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Implementing telemetry on new species in remote areas: recommendations from a large-scale satellite tracking study of African waterfowl

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We provide recommendations for implementing telemetry studies on waterfowl on the basis of our experience in a tracking study conducted in three countries of sub-Saharan Africa. The aim of the study was to document movements by duck species identified as priority candidates for the potential spread of avian influenza. Our study design included both captive and field test components on four wild duck species (Garganey, Comb Duck, White-faced Duck and Fulvous Duck). We used our location data to evaluate marking success and determine when signal loss occurred. The captive study of eight ducks marked with non-working transmitters in a zoo in Montpellier, France, prior to fieldwork showed no evidence of adverse effects, and the harness design appeared to work well. The field study in Malawi, Nigeria and Mali started in 2007 on 2 February, 6 February and 14 February, and ended on 22 November 2007 (288 d), 20 January 2010 (1 079 d), and 3 November 2008 (628 d), respectively. The field study indicated that 38 of 47 (81%) of the platform transmitter terminals (PTTs) kept transmitting after initial deployment, and the transmitters provided 15 576 locations. Signal loss during the field study was attributed to three main causes: PTT loss, PTT failure and mortality (natural, human-caused and PTT-related). The PTT signal quality varied by geographic region, and interference caused signal loss in the Mediterranean Sea region. We recommend careful attention at the beginning of the study to determine the optimum timing of transmitter deployment and the number of transmitters to be deployed per species. These sample sizes should be calculated by taking into account region-specific causes of signal loss to ensure research objectives are met. These recommendations should be useful for researchers undertaking a satellite tracking program, especially when working in remote areas of Africa where logistics are difficult or with poorly-known species.

Introduction

Satellite tracking has become a major tool in the study of wildlife movements because it can provide detailed information about movement routes over large and remote areas (Strikwerda et al. 1986). When designing telemetry studies for wild birds, numerous factors must be considered including bird morphology and behaviour, potential impacts of transmitters on tagged individuals, and the frequency and quality of remotely sensed location data (Pennycuick and Fuller 1987, Hooge 1991, Murray and Fuller 2000, Millspaugh and Marzluff 2001, Roshier and Asmus 2009). These issues are particularly important when working with species that have not been studied before or in new habitats or locations (Kenward 2001).

Recently, Africa has become a focal region in the study of potential avian influenza transmission by wild birds. Monitoring programmes have been established in many countries to determine the types and prevalence of viruses carried by wild birds, including highly pathogenic avian influenza H5N1 (Gaidet et al. 2007). Ecological study can greatly enhance our understanding of influenza transmission pathways (Whitworth et al. 2007, Gilbert et al. 2008, Muzaffar et al. 2009) and satellite tracking programs are particularly useful for gathering information about wild bird movements in relation to past disease outbreaks, interactions with domestic animals, and other transmission risk factors (Muzaffar et al. 2008, Newman 2008, Prosser et al. 2009, Takekawa et al. in press). However, seasonal movements and habitat use patterns of birds in Africa, particularly in sub-Saharan regions of the continent, are poorly studied compared to Europe and North America. Few telemetry studies have been conducted on wild birds in sub-Saharan Africa (Meyburg et al. 2001, 2004, Bamford et al. 2007, Christensen et al. 2008, Gerkmann et al. 2008), especially on wild waterfowl (Petrie et al. 1996).

In this paper, we describe our experience with satellite transmitters used in a tracking study conducted in three countries of sub-Saharan Africa: Mali, Malawi, and Nigeria. The species studied were: Garganey (*Anas quequedula*), a migrant from Eurasia and the most abundant Palaearctic duck wintering in Africa (Scott and Rose 1996, Trolliet and Girard 2006); Comb Duck (*Sarkidiornis melanotos*), a large African duck known to perform extensive intra-African movements including transequatorial migration (Brown et al. 1982); White-faced Duck (*Dendrocygna viduata*), the most common Afrotropical duck and for which movements are generally considered seminomadic (Petrie et al. 1996); and Fulvous Duck (*Dendrocygna bicolor*), congener of the White-Faced Duck in Africa that occupies similar habitats. These species were chosen due to the role they may play in maintaining and spreading avian influenza viruses. Our objective was to evaluate the use of satellite transmitters on African ducks, effectiveness of the attachment on the basis of retention and lifespan, effects on tagged individuals, and quality and duration of locations. Our study design included both captive and field-released individuals, which enabled us to comment on overall performance and offer recommendations for other researchers considering satellite tracking programs in remote locations with minimal infrastructures.

Materials and methods

Transmitter packages and attachment technique

We used three different solar-powered platform terminal transmitters (PTTs; Microwave Telemetry Inc., Columbia, MD, USA): 12 g for Garganeys, 18 g for White-Faced Ducks and Fulvous Ducks, and 30 g for Comb Ducks. Transmitter sizes were selected to ensure that the PTTs did not exceed 3% of the bird's body weight (Steenhof et al. 2006). We used a satellite transmitter and attachment technique similar to the one described by Miller et al. (2005), which proved successful in North America for tracking Northern Pintail (*Anas acuta*) during migration. We mounted the PTTs dorsally between the wings by fashioning a harness of woven Teflon ribbon (Bally Ribbon Mills, Bally, PA, USA), using 0.48 cm, 0.84 cm or 1.40 cm wide straps for Garganeys, whistling ducks, and Comb Ducks, respectively (Figure 1). The completed harness included keel and body loops connected along the keel with a strap following Miller et al. (Miller et al. 2005) and similar to the designs used by Malecki et al. (2001) and Petrie et al. (1996). Our ventral body attachment consisted of a single length of ribbon without metal clips or buckles and with knots hardened using superglue (Henkel Loctite Corp., Rocky Hill, CT, USA).

