Ornis Fennica 92:101–111. 2015

No strong effects of leg-flagged geolocators on return rates or reproduction of a small long-distance migratory shorebird

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Received 18 November 2014, accepted 26 March 2015

Small light-level geolocators have revolutionized research on avian migration and breeding ecology. However, proper evaluations of their impact on the life history of individuals compared to control individuals that experience the same conditions are still rare. Geolocator effects may be species specific and depend on the type of mounting, sex and size of individuals. While geolocators have been used extensively and without negative effects on large shorebirds, relatively little is known about their effects on small shorebirds, especially of those attached on leg-flags. We mounted 30 leg-flagged geolocators (15 on each sex) on Southern Dunlins (*Calidris alpina schinzii*) – a small, long distance migratory shorebird (40–52 grams) – and examined the effects of geolocators on return rates and reproduction through comparisons to a control group. The whole attachment weighed 1.5–2% of an individual's body mass. We found no evidence of lowered return rates. Out of 30 birds, 22 (73%) returned from both groups. Returning birds had similar breeding probability, timing of breeding, clutch size and nesting success. The proportion of unhatched eggs was higher in the geolocator group, but this difference was not significant. Inspection of unhatched eggs from the treatment group suggested no clear damage to eggs caused by geolocators. Our results suggest that at least one small wader species can withstand the extra weight imposed by appropriately sized geolocators. However, our study lasted only for one year, and long term evaluations that capture the full suite of environmental conditions and assess impact on brood care are needed.

1. Introduction

Ecological research is leaping forwards with the development of data retrieval systems such as PIT tags, GPS-devices, satellite tracking and light level geolocators (Stutchbury *et al*. 2009, Ponchon *et al*. 2013, Hays 2014). Until recently, large-scale animal migration movements could only be studied with large animals because the technology was large and heavy. The critical percentage of body mass often considered acceptable for a device carried by an individual is 5%, but a safer value may be closer to 2–3% (Kenwood 2004, Clark *et al*. 2010, Constantini & Møller 2013), and such assessment must consider a range of other tagging factors such as positioning, attachment, size, shape, aerodynamics, behaviour, habitat, etc.

The recent development of geolocators has revolutionized avian migration research (e.g., Stutchbury *et al*. 2009, Klaassen *et al*. 2011). Geolocators are small in size and light in mass, providing a possibility for migration research on small bird species. The devices gather data on light levels which can be translated to locations with an accuracy of approximately 100 km (Lisovski *et al*. 2012), and are also increasingly used to study breeding biology (e.g., Bulla *et al*. 2013). However, despite their continued use, the impacts of geolocators on smaller species are seldom evaluated relative to suitable controls.

Evaluating the impact of any tag used on animals is important, for obvious ethical reasons, but also to aid continued research and development with respect to the application of devices. Geolocators may reduce survival, and may also affect breeding probability and reproductive success (Constantini & Møller 2013). Especially in small passerines, negative impacts have been noted (Arlt *et al*. 2013, Bridge *et al*. 2013, Gómez *et al*. 2014, Scandolara *et al*. 2014). Geolocators are mounted either on leg-flags (large species) or leg-loop harnesses (small species), methods that may have different consequences for aerodynamic drag during migration (Bowlin *et al*. 2010) and also for fitness (Constantini & Møller 2013).

Studies on the effects of geolocators are still rare among waders. Large species do not seem to be affected by leg-flags (Niles *et al*. 2010, Johnson *et al*. 2011, Minton *et al*. 2011, Burger *et al*. 2012), but the results in most of these studies may not be reliable as the geolocator birds may have been more targeted than the controls (Niles *et al*. 2010). Furthermore, mortality effects are more likely in small species (Constantini & Møller 2013). Two studies on small sized waders suggest no evident effects of leg-loop harnessed geolocators (mass 25–40 g; Hedenström *et al*. 2013, Lislevand & Hahn 2013). Unfortunately, these and many other studies are based on small sample sizes, low test power and lack of proper control groups (Constantini & Møller 2013). Furthermore, so far no study has evaluated the effect of leg-flagged geolocators on survival or reproduction of a small wader species.

