Tracking movements of *Athene* owls: the application of North American experiences to Europe

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Abstract

Tracking movements of Athene *owls: the application of North American experiences to Europe*.— Migration and dispersal are important ecological and evolutionary processes and understanding them is a requirement for species conservation efforts. Burrowing owl, *Athene cunicularia*, the North American equivalent of little owl, *A. noctua,* is migratory in the northern parts of its range. In Canada their populations have declined dramatically and are classified as endangered. Movements of burrowing owls have been studied using banding (ringing), VHF telemetry, stable isotopes, genetics (DNA), geolocators and satellite transmitters. Geolocators and satellite transmitters provide the most reliable information about migrations but to operate successfully they are both dependent upon exposure to sunlight, which can be limited for nocturnal owls. Ringing encounters and winter influxes of little owls into Spain, including the Balearic Islands, indicate that some migration movement may be occurring. A stable isotope study could determine if wintering owls in southern Europe includes owls originating in northern Europe.

Key words: *Athene*, Movements, Migration, Dispersal, Techniques.

Resumen

Seguimiento de los desplazamiento de los mochuelos del género Athene*: aplicación de las experiencias norteamericanas a Europa*.— Migración y dispersión son procesos importantes desde el punto de vista de la ecología y la evolución, y entenderlos es un requisito importante para los programas de conservación de las especies. El mochuelo de madriguera, *Athene cunicularia*, el equivalente norteamericano del mochuelo europeo, *A. noctua,* es migratorio en las zonas septentrionales de su área de acción. En Canadá sus poblaciones han disminuido de forma notoria, y se han clasificado como amenazadas. Se han estudiado los desplazamientos del mochuelo de madriguera utilizando el anillado, la telemetría VHF, los isótopos estables, la genética (ADN), los geolocalizadores y los transmisores por satélite. Los geolocalizadores y los transmisores por satélite proporcionan la información más fiable sobre las migraciones, pero su buen funcionamiento depende de la exposición a la luz solar, que es limitada en el caso de las rapaces nocturnas. Los hallazgos de animales anillados, y los flujos migratorios invernales del mochuelo común hacia España, incluyendo las Islas Baleares, indican que pueden estarse dando desplazamientos migratorios. Un estudio mediante isótopos estables podría determinar si entre los mochuelos que invernan en el sur de Europa, se incluyen mochuelos del norte de Europa.

Palabras clave: Athene, Desplazamientos, Migración, Dispersión, Técnicas.

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Introduction

Migration and dispersal are important ecological and evolutionary processes and understanding them is a requirement for species conservation efforts (Faaborg et al., 2010). Additionally, species specific information on winter range, winter habitat use and survival are needed to fully develop and implement conservation action (Terborgh, 1989; Stutchbury, 2007). Despite the importance of movement issues on the conservation of avian species, knowledge about avian migration and dispersal is still patchy (Faaborg et al., 2010).

Burrowing owl (*Athene cunicularia*) is the Western Hemisphere equivalent of little owl (*A. noctua*). The western burrowing owl (*A. cunicularia hypugaea)*, which occurs in western North America, is totally migratory in the northern parts of its range and partially in the southern parts (Haug et al., 1993). In Europe, most researchers treat the little owl as a non–migrant species (Van Nieuwenhuyse et al., 2008), but some records indicate this premise should be examined more closely. Clavell (2002) documented 23 records of little owl on the Balearic Islands in the western Mediterranean Sea in autumn, which is consistent with a southward migration. Ferrer et al. (1994) stated the little owl was accidental on these islands and that one owl ringed in Germany was encountered on Menorca. Thus, the possibility that little owls are migratory in at least portions of its range should not be dismissed. These records are similar to autumn and winter ringing records of burrowing owls from Canada that indicated where this migratory species was wintering.

