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The effects of geolocator drag and weight on the flight ranges of small migrants

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Summary

1. Researchers are currently placing hundreds of geolocators on migratory animals. Return rates for some small birds carrying these devices have been lower than expected, potentially because geolocators increase drag during flight.

2. We measured the drag of three different geolocators (1·2 g BAS-MK10, 1·0 g SOI-GL10·09 and 0·5 g SOI-GL05·10) in backpack-style harnesses on two preserved bird bodies in a wind tunnel. We then used these measurements to estimate the effects of this drag on the flight ranges of several small migratory birds.

3. Both the BAS-MK10 and SOI-GL05·10 significantly increased drag; the drag was also considerably higher when a geolocator was attached between the wings (wing harness) than on the rump (leg-loop harness).

4. The effects of the increased drag of these devices on the predicted flight ranges of birds were similar to the effects of their weight and may thus explain the results of previous studies that showed decreased return rates when using geolocators and other tracking devices.

5. We recommend that researchers and manufacturers work to minimize the drag of geolocators and other externally attached tracking or data collection devices on flying and swimming animals. This can be accomplished with geolocators by attaching devices above birds' rumps instead of between their wings and flattening the devices to reduce their height.

Key-words: attachment methods, geologger, light logger, migration, radiotransmitter

Introduction

Small (0·5–1 g) light loggers, commonly called geolocators, represent an increasingly popular way to track migrants on a continental scale (Phillips *et al.* 2007; Guilford *et al.* 2009; Robinson *et al.* 2010; Stutchbury *et al.* 2009; Bächler *et al.* 2010). These devices record light levels over time, which can be used to estimate the position of the animal on the globe to within a few 100 km (Hill 1994; Phillips *et al.* 2004); their size means that they can be placed on animals that are too small to carry satellite telemetry tags (Gaunt *et al.* 1997). Since geolocators can potentially provide more accurate locations than stable isotope samples (see Hobson & Wassenaar 2008 for a review of stable isotope use) and can also provide daily locations for a number of years, they represent a powerful tool for those who wish to track small migrants.

However, placing tracking devices on migrating animals can have negative consequences (Barron, Brawn & Weatherhead 2010). In the first study to use geolocators on passerine birds, Stutchbury *et al.* (2009) recaptured only 10% of purple martins *Progne subis* with geolocators; the normal recapture rate for purple martins was 54%. Purple martins are long-distance migrants and aerial insectivores. Thus, any negative aerodynamic effect of geolocators might be felt more keenly by the martins than by other species; indeed, in the same study, Stutchbury *et al.* (2009) recaptured a normal percentage of wood thrushes *Hylocichla mustelina*, which are medium-distance migrants that forage primarily on the ground. A recent

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meta-analysis of the effects of tracking devices on birds found significant, although generally small, negative effects on a variety of behavioural and ecological parameters, including energy expenditure (Barron, Brawn & Weatherhead 2010). Because it is so difficult to examine migratory behaviour and physiology without tracking devices, however, there are no data on the effects of these devices on migratory performance in birds.

Although numerous studies have investigated the hydrodynamic effects of attaching tracking devices to swimming animals (e.g. Bannasch, Wilson & Culik 1994; Watson & Granger 1998), to our knowledge, only one study has measured the aerodynamic effects of tracking devices on flying animals: Obrecht, Pennycuick & Fuller (1988) measured the drag of large satellite transmitters on geese. Such studies can provide direct estimates of the effects of tracking devices and recommendations for their use and design (Caccamise & Hedin 1985; Obrecht, Pennycuick & Fuller 1988; Barron, Brawn & Weatherhead 2010). Because no studies have measured the aerodynamic effects of small transmitters or geolocators on birds, we wished to estimate the effects of the added drag and weight of several geolocators on small migrants. These effects should be similar to those of radiotransmitters or other devices of similar size and shape. We chose to study the common swift *Apus apus* (~40 g, wing span ~0·40 m), a European species that is quite similar morphologically and ecologically to the North American purple martin (~50 g, wing span ~0·40 m). Our goals were to measure the drag caused by several different geolocators, to use those measurements to estimate the effects of these devices on migrants' flight ranges, and to make recommendations for geolocator/transmitter design.