We deployed geolocators on the Southern Dunlin (*Calidris alpina schinzii*), a small shorebird (40–52 g) breeding on coastal meadows on the Baltic Sea. Geolocators are planned to be used as part of a conservation project to determine the exact wintering sites for this endangered declining population, which are currently unknown (Thorup *et al*. 2009). The geolocators were mounted on birds belonging to a long term life history study (Pakanen *et al*. 2011a, 2014), which gave us an excellent opportunity to effectively test detailed effects of geolocators on return rates (proxy for survival) and reproduction, by using a control group.

2. Material and methods

We mounted geolocators on breeding Southern Dunlin near Oulu in the Bothnian Bay, Finland in 2013 (64°50’N, 25°00’E). The study population occurred on seven separate coastal meadows. Geolocators were only deployed on adults that bred successfully in 2013. Adults were captured with mist-nets or cages, while brooding chicks, between 31st May and 19th of July. This was done to minimize potential negative effects on eggs during incubation.

A total of 30 geolocators were mounted, fifteen on each sex. We used light-level geolocators (Intigeo-W65A9, Migrate Technology Ltd) mounted on the tibia with plastic (Salbex) leg-flags (Fig. 1). Geolocators were attached to the flags with Loctite “All-Plastics superglue” and monofilament string (fishing line 0.20 mm). The flag ends were glued together and the edges were melted together with a portable soldering iron. The device (locator + flag) mass was ca. 0.8 g. Hence, the leg-flagged geolocator constituted 1.5–2% of the Southern Dunlin mass (40–52 g). In most cases, one colour ring was placed under the flag to reduce joint abrasion (Fig. 1; Clark *et al.* 2010).

Our long term population study involves searching for all possible territories, nests and renests, and ringing all chicks and adult individuals with individually identifiable combinations of a metal ring and three colour rings (Pakanen 2011, Pakanen *et al*. 2011a, 2014). Field work in 2014, including recapture of birds, began in late April with territory searches and resighting of individuals on the breeding meadows. Work continued until mid-July with nest and brood searching en-

Fig. 1. Geolocators were mounted on the tibia of Southern Dunlin (*Calidris alpina schinzii*) using a plastic leg-flag. One plastic colour ring was added below the flag to reduce joint interference. Individual colour ring combinations are placed on tarsi. Photo: Kari Koivula.

abling us to effectively resight as many adults as possible and to follow their reproductive success.

After finding the nest of a geolocator bird, the geolocator was removed as soon as possible. Some birds were caught after incubating for one day while others were caught when brooding chicks. Because the Baltic Dunlin is endangered and declining throughout its range (HELCOM 2013), we have a protocol in our long-term study by which we aim to reduce researcher effects on the birds in this population as much as possible. Therefore, we do not catch adults from their nest (the only reliable technique) if there is no need. Because we are able to non-invasively confirm the presence of individuals based on their colour rings, we decided not to catch birds of the control group. We deemed that the data that could be gathered from catching control birds did not justify catching these birds for this study.

2.1. Analysing effects of geolocators on return rates and reproduction

We compared the return rates and reproduction of birds carrying leg-flagged geolocators and control birds. The birds included in this comparison could not be pre-selected because they were required to be successful in hatching their nest. Thus, the geolocator birds were picked at random as their nests hatched so that at some nests the parents were given geolocators and in some nests the parents did not receive geolocators. The latter group of birds constituted the control group. These groups did not differ by any characteristics other than that five individuals were not successful in hatching their eggs (Table 1). The nests of these five individuals were not predated (cause of failures were: flooding 3, unfertile eggs 2) and the parents were alive after breeding failure. The groups differed in

Table 1. Characteristics of the Southern Dunlin (*Calidris alpina schinzii*) belonging to the geolocator and control treatments.