Migration movements may be more pronounced in certain age or sex groups. Ogonowski & Conway (2009) found the probability of burrowing owls in Arizona migrating decreased with age and was less likely for males than females. Also the migratory tendency could change from one year to the next. Local natal and breeding dispersal has been demonstrated in little owls (Van Nieuwenhuyse et al., 2008). If little owls are found to migrate longer distances, then evidence of longer range dispersal should also be considered. Dispersal of one–year old owls, natal dispersal, is particularly likely since these birds are setting up nests for the first time. Breeding dispersal, adult movements between years, may be less likely since adults have established a nest once and may have become resident at that site. However, short–distance breeding dispersal has been documented in non–migrant populations of burrowing owls in California (Rosier et al., 2006) and long distance breeding dispersal has been documented in Canadian burrowing owls (Duxbury, 2004; Holroyd et al., 2011).

In Canada, burrowing owls are migratory because of the severe weather conditions across their range in winter. The Canadian population has declined dramatically and the species is classified as Endangered (Wiggins, 2006). The prairie population in Canada declined 95% in the 1990s (Holroyd et al., 2001) and has remained below 5% of the 1990 numbers since then. In the past twenty years, studies in Canada have focused on productivity, diet, and foraging behaviours in an effort to determine limiting factors that could be implicated in the declines (Wellicome, 2000; Todd, 2001; Sissons, 2003; Shyry, 2005). However, mortality away from the breeding season (Terborgh, 1980) and inter–year dispersal could also be implicated in the declines (Macdonald & Johnson, 2001). Thus, studies of burrowing owls after they depart the breeding grounds were undertaken. Until 1990, the winter destinations of burrowing owls from Canada were unknown. Ringing recoveries on migration indicated they were headed south–easterly across the Great Plains of the USA (James, 1992). In order to undertake studies of burrowing owls' winter survival and ecology the movements and destinations of owls after the breeding season had to be determined.

This article reviews the techniques used in Canada to track migrant and dispersing burrowing owls, applications that could be useful to determine if little owls are migratory. Movements of burrowing owls have been studied using ringing (James, 1992; Holroyd et al., 2011), VHF telemetry (Holroyd et al., 2010), stable isotopes (Duxbury, 2004), genetics (DNA; Macias–Duarte, 2011), geolocators and satellite transmitters. This article reviews the results of these various techniques, their logistical issues and expenses, and their possible applications to study little owl movements. The information regarding the geolocators and satellite transmitters is published here for the first time.

Ringing

The attachment of metal rings on the legs of birds has a long history and the resulting encounters have been analyzed for many species. Encounters are defined by the North American Bird Banding Office as any handling of a banded bird, dead or alive subsequent to the initial banding (http://www.pwrc.usgs.gov/bbl/manual/glossary.cfm). As of the end of 2009, a total of 38,242 burrowing owls had been ringed in North America, of which 11,611 were ringed in Canada (L. Laurin, Canadian Bird Banding Office). Reported encounters of ringed owls have been few (Holroyd et al., 2010), but the number of encounters has increased in recent years due to three factors: extensive use of alpha–numeric coloured, anodized aluminum, rivet rings (Acraft Sign and Nameplate Co., Edmonton, AB, Canada), digital photography, which enables the reading of the alpha–numeric codes of color rings, and internet communication. Until recently, there was not an easy way for Mexicans to report rings but the inclusion of Mexico in a 1–800 free call reporting system and the wider use of the internet may help.

By 1987 only three encounters with burrowing owls ringed in prairie Canada had been recorded in the USA and none in Mexico, and none in winter; the encounters were in spring and autumn and all in the US Great Plains (James, 1992). At that time, 1.0% of 2,512 owls ringed in the US had been encountered between November–February, *i.e.* winter. By 2003, some 20,597 burrowing owls had been ringed in Canada, US and Mexico but they resulted in only

260 (1.3%) encounters (Harman & Barclay, 2007). Of these encounters, 102 were in California (2.2% of 4,708 ringed). Thus only 158 encounters occurred from 15,889 owls ringed in US and Canada outside California for a return rate of 0.99%.

