Biologging is suspect to cause corneal opacity in two populations of wild living Northern Bald Ibises (*Geronticus eremita)*

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Abstract

Background In this paper, we present evidence that biologging is strongly correlated with eye irritation, suggesting a causal relationship with obvious impairing effects for the affected individuals. A migratory population of Northern Bald Ibises (Geronticus eremita) is reintroduced in Europe, in the course of a LIFE+ project (LIFE Northern Bald Ibis). Since 2014, all individuals are equipped with GPS-devices. Remote monitoring of the whole population allows the implementation of focussed measures against major mortality causes. Initially all birds carried battery-powered devices, fixed on the lower back of the birds. Since 2016, an increasing amount of birds were equipped with solar-powered devices, fixed on the upper back, as this is the more sun-exposed position. In 2016, we observed for the first time an opacity in the cornea of one eye (unilateral corneal opacity; UCO). From 2016 to 2018, a total of 25 birds were affected by UCO, with varying intensity up to blindness. However, only birds carrying a device on the upper back were affected (2017 up to 70% of this group). In contrasts, none of the birds which carried devices on the lower back ever showed UCO symptoms. This unexpected relationship between tagging and UCO was discovered in 2017. Since then, we started countermeasures by removing the device or repositioning it on the lower back.

Results Northern Bald Ibises roost with their head on the back, one eye closely placed to the device. Thus, we conclude that the most parsimonious explanation for the symptomatology is either a repetitive slight temperature rise in the corneal tissue due to electromagnetic radiation by the GSM module of the device or a repetitive slight mechanical irritation of the corneal surface. Concrete evidence is missing so far. On our advice, UCO was also found in Northern Bald Ibises of a Spanish reintroduction project, in a completely consistent context.

Conclusion Our results indicate that further research in the fast-growing field of biologging is urgently needed. The findings question the positioning of devices on the upper back in birds roosting with the head on the back.

Background

Biologging, defined as the use of miniaturized animal-attached tags for logging and/or relaying of data (Rutz & Hays, 2009), is a fast-growing field of basic and applied research in biology. Rapid technological development over the last decades allowed developing small and light devices applicable to an even wider range of species throughout the taxa down to the smallest birds and even large insects (Kays, Crofoot, Jetz, & Wikelski, 2015; M. Wikelski et al., 2007). Also the scope of applications steadily increases, conventional radio tracking and remote GPS-monitoring is completed by the measurement and transmission or logging of biological and environmental parameters and even video footage (Bluff & Rutz, 2008). Consequently, the importance of biologging for basic and applied research is constantly expanding (Kays et al., 2015; Rutz & Hays, 2009). Visions about future applications are far reaching, including the use of birds populations as living sentinels for climate change and other environmental threats (Pschera, 2014; Martin Wikelski & Tertitski, 2016), the fisheries management (Lowerre-Barbieri, Kays, Thorson, & Wikelski, 2018) or instant anti-poaching tags to prevent species from environmental crime (Fritz, Unsoeld, & Voelkl, 2019; O'Donoghue & Rutz, 2016).

Placement of the devices ranges from intra-peritonealor subcutaneous implants (Mellish, Thomton, & Horning, 2007; Wascher, Scheiber, Weiß, & Kotrschal, 2009) to external placement at different locations of the animal's body (Kays et al., 2015). In birds, as a proprietary animal group for biologging, a common position for external attachment is the lower back, where the device is fixed by various kinds' of leg-loop harnesses. However, at this position the device is usually covered by wing-feathers when the bird is perching. This is asignificant disadvantage for solar-powered devices which are dependent on sun exposure. Therefore, solar-powered devices are mainly placed at a more sun-exposed upper back position, fixed by various types of wing-loop harnesses.

