Development of a weak-link wing harness for use on large gulls (Laridae): methodology, evaluation and recommendations

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Abstract

Both for the welfare of the birds studied and the validity of the results obtained, it is important that biologging attachment methods should be suitably safe and effective. We describe a weak-link wing harness, designed for long-term attachment, which safely detaches from the bird without need for recapture, and a UK field trial on two species of gull with contrasting life-histories, Herring Gull *Larus argentatus* and Lesser Black-backed Gull *L. fuscus*. We fitted 15 GPS devices to Herring Gulls in 2014 using three different weak-link materials: cotton thread, cotton piping cord and nitrile rubber. Productivity and return rates were compared against those fitted with permanent harnesses and a control group. A further 36 weak-link harnesses were fitted to Lesser Black-backed Gulls in 2017 and 2018 using GPS-GSM devices that provided more accurate attachment durations. The weak-link design was suitable for Herring and Lesser Black-backed Gulls and harnesses detached completely. Devices fitted with cotton piping cord or nitrile weak-link harnesses remained attached to Herring Gulls for up to four years. Cotton thread was less durable, with harnesses detaching in 1–2 years. We did not detect any significant effects on breeding success or return rates from the harnesses, although small effects sizes cannot be discounted. Devices fitted to Lesser Black-backed Gulls with 6-ply cotton, 18-ply cotton or piping cord weak-link harnesses had respective mean (± standard error) minimum attachment durations of 102 ± 13.6 days (N = 15), 358 ± 42 days (N = 18) and 596 ± 225 days (N = 2). The use of weak-link harnesses can provide a flexible and favourable alternative to permanent designs mitigating some of the associated risks.

Introduction

The use of biologging and telemetry devices has become widespread in avian ecological research in recent decades (Geen *et al*. 2019; Ropert-Coudert *et al*. 2009). While the insights gained from bird-borne devices are well recognised, these must be offset against the potential to cause detrimental effects to individuals. The ethical considerations for those undertaking biologging methods and the importance of not unduly impacting a bird's welfare have been widely discussed (Wilson & McMahon 2006; McMahon *et al*. 2011). Any impact on a bird's welfare may also cause biases in the data collected, undermining study aims. The attachment of devices to birds may have direct impacts on an individual's health or its behaviour, potentially resulting in impacts to fitness, i.e. reproductive success and survival. Recent reviews have evaluated these potential effects and their impacts; however, there is still a need for improvement in reporting (Barron *et al*. 2010; Bodey *et al*. 2018; Geen *et al*. 2019).

A number of factors may determine whether deployments of devices on birds may affect them, meaning that it may be difficult to predict the likelihood of impacts (McMahon *et al*. 2011). Thresholds of device mass relative to body mass are most commonly used to assess risk, with devices over 5% of an individual's body mass most likely to have negative effects (Geen *et al*. 2019). Relative device masses have not necessarily decreased over time, however, instead newer lighter technology has enabled the deployment of additional sensors within devices and for smaller individuals and species to be studied (Portugal & White 2018). Additionally, the design and influence on drag (Vandenabeele *et al*. 2012) as well as the attachment methods (Geen *et al*. 2019) can influence the likelihood of detrimental effects, even if the mass of the devices is under 5% relative to the individual (Bodey *et al*. 2018).

A shortcoming of temporary attachment methods, such as glue-mounting, is that data are collected only over a brief period and may not represent other times in an individual's annual cycle. With improvements in device longevity, it is now commonplace to track individuals, of larger species, continuously over multiple years, which typically requires the use of harnesses to ensure the long-term retention of devices (Klaassen *et al*. 2014). Harnesses have been used widely for many years, particularly on raptors (Kenward 1985), with design varying according to species and the intended position of the device on the bird. Harnesses are generally considered higher risk than temporary methods of attachment (Bodey *et al*. 2018; Geen *et al*. 2019) since there may be the risk of injury or direct mortality, for example from entanglement (Foster *et al*. 1992), if they are poorly designed or fitted, or fall off or become damaged after wear. As with other attachment methods, impacts on breeding productivity have also been reported (Mallory & Gilbert 2008; Phillips *et al*. 2003) which may be sustained if the device is not shed. The suitability of harnesses and their design can also vary between taxa (Withey *et al*. 2001). For example, one study found no short-term impacts from the use of wing harnesses on Lesser Black-backed Gulls *Larus fuscus* (Shamoun-Baranes *et al*. 2011) and showed this was a preferable design with greater attachment longevity and less feather shading of the device's solar cells compared to a leg loop harness (Thaxter *et al*. 2014). However, when the same attachment was used on Great Skua *Stercorarius skua* overwinter survival was reduced (Thaxter *et al*. 2015). This is in contrast to Mallory & Gilbert (2008) who reported successful use of leg loop harnesses on South Polar Skua *Stercorarius maccormicki*, a structurally similar species.