The low encounter rate of ringed burrowing owls provided limited information on their seasonal movements. The lack of winter recoveries led James (1992) to hypothesize that Canadian owls were exhibiting leap–frog migration over US wintering grounds to winter in Mexico. By 2008, 10 ring encounters from the Great Plains of Canada had defined a migration route south into Texas but still none in Mexico (Holroyd et al., 2010). Sixteen encounters from British Columbia showed a western migration route into the three western US states (ibid). Only six interstate movements had been documented in California by 2003 (Harman & Barclay, 2007). Despite a major effort to ring over 20,000 owls, little was known about their wintering grounds.

Ring encounters provided some clues regarding natal and breeding dispersal. In 2002, encounter data from the US Bird Banding Office provided records of 43 summer encounters of burrowing owls. Of these, nine were restricted to the non–migratory Florida population, and 23 were in the same year as ringing. The 11 remaining summer encounters were one to three years after ringing with an average movement of 127 km. If these owls were breeding at each site, this distance provided a first estimate of inter–annual dispersal. This estimate does not include zero dispersal distances since many researchers do not report owls returning to their ringing site to the Bird Banding Office.

In 2003, a unique burrowing owl ring encounter provided an unusual breeding dispersal record. A female with a vascularized brood patch, a mate and one young ringed in Tucson, Arizona, USA on 30 April 2003 was encountered 1,860 km north in southern Saskatchewan, Canada, in July of the same year with a new male and seven nestlings (Holroyd et al., 2011). Two intensive studies, the use of colour rings and an observant biologist led to this record long–distance nesting dispersal.

Ring encounters provide additional information, such as causes of death. For example, in California, 7.4% were caught due to an injury, 4.6% were shot, 4.6% were found dead in buildings, 2.8% were hit by vehicles, and 1.9% were hit by aircraft, but 48% were found dead due to unknown causes (Harman & Barclay, 2007). These causes of death are biased due to the likelihood of the public finding an owl. Any owl that dies underground will not be found and if they are eaten by a raptor they are less likely to be found than if they hit a building or aircraft. The known causes of death cannot therefore be accepted to represent the true mortality factors.

In conclusion, ringing of owls in Canada failed to identify the owls' wintering grounds, gave a biased view of the causes of death, and provided very limited information on dispersal. The ringing of over 38,000 owls did provide some information on migration routes from Canada, and also on wintering locations of British Columbia and USA owls (Holroyd et al., 2010).

VHF telemetry

VHF telemetry was used to locate wintering burrowing owls that had transmitters attached in Canada the previous summer (Holroyd et al., 2010). The transmitters were initially used for 2–month foraging studies of burrowing owls in Canada (Todd, 2001; Sissons, 2003; Shyry, 2005). With slightly larger batteries the transmitters were manufactured to last 6–9 months (Holohil Systems Ltd., Newmarket, Ontario, Canada). A fixed wing aircraft flew for a total of 167.7 hours over southern Texas and north–eastern and central Mexico during three winters (1997–2000), resulting in nine of 125 transmitters being located. Three of these encounters were in Mexico, the first indication that burrowing owls from Canada wintered south of the US (see Holroyd et al., 2010 for more details).

These nine records were effectively ring encounters but they had the added advantage that the owls were located while they were still present at their wintering sites. It was therefore possible to gather specific information about habitat and winter movements of the owls (Holroyd et al., 2010). The habitat information indicated burrowing owls utilize a much broader range of habitats in winter than they do in summer. They wintered in shrubland with access to grassland or cropland where they forage; they were not limited to open grassland as they are in Canada in summer. Indeed, the telemetry offered an unbiased search method that explored all habitat types in an area. This aerial telemetry provided valuable insights into the distribution and habitats of burrowing owls from Canada in winter. However, it was costly and the encounter rate was low, likely hindered by the nocturnal, burrow dwelling habits of the species.