The rapidly increasing application of biologging technology also causes a growing debate on trade-offs, deleterious effects and related ethical issues (Bodey et al., 2017; Bowlin et al., 2010; Thaxter et al., 2016; Vandenabeele, Shepard, Grogan, & Al., 2012). In birds, controversial discussions on impairing effects of biologging are mainly focussed on the ratio of tag mass to body mass and in many biologging studies tag mass below a 5% threshold is the major justification for tag-use (Bodey et al., 2017). However, in a study with 80 seabirds species Vandenabeele et al. (2012) found that devices with only 3% of the bird's body mass resulted in an increase in energy expenditure for flight ranging from 4.67% to 5.71%.In a meta-analysis Bodey et al. (2017) even found negative effects upon survival, reproduction and parental care when tags weight more than 1% of species' body mass. Moreover, a recent study indicates that the miniaturization of biologging devices has not resulted in a decrease in the relative device mass borne by animals, but instead has prompted researchers to monitor smaller and smaller species (Portugal & White, 2018).

Furthermore, there is increasing evidence that the weight of the device relative to the carriers´ body mass is not the only and probably even not the major parameter which causes impairing effects for the carrier. There is increasing evidence, that in flying and aquatic animals aerodynamic respectively hydrodynamic forces can vary considerably dependent on the shape and profile of the housing as well as placement on the body (Bowlin et al., 2010; Obrecht, Pennycuick, & Fuller, 1988; Pennycuick et al., 2012; Thaxter et al., 2016). For example, computational fluid dynamics modelling indicate that a conventional tag can induce up to 22% larger drag compared to a streamlined tag (Kay et al., 2019).

The European LIFE+ reintroduction project, LIFE Northern Bald Ibis (*Geronticus eremita*, NBI) aims to establish a migratory population in Central Europe with a migration tradition to the southern Tuscany (Fritz et al., 2017, 2019;www.waldrapp.eu). The main translocation method is the human-led migration, where human-raised juveniles follow microlight planes from their breeding sites north of the Alps to the common wintering site in Tuscany, WWF nature reserve Laguna di Orbetello, where they are released into the wild population. A steadily increasing number of wild living birds migrate between the common wintering site and three breeding sites north of the Alps. Chicks fledge every year in the wild and follow adult conspecifics to the wintering site.

A pivotal measure for an efficient and focussed management of a migratory species with large scale movements is biologging, particular in the case of an endangered species like the NBI where little is known about the former migratory behaviour (Bowden et al., 2008; Fritz & Unsöld, 2015; Serra et al., 2015). Since 2014, all individuals in the release population are equipped with GPS tags. This allows daily remote monitoring of the whole population, even during the migration period, when the birds perform large scale movements of up to 360 km per day. Due to the monitoring data, we could show that illegal hunting in Italy caused up to 60% of the losses each season. The start of the LIFE+ project in 2014, allowed by using biologging technology the implementation of a campaign against illegal bird hunting in Italy and even identification and prosecution of a hunter which shot two birds. Meanwhile, the loss rate due to illegal hunted birds could be halved, mainly as a consequence of actions taken on the basis of the biologging data (Fritz, 2015; Fritz et al., 2019).

In this paper, we present evidence for a hitherto unknown physiological effect, the so-called unilateral opacity (UCO) of the cornea in NBI. We also provide strong evidence that UCO is causally related to biologging. UCO affected a substantial proportion of the release population. In a few cases, it caused significant deleterious effects up to complete loss of eye light in the affected eye. Another NBI reintroduction project in Andalusia,Spain, screened a proportion of their population on our advice and found same symptomes, in a consistent context.

Methods

The European migratory release population of Northern Bald Ibises currently consist of 102 individuals (status end of 2018; Fritz et al., 2019). In 2018, a total of 21 NBIs returned independently to one of the two breeding areas north of the Alps, Kuchl (Austria) and Burghausen (Bavaria). They raised a total of 26 chicks, and all together returned to the wintering site in autumn. The reintroduction is still ongoing. We currently establish a third breeding colony in Überlingen at Lake Constance (Baden-Württemberg) with the human-led migration as the main release method (Fritz et al., 2017).