Tagged Lesser Black-backed Gull.
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The use of permanent harnesses poses an ethical problem, particularly if recapture is not likely, as individuals may bear a device indefinitely, usually beyond the functional lifespan of the device itself. If during long-term deployments, permanent harnesses wear to the point of failure, this may result in an incomplete detachment, potentially causing injury or mortality through tangling. Using harnesses which incorporate a weak-link, designed to enable the entire harness and device to be safely shed at some future point, provides a favourable alternative to permanent harnesses. Weak-links are not a novel idea and have been incorporated into harness design for decades (Karl & Clout 1987) and are widely used, mostly on raptors (Bedrosian *et al*. 2015; McIntyre *et al*. 2009), but also on other taxa (Bedrosian & Craighead 2007; Deguchi *et al*. 2014; Higuchi *et al*. 2004; Parejo *et al*. 2015). However, there are uncertainties about the reliability of weak-link harnesses (Kenward 1985) and evaluation of their use remains scarce in the literature.

Here we describe a weak-link wing harness, designed for long-term attachment, but also to safely detach from the bird without need for recapture. We also evaluate field trials of the design deployed on Herring Gull *L. argentatus* in 2014 and Lesser Black-backed Gull in 2017 and 2018, species with contrasting life-history traits, the former being largely resident and the latter largely migratory. We evaluate both (i) the harness performance, through harness retention rates, minimum attachment duration and assessment of the harnesses on recaptured birds, and (ii) the potential impacts on birds, through inspection of recaptured individuals and comparison of the breeding productivity and return rates between tagged and control groups of Herring Gulls. We also provide recommendations for future use of the design.

Methods

Harness design and construction

Our weak-link harness design was based on a modified wing harness described in Thaxter *et al*. (2014) and attached in the same way (Figure 1). The harness was constructed using Teflon tubular ribbon (6.35 mm flat diameter, Bally Ribbon Mills 8476-.25", Pennsylvania, USA) with a core of 1 mm braided nylon wader mist-net shelf string (British Trust for Ornithology, Thetford, UK). Four separate straps make up the harness, each with a fixed eye secured together around a central loop of different material, acting as the weak-link, which sits at the base of the tracheal pit, around the apex of the keel, in lieu of a reef knot tied directly in the harness as found in the permanent design. When the weak-link material breaks, all four harness straps detach simultaneously.

The weak-link loop may be constructed from materials of varying strength to allow for different expected deployment durations. For our trial, we used either stranded cotton (DMC 117MC-E, Mulhouse, France), 2 mm twisted cotton piping cord (Tootal Craft, Hungary) or 2.5 mm nitrile rubber cord (Polymax 2001107, Bordon, UK). Each weak-link was formed into a secure fixed loop c.10 mm in diameter (Figure 2). Construction of the harness is briefly outlined here but full instructions are included in online Supplementary Material. To form the loops on the harness straps, to attach