Genetics (DNA)

The analysis of the genetic structure of burrowing owl populations in western North America has led to the conclusion that the populations are panmictic, with no structure to the populations' genetics (Korfanta et al., 2005; Desmond et al., 2001). Canadian samples were included in a broader and more intensive analysis of burrowing owl genetics that reached a similar conclusion (Macias–Duarte, 2011). This new study confirmed that western burrowing owls were genetically similar. However, the apparently isolated population around Mexico City was genetically distinct, and confirmed that the population on Isla Clarion, 700 km west of the tip of Baja California Sur, Mexico in the Pacific Ocean had been isolated for about 200,000 years (Macias–Duarte, 2011). Although genetics will not identify current movements of owls, it is a powerful tool to interpret past movements and isolation of burrowing owls. All three studies have shown there is no genetic isolation in the western burrowing owl from northern Mexico, through the western USA to south–western Canada. Genetic markers have been used in other species to show migratory pathways (see Boulet & Norris, 2006 review), a technique which may apply to little owls.

Stable isotopes

Stable isotopes analysis (SIA) of feathers has been used to track bird movements (Chamberlain et al., 1997); both migration and dispersal (Hobson & Wassenaar, 2008). This aspect of SIA determines the location where feathers were grown. Determining movements with SIA has several advantages but also limitations. The approximate origin of every feather collected can be determined through this technique. Tail feathers were collected from burrowing owls trapped during winter and summer studies. The stable isotope ratios of H, C and N in the feathers were compared to a map of stable isotope ratios in nestling feathers (Duxbury, 2004). Feathers collected in winter provided an approximate location where the owls grew the tail feather the previous summer. Feathers collected in the breeding season before molt provided an approximate location where the owls grew the feathers the previous breeding season, thus an indication of breeding and natal dispersal. The technique is most easily interpreted with feathers since they are a stable tissue but an often unproven assumption is that adult owls grow feathers where they breed, which may not always be true. The moult cycle of the bird must be fully understood before deciding which feathers should be used. One large advantage of SIA is that the moult location for each owl handled can be determined through its feathers. The disadvantages are that the locations are approximate with errors of ± 125 km (Duxbury, 2004), and recent studies have demonstrated further factors that introduce error (Meehan et al., 2003; Smith et al., 2009).

Despite these issues, SIA provided the origin of owls trapped in the winter in Texas and Mexico (Duxbury, 2004). Seven of 105 owl feather samples collected in winter in central Mexico were grown in Canada the previous summer. The majority of feather samples showed that most owls wintering in south Texas and central Mexico were short distant migrants from northern Mexico and southern USA.

In addition, SIA was used to study breeding dispersal by obtaining estimations of where breeding owls had grown their feathers the previous season (Duxbury, 2004). Feather samples collected in summer from breeding owls in Canada showed that burrowing owls relocated an average 400 km between breeding seasons. Over half of the breeding owls in prairie Canada each year were in the USA or Mexico the previous year. Duxbury (2004) estimated that the net loss of owls to the northern US Great Plains approximately equaled the 20% decline in the owl population from prairie Canada. The high rate of dispersal had a marked impact on the population dynamics of owls in prairie Canada.

Geolocators

The advent of small geolocators or light–level data loggers provides new opportunities to learn more about small species' migrations (Stutchbury et al., 2009). Geolocators provide information about the departure dates, stop–overs, migration route and arrival at wintering grounds, and the units are small enough to be carried by small birds. Fourteen ~7 gm geolocators were attached to adult breeding burrowing owls in July 2005 at the Onefour Agricultural Research Sub–Station in extreme south–eastern Alberta, Canada (49.04ºN 110.38ºW). The geolocators determined the light levels every minute and recorded the time, GMT. One unit was retrieved from an owl in June 2006. The fate of the other 13 owls is unknown. The unit operated from August 1to December 25 in 2005. The movements of the owl were interpreted from dawn and dusk determined from the unit's records of light levels and time. Each 4' change in dawn and dusk from GMT = 1 degree of longitude. Day length was used to determine latitude with the aid of the US Navy website (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). A geolocator that remained at the capture site at Onefour was used to determine that the combined error in estimation of dawn, dusk and day length resulted in errors of 55.5 km (SD ± 83.9) longitude and 25.0 km (SD ± 194.8) latitude in August. These error estimates are within the blanket error ± 300 km quoted in Stutchbury et al. (2009).