Since the start of the European LIFE+ project (LIFE Northern Bald Ibis) in 2014, all individuals in the release population were equipped with GPS devices. Different tag types were used (Tab.1). From 2014 to 2015, all birds carried battery powered devices (type 1), fixed via leg-loop harness on the lower back. In 2016 and 2017, some birds´type 1 tags were replaced by type 2 solar-tags and all newly released or wild-hatched birds were equipped with type 2 solar-tags. End of 2017, 72% of the whole population (N=84) still carried type 1 battery powered devices at the lower back position, while 28% carried type 2solar-tagsfixed at the upper-back. In 2018, most of the type 1 and type 2 devices were replaced by type 3 solar-tags so that end of 2018 84% of the whole population (N=102) carried type 3 solar-tags.

Table 1

Technical parameters of the different devices are outlined in Tab.1. To calculate the relative mass of the devices we calculated the mean body weight of 20 adult females (1.257g, SD=60g) and 20 adult males (1.390g, SD=58g). The relative mass of all tags was below 5% of the birds' body mass, all solar-tags were below 3% of the birds' body mass.

Release of the NBI in course of the European LIFE project is approved by the regarding national authorities. This includes also the equipment of the birds with transmitters. Due to the national approvals, equipment with GPS-devices is even mandatory for NBIs released in Bavaria or Baden-Württemberg, Germany. Tagging is done by experienced field managers (D. Trobe, C. Esterer) based on current standards. All birds in the population are visually monitored during their stay in the wintering or breeding site. Birds with conspicuous behaviour or obvious problems can be re-caught for further examination and potential treatment (Fritz et al., 2019).

Statistical analyses were made using the software R version 6.3.1. (R Core Team, 2014). The frequency of incidences of UCO was compared using Chi-squared tests and side preferences during roosting was compared with a Wilcoxon signed rank test. A Yates continuity correction was used for Chi-squared tests to prevent overestimation of statistical significance when frequencies were low. In cases where one observed frequency was zero, the asymptotic approximation of C^2 is unreliable and p-values were estimated using a Monte Carlo method.

Results

During a routine veterinary screening in spring 2016, an adult male (ID 027; Tab.2) was found to have a serious opacity at the cornea of the left eye. This was the first time that UCO was observed in our bird population. We assumed it to be a singular case with traumatic cause. The affected bird died one month later during the spring migration due to unknown reasons. During a routine screening at the beginning of 2017, two birds with severe panuveitis were detected (ID 144, ID 057). In both cases the destruction of the eyes was obvious. In one female (ID 144, Tab.2) the ongoing inflammation lead to removal of her eyeball.

Tab.2

Alarmed by these cases, most birds in the release population were successively caught and screened.

Even with the plain eye and without any ophthalmological instruments the opacities were obvious for the observer. In 2017, a total of 16 cases of UCO were detected in total and in 2018, again eight cases. Thus, together with the single case in 2016, a total of 25 birds were found to have UCO. Raised awareness had the advantage that in most birds UCO was detected at an early stage (Tab.2). Fluorescein tests were negative in all tested cases. Depending on the degree of corneal opacity (Fig.1) we distinguished five stages of UCO, from stage 1 with small-scale opacity, where iris and pupil are fully recognizable, to stage 5 with complete corneal opacity, where the iris and pupil are no longer visible. Allocation of the intensity score were done by eight coders based on pictures of the affected eyes (Tab.2). In 11 cases, no pictures were taken and allocation was done out in the field by one field manager (D. Trobe) only.

Fig.1

Several ophthalmological examinations in living animals (ID 057, ID 144), in enucleated eyes (ID 144; ID 067) or in eyes of dead birds (ID 116 and others) were performed by veterinary ophthalmologists and human physicians. The general appearance was partial or complete cloudiness of the cornea, with the superficial stroma being mainly affected and intact corneal epithelium. In several cases, the cornea showed vessel ingrowth. In advanced stages, the lens of the affected eye was cataractous and partial liquefaction and vacuolization of lens material had occurred. These eyes showed inflammatory changes like conjunctivitis and uveitis. Squeal of inflammation and lens material resorption led to iridodonesis, dyscoria and posterior synechiae formation.