Materials and methods

We performed our tests on an aerodynamic balance in the Lund University wind tunnel. The balance, which allowed us to measure drag (D), was calibrated over a range of 0–0·0491 N in increments of 0·0098 N (1·00 g; see Appendix S1 for details). We used three geolocators for this study (Fig. 1a): one 1·2 g 20·7 × 8·6 × 6·6 mm (length by width by height) from the British Antarctic Survey (BAS-MK10 without stalk), and two from the Swiss Ornithological Institute: a 1·0 g 22·6 × 10·0 × 3·4 mm geolocator (SOI-GL10·09), and a prototype of a 0·5 g 11·8 × 7·6 × 4·1 mm geolocator (SOI-GL05·10). We attached them to two wingless bodies of common swifts preserved in a flight posture by a taxidermist and measured the drag on each body at equivalent airspeeds of 8·0 m/s, 10·0 m/s and 12·0 m/s. The bodies were placed at a zero angle; i.e. an imaginary line connecting the bill and the tail was horizontal (Fig. 1b and c). We chose this angle because it minimizes the area presented to the flow (frontal area, Fig. 1b and c) and can therefore be expected to minimize body drag.

At each speed, the drag on the bodies was measured without a logger and with the loggers attached on the rump via a leg-loop harness (e.g. a Rappole–Tipton style harness; Rappole & Tipton 1991). We also attached the BAS-MK10 logger between the wings via a wing harness to explore the effects of different harness types. Thus, we studied four different logger/location combinations: SOI-GL10·09 'leg'; SOI-GL05·10 'leg'; BAS-MK10 'leg'; and BAS-MK10 'wing'. We replicated drag measurements six times for each body, logger/location, and speed combination (see Appendix S1). We then created a General Linear Model (GLM) in SPSS v. (SPSS. Inc., Chicago, Illinois, USA) 17·0·0 to investigate the effects of logger/location combination (fixed) and speed and bird body (random) on drag. The initial model included all possible interactions between the three independent variables, but since the three-way interaction between logger/location combination, speed, and body was not significant, we removed it from the model (see Table 1).

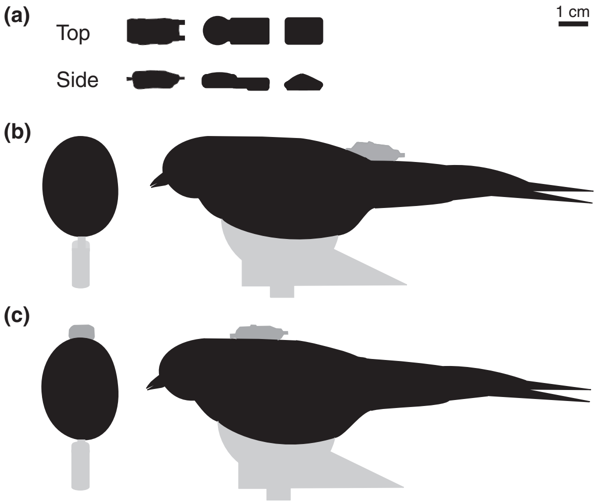

Fig. 1. Experimental setup. Panel (a) shows the silhouettes of the loggers we used (from left to right: BAS-MK10, SOI-GL10·09 and SOI-GL05·10), whereas the other two panels show a BAS-MK10 logger in (b) a leg-loop harness and (c) a wing harness. In the composite figures, black indicates the swift, medium grey indicates the logger and light grey indicates the sting. Note that the BAS-MK10 cannot be seen from the front when the logger is in a leg-loop harness, resulting in no increase in body frontal area in panel (b). The drag of the sting (light grey area) was measured separately and subtracted from all other measurements (see Appendix S1 for details).