The owl followed the migration route shown from ring encounters in the Great Plains to Texas (Holroyd et al., 2010), before turning west into central Mexico (fig. 1). The owl appears to have remained in the high plains until it reached northern Texas when it went to the coastal Gulf lowlands, then into the *bajio* of central Mexico.

When the geolocator quit on December 25, the owl may not have completed its migration since it moved in the weeks prior to this date, being stationary in central Mexico for only about 10 days. However, VHF telemetry of burrowing owls indicated that owls do remain on a wintering location starting in December and do not wander throughout the winter (unpubl. data). The winter location was near where other owls from Canada have been tracked (Holroyd et al., 2010).

Previously, the length of time that burrowing owls spend on migration was estimated from known arrival and departure dates. The new information provided by this geolocator was the dates of start and end of migration, a minimum length of the migration of at least 3 months, and the dates and location of two staging sites. A significant disadvantage is that only one of 14 geolocators was recovered. Units must be recovered before any data can be extracted since they do not transmit any data. Thus any owls that dispersed to breed outside a study area are not likely to be detected and their movements not recorded. The return rate of the male owls with data–loggers was lower than the anticipated return rate for ringed adult male owls. Other authors report low recovery rates (*e.g.* 10% for purple martin, Stutchbury et al.,, 2009; 13% female, but 66% of male wood thrush, Stutchbury et al., 2010). In addition, the locations have a large error estimate as shown by the irregular directions of the apparent movement. The line was not 'smoothed' as done by Stutchbury et al. (2009, 2010) since smoothing masks how variable the apparent movement can be without manipulation.