Captive study

To validate the attachment technique on these new species, a captive animal monitoring test was implemented at Le Zoo de Lunaret, Montpellier, France, in the winter before

Figure 1: Images taken during the field missions showing (a) the deployment of a 30 g solar-powered GPS-ARGOS PTT on a Comb Duck, (b) a Comb Duck equipped with a 30 g solar-powered GPS-ARGOS PTT, (c) a Garganey equipped with a 12 g solar-powered ARGOS PTT, and (d) a Fulvous Duck equipped with a 18 g solar-powered ARGOS PTT

the beginning of the field study in Africa. The goal of this captive study was to adapt the attachment technique to new species that may have distinct body shapes. Thus, only a few birds per species were necessary. We attached dummy PTTs to three Garganeys, three Fulvous Ducks, and two Comb Ducks that were maintained in captivity and had clipped wings. The harnesses were attached in an examination room under supervision of a wildlife veterinarian by the biologists who later conducted the field work. The Garganeys and Fulvous Ducks were kept in a cage for three weeks for observation. Each duck was weighed and visually inspected every second day for injury or evidence of impact on its physical condition. To check PTT stability and fit, we measured three distances: from the rear knot of the harness to the end of the keel, from the harness to the left shoulder peak, and from the harness to the right shoulder peak. The ducks were released in a pond on the zoo grounds that resembled conditions of a natural wetland. The Comb Ducks were not delivered to the zoo until after the Garganeys and Fulvous Ducks had already been released into the pond and, owing to time constraints, we released them directly into the pond after PTTs were attached. Once in the pond, ducks were observed every second day, and they remained there for one month before being recaptured and inspected.

Field study

Two field sites were selected in West Africa: the Inner Niger Delta (15°13′ N, 4°19′ W) in Mali and the Hadejia-Nguru wetlands (12°48′ N, 10°44′ E) in Nigeria (Figure 2). Both are major Sahelian wetlands of great international importance for migratory and resident waterbirds, which support large numbers of Garganeys and African ducks. A third site was selected in south-central Africa: Lake Chilwa (15°20′ S, 35°30′ E) in Malawi (Figure 2), which supports large concentrations of African ducks originating from areas in eastern and southern Africa. Field work at all three sites was conducted between 29 January and 27 February 2007. This period corresponded to the middle of the dry season in West Africa when waterbirds congregate at major water bodies, and Palaearctic migrants forage intensively prior to spring migration. In Malawi, the timing corresponded to the rainy season when Comb Ducks, Fulvous Ducks, and White-Faced ducks are breeding (Brown et al. 1982).

We captured birds using a variety of techniques including baited traps (corn, sorghum, and millet), mist nets (main technique used in Mali and Malawi), and leg nooses. Most captures were made with the assistance of local hunters and trappers. Only birds that we visually determined were in good condition (lacking obvious injury, exhibiting normal locomotion, and showing no signs of emaciation) were fitted with PTTs; birds that were stressed because of handling duration (Balcombe et al. 2004) or poor condition (Sockman and Schwabl 2001) were released without transmitters. We followed field procedures for capture, handling, and tagging that were approved by the US Geological Survey, Western Ecological Research Center Animal Care and Use Committee. A total of 47 birds were marked with PTTs, including three that were fitted with PTTs redeployed after the initial marked bird died (Table 1). We could not capture as many White-Faced Ducks as expected. During the last field mission in Mali, it was thus decided to attach the remaining 18 g transmitters on Fulvous Ducks where possible, and finally on Comb Ducks. During the first 5 d after release, birds were monitored intensively and those that did not appear to be moving were located by the field teams to determine their status. Thereafter, their status was inferred from the satellite data.

The PTTs were programmed to transmit depending on their battery capacity or solar efficiency. The on:off duty cycle of the 12 g was 8 h every 24 h, the 18 g was 10 h every 24 h, and the 30 g transmitted for a varying amount

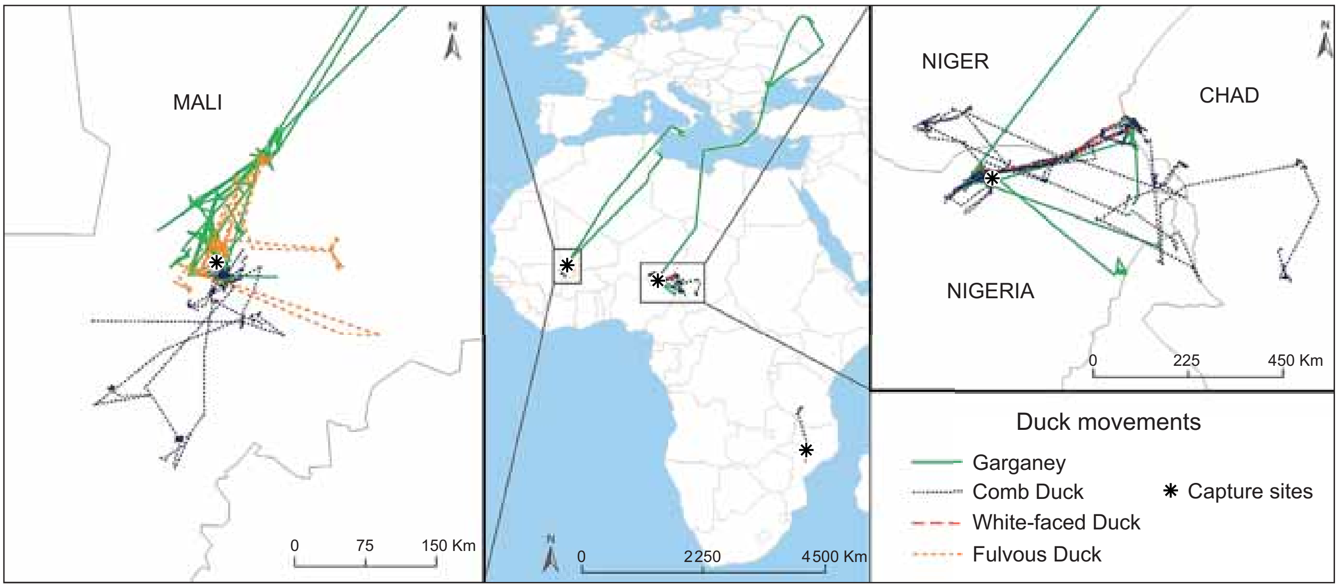

Figure 2: Location of study sites in Mali, Nigeria and Malawi, where wild ducks were caught and marked