We used the parameter estimates from this model to calculate the increase in the drag coefficient (ΔC_D) due to each logger's presence by $\Delta C_D = \Delta D/qS$. ΔD was the estimated increase in drag, q ($0{\cdot}5\rho U^2$, where ρ is air density and U is airspeed) was the dynamic pressure and S was the frontal surface area of the bird's body (e.g. Fig. 1b and c). We then used Pennycuick's (1989) flight model to estimate the flight ranges (the distance an animal can fly given a certain amount of fuel) with (i) no increased drag or weight, (ii) the increased drag of the

Table 1. Results of GLM predicting drag measurements

	d.f.	*F*	*P*
Intercept	1 2·892	16·414	0·029
Logger	4 6·291	6·861	0·018
Speed	2 2·074	42·211	0·021
Body	1 2·091	24·979	0·034
Logger × speed interaction	8 160	2·194	0·030
Logger × body interaction	4 160	2·484	0·046
Speed × body interaction	2 160	64·727	> 0·001

geolocators, (iii) the increased weight of the geolocators, and (iv) both the increased drag and weight of geolocators of seven migratory species ranging in size from 11 to 127 g, including the common swift. We calculated flight ranges for 150% of lean body mass, the average fuel load for migrating passerines prior to crossing a major ecological barrier (Alerstam & Lindström 1990). We added ΔC_D of the loggers to 0·100, our initial body drag ($C_{D,\text{body}}$). We estimated the effects of geolocator weight under an 'added weight' scenario, where the bird migrated with an extra 0·5 or 1·0 g, and a 'decreased fuel' scenario, where the bird decreased its fat load by 0·5 or 1·0 g. Birds' actual responses are likely to fall somewhere between these two extremes.

Results

Geolocators significantly increased drag on the swift bodies ($F_{4,6{\cdot}3} = 6{\cdot}861$, $P = 0{\cdot}018$), although the exact values were tempered by speed (logger × speed interaction term, $F_{8,160} = 2{\cdot}194$, $P = 0{\cdot}030$) and which body we used (logger × body interaction term, $F_{4,160} = 2{\cdot}484$, $P = 0{\cdot}046$). The full GLM is presented in Table 1. *Post hoc* Bonferroni tests found that two of the three loggers (SOI-GL05·10 and BAS-MK10) created significantly more drag than the control (Fig. 2a). The logger in a wing harness also created more drag than it did in a leg harness (Fig. 2b).

Of the four logger/location combinations we investigated, only the logger in a wing harness increased S relative to the control (Fig. 1). The ΔC_D for this logger, after adjusting for this change, was not significantly different from the ΔC_D of the logger in a leg-loop harness ($P > 0{\cdot}05$). In other words, the wing harness increased drag relative to the leg-loop harness because it placed the logger in a position that increased the bird's frontal area.

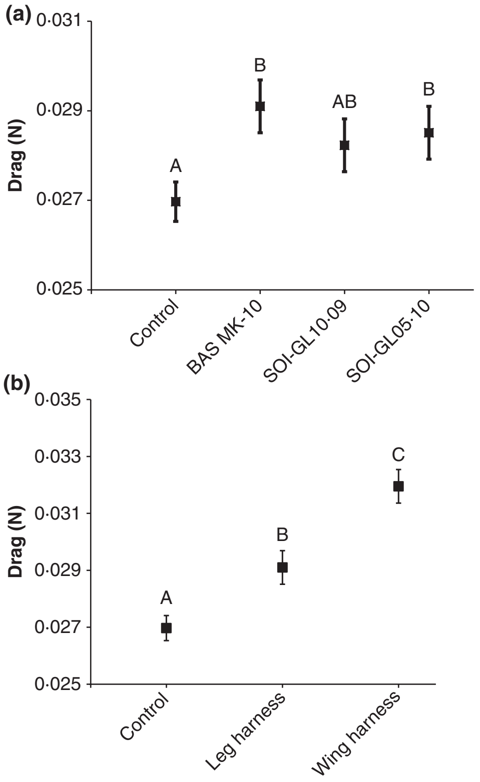

Fig. 2. Drag due to geolocators. Shown are parameter estimates ± 1 SEM for the drag of (a) all three geolocators and (b) the BAS-MK10 logger in two different locations. Letters indicate statistically separate groups based on Bonferroni *post hoc* tests. Note the different scales in the two panels.