The clinical examination of the birds revealed no clear cause for the symptoms. Infections of conjunctiva and cornea can lead to opacification of the cornea with the vessel ingrowth. However, virological and bacteriological examinations did not provide any significant results nor did the histological examinations (ID 067) reveal any evidence of infection. Also, no indications for a trauma or a mechanical damage of the cornea surface were found. Two affected birds (ID 144, ID 057) were treated with antibiotics and cortisone, without noticeable effect. Therefore no further birds were treated.

In spring 2017, we recognized a clear relationship between UCO and biologging. Only birds with solar-powered tags (type 2), fixed via wing-loop on the upper back, have been affected. This was remarkable, because beginning of 2017, only 25 out of 79 individuals (32%) carried type2 devices, while all the rest (68%) were equipped with battery-powered devices (type1), fixed with leg-loops on the lower back. This pattern holds for all 25 UCO cases, without any exception, resulting in a highly significant deviation from the expected frequency distribution (Chi-squared test with Yates' continuity correction, C^2= 39.46, *df*=1, p=3.34×10^{-10}).

Until the end of 2017, we used only solar tags of type 2 (tab.1). In 2018, we started using another type of solar tags (type 3; tab.1), also placed on the upper back. In the following, we had eight cases of UCO with birds carrying a type 3 device. None of these birds carried a type 2 device before, so a delayed effect of a type 2 device can be excluded. Thus, we have no indication for a causal relationship between a special type of solar-tag and the symptomatology.

From 2017, different measures were taken after detection of the symptomes, either removal of the solar-tag (N=5) or re-positioning of the solar-tag from the upper back to the lower back, fixed via leg-loop harness (N=10). In those cases where the effect of the measure could be determined removing or repositioning the device lead significantly more often to recovery than taking no action (C^2=13.36, p=0.004, Pearson's Chi-squared test with simulated p-value based on 10^6 replicates). In fact, in all except of one case (ID 144; see next paragraph) taking either measure led to recovery within a few months.

If no measures were taken, survival was found to be significantly lower (C^2=14.52, p=0.00014, Pearson's Chi-squared test with simulated p-value based on 10^6 replicates). We have no cases where an affected bird recovers if the tag remains; rather the opacity further advances and becomes irreversible. This was particularly indicated by the early cases (ID 057, ID 144), where the device was not immediately removed from the upper back position, because a relationship was not suspected at that time. In these cases, the condition has worsened progressively until the birds lost all sight in the regarding eye. In one case (ID 144), the affected eye even had to be removed due to severe inflammation.

Eye opacity was found in birds from three different breeding colonies (Tab. 2) and in both males (N=12) and females (N=13). Affected birds were partly members of the founder generation (F0: N=10), stemming from different European zoos, and partly wild-born (F1: N=15). Kinship data and genetic data(Wirtz et al., 2018) did not hint at any particular relationship between the affected individuals. Left and right eyes were equally affected by UCO (left: N=12, right: N=13).

Fig.2

Northern Bald Ibises roost with their head on the back. In this position, on eye comes close to a device fixed on the upper-back position (Fig.2). Thus, short distance effects of the device on the near-positioned eye are most probably the proximate functional cause for UCO.

To test, if individual side preference in head positioning during roosting explains the unilaterality, we surveyed a group of 32 human-raised juvenile Northern Bald Ibises. All of the birds changed between left side (overall 51.2 % of all instances) and right side (48.8%). A non-parametric sign test suggests no difference between the two sides (Wilcoxon signed rank test, W=202.5, p=0.4975, two-tailed). Thus, individual side preference in head positioning during roosting do not explain the unilaterality. This also corresponds with patterns found in three birds (ID 184, 133, 029) which where twice affected by one-eye opacity. In those three cases we tried to counter eye opacity by replacing type 2devices by type 3 devices (at the same wing-loop position). In one case (ID 184), the same eye was repeatedly affected, while in two individuals (ID 133, 029) the other eye was affected the second time.