of time depending on satellite overpasses every 48 h. Data were received via the Argos Data Collection and Location System (CLS, Toulouse, France) via receivers aboard polar-orbiting weather satellites. In addition to Argos locations (classes 0, 1, 2, 3, A and B), the 30 g PTTs also logged GPS locations (class G) every 2 h and transmitted the data via the Argos system. The accuracy of each location was rated by an error class. Location class G indicated that the position was a GPS fix with mean accuracy estimated at ±18.5 m, providing our most accurate locations. Argos location classes 0, 1, 2 and 3 indicated the location was derived from ≥4 transmissions with Argos satellites, with 1-sigma error radius of >1 000 m, 350–1,000 m, 150–350 m, and ≤150 m, respectively. Location classes A (three transmissions) and B (two transmissions) were not assigned accuracy estimates by CLS, and location class Z indicated that only a single transmission was received and no location estimate could be made. We used all these seven location classes in our analysis.

Table 1: Number and types of satellite transmitters (PTT) deployed in Africa by country, species, and PTT size

Country	Species	12 g	18 g	30 g	Total
Malawi	Comb Duck			3	3
	White-Faced Duck		2		2
Mali	Comb Duck		2	8	10
	Garganey	10			10
	White-Faced Duck		2		2
	Fulvous Duck		3		3
Nigeria	Comb Duck			7	7
	Garganey	8			8
	White-Faced Duck		2		2
Total		18	11	18	47

Data analysis

We used location data to evaluate the longevity of PTT signal transmission and determine when signal loss occurred. We began by summarising the duration over which locations were received and then examined changes in the number of messages per location over time. We defined signal loss when meaningful data ceased to be received from a bird, although infrequent transmissions may have been detected. The first two weeks after release was a critical period for detecting capture or handling stress, and negative effects associated with instrumentation (Esler et al. 2000, Iverson et al. 2006). Therefore, we divided signal loss into (1) early deployment (≤14 d) and (2) tracking periods (>14 d). For each signal loss, we recorded the last known location, habitat type from a satellite image, season, annual cycle stage (e.g. breeding), and intensity of hunting when available.

Results

Captive study

During the first monitoring period when the birds were held in cages, the Garganeys and Fulvous Ducks remained in good health and showed no evidence of adverse effects such as injury, abrasions, weight loss or poorly fitted harnesses (Table 2). During the second monitoring period when birds were released in the pond, two Garganeys died. However, five other ducks from the regular zoo population also died in the pond without having been marked with PTTs. Necropsies did not indicate any specific causes for the mortalities, and the reason may have been the inclement December weather. The surviving birds showed no indication of injury or poorly fitted harnesses; however, the remaining Garganey and the three Fulvous Ducks lost 10–15% of their body weight while in the pond (Table 2).

Table 2: Results from the captive study. Summary of inspection of transmitters attached to Fulvous Ducks (FUWD) and Garganey (GARG) outfitted with dummy transmitters and monitored during captive studies at Le Zoo du Lunaret, Montpellier, France (13 November 2005 to 3 January 2006)

		Cage[A]			Pond	
Individual	Critera	13 Nov.	20 Nov.	27 Nov.	04 Dec.	03 Jan.
FUWD-1	Weight (g)	816	812	802	818	736
	Distance keel – rear knot (cm)	4.5	5.5	5.5	5.5	5.5
	Distance to left/right shoulder peak (cm)	0/0	0.5/0.5	1/0	1/0	0/0
FUWD-2	Weight (g)	825	832	809	811	729
	Distance keel – rear knot (cm)	3.8	5	5	5	5
	Distance to left/right shoulder peak (cm)	0/0	0/0	0/0	0/0	0/0
FUWD-3	Weight (g)	853	850	850	859	746
	Distance keel – rear knot (cm)	3.8	4	5	4.5	5
	Distance to left/right shoulder peak (cm)	0/0	0/0	0/0	0/0	0/0
GARG-1	Weight (g)	427	426	424	419	358
	Distance keel – rear knot (cm)	3.8	5.5	5	5	5
	Distance to left/right shoulder peak (cm)	0/0	0/0	0/0	0/0	0/0
GARG-2	Weight (g)	340	342	353	353	dead
	Distance keel – rear knot (cm)	3.8	5	5.5	5	
	Distance to left/right shoulder peak (cm)	0/0	1/1	0.5/0.5	0.5/0.5	
GARG-3	Weight (g)	453	455	459	469	dead
	Distance keel – rear knot (cm)	4.6	6	5.5	5.5	
	Distance to left/right shoulder peak (cm)	0/0	1/1	1/1	1.5/1.5	

[A] Individuals were inspected every second day while in cages. Condition is summarised by week in this table

There was no evidence of injury for the Comb Ducks and their harnesses appeared to fit well, although their mass was not assessed.

Field study

Nine of 47 PTTs (19% of the total sample) ceased transmitting during early deployment, seven during the first 3 d after release. These included one Garganey (in Nigeria), two Fulvous Ducks (in Mali), and four Comb Ducks (two in Mali and two in Malawi) (Figure 3). Four of these PTTs were subsequently recovered from dead birds by our field teams in Mali and Nigeria. Although cause of death could not be determined, it was probably related to the stress induced by the capture and the handling since the PTTs were all in good working order and three were redeployed on new individuals. The 38 transmitters that survived initial deployment provided 15 576 locations (3 469 d with at least one location) over 205 months (i.e. a mean of 410 locations over 5.4 months per PTT). One PTT was still transmitting in October 2009, 980 d (2.7 years) after its release.