Characteristic	Geolocator	Control	Test
Number of males	15	15	–
Number of females	15	15	–
Clutch size ±SD	4 ± 0	4 ± 0	–
Hatching% of eggs (*n*)	95% (56)	98% (51)	$p = 0.68$
Proportion of first time breeders	40%	43%	$p = 1$
Proportion of immigrants	30%	33%	$p = 1$
Time of breeding	12.03 ± 6.17	14.93 ± 8.74	$p = 0.14$
Mass (g)	44.86 ± 2.53	46.29 ± 3.64	$p = 0.10$

their capture history. Only 43% ($n = 30$) of the control birds were trapped in 2013, while all birds in the geolocator group were captured.

We used return rates as a proxy for survival (resighted in 2014) because the data did not allow us to analyse apparent survival (i.e., control for recapture rate). This should not pose a large problem because the treatment should not influence the recapture probability of the birds. Return rates were analysed with generalized linear models (GLM, binomial errors and logit link) in R 3.0.3 (R Development Core Team 2007) with sex, age (first time breeder vs. old breeder) and mass as factors. We also considered a potential bias from dispersal status which can potentially affect return rates (immigrant vs. philopatric; Pakanen *et al*. 2010, 2011b). We examined if changes in body condition (body mass before mounting and after removal the geolocator) were in line with results on the return rates. These data were not available for the control group.

We used the Akaike's Information Criterion with the small sample size correction (AICc) to assess the relative fit of the models for return rates. We considered a difference of > 2 in model AICc values to infer a real difference in model support (Burnham & Anderson 2002). We also calculated evidence ratios (ER) by comparing Akaike weights (w) of constrained and reduced models (w_1 / w_2). Evidence ratios quantify the relative support for inclusion of explanatory variables (Burnham & Anderson 2002).

During the return year (2014), we examined reproductive success in detail with the probability of breeding, the timing of breeding, clutch size, nesting success and hatching of eggs. Breeding probability was the proportion of individuals observed breeding or attempting to breed (paired at territory) out of all resighted individuals. Timing of breeding, i.e., laying of the first egg, was estimated from egg count when the nest was found (for incomplete clutches), egg flotation (Liebezeit *et al*. 2007) and hatching date by assuming 26 days of incubation and laying (Pakanen *et al*. 2011a). Nesting success was the probability of successfully hatching chicks (produced chicks: yes/no) and also included re-nesting attempts.

Leg-flag geolocators may cause hatching failure due to egg shell damage. Hatching of eggs was first examined by comparing the proportion of nests including unhatched eggs. We also examined the probability of hatching per egg. Because some geolocators were taken off early in incubation while others only at hatching, and because in some nests both sexes had geolocators, we related the amount of unhatched eggs per nest to the exposure time to geolocators during incubation. Both sexes were assumed to incubate 50% of the time.

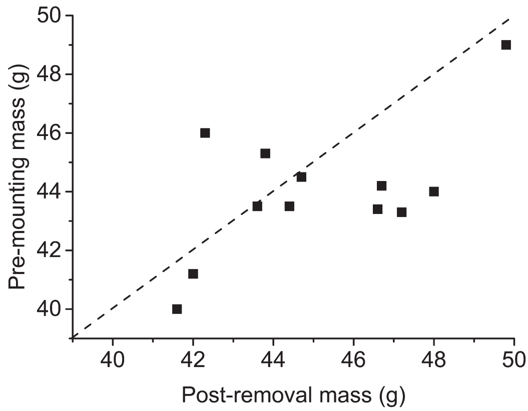

Fig. 2. The relationship between individual body masses of the Southern Dunlin (*Calidris alpina schinzii*) before deployment and post-removal of the geolocators after a year. The diagonal dashed line shows area of no change in mass (not a line fitted to the data). Points below the line depict an increase and above the line a decrease in mass.

3. Results

3.1. Return rates and body condition

After removal of the geolocator, the tibia of most birds was healthy but often had thinner, lighter and softer skin. However, body condition (mass) of the birds was not affected by the geolocator (pre-mounting mass: 44.00 g, SD 2.25; post removal mass: 45.06 g, SD 2.59, $n = 12$, paired t-test, $t = 1.66$, $df = 11$, $p = 0.13$; Fig. 2). The timing (within season) of mass measurements may differ within birds, which may affect the result to some extent.