Discussion

Since 2014, all Northern Bald Ibises of the release population carry GPS devices to allow remote monitoring of the whole population. In addition, we regularly observe most of the birds and an essential part of the individuals are caught once a year for veterinary screening. Observation and screening was the reason that we became aware of the UCO symptomatology, which was completely unknown so far.

Meanwhile it became apparent that UCO is related to the placement of a GPS-device via wing-loop harness at the upper back. This was substantiated by each new case. The habit of the birds to roost with the head on the back suggests a plausible causal relationship between the placement of the GPS device and UCO. This roosting position brings one eye close to the device placed at the upper-back position. Thus, a cumulative proximity effect on the nearby eye during roosting phases seems to be the most parsimonious proximate cause for UCO. We initially assumed that the symptoms are caused by a particular type of solar tag (type 2; Tab. 1). For this reason, we switched to a new type of solar transmitter (type 3) at the beginning of 2018. But it soon became evident, that type 3 causes the same symptoms.

A striking feature of UCO is that in all cases only one eye is affected, left and right equally. An individual side preference, when the birds turn the head to the back into the sleeping position, seems to be an obvious explanation for unilaterality. This would frequently bring always the same eye closer to the device. However, we found no evidence for individual side preference in Northern Bald Ibises with respect to this behaviour. This is also confirmed by the pattern found in three birds which where twice affected by UCO. In two of these birds, the second case of opacity affected the other eye than in the first case. An alternative explanation for unilaterality is that the individual side preference is triggered by the onset of illness. In particular, if the visual acuity of one eye is affected by UCO, the bird may tend to position the head mainly in a way that the unaffected eye is used for regular vigilance during roosting (Fig. 2).

The course of the disease seems to affect first only the superficial stroma of the cornea. Vessel ingrowth, like it was the case in several affected individuals, is a sign for chronicity. However, no evidence of infection was found nor any indication for a mechanical damage of the cornea surface. Eyes with advanced stages of opacity showed cataracts in combination with conjunctivitis and uveitis that led to irreparable damage and complete loss of sight in the affected eye.

Since UCO was initially unknown for other NBI populations or other species, we assumed the ultimate cause for the disease could be a population-specific effect. However, genetics or environmental effects like contamination seem unlikely given the aetiology and incidence pattern. Two infections are known to incidentally cause uveitis under specific conditions, Toxoplasmosis (Vickers et al., 1992; Williams et al., 2001)and the West Nile Virus (Pauli et al., 2007; Wünschmann et al., 2017). However, these infections rather affect the retina than the cornea. Moreover, the consistent unilaterality as well as the fast recovery of the carrier after removal or repositioning of the device can hardly be explained by such infectious diseases.

An alternative cause for a population-specific effect could be specific chemical components of the used devices. For example, solar panels can be provided with a coating containing organometallic compounds, which are known to have toxic effects (Wai-Yeung & Cheuk-Lam, 2010). Also, silicon tetrachloride, included in new types of solar-panels, can in combination with water lead to the formation of hydrochloric acid which cause tissue-damages (Braga et al., 2008). However, to our knowledge such compounds were not used in either of the devices. We can also exclude light reflection by the solar panel as a potential cause for UCO, because the panel of the type 3 solar-tag is non-reflective (Fig. 2).

By exclusion of these seemingly implausible ultimate causes for UCO, we ended up with two remaining hypotheses. One is a persistent slight mechanical irritation of the corneal front stroma in the nearby eye during roosting. However, examination of several eyes revealed no indication for mechanical damage of the cornea surface. Moreover, such a mechanical effect requires frequent physical contact between the corneal surface and the device. But even though the eye is close to the device during roosting, a frequent direct contact between the cornea and the device seems unlikely.