Several factors were correlated with signal loss during the regular tracking stage. Hunting pressure was particularly intense during the first 1–2 months after release at the West African study sites. A review of satellite images confirmed the last known location for at least one individual was in a village (Figure 4), and its previous location was in a bourgou (*Echinocloa stagnina*) field where Garganey hunters often deployed nets. For several other individuals, signal loss was preceded by locations in areas known to be favourable for Garganey trapping. Concurrent with this period of elevated hunting and extending 100 d after release, substantial movements were documented for all four species. For the Garganey, this period coincided with the end of their wintering period and onset of spring migration. Three PTTs on Garganeys were last detected as they moved northward for at least 600 km across the Sahara. In total, signal loss occurred for 14 of 17 PTTs attached on Garganeys during the interval 15–100 d after release (February–May) when hunting pressure was severe and spring migration was underway.

Signal loss also occurred during the 1–100 d postrelease interval for White-Faced Ducks and Comb Ducks, as four of five PTTs from White-Faced Ducks and seven of 15 PTTs from Comb Ducks ceased transmitting (Figure 3). In Malawi, this period coincided with the end of the rainy season and onset of postbreeding movements to new habitats. In Nigeria and Mali, these species departed drying wetlands for areas that remained flooded. In most cases, long-distance movements were observed prior to signal loss, suggesting that predation occurred or birds may have been unable to complete strenuous migration flights.

A final period of signal loss occurred from 140–190 d after release (Figure 3) and corresponded to the rainy season in Mali and Nigeria (July to September). Losses during this period primarily affected Comb Ducks during their breeding period. Comb Ducks are cavity nesters and evidence from Mali, where four of the five PTT signal losses occurred, indicate that signals were last received in flooded woodland habitats that were identified by local people as breeding locations. Their location suggests some likely reasons for signal loss, including poor charging of the battery while the birds nested in holes or harness loss associated with females gaining weight for egg production and nesting.

We also noted that the number of messages received per location was highly sensitive to flight behaviour. There was a tendency for fewer messages to be relayed to the Argos system during periods of sustained high-speed flight

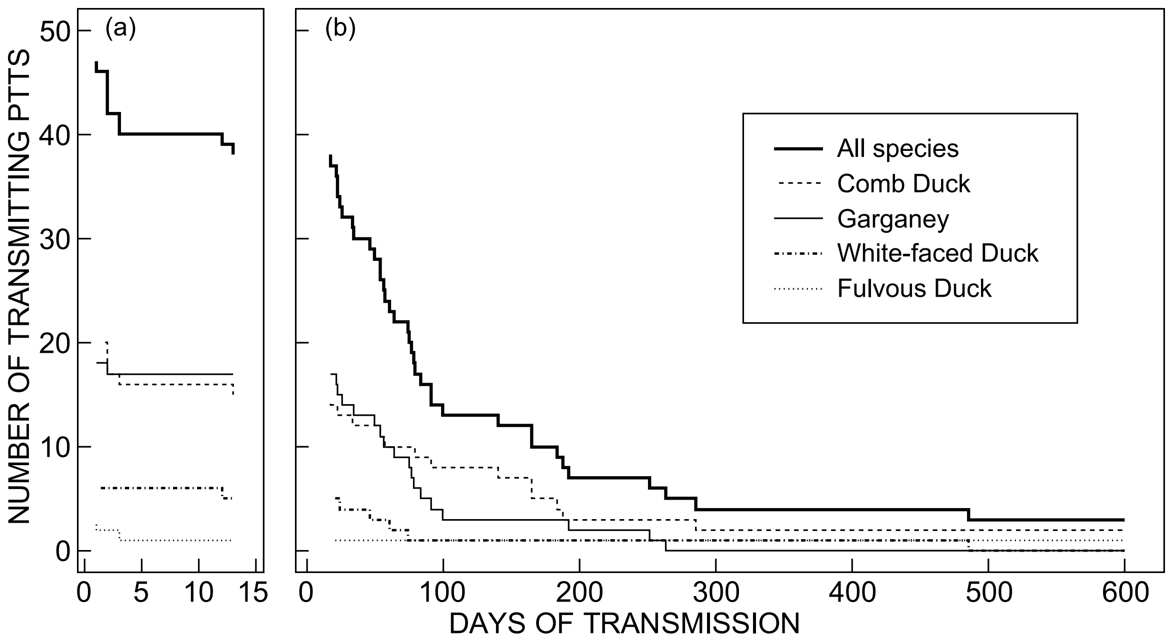

Figure 3: Transmission duration of 47 PTTs deployed for this study including cumulative number of each type of PTT that were transmitting after their release on day 1. Signal loss was divided into the early release period (a; days 1 to 14) and tracking period (b; days 14 to 100 and days 140 to 190)

compared to the period immediately preceding migration (Figure 5). Signal quality also varied by geographic region, with significantly fewer messages per location (χ^2 test with $p < 0.0001$ for each of the three birds, n total = 4 139 messages) in the Mediterranean Sea area than in sub-Saharan West Africa (Figure 5, Table 3).

Discussion

Results from our telemetry work in Africa have already revealed important spatiotemporal linkages across continents (Gaidet et al. 2008a) and relationships of movements by birds to areas infected with avian influenza within sub-Saharan Africa (Gaidet et al. 2008b). New information has also been collected documenting movement patterns and habitat selection of African ducks through the annual cycle, as four birds were tracked for more than a year, including one Comb Duck still transmitting two-and-a-half years after its release. We had significant signal loss recorded during our study for numerous reasons, but we had the luxury of deploying a relatively large number of waterfowl with transmitters, and the final sample size was adequate to address most of our study questions. Although it is rarely possible to determine exact causes of signal loss (Hays et al. 2007), we identified several factors to consider in undertaking telemetry research in remote and logistically challenging areas such as much of tropical Africa.