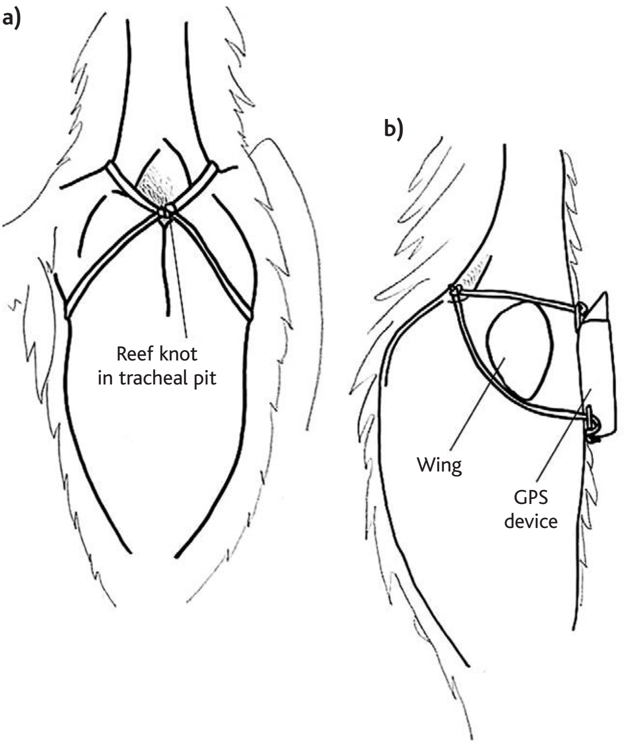

Figure 1. Diagram of the attachment and position of the permanent wing harness used, reproduced from Thaxter *et al*. (2014). The weak-link modification replaces the reef knot in the tracheal pit but is otherwise fitted in the same position.

to the weak-link; c. 20 mm of braided nylon was firmly sewn, using nylon thread, onto a laterally folded end of Teflon ribbon, forming a point. Using a blunt needle, a hole c. 20 mm from the sewn end was pushed through one layer of the Teflon (into the tube). The braided nylon was threaded through the hole and the tube of Teflon using a plastic needle, ensuring that the weak-link was captured within the loop that this creates. Both ends of the harness strap were then sewn and a small amount of superglue added to fix the diameter of the loop around the weak-link and the nylon core in place. The diameter of the fixed loops at the end of the Teflon straps were sufficiently small to allow some friction with the weak-link material to prevent any considerable movement leading to an asymmetric fit on the keel but not too tight that any of the weak-link materials wouldn't run freely through with a little pressure when broken.

One additional modification we used for the piping cord weak-link, to reduce bulk of the weak-link when using thicker material, was to use two harness straps with inverted ends, to prevent fraying, and two with looped ends to secure to the weak-link. The inverted straps were constructed by pushing c. 20 mm of Teflon back in on itself and threading with braided nylon. Piping cord was pushed into one of these ends and sewn firmly in place, then threaded through the loops twice, leaving c.15 mm exposed which could be inserted into the second inverted strap and sewn in place (Figure 2).

Finally, harness straps were marked using metallic marker pens at 50 mm intervals from the weak-link attachment to provide reference points when later recording harness size during fitting. The two anterior harness straps were then tied, using a reef knot, around the front attachment point of the GPS device ready for deployment. The finished weak-link harnesses weighed c. 3.5–4 g (once excess was removed after fitting) and took approximately one hour to construct. In the field, harnesses were fitted to individuals using the same methods described in Thaxter *et al*. (2014) except that the harness was fixed to the front attachment of the device, as well as the back, by sewing and superglue once a correct fit was obtained.

Study sites and deployments

In 2014, we deployed 24 GPS devices on breeding Herring Gulls, 15 with weak-link harnesses and nine with permanent harnesses, at South Walney Nature Reserve, Cumbria, UK, within the Morecambe Bay and Duddon Estuary Special Protection Area (SPA) (54°3'N 3°11'W). A further 36 devices were deployed using weak-link harnesses on Lesser Black-backed Gulls in 2017 and 2018 at Barrow-in-Furness, Cumbria, UK (54°6'N 3°13'W); the Ribble Estuary in the Ribble and Alt Estuaries SPA, Lancashire, UK (53°43'N, 2°56'W) and the Bowland Fells SPA, Lancashire, UK (54°2'N, 2°35'W) (Table 1). Herring Gulls were fitted with nanoFix®GEO+RF devices (Pathtrack, Otley, UK) with front and rear attachment tubes. Lesser Black-backed Gulls were fitted with Flyway-18 GPS-GSM (Movetech Telemetry, Thetford, UK) devices with a three-point attachment design. The Pathtrack devices remotely download data locally via UHF radio to base stations placed in the breeding colony. Movetech Telemetry devices transmitted data in near real-time using General Packet Radio Service (GPRS), accessible through Movebank (www.movebank.org). It was anticipated that devices would function for approximately two years. The combined weight of device, harness and any additional identifying marks were c. 20.5 g for Herring Gull and c. 25 g for Lesser Black-backed Gulls which equated to a mean ± S.E. of 2.1 ± 0.06% and 2.8 ± 0.03% respectively of the individual mass.