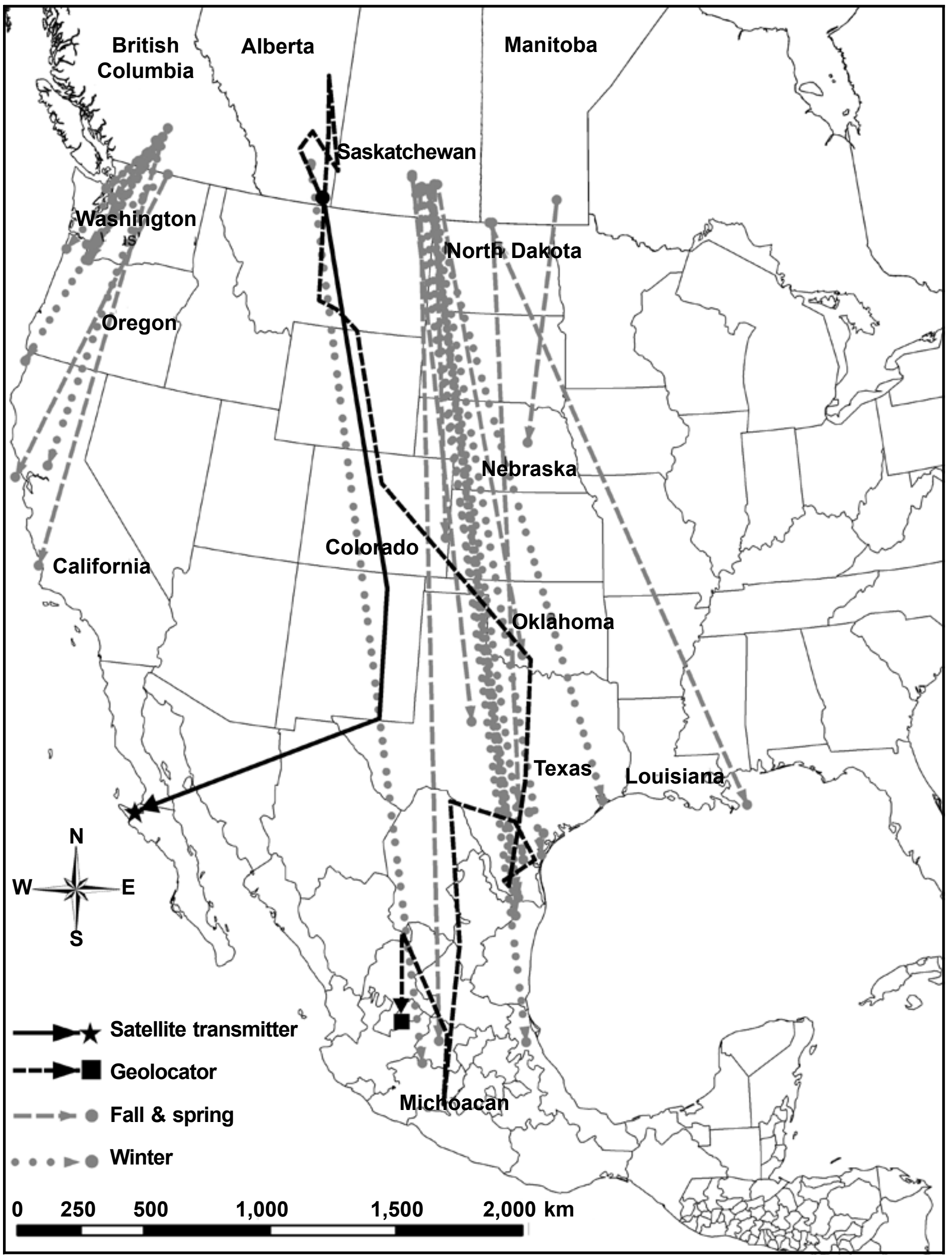

Fig. 1. The migration of burrowing owls from Canada as indicated by a geolocator and satellite transmitter superimposed on ring recoveries and VHF telemetry (Holroyd et al., 2010).

Fig. 1. Migraciones del mochuelo de madriguera desde el Canadá, tal como indican los estudios con geolocalizadores y transmisores por satélite, superpuestos a la recuperación de animales anillados y a la telemetría VHF (Holroyd et al., 2010).

Satellite transmitters

Satellite transmitters (PTTs) have been used to track larger birds for two decades (*e.g.* Fuller et al., 1998; Kochert et al., 2011). In January 2010, Microwave Telemetry Inc (Maryland, USA) introduced a 5 gm solar satellite transmitter. The transmitters send signals on a predetermined duty cycle that are received by polar orbiting NOAA/ARGOS satellites which triangulate the location of the transmitter using Doppler shift algorithms of the Argos satellite positioning system.

In 2010, 5–5 gm PTTs were attached to adult breeding burrowing owls in southern Alberta and Saskatchewan using Teflon back–pack harnesses. The project's objective were to study the owls' migration routes and timing, and to determine wintering areas, non–breeding habitats and breeding dispersal. These transmitters operated with a duty cycle of 8 hours on, 48 hours off. Accuracy varied from a minimum error of 150 m to over 1 km, depending upon the ARGOS satellites' view of the transmitter.

The signal from one PTT on a female owl ended in August at the nest site, with evidence (a freshly eaten skull and digging) suggesting the female died as a result of predation by a swift fox, *Vulpes velox*. Three PTTs, on one female and two male owls, stopped sending signals in September. The voltage of the units declined prior to the end of messages, presumably from declining light levels and possibly due to owls spending more time in burrows after the completion of the post–fledging foraging period. One of these three PTTs was recovered from a male in July 2011 near its original capture site. The PTT was not working, possibly due to damage to the casing. The second PTT, on a female, started transmitting the following summer on July 4, 2011 after being silent all winter. A site visit confirmed she was nesting with at least four young about 55 km east of the original capture site. The third of three PTTs has not been reported since it went silent in September 2010. The fifth transmitter is described below. Thus of five transmitters, one owl was depredated, one operated for a year, and three quit after two months but one was recovered, one restarted transmissions in the follow summer, and the fate of the other was unknown.

