VOLUME 29 AIRO 2021

Owl telemetry – a comparison of transmitter designs and harness methods for Ural Owls (*Strix uralensis*) in Austria

Telemetria de aves de rapina noturnas – comparação de emissores e arneses para coruja dos Urales (*Strix uralensis*) na Áustria

Ingrid Kohl[1*], Christoph Leditznig[2],
Franz Aigner[2]

1 REWILD Institute – Research on Ecosystems and Wilderness, A-1130 Vienna, AUSTRIA

2 Dürrenstein Wilderness Area Administration, Brandstatt 61, A-3270 Scheibbs, AUSTRIA

*** Corresponding author:** office@rewild.institute

ABSTRACT

From 2009 to 2017, 142 young Ural Owls (*Strix uralensis*) were reintroduced into the mountain forests of the Dürrenstein Wilderness Area of Austria. To monitor owl dispersal and survival, 110 transmitters, consisting of five transmitter models and three telemetry systems were used. These models and systems are compared relative to design, signal transmission rates, attachment methods, break-away harness materials and relative costs. The best units were battery powered GPS-GSM transmitters with break-away perbunan rings and leg-loop harness mounts. Further improvements of predetermined breaking points such as cotton threads and perbunan seal rings are still in process. Advancements in transmitter technology have aided the successful reintroduction of Ural Owls to Austria's forests.

Keywords: Dürrenstein Wilderness Area, owl telemetry, predetermined breaking points, transmitter designs, transmitter mounting methods

RESUMO

De 2009 a 2017, foram reintroduzidos 142 juvenis de corujas dos Urales (*Strix uralensis*) nas florestas montanhosas da Área Silvestre de Dürrenstein, na Áustria. Para monitorizar a sua dispersão e a sobrevivência, foram utilizados 110 emissores, constituídos por cinco modelos de emissores e três sistemas de telemetria. Esses modelos e sistemas foram comparados em termos de desenho, taxas de transmissão de sinal, métodos de fixação, materiais usados no arnês e custos relativos. As melhores unidades foram os emissores GPS-GSM alimentados por bateria, com anéis de rutura de nitrilo e com montagem de arnês no tarso. Estão em desenvolvimento outras melhorias nos pontos de rutura pré-determinados, tais como fios de algodão e anéis vedantes de nitrilo. Os avanços na tecnologia de emissores contribuíram para o sucesso da reintrodução da coruja dos Urales nas florestas da Áustria.

Palavras-chave: desenho de emissores, métodos de instalação de emissores, pontos de rutura pré-determinados, Área Silvestre de Dürrenstein, telemetria de aves de rapina noturnas

Introduction

Telemetry and its variants, such as geolocators, are increasingly used in field research to obtain large amounts of data with relatively little effort (Meyburg et al. 2016, Vlček & Schmidberger 2014). Exo et al. (2013) describe the benefits of telemetry for recording environmentally relevant animal behavior to inform conservation action. The use of telemetry as a research tool to gather information must be matched to specific research questions and hypothesis testing (Leditznig 1999, Leditznig & Langer 2017). Examples include documenting foraging behaviour and habitat use (Kubetzki 2013, Mendel & Garthe 2010, Schmajohann 2013).

In the first half of the 20th century the Ural Owl (*Strix uralensis*) (Fig. 1, 2) became extirpated in Austria. In 2008, the Research Institute of Wildlife Ecology (FIWI) and the Dürrenstein Wilderness Area Administration (DWA) began a Ural Owl reintroduction project in the DWA. The project used transmitter data to estimate survival and mortality, document reproduction and breeding dispersal, and to assess the viability and connectivity of restored populations (Kohl & Leditznig 2012, Leditznig & Kohl 2013, Kohl & Leditznig 2017). Over 10 years the DWA worked with Biotrack/Lotek and ECOTONE to develop transmitter designs suited to the natural history and adaptations of the Ural Owl and in steep mountain forests (Kohl & Leditznig 2017). This included the development of transmitter mounts and harness predetermined breakaway mechanisms to release transmitters when batteries expired. This paper discusses the advantages and disadvantages of specific telemetry systems used in the above project. Other telemetry attachment systems (i.e., neck, leg or implant) are not covered here (Wikelski et al. 2015, König et al. 2016). Peer-reviewed humane wild animal handling protocols were followed to minimize stress to the owls (Kurt 1995, Leditznig 1999).

Figure 1 - Adult Ural Owl (*Strix uralensis*) in Austria. Adaptations of owls are challenges for telemetry (photo: Christoph Leditznig).

Figura 1 - Adulto de coruja dos Urales (*Strix uralensis*) na Áustria. As adaptações das aves de rapina noturnas são um desafio para a telemetria (Foto: Christoph Leditznig).

Figure 2 - Young Ural Owl (*Strix uralensis*) in Austria. Young owls were released at about 90 d old and tracked with telemetry (photo: Christoph Leditznig).

Figura 2 - Coruja dos Urales juvenil. Os juvenis foram libertados com uma idade de cerca de 90 dias e seguidos por telemetria (foto: Christoph Leditznig).

Figure 3 - Primeval Forest Rothwald in the Dürrenstein Wilderness Area, Austria (photo: Hans Glader).

Figura 3 - Floresta Virgem de Rothwald na Área Silvestre de Dürrenstein, Áustria (foto: Hans Glader).

Table 1 - Comparison of the different transmitter models - a summary.

Tabela 1 - Comparação dos diferentes modelos de emissores - resumo.