The GSM component of the remote monitoring devices transmits electromagnetic radiation in the range of radio waves, with peak power up to 2 watts (D. Mindaugas, personal communication; www.ornitela.com). Several studies indicate, that this radiation may cause negative effects on the organism, like DNA breakage, abnormal brain functions, reduced sperm mobility or increased reactive oxygen species concentrations(Al-Khlaiwi & Meo, 2004; Daniels et al., 2009; Kesari et al., 2013; Mailankot et al., 2009). However, Ziegelberger (2009)cautions that today there is no solid evidence supporting the notion that this radiation can lead to severe organic effects.

In contrast, a thermal proximity effect of electromagnetic radiation is well measurable. Mobile phones, held on the ear, cause a temperature rise of up to 2.9 °C in the surrounding tissue, particularly in the ear channel (Forouharmajd, Pourabdian, & Ebrahimi, 2018; Rusnani & Norsuzila, 2008; Tahvanainen et al., 2007). Animal studies indicate that a variety of behavioural and physiological disorders can be provoked by temperature rises even below 1°C (Hyland, 2000). Corneal tissue is known to be amongst the most thermally vulnerable areas of the body, mainly due to limited thermo-regulation because of low blood supply (Shafahi & Vafai, 2010). Thus, a thermal proximity effect due to electromagnetic radiation in the cornea of the eye which comes close GSM module seems plausible. A solar-tag transmits several times a day, dependent on the setting and the availability of solar energy. If animals stay outside the optimal network coverage, which happens regularly, connection setup and transmission require radiation close to peak power. Under these circumstances, the transmission of the device exceeds the maximum energy emitted by legally sold mobile devices (maximum SAR level1.6 watts per kg; Lee, et al. 2017).Thus, a thermal effect due to electromagnetic radiation seems to be the most probable cause for UCO. However, a verification of this assumption remains pending. It also has to be noted that battery warming could likewise cause significant temperature rise in the nearby tissue (Tahvanainen et al., 2007). Also, an empirical proof is needed about the effect of battery-powered devices at the upper-back position; so far we only have data from solar-powered devises causing UCO.

Conservation Implications

From 2016 till start of the countermeasures end of 2017, a total of 34 individuals were equipped with GPS-devices at the upper-back position. 17 of these birds (50%) were affected by UCO. This is a substantial proportion, particularly in a founder population of an endangered species. However, in the absence of further evidence, UCO remained an isolated phenomenon of our NBIs population. End of 2019, this changed fundamentally. Nine NBIs of an independent release population in Andalusia (Proyectoeremita; López & Quevedo, 2016) were caught and screened upon our suggestion. All those birds carried solar-tags on the upper back and five of them showed various degrees of UCO (Fig.3).

Fig.3

The discovery in the Andalusian population proves that UCO can affect NBIs in general. Potential species-specific causes like particular susceptibility to this disease or morphological or behavioural peculiarities may increase the susceptibility of the NBI. But it does not justify the assumption that the symptoms are limited to this species. A plausible reason for the lack of evidence in other bird species is the difficulty to recognize the symptomatic in the wild. The recent discovery of UCO in the Spanish NBI population confirms this assumption. Even though the Spanish release population is monitored and equipped with GPS-tags on the upper-back position since years, discovery of UCO happened just recently, after raised awareness due to our observations.

We expect that this publication will lead to raised regard and thus more discoveries of UCO in further populations of biologged NBIs as well as other bird species. UCO could also be related to already observed fitness-impairing effect of biologging, where the causal relationship is yet unknown. For example, during an ongoing reintroduction project of the Nippon Ibis (*Nipponianippon*) at Sado Island (Nagata & Yamagish, 2013) the post-release monitoring indicated that birds released with solar-powered GPS tags on the back had a significantly lower survival rate compared to released birds without GPS device. Consequently, no further of these birds are equipped with GPS devices for release (H. Nagata,pers.com.).