In our study, 19% of all PTTs were lost during early deployment. During the first two weeks, signal loss could be attributed to PTT loss, capture stress, PTT failure or mortality. To avoid PTT losses, we evaluated transmitter-fit in a controlled setting and did not detect problems with our attachment method. Our field biologists were highly experienced in waterfowl telemetry research and worked closely with local hunters to capture the ducks. We tried to minimise the capture and handling stress of the birds by limiting the handling duration (Balcombe et al. 2004) and by selecting birds in good condition (Pollock et al. 1989, Sockman and Schwabl 2001). However, African hunters normally catch birds for subsistence or sale rather than scientific research where birds need to be kept in good condition. In Mali and Malawi, most of the captures were made during predawn hours in nets suspended above flooded vegetation, and the birds may have been held for several hours before recovery. Rates of signal loss during the immediate postrelease (within 4 d after releasing) period tended to be higher in Mali (four out of 25; 16%) and Malawi (two out of five; 40%) than in Nigeria (one out of 17; 5.9%), where most birds were captured with baited traps and leg nooses. We suspect that the ducks that were captured with nets by local hunters were not retrieved until several hours later and encountered greater stress than those captured in baited traps and leg nooses. Those results were consistent with an increased risk of dying during the first 4 d after releasing as shown by Cox and Afton (1998) on female pintails.

In most telemetry studies, once birds recover from the capture and acclimate to their transmitters, their movement behaviour during the tracking period is considered the same as for birds without transmitters (Esler et al. 2000, Iverson et al. 2006). Signal loss after acclimatisation may be attributed to three main causes: PTT loss, PTT failure and mortality (natural, human-caused and PTT-related).

Figure 4: Satellite image depicting the last three locations of PTT 73008, attached to a male Garganey in Mali. The three locations in a village follow a previous location in a bourgou (*Echinocloa stagnina*) field where Garganey hunters deploy their nets. It is likely that the Garganey was captured by local hunters from this village

First, transmitters may be lost because the harness attachment fails, a bird may damage the harness, or seasonal changes in body size may result in a harness becoming loose. In any of these scenarios, the PTT can fall off the bird. Waterfowl may change their mass by a large amount during nesting, moulting or wintering periods when they may expend large amounts of energy (Owen and Black 1989, Loesch et al. 1992).

Second, PTT failure may occur. All PTTs have a projected lifespan determined by the battery and duty cycle, but PTTs are complicated devices and not all achieve this projection. Solar-powered PTTs are particularly susceptible to loss of power due to low sunlight (Hake et al. 2001) and feathers covering solar cells. Also, comb ducks nest in tree cavities (Brown et al. 1982), and we suspect that use of seasonally flooded forest habitat decreased the opportunity for PTT solar panels to recharge, particularly when females are in cavities on nests. We also showed that PTT failure may have also been related to decreasing signal quality in the Mediterranean region, due to major interferences in this area (Collecte Localisation Satellites pers. comm.).

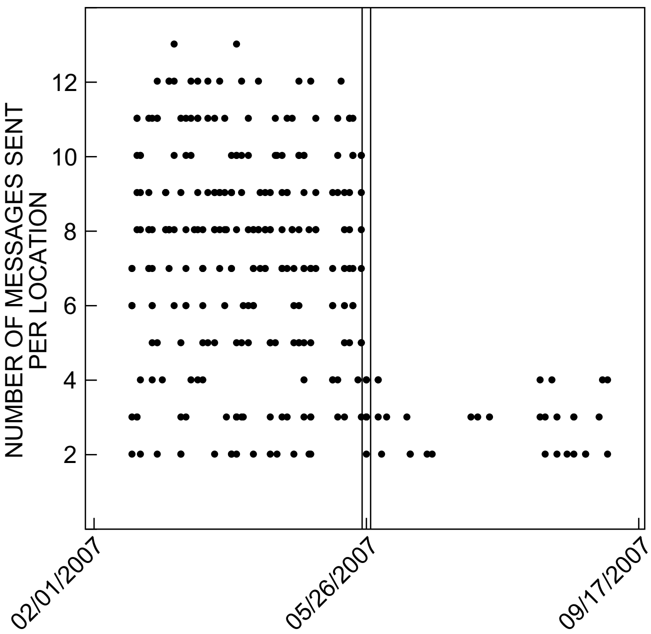

Figure 5: Number of messages received for each location obtained from PTT 73006 between its release on 14 February 2007 and its last location on 4 September 2007. Each symbol corresponds to a message, and the vertical line shows the date of the migration of the bird from Mali to Tunisia on 26 May 2007 when it entered the Mediterranean region

Third, signal loss may be attributed to bird mortality. PTT-marked birds experience natural mortality (predation or death not influenced by the PTT). However, this is difficult to distinguish from PTT-induced mortality, especially when the transmitters cannot be recovered because of logistics. Comparing the mortality rate with that estimated by other means, such as a band recovery study, may suggest expected mortality rates (Paquette et al. 1997, Hupp et al. 2009). Mortality may occur due to anthropogenic effects including habitat contamination or hunting (Halse et al. 1993, Combreau et al. 2001). We concluded that high hunting pressure in West Africa during February and March (Wymenga et al. 2002) was an important source of signal loss, with concurrent issues surrounding the onset of spring migration by Garganeys and intra-African seasonal movements by Fulvous Ducks, White-Faced Ducks and Comb Ducks. The last transmissions of several PTTs were located in areas known to be important trapping locations for local hunters in Mali and Nigeria. Finally, PTTs and harness attachments may adversely affect survival. We observed most of the signal losses during periods of seasonal movement. Several Garganeys were located for the last time during their northward migration across the Sahara, and signals for Afrotropical ducks were also lost during seasonal movement periods. These losses could have been a result of natural mortality; however, birds with PTTs have higher wing-loading compared with birds without PTTs, potentially making them less manoeuvrable and reducing their endurance (Pietz et al. 1993). A harness that is fitted incorrectly or becomes too tight or too loose due to seasonal changes in mass may impede flight or feeding of birds and cause or contribute to mortality.

Recommendations

Marking a bird will affect its behaviour and survival to some extent (Pietz et al. 1993, Ward and Flint 1995, Dzus and Clark 1996, Petrie et al. 1996, Hupp et al. 2003), but it may be possible to minimise these effects by considering the different factors involved. On the basis of our experience with satellite telemetry on waterfowl in Africa, we offer two sets of recommendations for researchers embarking on telemetry studies.