Geolocators did not affect return rates (Table 2), which were the same for both groups (73%, 22 of 30 individuals). Return rates of females (0.60) were lower than that of males (0.87; models 1 and 6, ΔAICc = 3.51; ER = 5.8), and return rates declined with timing of breeding in 2013 (ΔAICc =

Table 2. Results of a generalized linear model (GLM) for analyzing return rates of the Southern dunlin (*Calidris alpina schinzii*) breeding in Finland. Additive (+) and interactive (:) effects or geolocator attachment (*GEO*), timing of breeding in 2013 (*TIME*), sex (*SEX*), mass (*MASS*) and dispersal status (*DS*). For each model we report the model number (#), model structure, Akaike's information criterion corrected for small sample size (AICc), difference in AICc compared to the best fitting model (ΔAICc), and Akaike weights (*w*).

#	Model structure	AICc	ΔAICc	*w*
1	*SEX*	68.15	0.00	0.352
2	*TIME*	69.58	1.43	0.172
3	*GEO* + *SEX*	70.37	2.22	0.116
4	*GEO* + *SEX* + *GEO*:*SEX*	70.91	2.76	0.088
5	*GEO* + *TIME*	71.59	3.44	0.063
6	Constant only	71.66	3.51	0.061
7	*GEO* + *TIME* + *GEO*:*TIME*	73.02	4.87	0.031
8	*AGE*	73.76	5.61	0.021
9	*MASS*	73.77	5.62	0.021
10	*DS*	73.80	5.65	0.021
11	*GEO*	73.80	5.65	0.021
12	*GEO* + *AGE*	75.98	7.83	0.007
13	*GEO* + *MASS* + *GEO*:*MASS*	75.98	7.83	0.007
14	*GEO* + *MASS*	75.99	7.84	0.007
15	*GEO* + *DS*	76.02	7.86	0.007
16	*GEO* + *AGE* + *GEO*:*AGE*	77.72	9.56	0.003
17	*GEO* + *DS* + *GEO*:*DS*	78.10	9.95	0.002

2.08; ER = 2.8). There was a small tendency for an interaction between sex and geolocator treatment (Table 2, models 3 and 4, Fig. 3a) but not between timing of breeding and geolocator treatment (Table 2, models 5 and 7). Dispersal status, mass, age and their interactions with geolocator treatment did not affect return rates (Table 2). See Appendix for regression coefficients with SE.

3.2. Reproduction

Breeding probability did not differ between geolocator (95.5%; $n = 22$) and control groups (95.5%; $n = 22$). Of the 21 breeding individuals in both groups, 10 geolocator and 12 control birds paired within their groups. One pair included a geolocator bird and a control bird. The rest (10 geolocator birds and 8 control birds) paired with other birds.

There were no differences in the timing of breeding (May day 1) in females (control group = 10.9, SD 7.72, $n = 9$; geolocator group = 15.4, SD 4.51, $n = 5$; $t = 1.38$, $df = 11.88$, $p = 0.19$; Fig. 3b) or males (control group = 12.8, SD 8.12, $n = 8$; geolocator group = 10.8, SD 6.24, $n = 11$; $t = -0.56$, $df = 12.67$, $p = 0.58$; Fig. 3b). When including only one observation per pair (and excluding the geolocator x control pair), there were no differences in clutch size (geolocator group: 4 eggs, $n = 13$; control group: 4 eggs, $n = 13$) or nesting success (geolocator group: 0.80, $n = 15$; control group: 0.79, $n = 14$). We found unhatched eggs from 45% of successful nests of geolocator birds ($n = 11$) and in 16.7% ($n = 12$) of control birds' successful nests. The difference is not significant ($\chi^2 = 1.09$, $df = 1$, $p = 0.30$; Fig. 3c). Without any reference to a nest, hatching percentage of eggs from successful nests was similar in both groups (geolocator group: 0.87, $n = 52$; control group: 0.90, $n = 60$; Fig 3c). Within the geolocator group, the exposure time to geolocators during incubation was not associated with the amount of unhatched eggs ($t = 0.31$, $df = 10$, $p = 0.76$; Fig 3d).