	RADIO-TELEMETRY (TAIL FEATHERS MOUNTING)	RADIO-TELEMETRY (PELVIS HARNESS MOUNTING)	SATELLITE TELEMETRY	GPS-GSM-TELEMETRY (SOLAR-POWERED)	GPS-GSM-TELEMETRY (BATERY-POWERED)
Mounting	tail	pelvis	pelvis	pelvis	pelvis
Weight	17 g	23 - 27 g	20 g	27 g	31 g
Proportion weight (800g)	2.1 %	2.8 %	2.5 %	3.3 %	3.8 %
Costs transmitter	200 €	250 €	2,500 €	1,150 €	720 €
Follow-up costs / transmitter / month	ca. 400 €	ca. 400 €	5 €	13 €	13 €
Follow-up costs / transmitter / year	ca. 5,000 € (travel expenses, mileage allowance)	ca. 5,000 € (travel expenses, mileage allowance)	60 €	160 €	160 €
Work associated with telemetry technology	Radio-Telemetry & data processing & transfer to server (web map & database)	Radio-Telemetry & data processing & transfer to server (web map & database)	Data processing & transfer to server (web map & database)	Data processing & transfer to server (web map & database)	Data processing & transfer to server (web map & database)
Working hours / transmitter / year	approx. 140	approx. 140	approx. 40	approx. 40	approx. 40
Transmission period	1 year	1.5 years	1.5 years	1 month without sun exposure, else several years	1.5 to 2years
Number of used transmitters	18	46	3	5	38
Years	2009, 2010	2010 - 2014	2012 (2013)	2013	since 2014
Characteristics				Discovery of nest box broods	Discovery of tree hole broods
Advantage(s)	timely search, relatively low burden for the bird	timely search, reception over larger distances	Data transmission	GSM data transmission, (in theory: transmission duration)	GSM data transmission, costs, less emissions, data handling, brood search, temperature measurement
Disadvantage(s)	Personnel expenses, travel expenses, emissions, transmitter loss before breeding season	Personnel expenses, travel expenses, emissions, transmitter loss before breeding season, antenna bitten off by owl - signal became weaker	Cost, inaccuracy, data handling, search difficult	Use of solar panel not possible due to owl plumage	Search harder / delayed, transfer stop when in breeding cavity

Study Area

The Dürrenstein Wilderness Area (DWA - 3,500 ha; 600 to 1,878 m a.s.l), including the 400 ha Primeval Forest Rothwald (Fig. 3), offered ideal Ural Owl habitat with a relatively high abundance of deadwood and tree cavities. The DWA is classified as IUCN Strict Nature Reserve Category Ia, IUCN Wilderness Area Category Ib and an UNESCO Natural World Heritage Site. Tree species present include Norway Spruce (*Picea abies*), European Silver Fir (*Abies alba*) and European Beech (*Fagus sylvatica*). European Larch (*Larix decidua*) and the Sycamore Maple (*Acer pseudoplatanus*) were also important tree species present. Sycamore Maple and Norway Spruce form cavities used by owls and other wildlife. The DWA is ideal habitat for other owls (Tengmalm's Owls *Aegolius funereus*) but also for woodpeckers (White-backed Woodpecker *Dendrocopos leucotos*). Geologically it is part of the Northern Limestone Alps with an annual precipitation of 1,700 to 2,400 mm. Two Ural Owl release aviaries were located at 725 and 785 m a.s.l. and transmitter-marked owls dispersed up to 150 km (Kohl & Leditznig 2017).

Monitoring Tools

From 2009 to 2017, 110 transmitters (five models, three systems) were used to monitor success of the Ural Owl reintroduction project (Fig. 4) and yielded more than 14,000 owl positions (Fig. 5). Radio-telemetry Tail Mount (RT1), Radio-telemetry Pelvis Mount (RT2), Satellite Telemetry (ST), GPS-GSM Solar (GTS) and GPS-GSM Battery (GTB) transmitters were used with various mounting methods and associated predetermined breaking points (Table 1).

Transmitter weight should not exceed a maximum of 5% of bird body weight (Brander & Cochran 1969, Barron et al. 2010, Naef-Daenzer et al. 2005) but this may not apply to every bird species or mounting method. Hence, as a precaution, we chose not to exceed 4% of Ural Owl weight (range 2.1 to 3.8%). An 800 g owl mass was used to calculate the relative transmitter weight (Table 1) as it was between that of light males (600 g) and larger females (>1,000 g).

Results and Discussion

The five telemetry transmitters used between 2009 and 2016 differed in terms of technical and financial parameters that were important for the Ural Owl recovery project (Table 1; Kohl & Leditznig 2017). The advantages and disadvantages of each type and attachment and release mechanisms are discussed below (see also Table 1).

Transmitter Systems

Radio-telemetry Tail Mount (RT1) and Radio-telemtry Pelvis Mount (RT2) Transmitters

Eighteen Biotrack radio-telemetry transmitters (RT1) were attached to the central tail feathers (Fig. 9). The duration of these units was up to one year. Forty-six slightly heavier Biotrack radio-telemetry transmitters (RT2) were attached with the pelvis harness mounting method (Fig. 10). The duration of these units was up to 1.5 years. For RT1 and RT2, RX 98 hand-held receivers with hand-held H directional external antennas (Followit Lindesberg AB, formerly Televilt) were used to locate owls by signal triangulation; one RX 98 receiver had an integrated antenna. In addition, three round car antennas and two recording units were used. A Lotek/Biotrack hand receiver and automatic recording units were also used to track frequency of visits of young owls to feeding tables.

These units were light weight and relatively inexpensive. They enabled accurate and prompt relocations facilitating transmitter recovery, especially RT2s with stronger batteries. The stronger RT2 signals could be

Figure 4 - Number of Ural Owls (*Strix uralensis*) released in Austria with and without transmitters.

Figura 4 - Número de corujas dos Urales libertadas na Áustria com e sem emissores.

Figure 5 - Number of daily Ural Owls (*Strix uralensis*) positions per transmitter type in Austria (2009-2017).

Figura 5 - Número de posições diárias registadas por tipo de emissor na Áustria (2009-2017).