In Pennycuick's (1989) flight model, the drag caused by the geolocators typically decreased flight range more than a 1·0 g added weight, but less than a 1·0 g reduction in fuel (Fig. 3a). In fact, even though the SOI-GL05·10 logger was half the size of the SOI-GL10·09 logger, the additional drag of the former meant that the overall effects (drag + weight) on the birds' ranges were quite similar under an added weight scenario, although, under a decreased fuel scenario, the SOI-GL05·10 clearly outperformed the SOI-GL10·09 (Fig. 3b). The reductions in flight range from using a wing harness were often greater than any reductions from the geolocator weight (Fig. 3c).

Discussion

Geolocators significantly increased drag on the swift bodies. The estimated effects of this added drag on the flight ranges of small migrants were on the same order of magnitude as the estimated effects of the weight of the geolocators, suggesting that minimizing drag is just as important as minimizing weight when attempting to mitigate the effects of tracking devices on flying animals, something that has already been demonstrated in swimming animals (e.g. Bannasch, Wilson & Culik 1994; Watson & Granger 1998; Steinhausen, Andersen & Steffensen 2006). To reduce the drag of tracking devices on birds, we recommend attaching devices on the rump instead of between the wings to avoid increasing frontal area. We also suggest that companies creating geolocators or radiotransmitters flatten the devices; for example, the SOI-GL10·09, which did not statistically increase drag over the control measurements, was designed with the battery in front of the electronics rather than on top of them (Fig. 1a), considerably reducing the logger's height.

Drag estimates on preserved bodies can be problematic for a number of reasons (Hedenström & Liechti 2001). In this case, the most worrisome issue is the fact that a live bird can preen a geolocator into its feathers much more adeptly than we could adjust the feathers on the preserved bird bodies, although the added volume of the logger will displace feathers on a live bird and increase drag regardless of how well the animal covers it. We did our best to cover the geolocators and harnesses with feathers, but covering the geolocator on the swift bodies was impossible in the case of the BAS-MK10 because it was too thick. Our drag estimates, particularly of this logger, should therefore be considered worst-case scenarios. A second issue is the fact that we extrapolated our measurements to species other than swifts. Since larger birds have larger feathers, they may be better able to preen the logger into their feathers; the reverse would be true for smaller birds. We therefore may have overestimated the effects of drag on the flight ranges of larger birds and underestimated them for smaller birds. Finally,