4. Discussion

We found no obvious effects of geolocators on the return rates or reproduction of the Southern Dunlin, a small migratory wader weighing 40–52 g. Our results are in line with previous studies on much larger shorebirds (Johnson *et al*. 2011, Minton *et al*. 2011) and suggest that leg-flag

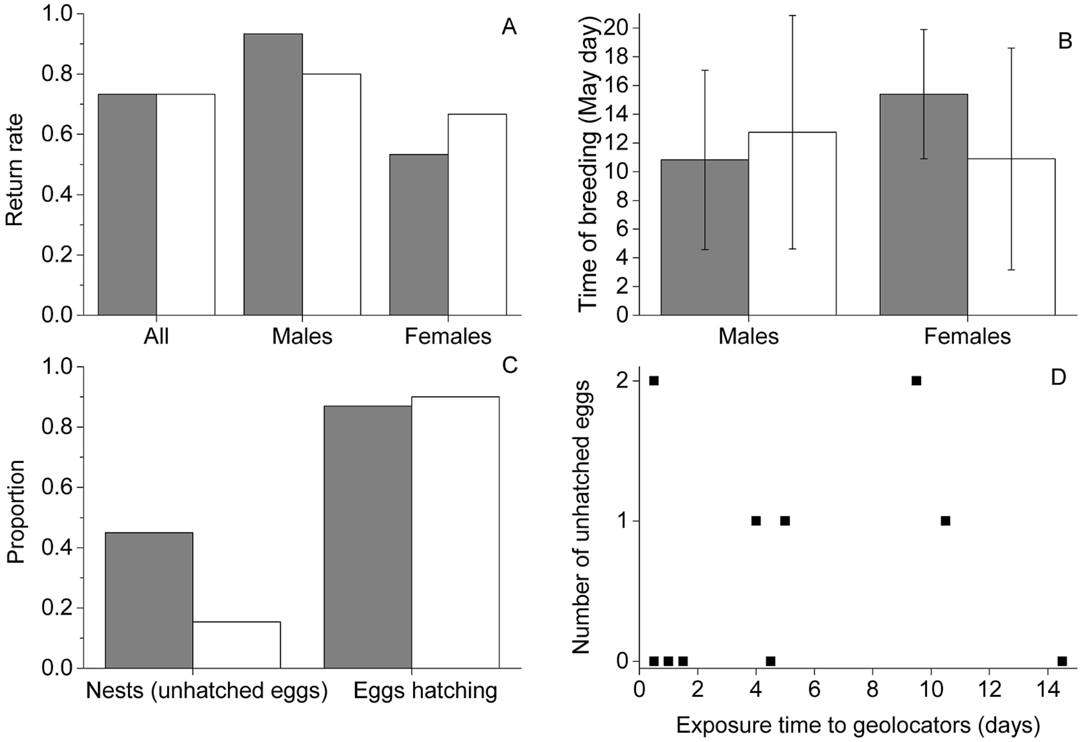

Fig. 3. Comparison of a) return rates, b) timing of breeding and c) the proportion of nests with unhatched eggs and the proportion of eggs hatching of the Southern Dunlin (*Calidris alpina schinzii*) between geolocator birds (gray) and the control birds (white). Panel d) shows the relationship between exposure time to geolocators and the number of unhatched eggs in the nest. Whiskers denote SDs.

mounted devices weighing less than 2% of body mass are also safe for small shorebirds (Kenwood 2004, Clark *et al*. 2010). On the other hand, the results contrast with studies on passerines that have found effects on both survival and reproduction from harness mounted geolocators (Bridge *et al*. 2013, Constantini & Møller 2013, Arlt *et al*. 2013, Scandolara *et al*. 2014). In passerines, there appears to be a threshold body mass (35 g) below which the ability to withstand additional weight becomes more difficult (Bridge *et al*. 2013). If such a threshold exists in shorebirds, the smallest wader species weighing less than 40 grams may show responses (see Lislevand & Hahn 2013, Smith *et al*. 2014).