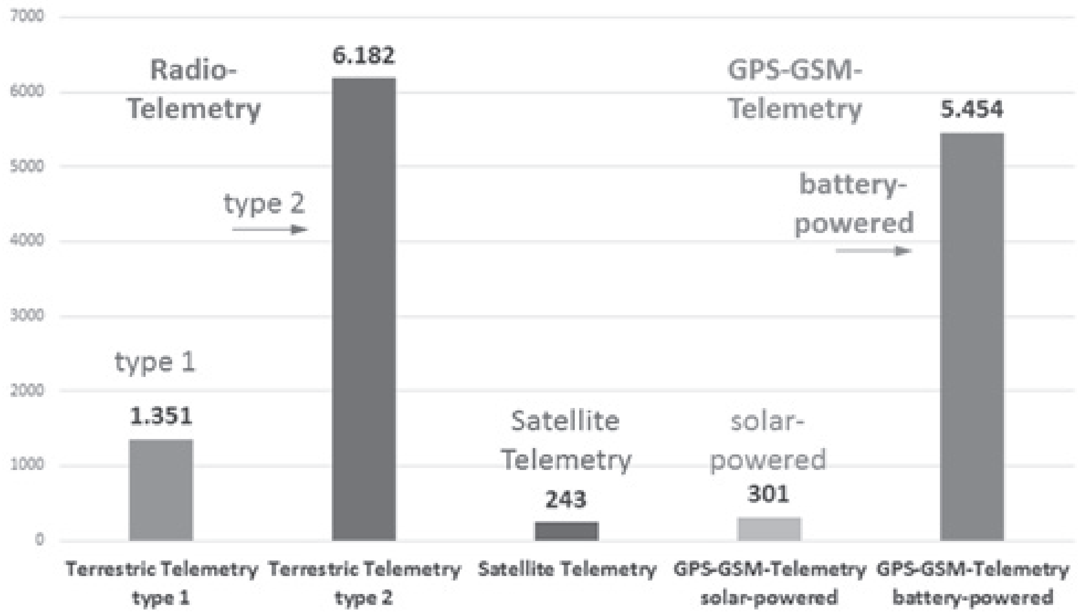

Figure 6 - Cotton thread predetermined breaking point (photo: Adrian Äbischer).

Figura 6 - Ponto de rutura predefinido em fio de algodão (foto: Adrian Äbischer).

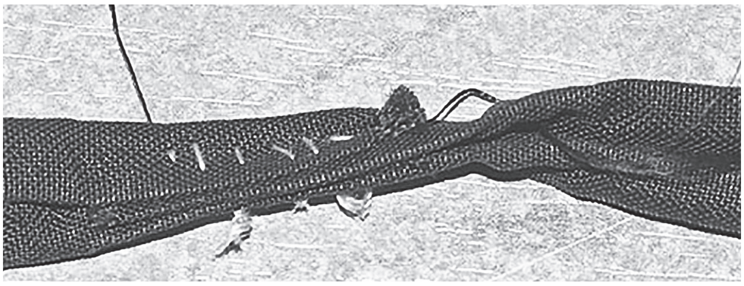

Figure 7 - Perbunan seal ring predetermined breaking points (photo: Christoph Leditznig).

Figura 7 - Pontos de rutura predefinidos feitos com anéis vedantes de nitrilo (foto: Christoph Leditznig).

Figure 8 - Radio-transmitter type 1 – central tail feathers mounting method (photo: Christoph Leditznig).

Figura 8 - Rádio-emissor tipo 1 - método de fixação nas retrizes centrais (foto: Christoph Leditznig).

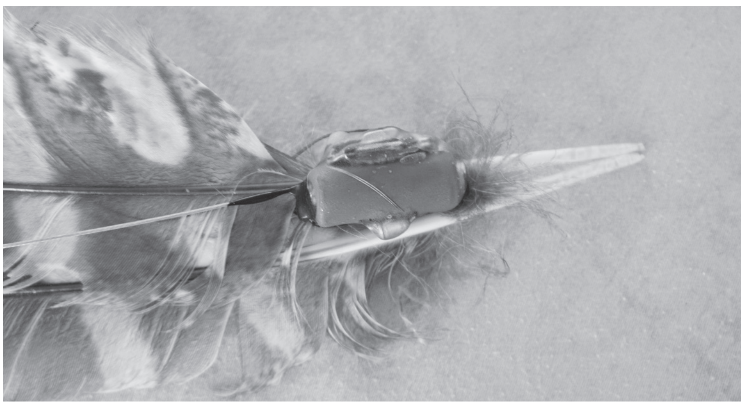

Figure 9 - Radio-transmitter type 2 – pelvis harness mounting method. Photo taken after the perbunan seal ring predetermined breaking point separated and showing half of the antenna removed by a Ural Owl (*Strix uralensis*) (photo: Christoph Leditznig).

Figura 9 - Rádio-emissor tipo 2 – método de fixação por arnês pélvico. Foto tirada após a quebra do anel vedante de nitrilo (ponto de rutura predefinido) e com metade da antena removida pela coruja dos Urales (*Strux uralensis*) (foto: Christoph Leditznig).

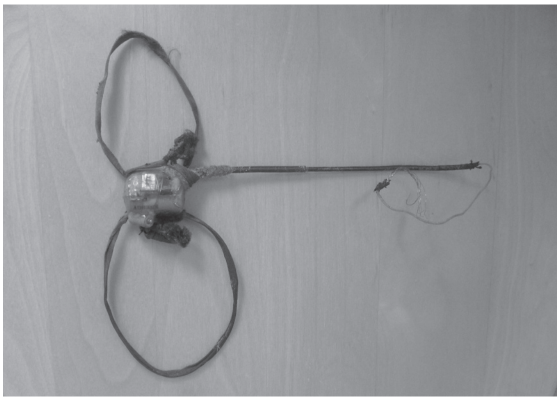

Figure 10 - Satellite transmitter attached by a pelvis harness mount to an adult Ural Owl *(Strix uralensis)* (photo: Wilhelm Leditznig).

Figura 10 - Emissor de satélite montado com o método de fixação por arnês pélvico num adulto de coruja dos Urales (*Strix uralensis*) (foto: Wilhelm Leditznig).

Figure 11 - One of several solar-powered GPS-GSM-transmitters tested on Ural Owls (*Strix uralensis*) showing a feather shield and two solar panels (photo: Christoph Leditznig).