Recently, we got a first indication of a similar phenomenon in two South Africa rodents, the striped mice (*Rhabdomyspumilio*) and Karoo bush rat (*Myotomysunisulcatus*). Individuals of both species were equipped with battery-powered collar tags. In some of these individuals, tagging caused opacity and protruding eyeballs in both eyes. The effect usually disappeared when the collars were removed (C. Schradin& M.Gatta, pers.com.). A striking difference in the symptomatic of these rodent species is that the effect is the synchronous impairment of both eyes. This could be caused by the fact that in these small, short necked animals both eyes are close enough to the device to cause thermal proximity effects. However, pressure on blood veins caused by a tight neck-collar has been brought up as an alternative explanation for the phenomenon in these rodent species (C. Schradin, personal communication).

The effective fitness-impairing effect of UCO in our reintroduced population is difficult to estimate, because of the countermeasures taken from 2017. In most cases, removal or re-positioning of the device had led to a fast regeneration of the eye. But we suppose from the earlier cases (ID 027, 057, 144), where the device remained at the upper-back position, that UCO could cause a serious and irreparably damage of the eye and accompanying effects like conjunctivitis and uveitis. Thus, we conclude that without countermeasures the fitness of up to 50% of the individuals carrying a device on the upper back position would have been seriously impaired by UCO.

In our reintroduced Northern Bald Ibis population, we have now attached all devices on the lower back via leg-loop harnesses. Currently more than 100 birds carry different types of devices on this position, battery powered or solar-powered. Despite of a continuous monitoring, no bird with a device on the lower back ever showed UCO symptoms.

The lower-back position is clearly sub-optimal for solar-tags, because the solar panels are easily covered by wing feathers when the bird is not flying. On the other hand, this position has apparent aerodynamic advantages compared to the upper-back position. Wind tunnel studies indicate, that the drag is considerably lower when a device is attached to the lower-back position compared to a similar devise at the upper back position which is more aerodynamically exposed (Bowlin et al., 2010; Pennycuick et al., 2012). This is confirmed by observations in our project. During flights of human-raised NBIs accompanied by a microlight plane we repeatedly observed an extraordinary fast fatigue of birds with device on the upper-back compared to birds without or with devices on the lower-back position (Fig.4).

These observations seem to be in contrast to a recent study on effects of biologgers on behaviour and corticosterone metabolites of Northern Bald Ibises (Puehringer-Sturmayr et al., 2020). They found that attachment of GPS-devices did not affect various behaviours. Only a slight change in the levels of excreted corticosterone metabolites was found. However, the study was done with a semi-captive population and during the major part of the data collection the individuals were kept in an enclosure and prevented from flights. Flight behaviour was not rated at all. Thus, the significance of their outcome is questionable, especially for migratory bird species which perform long-distant flights.

Fig.4

Conclusions

The data presented in this paper and the corresponding observations in the Andalusian NBI project provide clear evidence that tags fixed via wing-loop harness on the upper back position are the proximate cause for UCO. However, the available data do not allow drawing final conclusions about the causal mechanism. In this context, further investigations are needed, with a particular focus on thermal proximity effects caused by electromagnetic radiation.

Our findings give no reason to question biologging in general. But the UCO example highlights that a comprehensive monitoring of tagged individuals is needed and that it is important to consider apparently unrelated side effects in tagged individuals. It is clear that in most cases, where individuals are equipped with GPS devices, close-up screening and observational data collections are hardly possible and practicable. Accordingly, in a meta-study Geen et al. (2019) found that ca 55% of biologging studies contained no information on potential effects and in many more documentation was inadequate. At least, approaches designed to minimize potential effects of devices on individual birds and to improve scientific rigour were found to have advanced substantially.