Figure 2. Close up image of each of the three materials trialled on Herring Gull *Larus argentatus* to form the weak-link in the harness. Top left; cotton thread, top right; cotton piping cord and bottom left; nitrile rubber.

Breeding adult gulls were captured on the nest during late incubation using a walk-in wire mesh nest trap or a customised remote-controlled nest-snare trap. Herring Gulls were trapped on full clutches of three eggs and Lesser Black-backed Gulls were trapped on either two or three eggs. Only a single adult from a pair was fitted with a device and if no birds were caught at a nest within c. 30 minutes then the trap was removed allowing adults to return. No trapping efforts were made during inclement weather. All individuals were also fitted with metal rings and unique colour rings for subsequent field identification. Typical overall capture, holding and handling time for tagged individuals was c. 40 minutes, with the tagging component taking c. 20 minutes. The Herring Gull control group consisted of individuals trapped during the same period and areas of the colony where device deployment took place, and groups were matched based on body mass (mean ± S.E.; Tagged - 965 ± 25 g, N = 24, Control - 965 ± 20 g, N = 41). The likely sex ratios in each group based on bill measurements (Demongin 2016) were 14:9 and 22:19 males to females for the tagged and control groups respectively, however there is some overlap in size and sex was not confirmed using any other method.

All work was carried out by individuals with suitable British Trust for Ornithology (BTO) permits with approval from the Special Methods Technical Panel, part of the BTO Ringing Committee.

Evaluation of harness performance

The retention of harnesses and devices was evaluated through the GPS data received from the devices themselves and field observations of the birds. We undertook regular searches for colour-ringed Herring Gulls at South Walney throughout 2014, the breeding season of capture, and subsequent breeding seasons up until 2018. Birds fitted with weak-link harnesses and observed still to be carrying devices in years subsequent to capture were targeted for recapture to examine the physical condition of the bird and the harness and to remove non-functioning devices. For Herring Gulls fitted with Pathtrack devices, GPS data were only obtainable when birds were within range of the base station system at the colony. We thus undertook a simple annual assessment of harness retention rates for returning birds.

The Movetech Telemetry GPS-GSM devices provided location data in near real-time which also allowed us to estimate more accurate attachment durations using the last confirmed date of data transmission. The sudden loss of data transmission may be caused by either loss of harness, device transmission failure or mortality, so the attachment durations reported here are only a minimum. Additionally, we were able to investigate several cases of periods of stationary GPS fixes received from the GSM devices with visits to the location and visual searching for either device or individual, to confirm either drop-off event or mortality.

Evaluation of the potential impacts of harnesses and devices

The potential impacts of harnesses and devices were evaluated for Herring Gulls at South Walney through comparison of the breeding productivity and return rates of tagged and control groups. Comparable monitoring of Lesser Black-backed Gulls was not feasible at the colonies studied due to limited access or unsuitable vantage points for resighting. Only apparent return rates of individuals tagged in 2017 at Barrow during 2018 compared with a control group of Lesser Black-backed Gulls captured at the same site in 2017 are presented here. However, previous studies have demonstrated no negative impacts to Lesser Black-backed Gulls fitted with devices using permanent wing harnesses compared with untagged individuals (Thaxter *et al*. 2015).

The productivity of tagged and control groups of Herring Gulls was recorded in 2014, the original year of capture, and the subsequent 2015 breeding season. The South Walney colony experienced a widespread crash in productivity after 2015 and thus it was not possible to effectively monitor each tagged individual's productivity in subsequent years. Between two and six visits were made to each nest of tagged and control birds between mid-May and early July to record numbers of eggs and young, and thus minimum hatch rates. We did not follow the outcome of nests through to fledging due to the difficulties of identifying individual chicks once they became mobile (South Walney being a large mixed colony of both Herring and Lesser Black-backed Gulls). Differences in the clutch size and the minimum number of eggs hatched between birds fitted with weak-link and permanent harnesses and control birds were analysed using a Generalised Linear Model (GLM) with a quasi-Poisson error distribution including harness type as a fixed effect. Differences in the propensity of tagged and control adults to breed in 2015 were analysed using a GLM with a binomial error structure, again considering harness type as a fixed effect.