4.1. Return rates and body condition

Birds carrying geolocators returned at an equal rate to the control group. Females had lower return rates than males, and there was a non-significant tendency in geolocator females to have a lower return rate than control females. Despite the physiological and behavioural differences between the sexes, our results suggest that this difference is unlikely to reflect survival. Firstly, any consequences to survival would be more evident with lighter males (mean mass = 43.9 g) than the heavier females (mean mass = 46.2 g). Secondly, we found no effect of mass on return rates, and subsequent body condition was not affected by geolocators (Fig. 2). Lower return rates of females in general may have been a consequence of the lower recapture rates (Pakanen 2011). Thus, it is possible that dispersal of a few females may have hindered our ability to find them. In fact, we observed three geolocator females dispersing between breeding sites, 2.2, 15 and 23 kilometers apart, which is normally rare (Pakanen 2011).

The only evidence of negative effects on the Dunlin was the somewhat thinner and softer skin on the tibia under the flags of some individuals. Whether or not this makes them vulnerable to injury is unknown, and a follow-up study of return rates in later years after retrieval of the geolocator is warranted.

4.2. Reproduction

We found no evidence that the geolocators changed breeding behaviour of the Southern Dunlin. The birds bred with the same likelihood, timing and effort (clutch size). Importantly, neither was breeding success compromised. The impact of leg-flagged geolocators on hatching success has not been previously assessed (Niles *et al*. 2010). We found no clear indications of egg damage. The proportion of nests that included unhatched eggs was higher in geolocator birds but the difference was not significant. This difference disappeared when examining the hatching percentage of the eggs themselves without reference to a nest. In addition, exposure time to geolocators during incubation was not related to the number of unhatched eggs, suggesting that failure to hatch was not caused by geolocator damaging the eggs but rather by some other factor. Indeed, only one unhatched egg had a crack which may have been caused by the geolocator. The small difference in unhatched eggs between geolocator and control nests may have resulted from recapturing the geolocator birds (control birds were not recaptured). Sometimes birds can leave their nests for extended periods after capturing which may be detrimental to the eggs if weather conditions are too cold.

4.3. Conclusions

We found no evidence that geolocators would have major impacts on return rates or reproduction for a small long distant migratory wader. However, we recognize our small sample size and the potential for low power to detect effects. For example, a decrease in survival of 10–20 percent would be biologically important for this long-lived species. However, finding a statistically significant (p = 0.05) result for a 10% decrease or a 20% decrease in return rates would have needed a sample sizes of 338 or 90, respectively. Therefore, the use of geolocators may have had some undetected influences. Deploying devices on animals is not without consequences. They are known to increase stress levels (Elliott *et al*. 2012), and their effects may be too subtle to be detected with limited data. Hence, we urge researchers to stay vigilant for any possible adverse effects when conducting geolocator studies. Finally, our comparison was not complete; the time frame did not allow us to assess possible impacts on brood rearing and consequences for juvenile survival.

Further research is needed to increase understanding on the impact of these devices on life history in the long term. For example, in this study the return rates of both groups (73%) were high, being close to the long term average apparent survival rate (75%, corrected for a recapture probability of 84–88%; Pakanen 2011). It is thus possible that 2013/2014 was a favourable year. Adverse effects may arise more likely in harsh conditions, warranting long term studies that capture the full suite of environmental conditions.

Acknowledgements. We thank the Faculty of Science of University of Oulu for funding the geolocators, and Jos van Winckel and Antti Rönkä for help in the field. This study complied with national law and was conducted under permission and supervision from the regional Centre for Economic Development, Transport and the Environment (license number POPELY/15/07.01/2013).