The call for more systematic documentation of potential effects of biologging in peer-reviewed publications to support more rigorous science and to further improve bird welfare seems well founded. We also agree with the increasingly expressed demand that ethical standards of biologging studies should not be limited to the compliance with an arbitrary 5% or 3% rule related to the body mass(Portugal & White, 2018). Other possible effects of biologging should be taken into consideration and assessment of return rates or other reasonable parameters relative to control birds be incorporated (Bodey et al., 2017; Geen et al. 2019; Schacter & Jones, 2017). It must be assumed that biologging in any case affects the individual to a certain extent and potentially in unexpected ways. The burden and risk for the individuals needs to be kept as low as possible. Apart from that, biologging should only be used to the extent necessary in the context of reasonable questions or objectives.

Declarations

Abbreviations

NBI: Northern Bald Ibis

UCO: unilateral corneal opacity

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Authors' contributions

JF, CE, DT and AS conceived the study and collected the data. JF, BE, BG, MU, BV, HW and AS analysed the data and performed statistical analyses. JF, BV, HW and AS wrote the paper, with BG and BE providing major contributions. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or for the mentioned investigations are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable: the study does not involve humans. All authors adhered to the 'Guidelines for the use of animals in research' as published in Animal Behaviour (1991, 41, 183–186). This study complies with all current Austrian laws and regulations concerning work with wildlife. Biologging ist done in the context of the European LIFE+ reintroduction project (LIFE+12-BIO_AT_000143, LIFE Northern Bald Ibis), in accordance with the IUCN Reintroduction Guidelines as well as regarding European and National law. GPS tracking of all released individuals is a requirement for the national approvals in Baden-Wuerttemberg (55-4/8852.41 - Waldrapp - Üb.) and Bavaria (55.1-8646.NAT_03-10-1).

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Tables

Due to technical limitations, tables are only available as a download in the supplemental files section.

Figures

Figure 1

Intensity of the one-eye opacity symptomatology at discovery in five categories, depending on the degree of opacity of the cornea, from small-scale opacity, where the iris and pupil is entirely sharp recognizable (state 1, left) to a complete clouding of the cornea, where the iris and pupil are no longer clearly visible (state 5, right).Picture Copyright: Waldrappteam, LIFE Northern Bald Ibis.

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Intensity of the one-eye opacity symptomatology at discovery in five categories, depending on the degree of opacity of the cornea, from small-scale opacity, where the iris and pupil is entirely sharp recognizable (state 1, left) to a complete clouding of the cornea, where the iris and pupil are no longer clearly visible (state 5, right).Picture Copyright: Waldrappteam, LIFE Northern Bald Ibis.

Figure 2

Juvenile Northern Bald Ibis in a characteristic sleep and rest position with the head on the back, the bill between the wings and one eye very close to the GPS device. Picture Copyright: Waldrappteam, LIFE Northern Bald Ibis.

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Juvenile Northern Bald Ibis in a characteristic sleep and rest position with the head on the back, the bill between the wings and one eye very close to the GPS device. Picture Copyright: Waldrappteam, LIFE Northern Bald Ibis.

Figure 3

Northern Bald Ibis of the Spanish reintroduction project, ProjectoEremita, with the same UCO as in the migratory population of the Waldrappteam. Picture Copyright: Miguel Quevedo, Zoobotánico, Jerez.

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Northern Bald Ibis of the Spanish reintroduction project, ProjectoEremita, with the same UCO as in the migratory population of the Waldrappteam. Picture Copyright: Miguel Quevedo, Zoobotánico, Jerez.

Figure 4

Human-raised juvenile Northern Bald Ibis during a flight accompanied by the microlight. The picture is taken out of a slow motionvideo. It shows permanent moving feathers along the posterior body, indicating an increased drag and separation of the boundary layer.

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Human-raised juvenile Northern Bald Ibis during a flight accompanied by the microlight. The picture is taken out of a slow motionvideo. It shows permanent moving feathers along the posterior body, indicating an increased drag and separation of the boundary layer.

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