Figura 11 - Exemplo de um tipo de emissor GPS-GSM alimentado a energia solar testado na coruja dos Urales (*Strix uralensis*), mostrando o protetor das penas e dois painéis solares (foto: Christoph Leditznig).

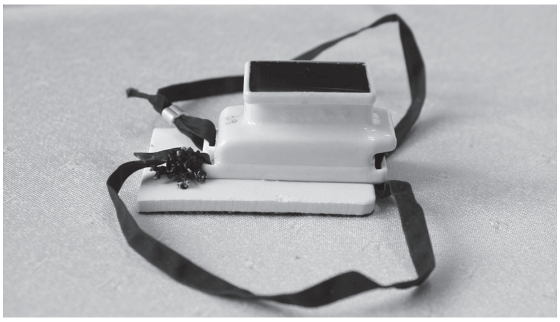

Figure 12 - GPS-GSM-transmitter backpack mounting method with internal predetermined breaking point (photo: Christoph Leditznig).

Figura 12 - Emissor GPS-GSM com montagem no dorso (tipo "mochila") com ponto de rutura predefinido (foto: Christoph Leditznig).

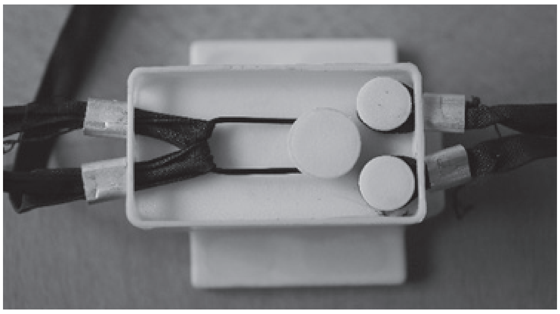

Figure 13 - The first battery-powered GPS-GSM-transmitter used on Ural Owls (*Strix uralensis*). The soft cover was destroyed when owls bit it within a few days (photo: Christoph Leditznig).

Figura 13 - O primeiro emissor GPS-GSM alimentado por bateria usado na coruja dos Urales (*Strix uralensis*). A cobertura macia foi destruída pelas corujas em poucos dias (foto: Christoph Leditznig).

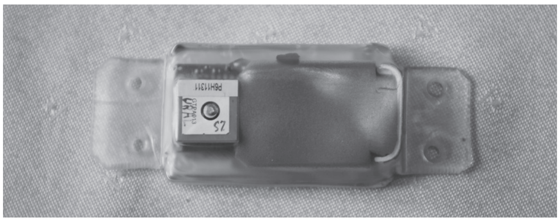

Figure 14 - The hard-covered battery-powered GPS-GSM-transmitter that withstood owl bites (photos: Christoph Leditznig).

Figura 14 - Emissor GPS-GSM alimentado por bateria com cobertura rígida que resistiu às bicadas das corujas (fotos: Christoph Leditznig).

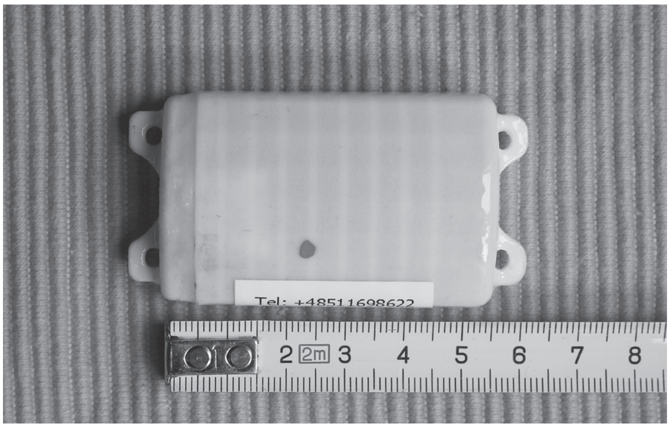

Figure 15 - The final battery-powered GPS-GSM-transmitter design in use since 2014 (photo: Ingrid Kohl).

Figura 15 - Versão final do emissor GPS-GSM alimentado por bateria, usado no projeto desde 2014 (foto: Ingrid Kohl).

detected up to 50% farther than RT1 signals. Stronger signals resulted from slower signal frequency and a longer signal duration. Three transmitter signals types could be distinguished: rest, activity and inactivity (nesting, transmitter loss, mortality). The associated Lotek/Biotrack receiving unit better detected signals whereas Followit receivers were lighter and easier to handle.

Disadvantages included short detection range and battery life (RT1) and early tail feather moulting (RT1) which limited the location of post-release roosts, nest cavities and breeding areas. RT2 batteries lasted up to 1.5 yr and with the pelvis mount enabled more owl relocations. It was difficult to track owls in mountainous areas and with inactivity signals. In 2011, up to 21 young Ural Owls were relocated daily which took > 10 person hours per day. This generated high fossil fuel emission and fuel and time cost while driving about 50,000 km over 4 years by three research team members. Mountainous terrain often shielded signals precluding relocating marked owls, and owls often damaged antennae reducing detection distance.

Satellite (ST) Transmitters (Fig. 11)

Three light weight (20g) pelvis mounted North Star satellite transmitters with ARGOS data transmission and storage were used in 2012 and 2013. These units enabled the tracking of wide-ranging owls and assessment of reintroduction program with an automatic low-cost data collection system that saved the project staff time and money. A hand-held receiver could be used to search for signals.

Disadvantages included a high initial cost and large relocation inaccuracies (one in Atlantic Ocean). Small-scale owl movements in mountain valleys often resulted unsuitable signals. Batteries lasted up to 1.5 yr and provided signals for about 1 hr/day at a low rate (1 per min) and made obtaining relocations difficult and lengthy. All the aforementioned made it impossible to find nest cavities.