The fifth PTT operated through the autumn and winter of 2010 (fig. 1). It was attached to a female burrowing owl with young at the Onefour Agricultural Research Sub–Station in extreme south–eastern Alberta, Canada (49.04º N 110.38º W) on 24 June, 2010. She stayed in the vicinity of her nest through July. After the young fledged, she moved 5 km south to Montana, spending two months in cultivated fields adjacent to native prairie. Since micro–PTTs, unlike geolocators, provide locations in real time, researchers could visit her current pre–migration roosting and foraging sites. On October 21 she was in north–eastern New Mexico, 1,400 km from her Montana roost. Six days later, she was 470 km further south in south–east New Mexico. The next transmission on November 10 was 1,046 km west on the Baja California peninsula, Mexico (fig. 1).

This burrowing owl followed a new migration route previously not described. While ringing recoveries from prairie Canada have been between the Great Plains and Texas, this owl followed the foothills of the Rockies before heading west to a previously unknown wintering location. The owl spent the winter on the west coast of Baja California, Mexico, where researchers were able to study her habitat due to the transmission of current PTT signals.

Another major advantage of PTTs is that breeding and natal dispersal can be determined if they operate for a full year, identifying two sequential breeding sites. While breeding and natal dispersal records can result from ringing, they are rare for burrowing owls, as discussed above. Meyburg et al. (2011) were able to track a Eurasian hobby (*Falco subbuteo*) for two years and determine sequential breeding efforts; similar data have been collected for up to three breeding seasons for peregrine falcons, *Falco peregrinus*, (Holroyd & Trefry, unpubl. data). The locations can be geo–referenced with habitat data to determine the types of habitats used post–breeding, on migrations and in winter. Satellite transmitters are therefore the only option if the goal is to follow birds over more than one season. Like the geolocators, the small PTTs also require light to recharge the battery, and this can be problematic due to the lifestyle of the burrowing owl and feather coverage. However, techniques to overcome these problems, such as back pads to reduce feather coverage and programming the PTTs to receive less frequent signals, are options being tested.

Discussion

The combined studies of burrowing owls over the past 20 years in Canada provide data showing they winter in south Texas and across the full width of central Mexico from Veracruz to Baja California Sur. This leads to the conclusion that Canadian burrowing owls have weak or no migratory connectivity with specific wintering areas (as illustrated in figure 1 in Boulet & Norris, 2006). While the specific proportions of Canadian owls that migrate to various parts of the winter range are unknown, determining the exact proportions would be very expensive and time consuming with questionable conservation benefits. The wide geographic range of wintering areas and habitats also makes their protection a trinational conservation challenge (Holroyd, 2005)

All of the techniques reviewed here have advantages and disadvantages that include the type of data collected, cost, and delays in accessing the data (table 1). A few general statements can be made about the data collected.

Knowledge of burrowing owl migration and dispersal was very limited from ringing encounters. Recovery data can be geographically biased if reporting of rings is much more likely to occur in some areas. For example, ring recoveries from Texas and coastal California are more likely due to denser human populations, public education about rings, and access to easy methods of reporting. On the other hand, Mexico lacked a method of reporting rings easily until recently, and phone and mail access are still limited in rural areas. This led to the assumption that Canadian owls were going to Mexico. This initial analysis was in fact incorrect in that burrowing owls do not appear to demonstrate leap–frog migration as hypothesized by James (1992). Rather, aerial telemetry and stable isotope analysis indicate that Canadian owls winter from south Texas into central México mixed with owls from lower latitudes.

Newer models of geolocators appear more reliable and should function throughout an entire year, unlike the 2005 prototype reported here. However, stable isotope

Table 1. Advantages and disadvantages of techniques used by the authors to track burrowing owls.

Tabla 1. Ventajas y desventajas de las técnicas utilizadas por los autores, para el seguimiento de los mochuelos de madriguera.

