring methods reflect different segments of the Tawny Owl population responding to different environmental conditions. The number of territories depends on overall population size and habitat availability, but the number of breeding pairs depends on population size and habitat availability, but also on prey availability and fitness of owls for breeding in the current season. Although the actual breeding population measured using nest-boxes indicates current breeding activity of owls, the future development of the population could be estimated from the non-breeding territorial part of the population as a source of pairs for the breeding population.

Due to higher percentage of detected territories, the territory monitoring using playback method appeared to be more cost-beneficial and required lower field effort for producing reliable population trend estimates incorporating both breeding and non-breeding parts of the population of territorial and at least potentially breeding owls. Thus, the playback methods provide a more robust and representative method for monitoring Tawny Owls than monitoring of nest-box occupancy, which addresses the actual breeding population only. However, for more advanced monitoring schemes, a combination of both methods is recommended to be conducted simultaneously for producing more reliable forecasts of future population change.

In order to propose cost-effective playback protocols for the monitoring of Tawny Owl populations, we tested several aspects of the protocol set out by previous studies (see Introduction for overview). Although the Tawny Owl is one of the most vocal owl species in Europe (Mikkola 1983), silent listening for spontaneous owl calls alone is not enough to gather sufficient data for monitoring purposes (Zuberogoitia & Martínez Clement 2000, Worthington-Hill & Conway 2017). By adding 10 minutes of conspecific playback broadcast, a detection rate of 70% of occupied territories can be reached in one visit, or nearly 90% in just two visits. By adding a third visit, the detection rate can be increased to 95%, but we consider this increase rate too small to be cost-effective for monitoring purposes. We thus suggest that at least two visits to each territory should be made during the breeding season to obtain reliable data on established territories.

Tawny Owls responded to playback on average 5 minutes after the start of the broadcast, and 80% of the responses were recorded within the first 10 minutes. This response time may be variable according to habitat conditions, and in small forest fragments the response time was reported to be shorter than in large forested areas (Redpath 1994). However, our data were obtained in a large forest complex and are in accordance with similar studies reporting that within 10 minutes of playback about 70–85% of territories can be detected (Redpath 1994, Freeman *et al.* 2006, Worthington-Hill & Conway 2017). It also appears that the time to respond does not vary significantly between years, at least at the regional scale, therefore using constant broadcasting time in different years will provide consistent data quality.

When seeking to improve detection rates there are two possibilities: to prolong playback broadcasting or to make more survey visits. For detection of 90% or more of Tawny Owl territories, Redpath (1994) and Freeman *et al.* (2006) reported the need for 25 minutes and Worthington-Hill & Conway (2017) for 15 minutes of playback broadcasting. Here, we propose that a higher detection rate can be achieved by increasing the number of survey visits and using a constant 10 minutes playback broadcast, thus dispersing survey efforts to different nights with different survey conditions (e.g. weather, owl vocal activity and so on). We found that a detection rate of nearly 90% can then be achieved using only two survey visits. Additionally, Tawny Owls responded to heterospecific playbacks of sympatric owl species in a similar response time, but with a lower response rate. By using heterospecific playbacks, a detection rate similar to that in response to conspecific playback calls would not be achieved. Despite this, when conducting multi-species monitoring of owl assemblages, it is cost-effective to combine the results of playback surveys of different owl species due to heterospecific responses to optimize survey costs by decreasing the number of survey visits needed for detection of occupied territories. However, our study was conducted at a single site with specific structure of owl assemblage, so the pattern of heterospecific responses of Tawny Owls should be tested further in different habitats where it coexists with different owl species. We suggest playback of only one species is used on each visit to the territory and not several, due to the effects of broadcasting of superior owl competitor species on response rate of territorial individuals (Crozier *et al.* 2005, 2006, Lourenço *et al.* 2013).

Redpath (1994) proposed a quite complicated 30-minute survey procedure with a series of 1-minute intervals of imitating calls interrupted by 5-minute intervals of silent listening. He used human imitation of owl hoots for provoking a response (not playback recordings of original owl hoots) but imitation of owl hoots is no longer needed for owl surveys due to the current availability of high quality recordings. Freeman *et al.* (2006), Hardey *et al.* (2013) and Worthington-Hill & Conway (2017) recently still proposed similarly complicated protocols but using playback calls rather than human imitations, while several other studies used continuous playback, broadcast without silent interruptions in between (Jędrzejewski *et al.* 1996, Zuberogoitia & Martínez Clement 2000, Redpath *et al.* 2000, Vrezec 2003, Silva *et al.* 2012). We have shown that with continuous playback with a frequency of 4–5 hoots per minute (similar to Redpath (1994) with 4 imitated hoots per minute) we could obtain similar response rates as were achieved using the more complex protocols (Redpath 1994, Freeman *et al.* 2006, Worthington-Hill & Conway 2017). We therefore conclude that the use of complex playback protocols are not required for Tawny Owl surveys and that simplification to one playback session followed by a period of silent listening is sufficient. Furthermore, when thinking about establishment pan-European monitoring scheme for the Tawny Owl, we expect a variety of equipment will be used with high quality equipment producing clearer and louder sound. In our study we used different equipment throughout the study but set at approximately the same loudness according to the naked human ear, but we did not test the effect of loudness on owl response rate. However, previous studies on other owl species have shown loudness of the playback broadcasting had low or no effect on owl response rate (Dreiss *et al.* 2017). Despite this we propose that when applying the playback method for pan-European Tawny Owl monitoring the effect of sound emission parameters (loudness and quality of recording) on owl response rate should be tested in further studies, as well as some bioacoustically relevant parameters which indicate size, competitiveness and fitness of males such as frequency of calling, pitch and length of the call (Galeotti & Pavan 1993, Galeotti 1998, Galeotti & Sacchi 2001). This will enable the setting of standard protocols by obtaining comparable population data throughout the species range.

Tawny Owls responded to playback all year round, with the highest response rate recorded in autumn, particularly in September and October, and differences between periods were only marginal. However, the autumn period seems to be more variable in response rate compared to the spring breeding period. Furthermore, the spring period coincides with breeding activity (Southern 1970) and is thus more relevant in terms of breeding population estimation and monitoring. We therefore propose that monitoring of the breeding population is best conducted from January to May. However, due to similar year-round response rate of Tawny Owls, the surveys using playback could also be conducted in autumn if long-term monitoring implementation is more feasible then due to other capacity limitations.

In conclusion, we have summarized our recommended survey protocol for conducting long-term territory monitoring of Tawny Owl populations in Table 2. We propose 10 minutes of conspecific playback broadcasting, which enables a 70% detection rate after one visit and increases to nearly 90% after two visits. Heterospecific responses of Tawny Owls to the playbacks of other owl species monitored in the study area can be used to supplement surveys using conspecific playbacks, but not to replace them. Our study also did not evaluate the minimum number of

Table 2. Recommended protocol for Tawny Owl territory monitoring using the playback of conspecific male calls.

Parameter	Suggested values
Distance between survey points	1000 m or more
Playback	Male territorial call (4–5 hoots per minute)
Silence before playback	5 minutes
Playback duration	10 minutes (in applying 2 visits)/25 minutes (in applying 1 visit)
Silence after playback	5 minutes (if no response recorded earlier)
Number of visits	1 to 2 (2 recommended)
Period	January–May (optionally August–November)
Distance of vocalizing owls considered in the survey	about 500 m from survey point
Weather conditions	Calm nights without rain

survey points needed to obtain reliable trend estimates, which are dependent on overall Tawny Owl density in the area.

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