GPS-GSM Solar (GTS) Transmitters

Five GTS specially designed pelvis mount solar powered SULA and URAL units were developed by ECOTONE and DWA (Fig. 8, 12, 13, 14, 15, 16, 17) to incorporate Ural Owl natural history and plumage. The advantages and disadvantages below also apply to the one back-pack mount GTS used on an adult bird in 2014 (Fig. 13).

The GTS unit had two small solar panels that failed to charge its battery due to unfavorable weather, owls roosting by day in dark forests, and especially feathers obscuring solar panels. If GTSs had worked they could have provided reliable locations in the mountainous study area, enabled the tracking of wide-ranging owls and assessment of the reintroduction program, and the automatic low-cost data collection would have saved staff time and money. They were relatively light (27 g) and well suited for Ural Owls. The initial cost of these units was relatively high. Unfavorable GTS positions prevented GPS or GSM network reception and hence transmitter relocation. This resulted in much time spent searching for transmitters.

GPS-GSM Battery (GTB) Transmitters

GTBs were used since 2014 and are still in operation providing location data of released Ural Owls (Fig. 8, 14, 15, 16, 17). GTB weight was higher (31g) and only used on owls 750 g or heavier. For both the GTS and GTB units, position coordinates and temperatures were stored daily and transmitted every 4 days over the GSM net and downloaded. After downloading the data were processed, stored in a database and displayed on a DWA internal web map.

Advantages of these 31 g units included reliable automated telemetry signals in the mountainous study area. Tracking wide-ranging owls and assessment of reintroduction program was possible due to an operational battery life of 1.5 to 2 yr. The automatic low-cost data collection saved project staff time and money.

Figure 16 - Battery-powered GPS-GSM-transmitter attached to a Ural Owl (*Strix uralensis*) by the pelvis harness mount (photo: Christoph Leditznig).

Figura 16 - Emissor GPS-GSM alimentado por bateria, montado numa coruja dos Urales (*Strix uralensis*) através de arnês pélvico (foto: Christoph Leditznig).

Figure 17 - An active Ural Owl (*Strix uralensis*) natural tree cavity nest located by telemetry (photo: Christoph Leditznig).

Figura 17 - Ninho ativo de coruja dos Urales (*Strix uralensis*) numa cavidade natural localizado por telemetria (Foto: Christoph Leditznig).

Disadvantages included relatively heavier unit weight and high acquisition costs. More time was spent searching for transmitters when they were in an unfavorable position for network reception and they had infrequent (every 4 d) data transmissions. It was difficult to find nest sites in natural tree cavities as the units switched off when owls were breeding.

Mounting Systems

Central Tail Feather Mount

RT1s were mounted to the base of the two central tail feathers (Fig. 9). A sliced straw was slipped over the two central tail feathers and the tube, which was attached to the transmitter, was pulled over the feathers. After the straw was removed the transmitter was tied and glued to the feather bases. This attachment method is suitable when the weight of the transmitter is relatively low. There was no risk of bodily injuries such as harness abrasion or ingrowth and the transmitter was easily released when the tail feathers moulted. Other advantages included its relatively simple and fast mounting process (ca. 15 min/owl; see also Bowman & Aborn 2001). Disadvantages included occasional damage to the central tail feathers and early transmitter release due to premature moult of the supporting feathers.

Pelvis Harness Mount

RT2s, STs, GTSs and GTBs were attached to the lower back of the bird with two Teflon straps placed around the legs in the groin area (Fig. 7, 10, 11, 12, 16, 17; Rappole & Tipton 2009). This pelvis mount enabled the quick (10 min/owl) use of heavier transmitters with stronger transmitter signals and longer reception range. There was little plumage damage and less nutrition-related size variation in the pelvis region compared to the backpack mounting method. However, new plumage growth under the transmitter would not occur until after the transmitter detached. In one case an autopsy of a recovered owl revealed a healed skin abrasion caused by an overtightened leg loop but that the abrasion was not the cause of death.

Backpack Mount

One backpack mount transmitter (Fig. 13) was tested on a captive adult Ural because of the known risks such as injury or mortality due to fluctuations in pectoral muscle size and damage to new feather growth (Hirons et al. 1979, Morton et al. 2003, Robert et al. 2006, Bedrosian & Craighead 2007, Peniche et al. 2011, Michael et al. 2013). This attachment method can accommodate heavier radio transmitters with stronger transmitter signals and longer reception range. However, Ural Owl feathers covered the recharging panels of solar-powered transmitters (Äbischer pers. comm. 2011) and it took longer to attach the transmitter (>30 min/owl).

Predetermined breaking points

It is important to install a breaking point in the transmitter mount to release it at the end of the expected transmission period to free the owl unharmed and to retrieve the transmitter. For the pelvis harness mounts predetermined breaking points located at the junction of the teflon loop included cotton threads (Fig. 6), perbunan seal rings (Fig. 7) or metal staples (aluminium sleeves), depending on the expected transmitter life (Kohl & Leditznig 2017). Unfortunately there were no such mechanisms available for backpack mounts to avoid the risk of harness entanglement with the body or wings.

Pelvis (and backpack) mounting: Cotton threads

Sewing a cotton thread (Fig. 6) to the teflon harness was successfully used on Eagle Owls *Bubo bubo* in Switzerland (Äbischer et al. 2010, Äbischer pers. comm. 2011) however, Frey (pers. comm. 2017) reported that Bearded Vultures (*Gypaetus barbatus*) "greased" the threads which prevented the dissolution of the threads beyond the desired release date. All but two cotton thread breaking points used in this project separated after about a year thereby prematurely releasing transmitters and precluded the location of most post release broods. One Ural Owl carried its transmitter half a year after its first breeding season, and another carried its transmitter for 3 years. We concluded that abiotic conditions, wing movements and the biting of threads resulted in premature separation and transmitter loss and that this method was not reliable.

Perbunan seal rings

Perbunan or rubber seal rings were used (Fig. 7, 8) on Bearded Vultures (Hegglin pers. comm. 2011, Néouze et al. 2016, Frey pers. comm. 2017). These rings are threaded through a tube on the transmitter and fatigue fractures form over time where they bend due to abiotic influences, such as temperature fluctuations. After the rubber breaks, the pelvis mounted transmitters become loose and fall off. However, to stay within acceptable transmitter unit weight limits only thin Perbunan rings could be used resulting in premature transmitter loss and limited location of post-release broods.