Searches for colour-ringed individuals were used to calculate return rates of birds to the colony. Any individuals recorded only from transmission of telemetry data but not visually observed were excluded from return rate comparisons so detection probability was not skewed between tagged and control groups. We used a Generalised Linear Mixed-effects Model with a binomial error structure in the 'lme4' R package (Bates *et al*. 2015) to analyse observed return rates including harness type as a fixed effect and year and individual as random effects.

Significance was assessed by comparing models with and without the harness type factor, reporting the chi-squared significance of a change in deviance. Also due to limited sample sizes in our study, we anticipate only being able to detect large effect sizes (i.e. $d > 0.8$, Cohen 1988) with an acceptable level of statistical power (0.8).

All analyses were carried out using R 3.5.1 (R Core Team 2018).

Results

Evaluation of harness performance: deployments and recaptures

Of the 24 Herring Gulls fitted with devices and harnesses in 2014, five were subsequently recaptured and examined (2015 — one with a nitrile weak-link harness, one with a piping cord weak-link harness and two with permanent harnesses; 2016 — one with a piping cord weak-link harness). Although a small

Figure 3. Inspection of a cotton piping cord weak-link wing harness on Herring Gull *Larus argentatus* approximately two years after deployment.

sample, none showed any signs of abrasion from the harness or weak-link and the fit was still correct. Particular attention was paid to the area under the weak-link element and immediately behind the wings. Some feather loss had occurred immediately beneath the device but this still did not appear chafed or abraded, and one individual recaptured one year after removing the device for another inspection had no visible signs of ever having had the harness and device fitted. The individuals with permanent harnesses had the devices removed since they had failed prematurely. Similarly the individual recaptured with the nitrile weak-link had a failed device so the harness was removed; the nitrile weak-link did not show any appreciable signs of wear one year after deployment. The piping cord weak-link harness examined in 2015 a year after deployment also showed no signs of wear, whereas that examined in 2016 two years after deployment exhibited some wear (Figure 3).

Evaluation of harness performance: weak-link harness retention

Weak-link harness deployments, retention rates and durations are summarised in Table 1. Of the original sample of 15 weak-link harnesses fitted to Herring Gulls, those using piping cord (N = 5) and nitrile (N = 5) weak-links were more durable with the majority of individuals still bearing the harness for two years and one and two individuals respectively confirmed with the harness four years after fitting. One individual fitted with a piping cord weak-link harness was observed without its device and harness in 2018, four years after deployment, and the device having still been transmitting data in 2017; thus, it is known the piping cord link failed after three years. Of the five cotton weak-link harnesses deployed, only two were retained one and two years after deployment, although it should be noted that the return rates of the individuals that these were deployed on were apparently lower (Table 2). In 2017, one cotton weak-link harness was found dropped in the breeding colony and had detached completely as expected.

Table 1. Summary of weak-link harness deployments and retention rates and durations on (a) Herring Gulls *Larus argentatus* and (b) Lesser Black-backed Gulls *L. fuscus*. Retention rates were calculated from individuals confirmed to still have the harness attached, either through visual observation or remote data retrieval, at the breeding colony in subsequent years after deployment. Lesser Black-backed Gulls fitted with Movetech Telemetry GPS-GSM devices transmitted data remotely daily and allowed more precise estimates of attachment duration but only minimum reported as cessation of data transmission may also be a result of device failure or mortality and not all cases were determined. Mean values are presented with ± standard error.

(a) Herring Gull

Year	Site	Device	Weak-link material	Deployed	N	Minimum retention rate (N) 2015	2016	2017	2018
2014	South Walney	Pathtrack - 14 g	Cotton (18-ply)	1–3/6/14	5	0.40 (2)	0.40 (2)	0.00 (0)	0.00 (0)
			Nitrile	1–3/6/14	5*	1.00 (5)	0.75 (3)	0.50 (2)	0.50 (2)
			Piping cord	1–3/6/14	5	0.80 (4)	0.80 (4)	0.60 (3)	0.20 (1)