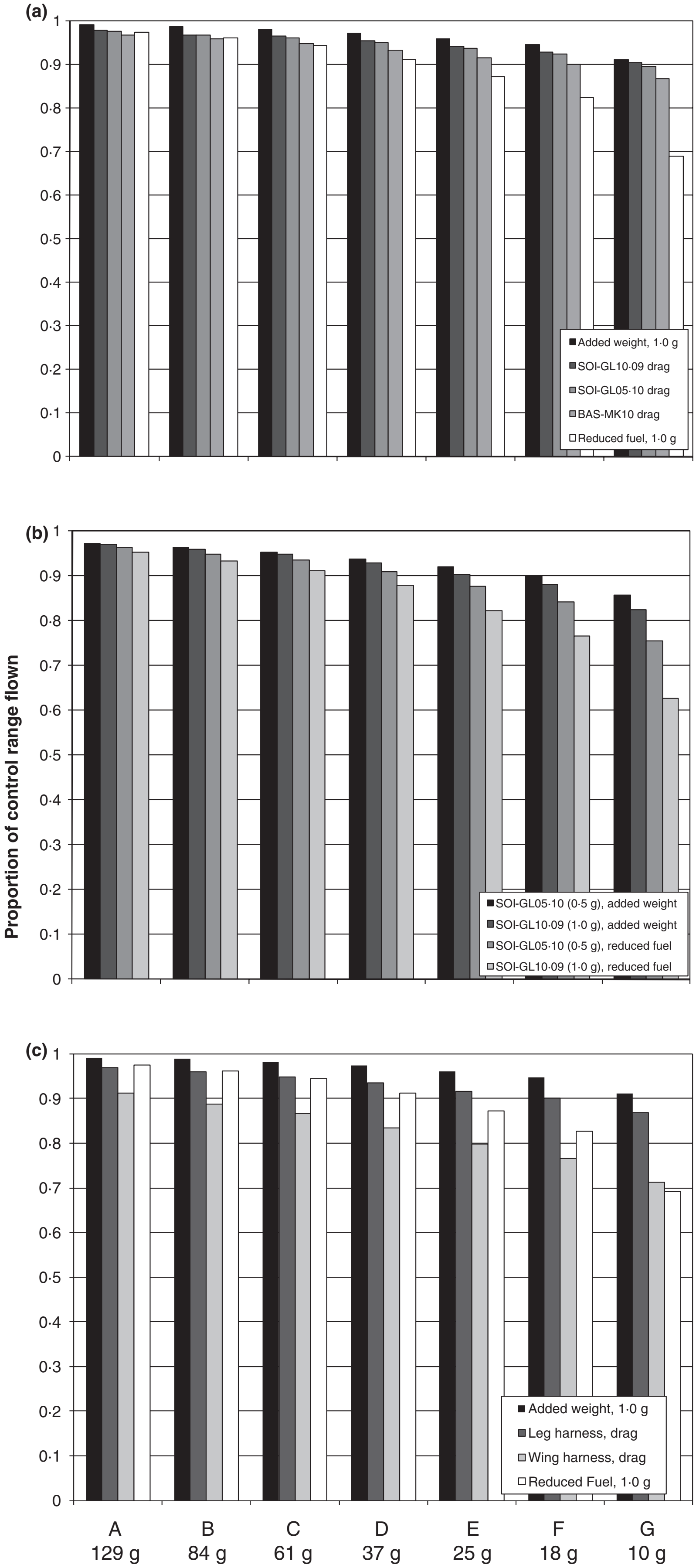

Fig. 3. Proportion of 'control' range (range without any additional drag or weight) flown by seven species at 1·5 times their lean body mass flying with (a) the added drag of the geolocators in comparison with a 1·0 g weight, (b) the total effects (drag + weight) of the 0·5 g SOI-GL05·10 and 1·0 g SOI-GL10·09 under the two weight scenarios used in the study (see Materials and methods), and (c) the drag of the BAS-MK10 in two different harnesses compared with a 1·0 g weight. Species used in the model were: A. Red Knot *Calidris canutus*, B. European Starling *Sturnus vulgaris,* C. Song Thrush *Turdus philomelos*, D. Common Swift *Apus apus*, E. Thrush Nightingale *Luscinia luscinia*, F. Garden Warbler *Sylvia borin*, G. Siskin *Carduelis spinus*. They are arranged in descending order of lean body mass (given in figure below letters).

although measuring body drag using wingless bodies is a standard practice in avian aerodynamics (e.g. Pennycuick, Fuller & Obrecht 1988; Tucker 1990; Maybury & Rayner 2001), it is possible that there are interactions between the air flow over the wings and the air flow over the body in flapping flight and that these could be affected by the presence of geolocators. We would need to measure drag on flapping birds with and without geolocators to address this issue.

The aerodynamic effects we have measured could explain the reduced return rate of purple martins in Stutchbury *et al.* (2009), especially given that they used a larger geolocator than the BAS-MK10 (BAS MK14-S), which also had a stalk. We did not test loggers with stalks, but we suspect that they would have higher drag than loggers without stalks. Stalks may also increase the accuracy of the locations obtained from the loggers (J. Fox, pers. comm.), however, so there may be a trade-off between the effects of geolocators on the birds and the quality of data obtained from geolocators. Regardless, the BAS-MK10 in a leg harness on a common swift under an 'added weight' scenario would decrease its migration range by *c.* 10%. Since martins and swifts are aerial insectivores and would constantly experience the effects of increased drag and weight, a 10% decrease in range could result in significant increases in daily energy expenditure and concomitant decreases in survival probability. Although we examined the effects of small devices on small animals, our results could also explain why, in a study on bar-tailed godwits (Gill *et al.* 2009), heavier implanted transmitters allowed animals to successfully migrate, while lighter external transmitters did not. Researchers attaching any device to flying or swimming animals need to be just as aware of the drag these devices create as they are of the devices' weights.

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Supporting information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Supplemental methods.