Rubber band

A rubber band predetermined breaking point inside the transmitter cover was developed by ECOTONE and WMA for the backpack transmitter (Fig. 13). In theory, the rubber band should enable flexibility to accommodate variation in breast muscle size over time, a break in the rubber band should release both rear Teflon straps simultaneously. However, backpack mounted transmitters were not used after one trial assessment with a captive Ural Owl.

Aluminium sleeves

A new breaking point system is being tested on five transmitters in consultation with ECOTONE that consists of an aluminum sleeve that holds the teflon straps together. It is unknown how long it will take for the teflon straps to abrade and release. Therefore, until the release times for this method are documented, two small perbunan seal rings are being used as breaking points for all other Ural Owl transmitter units.

Conclusions

In the first nine years of the project more than 13,500 locations of Ural Owls were registered by telemetry (Fig. 5, Table 1). The GTBs were the optimal telemetry system for assessing the Ural Owl reintroduction project and are still in operation and gathering position data (Kohl & Leditznig 2017). GTBs provided precise positions and automatically transmitted stored GPS and temperature data but were difficult to relocate as they did not send recovery-specific radio signals. Repeated same position signals and decreased temperature indicated transmitter recovery was needed. GTBs were also successful with Barn Owls (Brandt 1999) and Eagle Owls (Äbischer et al. 2010).

Transmitter and Mounting Methods Effects

Negative effects of transmitter or mounting methods are rarely reported which makes it difficult to learn from past studies. Telemetry should not affect animals (Kenward 1987). The low impact of tail mounted radio transmitters has made it popular, including in Eagle Owl and Ural Owl reintroduction programs (Frölich 1986, Schäffer 1990). Tail feathers are only temporarily damaged if the transmitters are sutured to them. However attachment of a transmitter to growing or recently grown tail feathers resulted in their premature moult (Leditznig 1999) and only light transmitters with a relatively short range can be used. Smaller solar-powered transmitters can now also be used (*e.g.* http://www.ecotone-telemetry.com/en) but transmission duration is limited by the tail feather moult cycle.

Backpack mounted radio transmitters have been used for decades (Exo 1987, Larsen et al. 1987, Nicholls & Fuller 1987, Exo 1988) but negative effects were not published. This mounting method is still common, especially for solar-powered and satellite-based transmitters (Herzog 2014, Meyburg et al. 2016, Néouze et al. 2016, Stickroth 2016, A. Gamauf pers. comm. 2014, N. Schönemann pers. comm. 2016). Consideration of breast musculature condition is particularly important when using backpack mounts to avoid damaging birds (Peniche et al. 2011, Robert et al. 2006, Michael et al. 2013, Bedrosian & Craighead 2007, Morton et al. 2003).

Peniche et al. (2011) examined 345 Red Kites *Milvus milvus* (1989 to 2009) as part of a reintroduction project using tail mounts (203 kites, 1989 to 2000) and backpack mounts (143 kites, 2000 to 2009). Since 2009, 180 dead kites have been autopsied. Four of 18 dead kites with backpack mounts carried the transmitters significantly longer than the others and were deemed to have died from harness related injuries such as lesions. There was no death among the birds who carried the transmitters for the average duration or for an under-average length of time. No injuries were found among tail-mounted Red Kites. It is likely that additional harness-related deaths occurred due to unrecorded recoveries of dead far-migrating kites.

Äbischer (pers. comm. 2011) did not detect any injuries on 40 young Eagle Owls with backpacks. All transmitters dropped off without problems using cotton thread predetermined breaking points. When contacted the telemetry company ECOTONE stated they lacked experience with owls and suitable predetermined breaking point mechanisms (Iliszko pers. comm. 2017). Such research and development is needed, especially with Bearded Vultures where backpack transmitters have been observed hanging down having failed to fall.

Pelvis mounts (leg-loop, hip-pack, Rappole mounting; Rappole et al. 2009) are relatively safer. Bowman & Aborn (2001) used backpack and pelvis mounts on Florida Scrub-Jays (*Aphelocoma coerulescens*) and concluded that only those with pelvis mounts did not significantly change their behavior. Pelvis mounts can be used successfully on small birds such as kingfishers (Kesler 2011) as well as on larger birds (Bearded Vulture, Néouze et al. 2016). Pelvis mount transmitters are located near a bird's centre of gravity, perhaps enabling birds to better accommodate the resulting added physical forces from the transmitter's weight.

All transmitter mounting methods should be monitored carefully and reported on. One Ural Owl in our study with a pelvis-mounted transmitter was found dead with a healed skin abrasion in the groin area due to the Teflon harness. While this abrasion did not cause the owl's death it presumably affected its behaviour.

Transmitter Weight

Special attention must be paid to ensuring that the 5% rule does not apply to every mounting method or bird species (Brander & Cochran 1969, Barron et al. 2010, Naef-Daenzer et al. 2005). While birds of prey and owls can carry heavier loads such as prey, this does not apply to all birds. Scherzinger (pers. comm. 2017) reported that in the Bavarian Forest grouse were tracked with 12 g transmitters, well below the 200 g or 5% maximum, taking into account a more realistic limit based on the species life history. It is also important to consider the nutritional status of birds. Annual weight fluctuations of 20% are possible suggesting the lowest weight be used to calculate acceptable transmitter weight. Bowman & Aborn (2001) showed that jays with backpack-transmitters that were only 2% of body mass traveled short distances on foot rather than un-marked birds flying the same route.

It is important to consider which transmitter model can be used depending on the maximum transmitter weight, the mounting option and the tracking objectives. More options are available, in general, the larger the bird. The large Bearded Vulture can be equipped with a large satellite transmitter with multiple solar panels, a large battery and comprehensive data storage media. In addition, a VHS transmitter can be integrated into this transmitter enabling locating the transmitter manually over land after the transmitter drops or if the bird dies. For our study, the 31 g GPS-GSM-transmitter was the 5% weight limit for lower weight Ural Owls and only owls >700 g were used.