(b) Lesser Black-backed Gull

Year	Sites	Device	Weak-link material	Deployed	N	Minimum retention rate (N) 2018	2019	Mean ± S.E. (range) minimum attachment duration (days)
2017	Barrow-in-Furness & Ribble Estuary	Movetech - 18–20 g	Cotton (6-ply)	24/5–23/6/17	15	0.00 (0)	0.00 (0)	102 ± 14 (27–210)
	Bowland Fells	Movetech - 18–20 g	Piping cord	21/5/2017	2	0.50 (1)	0.50 (1)	596 ± 225 (371–820)
2018	Barrow-in-Furness & Ribble Estuary	Movetech - 18–20 g	Cotton (18-ply)	22/5–13/6/2018	18**	-	0.66 (12)	358 ± 42 (60–604)

* One failed device removed from an individual in 2015 so effective sample size was four from 2016 onward. ** One individual found dead shortly after deployment excluded. Two more individuals stopped transmitting <100 days after deployment and assumed likely mortalities but not confirmed so included here.

Table 2. Comparisons of apparent return rates to the breeding colony assessed through resightings of colour-ringed birds and breeding productivity measures for Herring Gull *Larus argentatus* fitted with permanent or weak-link harnesses and control birds. All individuals were marked in 2014 at South Walney. Mean values are presented with ± standard error.

Harness	N	Apparent return rate (N) 2015	2016	2017	2018	Productivity 2014 Mean minimum eggs hatched (N)	2015 breeding rate (N)	2015 Mean clutch size
Weak-link - Cotton (18-ply)	5	0.60 (3)	0.40 (2)	0.20 (1)	0.00 (0)	1.20 ± 0.52 (5)	0 (0)	0
Weak-link - Nitrile	5	0.80 (4)	0.60 (3)	0.20 (1)	0.20 (1)	1.40 ± 0.61 (5)	0.40 (2)	2.50 ± 0.50
Weak-link - Piping cord	5	1.00 (5)	0.60 (3)	0.40 (2)	0.20 (1)	1.40 ± 0.46 (5)	0.40 (2)	2.00 ± 0.00
All weak-link	15	0.80 (12)	0.53 (8)	0.27 (4)	0.13 (2)	1.33 ± 0.31 (15)	0.27 (4)	2.25 ± 0.25
Permanent	9	0.56 (5)	0.22 (2)	0.33 (3)	0.11 (1)	1.33 ± 0.31 (9)	0.33 (3)	2.33 ± 0.33
Control	41	0.83 (34)	0.46 (19)	0.32 (13)	0.10 (4)	1.89 ± 0.17 (37)	0.24 (10)	2.40 ± 0.22

A reduced strength cotton weak-link was trialled in 2017 on Lesser Black-backed Gulls and these harnesses were shed from the birds sooner than those in the Herring Gull trial (Table 1). Of the 15 GPS-GSM devices fitted in 2017, we investigated seven cases of stationary GPS fixes by visiting the last known location and making visual searches for the bird or device. No dead birds were found, but two devices were recovered, again detached as expected. We confirmed that at least 80% (12 individuals) were visually resighted again and had dropped harnesses; based on the last date of data transmission, they remained attached for a mean of 102 days (Table 1).

An additional sample of Lesser Black-backed Gulls was fitted with GPS-GSM devices in 2018, all with 18-ply cotton weak-links (comparable strength to the original Herring Gull trial). These harnesses remained attached for longer than the 2017 sample (Table 1) with a mean duration of 358 days between deployment and last confirmed live transmission. For most individuals whose devices stopped transmitting data, it was not possible to determine whether the device or the harness failed or mortality had occurred as they were not observed again so the actual attachment period may be underestimated here. One individual was recovered dead shortly after tagging on a nearby landfill site. The cause of death was unknown and the harness was inspected and remained well fitted; data from this individual were excluded from harness retention results. One device was reported found on a public beach and had detached completely but the individual has not been resighted subsequently.