Table 3: Number of messages received for PTTs 73006, 73014 and 73018 when birds were located in sub-Saharan Africa and in the Mediterranean Sea area

Site	PTT	No. locations	No. messages	Messages location^{-1}	Messages d^{-1}
Africa	73006	268	1 892	7.06	19.31
	73014	102	679	6.66	12.13
	73018	181	1 208	6.67	18.30
	Total	551	3 779	6.86	17.18
Mediterranean Sea	73006	99	182	1.84	1.80
	73014	34	75	2.21	3.41
	73018	40	103	2.58	6.06
	Total	173	360	2.08	2.57

The first set of recommendations relates to selection of study species, sites, period, and marking equipment, before the beginning of the field study. Depending on the questions to be answered, several species could be selected for marking. The choice of the species should consider the average body mass, the results of captive tests implemented prior to the study where possible, and specific behaviours of certain species that may reduce the transmission quality (e.g. nesting in tree holes). The marking team should train before the mission in the field and, when possible, it is better to train on all the target species to adapt the attachment technique to any morphological specificity. Second, an estimate of expected signal loss related to each of the possible causes we reviewed should be made to determine the sample size that will achieve the objectives of the study. Different types of transmitters (e.g. implants versus harnesses, battery powered versus solar powered) may be selected (Demers et al. 2003, Iverson et al. 2006) on the basis of that evaluation. Third, several sites are often possible to use for catching birds and fitting the transmitters. A good site offers straightforward logistics for capture and handling of the birds. It is also important to review the transmission quality in the expected regions traversed by the birds. Transmission power may be increased in areas with interference. Fourth, periods for capture should be reviewed to maximise transmitter survival. In West Africa, we attempted to catch birds during a narrow window of time just before the beginning of migration because it was the traditional hunting season. We recommend avoiding areas where hunting pressure is intense or time captures to minimise the risk of hunting mortality whenever possible.

The second set of recommendations relate to application in the field. First, the capture technique should minimise any adverse effects to the bird. Capture time should be kept to a minimum, and birds should be released immediately after marking when possible. Second, the handling time should be minimised to reduce stress. The birds should be kept in quiet and dark conditions if possible prior to marking; we typically cover the eyes of our birds with a hood. An animal in a poor condition (e.g. drooping head, imbalance, high temperature) or with a poorly fitted transmitter should be released without being marked. Finally, following release the movement of the birds should be monitored closely for the first week. By obtaining locations of the transmitters every day via the internet, text messages, or calls in the field and checking on non-moving birds, some of the transmitters may be recovered and redeployed. In this study, we recovered four transmitters in the field and redeployed three of them. In remote areas, early tracking is critical since PTT recoveries will be very challenging afterwards.

Transmission failures may be caused by a large set of factors. Although it is difficult to attribute a specific reason for each transmission failure, it is worth considering all the reasons that are likely to occur to estimate the appropriate number of PTTs that should be deployed. Our recommendations include a list of detailed considerations that should help in establishing a suitable sample size for a successful telemetry project while minimising signal loss.

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References

Balcombe JP, Barnard ND, Sandusky C. 2004. Laboratory routines cause animal stress. *Contemporary Topics in Laboratory Animal Science* 43: 42–51.

Bamford AJ, Diekmann M, Monadjem A, Mendelsohn J. 2007. Ranging behaviour of Cape Vultures *Gyps coprotheres* from an endangered population in Namibia. *Bird Conservation International* 17: 331–339.

Brown LH, Urban EK, Newman K (eds). 1982. *The Birds of Africa*. London: Academic Press.

Christensen KD, Falk K, Jensen FP, Petersen BS. 2008. Abdim's Stork *Ciconia abdimii* in Niger: population size, breeding ecology and home range. *Ostrich* 79: 177–185.

Combreau O, Launay F, Lawrence M. 2001. An assessment of annual mortality rates in adult-sized migrant houbara bustards (*Chlamydotis [undulata] macqueenii*). *Animal Conservation* 4: 133–141.

Cox RR, Afton AD. 1998. Effects of capture and handling on survival of female Northern Pintails. *Journal of Field Ornithology* 69: 276–287.

Demers F, Giroux J-F, Gauthier G, Bêty J. 2003. Effects of collar-attached transmitters on behaviour, pair bond and breeding success of snow geese *Anser caerulescens* atlanticus. *Wildlife Biology* 9: 161–170.

Dzus EH, Clark RG. 1996. Effects of harness-style and abdominally implanted transmitters on survival and return rates of mallards. *Journal of Field Ornithology* 67: 549–557.

Esler D, Schmutz JA, Jarvis RL, Mulcahy DM. 2000. Winter survival of adult female harlequin ducks in relation to history of contamination by the Exxon valdez oil spill. *Journal of Wildlife Management* 64: 839–847.

Gaidet N, Cattoli G, Hammoumi S, Newman SH, Hagemeijer W, Takekawa JY, Cappelle J, Dodman T, Joannis T, Gil P, et al. 2008b. Evidence of infection by H5N2 highly pathogenic avian influenza viruses in healthy wild waterfowl. *PLoS Pathogens* 4: 1–9.

Gaidet N, Dodman T, Caron A, Balanca G, Desvaux S, Goutard F, Cattoli G, Lamarque F, Hagemeijer W, Monicat F. 2007. Avian influenza viruses in water birds, Africa. *Emerging Infectious Diseases* 13: 626–629.

Gaidet N, Newman SH, Hagemeijer W, Dodman T, Cappelle J, Hammoumi S, De Simone L, Takekawa JY. 2008a. Duck migration and past influenza A (H5N1) outbreak areas. *Emerging Infectious Diseases* 14: 1164–1166.

Gerkmann B, Kaatz M, Riede K, van den Elzen R. 2008. The Luangwa Valley, Zambia: flyway and stopover site for White Storks *Ciconia ciconia*. *Ostrich* 79: 171–176.