Technique			Relative cost
Numbered rings			1
	Advantages	1. Inexpensive	
		2. Exact location at start and end of movement known	
	Disadvantages	1. Low return rate	
		2. Route and timing of movement unknown	
		3. Delay in accessing data	
Colour rings			2
	Advantages	1. Relatively inexpensive	
		2. Identification possible with optical equipment	
	Disadvantages	1. Low return rate	
		2. Route and timing of movement unknown	
Genetics			3
	Advantages	1. Relatively inexpensive	
		2. Provides historical evidence of movements	
	Disadvantages	1. No precision of movements because of lack of genetic differentiation of most populations	
Geolocators			5
	Advantages	1. Provides data on timing and location of seasonal migration	
		2. Light weight (~1.5 gm)	
	Disadvantages	1. Low return rate	
		2. Bird must be recaptured to retrieve geolocator	
		3. Natal and breeding dispersals not recorded. Imprecise (~250km)	
		4. Delay in receiving locations.	
Aerial radio transmitters			6
	Advantages	1. Provides real time location	
	Disadvantages	1. Relatively expensive	
		2. Owls must be above ground to detect transmitter	
Stable isotopes			4
	Advantages	1. Applicable to all trapped birds	
		2. Multiple isotopes can increase accuracy estimate	
		3. Relatively inexpensive	
	Disadvantages	1. Mostly limited to feathers	
		2. Route and timing of movement unknown	
		3. Location of molt may differ from breeding site	
		4. Imprecise (~250 km)	
		5. Isoscape map required for each element	
		6. Requires clear view of sky at dawn and dusk	
Satellite telemetry			7
	Advantages	1. Provides relatively exact data on timing and location of seasonal movements and dispersal	
		2. Provides real time location	
	Disadvantages	1. Most costly	
		2. Weight (6 gm with harness) at maximum for 150 gm owl	
		3. Relatively long antennae	
		4. Requires clear view of sky most of the time	

analysis predicts high dispersal in this species and ring returns for adult males are 30%, so the probability of retrieving the units is low. The actual recovery rate of the units (1/14 = 7%) indicates caution and geolocators are not recommended for use with burrowing owls. Also, the errors associated with the units are large, and the owl's behavior of occupying burrows at dawn and dusk resulted in many days with no estimate of dawn and dusk. The satellite transmitter provided the highest quality data on movements of one owl, and it is the only technology that did so in 'real' time, such that the owl's staging areas in Montana and wintering area in Mexico were visited while the owl was present. PTT data could be used to estimate breeding, staging and wintering home ranges, although with some error due to the estimates of location based on Doppler shift algorithms.

The applicability of these techniques to determine movements of little owls is of course dependent on the scale and goals of the study and available funds. The encounters of rings have led many authors to conclude that the little owl is sedentary (Van Nieuwenhuyse et al., 2008). However, one ringing encounter from Germany to Menorca and influxes of owls in winter into the Balearic Islands and Spain indicate that some migration–like movement is undertaken by some little owls. In addition, little owls that experience more rigorous winters, such as in Kazakhstan, are nomadic or migratory (Gavrin, 1962 in Van Nieuwenhuyse et al., 2008: p. 302). Long distance breeding dispersal events have been documented with rings up to 600 km (reviewed in Van Nieuwenhuyse et al., 2008). The possibility that migration in little owls varies with age and sex, as occurs in burrowing owls (Ogonowski & Conway, 2009), should also be considered. Such dispersal has important implications for population dynamics and viability (Macdonald & Johnson, 2001). The extent of migration and dispersal of little owls within Europe should therefore be explored.

The little owl appears to spend more daytime hours in the dark, potentially limiting the usefulness of geolocators and solar satellite transmitters, but only a trial study would determine this. Stable isotope analysis would show large scale movements of little owls if they were sampled at the extremes of their range, and particularly on the Iberian Peninsula in winter. The moult is well documented for the species, an important consideration when determining which feathers to collect. Since the species retains some secondaries, after–second–year birds could provide feathers with data for more than one year. The variation in stable isotopes from northern to southern Europe for H and N are not as great as in North America (Bowen & West, 2008), but should be sufficient to show if owls are migrants from northern into southern Europe. Based on the experiences tracking migrating burrowing owls, movements of little owls using stable isotope analysis should be explored in Europe.

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