Position of Transmitter

The shape and position of the transmitter on the body of the bird must be streamlined to reduce drag to minimize impacts to flight (or swimming) and life-sustaining behaviors such as preening (reaching the oil gland), foraging, courtship, copulation, breeding or other essential movements or behaviors. The animal's welfare must come first, so the transmitter or harness must not harm the animal directly or indirectly, e.g. by tangling or causing injury.

Measuring Reintroduction Project Success

It is difficult to definitively measure success in reintroduction programs for small at-risk populations. Statistically robust conclusions require large sample sizes, such as those from England on Red Kites (Peniche et al. 2011). Smaller programs tend to provide inconclusive anecdotal evidence of success. The potential confounding effect of transmitters is another potential barrier to measuring outcomes (A. Gamauf, Honey Bussards, pers. comm. 2015, Meyburg et al. 2016, Thomson & Kaatz 2010). A multi-year study on Prairie Falcons (*Falco mexicanus*) (Steenhof et al. 2006) with backpack transmitters could not documented short-term effects of transmitters on breeding success and behavior could but the survival rate for birds with transmitters was lower than that for birds without transmitters (49% vs. 87%) over the same period. Bowman & Aborn (2001) showed that Florida Scrub-Jays (*Aphelocoma coerulescens*) with backpack transmitters flew less, were busier and were more susceptible to predators. In contrast, the telemetry of White Storks (*Ciconia ciconia*) in Switzerland is carried out successfully (http://www.storch-schweiz.ch/361.html). Studies using pelvis mounted transmitters (Mong 2005, Kesler 2011, Mallory et al. 2008, Hegglin pers. comm. 2011) or tail feather mounts (Leditznig 1999) indicate that these methods did not negatively affect breeding success. Twenty-three of 107 released Ural Owl with transmitters were found dead but transmitters were not found to be the cause of death.

If, after careful consideration, researchers decide that the use of telemetry is necessary then further consideration of the type, transmission duration, and predetermined breaking points are important relative to the welfare of the birds involved. It is imperative that an examination of the potential role of the transmitter and mounting system in the death of marked birds be conducted and published. Promoting awareness that a telemetry project is underway is important, especially for the reintroduction of extirpated or endangered species, as this may inhibit illegal poaching or poisoning of birds of prey including larger owls.

Acknowledgements

Thank you to project participants Katrin Ritzinger, Reinhard Pekny, Stefan Schörghuber, Hans Zehetner, Nina Schönemann, Wilhelm Leditznig, Thomas Leditznig, Alexander Maringer, Richard Zink, and Theresa Walther, partners including Gesäuse National Park, Austrian Federal Forests, Owls and Raptor Station OAW in Linz led by Reinhard Osterkorn, Owls and Raptor Station EGS Haringsee as well as participating land owners. Thanks to James Duncan for his extensive review of and helpful revisions to the manuscript. The study was funded by the Provincial Government of Lower Austria and the European Union (LE 14-20).

References

Äbischer, A., Nyffeler, P. & Arlettaz, R. 2010. Wide-Range dispersal in juvenile Eagle Owls (*Bubo bubo*) across the European Alps calls for transnational conservation. Journal of Ornithology 151: 1-9.

Barron, D.G., Brawn, J.D. & Weatherhead, P.J. 2010. Meta-analysis of transmitter effects on avian behaviour and ecology. Methods in Ecology and Evolution 1: 180–187.

Bedrosian, B. & Craighead, D. 2007. Evaluation of techniques for attaching transmitters to common raven nestlings. Northwestern Naturalist 88(1):1-6.

Bowman, R. & Aborn, D.A. 2001. Effects of different Radio Transmitter Harness on the Behavior of Florida Scrub-Jays. Florida Field Naturalist 29(3): 81-86.

Brander, R.B. & Cochran, W.W. 1969. Radio location telemetry. In: Giles Jr., R.H. (ed) Wildlife Management Techniques. The Wildlife Society, Washington, DC. pp.95-103.

Brandt, T. 1999. Die Schleiereule – Flexible Überlebens-Strategien eines Dorfbewohners. Der Falke (März): 68- 72.

Exo, K.M. 1987. Das Territorialverhalten des Steinkauzes (*Athene noctua*) - Eine verhaltensökologische Studie. PhD thesis. University of Köln.

Exo, K.M. 1988. Tagesperiodische Aktivitätsmuster des Steinkauzes (*Athene noctua*). Die Vogelwarte 35: 94-114.

Exo, M., Diedler, W. & Wikelski, M. 2013. Auf dem Weg zu neuen Methoden: Rund-um-die-Uhr-Beobachtung ein Leben lang. Der Falke 60 (Sonderheft): 20-25.

Frölich, K. 1986. Ein Versuch der Wiedereinbürgerung des Uhus *(Bubo b. bubo L. 1758)* in Schleswig Holstein. Ökologie der Vögel 8(1): 1-47.

Herzog F. 2014. Kuckucke mit Satellitensendern. Der Falke 9: 23-24.

Hirons G., Hardy A. & Stanley P. 1979. Starvation in young Tawny Owls. Bird Study 26(1): 59-63.

Kenward, R.E. 1987. Wildlife Radio Tagging, Equipment, Field techniques and Data Analysis. Academic Press, London, 222pp.

Kesler D.C. 2011. Non-Permanent Radiotelemetry Leg Harness for Small Birds. Journal of Wildlife Management 75(2): 467-471.

Kohl, I. & Leditznig, C. 2012. Einsatz der Telemetrie zur Unterstützung der Wiederansiedlung des Habichtskauz´ *Strix uralensis* im Wildnisgebiet Dürrenstein (Österreich). Vortrag bei der 27. Jahrestagung der AG Eulen 2011 in Bredelar. Eulen-Rundblick 62.