Gilbert M, Xiao XM, Pfeiffer DU, Epprecht M, Boles S, Czarnecki C, Chaitaweesub P, Kalpravidh W, Minh PQ, Otte MJ, Martin V, Slingenbergh J. 2008. Mapping H5N1 highly pathogenic avian influenza risk in Southeast Asia. *Proceedings of the National Academy of Sciences of the USA* 105: 4769–4774.

Hake M, Kjellén N, Alerstam T. 2001. Satellite tracking of Swedish Ospreys *Pandion haliaetus*: autumn migration routes and orientation. *Journal of Avian Biology* 32: 47–56.

Halse SA, James IR, Fitzgerald PE, Diepeveen DA, Munro DR. 1993. Survival and hunting mortality of Pacific black ducks and grey teal. *Journal of Wildlife Management* 57: 42–48.

Hays GC, Bradshaw CJA, James MC, Lovell P, Sims DW. 2007. Why do Argos satellite tags deployed on marine animals stop transmitting? *Journal of Experimental Marine Biology and Ecology* 349: 52–60.

Hooge PN. 1991. The effects of radio weight and harnesses on time budgets and movements of acorn woodpeckers. *Journal of Field Ornithology* 62: 230–238.

Hupp JW, Ruhl GA, Pearce JM, Mulcahy DM, Tomeo MA. 2003. Effects of implanted radio transmitters with percutaneous antennas on the behavior of Canada Geese. *Journal of Field Ornithology* 74: 250–256.

Hupp JW, Schmutz JA, Ely CR. 2009. Seasonal survival of radiomarked Emperor Geese in western Alaska. *Journal of Wildlife Management* 72: 1584–1595.

Iverson SA, Boyd WS, Esler D, Mulcahy DM, Bowman TD. 2006. Comparison of the effects and performance of four types of radiotransmitters for use with scoters. *Wildlife Society Bulletin* 34: 656–663.

Kenward RE (ed). 2001. *A Manual of Wildlife Radio Tagging*. London: Academic Press.

Loesch CR, Kaminski RM, Richardson DM. 1992. Endogenous Loss of Body Mass by Mallards in Winter. *Journal of Wildlife Management* 56: 735–739.

Malecki RA, Batt BDJ, Sheaffer SE. 2001. Spatial and temporal distribution of Atlantic population Canada geese. *Journal of Wildlife Management* 65: 242–247.

Meyburg B-U, Ellis DH, Meyburg C, Mendelsohn JM, Scheller W. 2001. Satellite tracking of two Lesser Spotted Eagles, *Aquila pomarina*, migrating from Namibia. *Ostrich* 72: 35–40.

Meyburg B-U, Gallardo M, Meyburg C, Dimitrova E. 2004. Migrations and sojourn in Africa of Egyptian vultures (*Neophron percnopterus*) tracked by satellite. *Journal of Ornithology* 145: 273–280.

Miller MR, Takekawa JY, Fleskes JP, Orthmeyer DL, Cassaza ML, Perry WM. 2005. Spring migration of Northern Pintails from California's Central Valley wintering area tracked with satellite telemetry: routes, timing and destinations. *Canadian Journal of Zoology* 83: 314–332.

Millspaugh J, Marzluff J (eds). 2001. *Radio Tracking and Animal Populations*. New York: Harcourt Publishers.

Murray DL, Fuller MR. 2000. Effects of marking on the life history patterns of vertebrate. In: Boitani L, Fuller T (eds), *Research Techniques in Ethology and Animal Ecology*. New York: Columbia University. pp 15–64.

Muzaffar SB, Takekawa JY, Prosser DJ, Douglas DC, Newman SH, Yan B, Xing Z, Hou Y, Palm E. 2008. Seasonal movements and migration of Pallas's Gulls *Larus ichthyaetus* from Qinghai Lake, China. *Forktail* 24: 100–107.

Muzaffar SB, Ydenberg RC, Jones IL. 2009. Avian influenza: an ecological and evolutionary perspective for waterbird scientists. *Waterbirds* 29: 243–257.

Newman SH. 2008. *The Role of Migratory Birds in the Spread of Highly Pathogenic Avian Influenza (H5N1): How to Catch Up With Emergence and Persistence*. In: Proceedings of the 15th Congress of the Federation of Asian Veterinary Associations and FAVA–OIE Joint Symposium on Emerging Diseases, Bangkok, Thailand, 27–29 October, 2008.

Owen M, Black JM. 1989. Factors affecting the survival of Barnacle Geese on migration from the breeding grounds. *Journal of Animal Ecology* 58: 603–617.

Paquette GA, Devries JH, Emery RB, Howerter DW, Joynt BL, Sankowski TP. 1997. Effects of transmitters on reproduction and survival of wild mallards. *Journal of Wildlife Management* 61: 953–961.

Pennycuick CJ, Fuller MR. 1987. Considerations of effects of radiotransmitters on bird flight. In: Kimmich HP, Neuman MR (eds), *Biotelemetry IX: Proceedings of the Ninth International Symposium on Biotelemetry*. Braunschweig: Doring-Druck. pp 327–330.

Petrie SA, Rogers KH, Baloyi FR. 1996. Effects of harness-attached satellite transmitters on captive whitefaced ducks *Dendrocygna viduata*. *South African Journal of Wildlife Research* 26: 93–95.

Pietz PJ, Krapu GL, Greenwood RJ, Lokemoen JT. 1993. Effects of harness transmitters on behavior and reproduction of wild mallards. *Journal of Wildlife Management* 57: 696–703.

Pollock KH, Winterstein SR, Michael JC. 1989. Estimation and analysis of survival distributions for radio-tagged animals. *Biometrics* 45: 99–109.

Prosser DJ, Takekawa JY, Newman SH, Yan BP, Douglas DC, Hou YS, Xing Z, Zhang DH, Li TX, Li YD et al. 2009. Satellite-marked waterfowl reveal migratory connection between H5N1 outbreak areas in China and Mongolia. *Ibis* 151: 568–576.