Paikanninlaitteiden vaikutukset etelänsuosirrin säilyvyyteen ja poikastuottoon

Pienikokoiset valon voimakkuutta mittaavat paikanninlaitteet (geolokaattorit) mahdollistavat lintujen muutto- ja talvehtimispaikkakartoituksen nykyään myös pienillä lajeilla. Geolokaattorit voivat kuitenkin haitata lintuja. Vaikutus voi riippua mm. lajin elintavoista, laitteen koosta suhteessa linnun kokoon ja laitteen kiinnitystavasta. Silti kontrolloituja vaikutuksia säilyvyyteen ja poikastuottoon on tutkittu vain vähän. Esimerkiksi jalkalippuun kiinnitettyjen geolokaattoreiden vaikutuksia pienillä kahlaajilla ei ole tutkittu lainkaan.

Asensimme 30 (15 pesinnässään onnistunutta koirasta ja naarasta) etelänsuosirrille (*Calidris alpina schinzii*) jalkalipun, johon oli kiinnitetty geolokaattori (kokonaisuus n. 1.5–2 % linnun massasta). Lisäksi valitsimme 30 kontrollilintua. Molemmista ryhmistä palasi pesimään 22 (73 %) yksilöä. Myöskään pesintätodennäköisyys, pesinnän ajoitus, munamäärä, tai pesinnän onnistuminen eivät olleet yhteydessä merkintään.

Geolokaattorilintujen onnistuneissa pesissä oli hieman useammin kuoriutumattomia munia, mutta ero ei ollut merkitsevä. Kuoriutumattomien munien määrä ei kuitenkaan ollut yhteydessä aikaan, jonka emot kantoivat geolokaattoria hautoessaan. Etelänsuosirrin tapainen laji pystyy siis kantamaan oikein asennettua ja sopivan kokoista geolokaattoria ilman ilmeisiä vaikutuksia elinkykyyn. Korostettakoon kuitenkin että tutkimus kesti vain yhden vuoden, joka saattoi olla ominaisuuksiltaan suotuisa. Tarvitaankin vielä pitkäaikaisempia tutkimuksia, joissa mahdollinen ympäristön ym. vaihtelu tulee kenties esille.

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Appendix 1. Regression coefficients (SE) for different parameters in models 1–17 (from Table 2) modelling return rates.

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Intercept	0.406 (0.373)	2.131 (0.660)	0.405 (0.482)	0.693 (0.548)	2.334 (0.810)	1.012 (0.292)	2.834 (1.034)	0.828 (0.971)
SEX	1.466 (0.654)	–	1.466 (0.654)	0.693 (0.847)	–	–	–	–
TIME	–	–0.078 (0.039)	–	–	–0.082 (0.040)	–	–0.111 (0.054)	–
GEO	–	–	–0.000 (0.612)	–0.560 (0.754)	–0.283 (0.627)	–	–1.436 (1.401)	–
AGE	–	–	–	–	–	–	–	0.116 (0.590)
MASS	–	–	–	–	–	–	–	0.015 (0.095)
DS	–	–	–	–	–	–	–	–
GEO:SEX	–	–	–	1.812 (1.434)	–	–	–	–
GEO:TIME	–	–	–	–	–	–	0.080 (0.086)	–
GEO:DS	–	–	–	–	–	–	–	–
GEO:MASS	–	–	–	–	–	–	–	–
GEO:AGE	–	–	–	–	–	–	–	–

Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17
0.310 (4.339)	1.030 (0.521)	1.012 (0.413)	0.830 (1.006)	–4.277 (5.327)	0.275 (4.474)	1.029 (0.590)	1.533 (1.420)	0.847 (0.690)
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–
–	–	–0.000 (0.584)	–0.004 (0.584)	14.702 (10.008)	0.018 (0.594)	0.0009 (0.584)	–1.399 (1.959)	0.405 (1.058)
–	–	–	0.117 (0.590)	–	–	–	–0.329 (0.847)	–
–	–	–	–	–	–	–	–	–
–	–0.026 (0.629)	–	–	0.115 (0.117)	0.016 (0.096)	–	–	–
–	–	–	–	–	–	–0.026 (0.629)	–	0.251 (0.862)
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–0.588 (1.272)
–	–	–	–	–0.322 (0.219)	–	–	–	–
–	–	–	–	–	–	–	0.888 (1.189)	–