Evaluation of the potential impacts of harnesses and devices

A full evaluation of the effects of the harnesses on return rates and productivity was not feasible for Lesser Black-backed Gulls in this study, however limited resighting data collected at the Barrow colony during 2018 for the 2017 cohorts did not suggest a negative effect on apparent return rates for tagged birds (0.46, 6/13 individuals) compared with a matched control group (0.19, 4/21). We therefore focussed evaluation on Herring Gulls at South Walney. Following deployments, we observed no evidence of immediate behavioural effects on the individuals fitted with harnesses, for example nest desertion or any indication of discomfort from the harness such as excessive preening. Comparisons of the breeding productivity and return rates to the colony of tagged (permanent and weak-link separately) and control groups are presented in Table 2. We did not detect any significant differences between tagged and control birds in the minimum number of eggs hatched in the breeding season that devices were fitted (χ^2_2 = -2.796, P = 0.151). Similarly, the propensity to breed (χ^2_2 = 1.138, P = 0.566) and clutch sizes (χ^2_1 = -0.023, P = 0.880) of tagged and control birds showed no differences the following year. Tagged (permanent or weak-link harnesses) and control birds also showed no significant differences in their return rates to the breeding colony (χ^2_2 = 1.989, P = 0.370) between 2014 and 2018. However, we only had the statistical power in our study to detect large effect sizes and there is an indication of lower hatching success in tagged birds (Table 2) during the year of deployment.

Discussion

Harness design and performance

In this paper, we describe the deployment of weak-link harnesses on two species of large gull. Various devices, including three- and four-point attachment designs, were successfully fitted using the harness design described here. Although data were not available for all devices deployed, information from recaptures of birds and recoveries of detached devices indicated that harnesses and devices were subsequently shed from birds without problems. By altering the material used for the weak-link, there is flexibility to allow differing attachment durations, which could be further developed with additional materials. A weak-link harness therefore does seem to be viable as an alternative to a permanent design for long-term deployments (of one year or more) for these species or potentially to other short-term attachment methods, such as glue or tape mounting, particularly if data are required for a period of several months or when individuals are moulting, although the use of any harness method will still include a greater underlying risk of detrimental effects.

There are benefits from continued innovation in harnessing techniques (Humphrey & Avery 2014) and dissemination of findings of harnessing effects for a wider range of species. Geen *et al*. (2019) reports a decline over time of reported negative effects of fitting devices generally across a wide range of avian taxa and methods. This is possibly due to improved practice over time or more suitable selection of species and attachment methods for devices building on an increasing knowledge base of methodology. Studies using captive individuals or dummy devices to test effectiveness of materials and attachment methods can yield useful insights (Herring & Gawlik 2010). However, there may be a discrepancy between studies of captive individuals and those carried out under field conditions (Chan *et al*. 2015), which may provide a better reflection on variation in performance. Further improvements in the selection and testing of materials used for the weak-links could help increase confidence in minimum and average attachment duration for a given species.

An important aspect in the use of devices on birds is the overall capture and handling time required to fit them. Increased time in captivity increases stress levels in birds (Romero & Romero 2002) and it is thought that the most significant increase comes between three and 30 minutes (Romero & Reed 2005). The weak-link design used in our trial did take longer to fit, if the neck loop needed resizing to fit the individual, than the permanent harnesses previously used for large gulls (Thaxter *et al*. 2014) but should add no more than approximately five minutes to overall handling time if carried out by experienced personnel. There was also a difference between devices as we found the neck loop was quick to adjust if necessary on a four-point attachment device (Pathtrack) but difficult on the bird for a three-point attachment (Movetech Telemetry). We overcame this by having a range of predetermined sizes made to select from so fewer needed adjusting during fitting. There will be future improvements to the attachment protocol which may reduce overall handling time which should continue to be trialled, for example the use of crimps to secure fit instead of sewing and glue (Lameris *et al.* 2017). Little is still known about the long-term effects of capture and handling induced stress, but individual seabirds are known to respond and recover differently in the short term (Weimerskirch *et al.* 2002) so any additional handling time for a weak-link harness should be considered against the potential risks of permanent harnesses and long-term attachment of devices which may result in increased stress to an individual overall (Elliott *et al.* 2012).

In all cases where tags were recovered after being lost from an individual, the weak-link acted as intended and the design appeared to work well. This is supported by the majority (80%) of the Lesser Black-backed Gulls tagged in 2017 being visually observed the following year without the device, apparently behaving normally.