Roshier DA, Asmus M. 2009. Use of satellite telemetry on small-bodied waterfowl in Australia. *Marine and Freshwater Research* 60: 299–305.

Scott DA, Rose PM (eds). 1996. *Atlas of Anatidae Populations in Africa and Western Eurasia*. Slimbridge: Wetlands International.

Sockman KW, Schwabl H. 2001. Plasma corticosterone in nestling American kestrels: effects of age, handling stress, yolk androgens, and body condition. *General and Comparative Endocrinology* 122: 205–212.

Steenhof K, Bates KK, Fuller MR, Kochert MN, McKinley JO, Lukacs PM. 2006. Effects of radiomarking on Prairie Falcons: attachment failures provide insights about survival. *Wildlife Society Bulletin* 34: 116–126.

Strikwerda TE, Fuller MR, Seegar WS, Howey PW, Black HD. 1986. Bird-borne satellite transmitter and location program. *Johns Hopkins APL Technical Digest* 7: 203–208.

Takekawa JY, Newman SH, Xiao X, Prosser DJ, Spragens KA, Palm EC, Yan B, Li T, Lei F, Zhao D, Douglas DC, Muzaffar SB, Ji W. 2010. Migration of waterfowl in the East Asian Flyway and spatial relationship to HPAI H5N1 outbreaks. *Avian Diseases* 54: 466–476.

Trolliet B, Girard O.2006. Anatidae numbers and distribution in West Africa in winter. In: Boere GC, Galbraith, CA, Stroud, DA (eds), *Waterbirds around the world*. Edinburgh: The Stationery Office. pp 226–227.

Ward DH, Flint PL. 1995. Effects of harness-attached transmitters on premigration and reproduction of brant. *Journal of Wildlife Management* 59: 39–46.

Whitworth D, Newman S, Mundkur T, Harris P (eds). 2007. *Wild Birds and Avian Influenza: an Introduction to Applied Field Research and Disease Sampling Techniques*. FAO Animal Production and Health Manual No. 5. Rome: FAO.

Wymenga E, Kone B, Kamp J, Zwarts L (eds). 2002. *Delta Interieur du Fleuve Niger: Ecologie et Gestion Durable des Ressources Naturelles*. Sévaré: Wetlands International; Rijkswaterstaat: RIZA; Wageningen: Alterra; Veenwouden: Altenburg and Wymenga.

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Appendix 1: Summary of the basic information for all of the 47 platform terminal transmitters (PTTs) that were deployed during the study

PTT ID	PTT Type	Species	Country	Releasing date	Duration (d)	Distance maximum from origin (km)
73002	12-g	Garganey	Mali	14 February 2007	251	126
73004	12-g	Garganey	Nigeria	6 February 2007	192	365
73005	12-g	Garganey	Nigeria	10 February 2007	75	55
73006	12-g	Garganey	Mali	14 February 2007	99	3 025
73008	12-g	Garganey	Mali	14 February 2007	34	44
73009	12-g	Garganey	Nigeria	9 February 2007	56	392
73010	12-g	Garganey	Nigeria	9 February 2007	83	79
73011	12-g	Garganey	Mali	14 February 2007	53	5
73012	12-g	Garganey	Mali	14 February 2007	21	45
73013	12-g	Garganey	Nigeria	9 February 2007	64	428
73014	12-g	Garganey	Nigeria	9 February 2007	263	5 214
73015	12-g	Garganey	Mali	14 February 2007	22	14
73016	12-g	Garganey	Mali	14 February 2007	25	14
73018	12-g	Garganey	Mali	14 February 2007	76	2 534
73019	12-g	Garganey	Mali	14 February 2007	91	1 163
73021	12-g	Garganey	Mali	14 February 2007	78	51
73024	18-g	White-Faced Duck	Malawi	8 February 2007	486	59
73026	18-g	White-Faced Duck	Malawi	9 February 2007	74	186
73027	18-g	White-Faced Duck	Mali	15 February 2007	12	3
73028	18-g	White-Faced Duck	Mali	14 February 2007	60	4
73029	18-g	Comb Duck	Mali	15 February 2007	22	8
73030	18-g	Fulvous Duck	Mali	18 February 2007	624	132
73033	18-g	White-Faced Duck	Nigeria	14 February 2007	24	36
73035	30-g	Comb Duck	Nigeria	07 February 2007	57	75
73036	30-g	Comb Duck	Nigeria	12 February 2007	13	32
73037	30-g	Comb Duck	Nigeria	14 February 2007	785	560
73038	30-g	Comb Duck	Nigeria	14 February 2007	977	478
73039	30-g	Comb Duck	Nigeria	15 February 2007	53	65
73040	30-g	Comb Duck	Nigeria	15 February 2007	91	186
73041	30-g	Comb Duck	Nigeria	15 February 2007	183	176
73045	30-g	Comb Duck	Mali	14 February 2007	79	30
73047	30-g	Comb Duck	Malawi	07 February 2007	3	1
73048	30-g	Comb Duck	Mali	14 February 2007	165	146
73050	30-g	Comb Duck	Mali	14 February 2007	33	9
73051	30-g	Comb Duck	Malawi	10 February 2007	2	2
73287	18-g	White-Faced Duck	Nigeria	14 February 2007	46	355
73291	18-g	Comb Duck	Mali	18 February 2007	183	216
73292	18-g	Fulvous Duck	Mali	15 February 2007	1	2
73293	18-g	Fulvous Duck	Mali	15 February 2007	3	3
73295	30-g	Comb Duck	Malawi	10 February 2007	285	655
74806	30-g	Comb Duck	Mali	15 February 2007	17	15
73003a	12-g	Garganey	Nigeria	15 February 2007	2	1
73003b	12-g	Garganey	Nigeria	6 February 2007	49	26
73046a	30-g	Comb Duck	Mali	14 February 2007	2	1
73046b	30-g	Comb Duck	Mali	17 February 2007	140	223
73049a	30-g	Comb Duck	Mali	14 February 2007	2	1
73049b	30-g	Comb Duck	Mali	17 February 2007	188	200