Kohl, I. & Leditznig, C. 2017. Ein Vergleich der unterschiedlichen Telemetrie-Syteme im Rahmen der Wiederansiedlung von Habichtskäuzen (Strix uralensis) im Wildnisgebiet Dürrenstein in den Jahren 2009 bis 2016. Silva Fera 6: 37-58.

König, C., Stübing, S. & Wahl, J. 2016. Herbst 2015: Frühe Kraniche, späte Mornellregenpfeifer und viele Erlenzeisige. Der Falke 1: 24-29.

Kubetzki, U. 2013. Eine Erfolgsgeschichte: Datenlogger in der Seevogelforschung. Der Falke 3: 92-98.

Kurt, F. 1995. Gekennzeichnet fürs Leben? Über die Markierung von Wildtieren. Weidwerk 7: 16-18.

Larsen, R.S., Sonerud, G.A. &. Stensrud, O.H. 1987. Dispersal and Mortality of Juvenile Eagle Owls Released from Captivity in Southeast Norway as Revealed by Radio Telemetry. Biology and Conservation of Northern Forest Owls, Symposium Proceedings, Winnipeg, Manitoba: 215-219.

Leditznig, C. 1999. Zur Ökologie des Uhus *(Bubo bubo)* im Südwesten Niederösterreichs und in den donaunahen Gebieten des Mühlviertels. Nahrungs-, Habitat- und Aktivitätsanalysen auf Basis radiotelemetrischer Untersuchungen. PhD thesis. University of Natural Resources and Life Sciences, Vienna, 200pp.

Leditznig, C. & Kohl, I. 2013. Die Wiederansiedlung des Habichtskauzes *(Strix uralensis)* in den nördlichen Kalkalpen. Silva Fera 2: 78-93.

Leditznig, C. & Langer, K. 2017. GPS-GSM-Telemetrie zur Überwachung gesund gepflegter Vögel. Informativ 85: 8-9.

Mallory, M.L. & Gilbert, C.D. 2008. Leg-loop harness design for attaching external transmitters to seabirds. Marine Ornithology 36: 183-188.

Mendel, B. & Garthe, S. 2010. Strategien bei der Nahrungssuche: Mit Hightech auf der Spur der Helgoländer Heringsmöwen. Der Falke 10: 402-408.

Meyburg, B.U., Roepke, D., Meyburg, C. & Baß, A. 2016. Das Leben deutscher Fischalder per Satellit verfolgt. Der Falke 2: 26-29.

Michael, S., Gartrell, B. & Hunter, S. 2013. Humeral remodeling and soft tissue injury of the wings caused by backpack harnesses for radio transmitters in New Zealand Takahē (Porphyrio hochstetteri). Journal of Wildlife Diseases 49(3): 552-559.

Mong, T.W. 2005. Using Radio-Telemetry to determine Range and Resource Requirements of Upland Sandpipers at an experimentally managed Prairie Landscape. MSc thesis, Kansas State University, Manhattan, Kansas, 65pp.

Morton, D.B., Hawkins, P., Bevan, R., Heath, K., Kirkwood, J., Pearce, P., Scott, L., Whelan, G. & Webb, A. 2003. Refinements in telemetry procedures. Seventh report of the BVAAWF/FRAME/RSPCA/UFAW Joint Working Group on Refinement, Part A. Laboratory Animals 37.

Naef-Daenzer, B., Früh, D., Stalder, M., Wetli, P. & Weise, E. 2005. Miniaturization (0.2·g) and evaluation of attachment techniques of telemetry transmitters. The Journal of Experimental Biology 208: 4063-4068.

Néouze, R., Lörcher, F. & Hegglin, D. 2016. Beringung und Monitoring: Daten für die Wissenschaft. Der Falke (Sonderheft Geier): 52-55.

Nicholls, T.H. & Fuller, M.R. 1987. "Owl Telemetry Techniques", Biology and Conservation of Northern Forest Owls. Symposium Proceedings, Winnipeg, Manitoba: 294-301.

Peniche, G., Vaughan-Higgins, R., Carter, I., Pocknell, A., Simpson, D. & Sainsbury, A. 2011. Long-term health effects of harness-mounted radio transmitters in red kites (*Milvus milvus*) in England. Veterinary Record: September 17.

Rappole, J.H. & Tipton, A.R. 2009. New harness design for attachment of radio transmitters to small passerines. Journal of Field Ornithology 62(3): 335-337.

Robert, M., Drolet, B., Savard, J.P.L. 2006. Effects of Backpack Radio-Transmitters on Female Barrow's Goldeneyes. Waterbirds 29(1): 115-120.

Schäffer, N. 1990. Beobachtungen an ausgewilderten Habichtskäuzen *Strix uralensis* – Eine Untersuchung mit Hilfe der Telemetrie. Ornithologischer Anzeiger 29: 139-154.

Schmajohann, H. 2013. Rastökologie: Was machen Zugvögel am Rastplatz. Der Falke (Sonderheft): 42-46.

Steenhof, K., Bates, K.K., Fuller, M.R., Kochert, M.N., McKinley, J.O. & Lukacs, P.M. 2006. Effects of Radiomarking on Prairie Falcons: Attachment Failures Provide Insights About Survival. Wildlife Society Bulletin 34(1): 116-126.

Stickroth, H. 2016. 2115 km Zug in dreieinhalb Tagen und ein Todfund in Afrika. Der Falke 5: 40-41.

Thomson, K.M. & Kaatz, C. 2010. Die NABU-Bundesarbeitsgruppe Weißstorchschutz – Vom Monitoring zum Aktionsplan. Der Falke 11: 458-462.

Vlček, J. & Schmidberger, M. 2014. Satellitentelemetrie von Wachtelkönigen. Der Falke 3: 16-17.

Wikelski, M., Müller, U. & Naumann, W. 2015. Das satellitenbasierte ICARUS-Projekt: Ein neues globales Tierbeobachtungssystem. Der Falke 10: 20-25.