Potential impacts of harnesses and devices

It is important to distinguish between what may be short-term effects of the attachment of devices to birds on an individual's behaviour — which should be considered when interpreting tracking data — and those which may have consequences for an individual's fitness, i.e. its breeding productivity or survival. Nevertheless, despite comprehensive reviews into the effects of using devices on birds (Bodey *et al.* 2018; Geen *et al.* 2019) there are still gaps in our understanding of how individuals respond to tagging. Some studies have reported short-term adjustments that have diminished over time, for example, Greenland White-fronted Geese *Anser albifrons* preened more 3–7 days after initial device attachment but returned to normal rates afterwards (Glahder *et al.* 1999). Whether potential negative effects would be cumulative over a longer time period is unclear, but any case where individuals adjust their behaviour, even if no long-term impacts on fitness are detected, may have important implications for the validity of data when inferring behaviour of untagged conspecifics (Gillies *et al.* 2020). Also, impacts on fitness may not be apparent at an individual level, if they are compensated for by an individual's partner. For example, hatching success in Audouin's Gulls *Ichthyaetus audouinii* was not impacted if neither or one of the adults was tagged, but reduced when both adults were tagged (Mañosa *et al.* 2004).

Previous studies have reported no negative effects of wing harnesses on the breeding productivity and return rates of Lesser Black-backed Gulls (Shamoun-Baranes *et al.* 2011; Thaxter *et al.* 2014). Nevertheless, there may be species-specific effects of harnessing (Mallory & Gilbert 2008). We found no significant differences in the productivity or return rates of Herring Gulls fitted with either permanent or weak-link harnesses and a control group of birds, although small or medium effects cannot be discounted due to the relatively low statistical power in this study, so further and more comprehensive evaluation is needed. This is particularly the case for the possible impact on productivity, as there was an indication, albeit not significant, of lower hatching success for Herring Gulls with harnesses compared with the control group. This was recorded during the year of deployment, and the capture and manipulation of birds took place at the end of the incubation period, so it is possible that impacts to hatching may be a short-term effect while birds adjust to the device. Further evaluations in subsequent years after deployment would help determine the long-term impacts.

Apparent return rates to the colony were comparable to published apparent survival rate estimates for Herring Gull (0.71, Rock & Vaughan 2013; 0.87, Allard *et al*. 2006; 0.79, Breton *et al*. 2008), at least in 2015. Return rates in subsequent years declined markedly, for all groups, and productivity could not be evaluated after 2015. This was due to failure of the colony as a whole at the early chick stage and a reduction or relocation of breeding pairs at the South Walney colony which precluded effective monitoring. Costs to an individual from bearing a device or a given attachment method may manifest only under certain conditions, for example, during periods of reduced resources (Vekasy *et al*. 1996) and it is possible that wider declines at the breeding colony masked changes in productivity or behaviour of tagged individuals. A more detailed investigation into the effects of harnessing on Herring Gulls would be advantageous but we found no evidence that the use of weak-link design would have any additional costs over a permanent design.

Recommendations

This study set out to evaluate trial deployments of weak-link wing harnesses on two study species, Herring Gull and Lesser Black-backed Gull, through assessment of harness and device retention and examination of the recaptured birds and their harnesses, and for Herring Gulls, through assessment of potential impacts on the birds' breeding productivity and return rates, through comparison with a control group.

We advocate the use of weak-link harnesses as an effective alternative to permanent harnesses that reduces the need to recapture individuals to remove harnesses and devices at the end of a study and may mitigate against risks of bearing a device indefinitely or an uncontrolled harness failure. Although our study and previous studies have reported no evidence of impacts to Herring or Lesser Black-backed Gulls from being fitted with harnesses (of any type), using a weak-link design is precautionary as the potential long-term impacts of permanent harnesses on gulls are yet to be determined. However, we would advise extra consideration in using weak-link harnesses if the primary objective of a study is to investigate mortality rates as incidents of mortality and harness detachment are not always distinguishable.

Weak-link harnesses may also be designed to allow for varying planned attachment durations. Our initial findings suggest that the piping cord and nitrile weak-link materials used would be suitable for deployments intended for 2–3 years, which is consistent with the expected lifespan of many current solar powered devices, but a proportion may still last beyond this. Cotton weak-links were suitable for shorter deployments of 1–2 years (18-ply) or less than one year (6-ply) and may be an effective alternative to other short-term attachment methods or for studies requiring data collection throughout a moult period.

However, our findings using GPS-GSM devices fitted with cotton weak-link harnesses highlight that it should be expected that there may be variation in attachment duration, which will depend on the habits and behaviour of tracked individuals. While our trial proved suitable for Herring and Lesser Black-backed Gulls, we recommend caution for other species and that the suitability of weak-link designs should be fully evaluated and reported for novel situations.

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