Two observations of acorn barnacles attached to GLS loggers on seabirds in the North Atlantic

Dunn R.E.*[1], Buckingham, L.[2], Bogdanova, M.I.[2], Daunt F.[2] & Newell, M.A.[2]

* ruthelizabethdunn@gmail.com

[1] Institute of Environment, Department of Biological Sciences, Florida International University, Miami, Florida, USA.

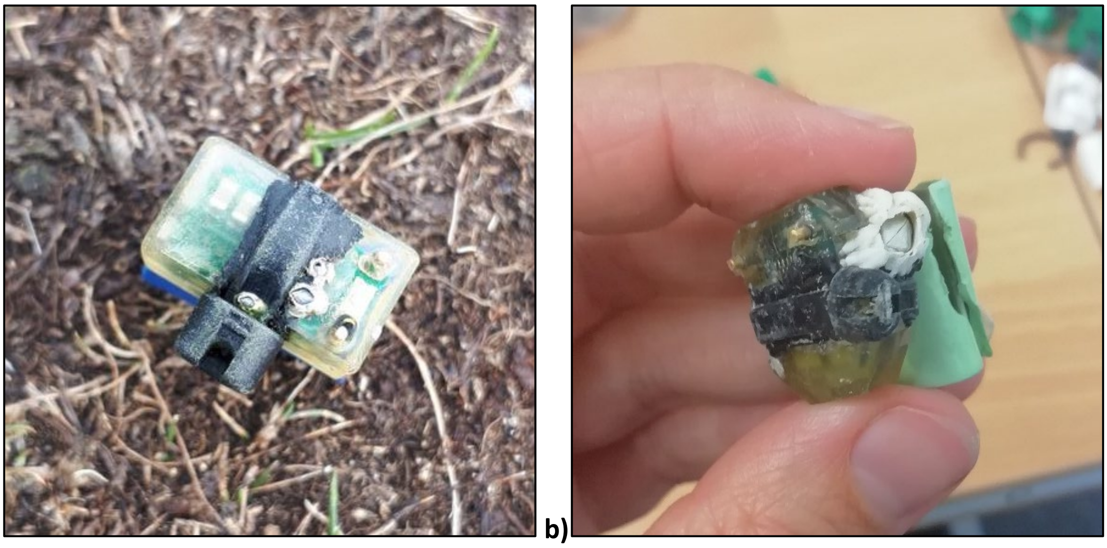
[2] UK Centre for Ecology & Hydrology, Bush Estate, Penicuik, UK.

Over the past 30 years, global location sensing (GLS) loggers have been deployed across a diverse range of seabird species all around the globe. GLS loggers, also termed geolocators, record ambient light from which latitude and longitude can be derived, providing estimates of seabird foraging areas and migratory routes. Between 2002 and 2020, GLS loggers have been successfully deployed and retrieved by UK Centre for Ecology & Hydrology (UKCEH) on seabirds at breeding colonies across the UK (Table 1). GLS loggers were attached to the birds via plastic leg-rings during the breeding season (June – July, although a small number were deployed on European shags *Phalacrocorax aristotelis* in May and common guillemots *Uria aalge* in March) and were then removed during subsequent breeding seasons when birds were recaptured. These data have provided insights into the migratory movements and wintering behaviour of Atlantic puffins *Fratercula arctica* (St. John Glew et al., 2019), black-legged kittiwakes *Rissa tridactyla* (Bogdanova et al., 2011), common guillemots (Dunn et al., 2020), European shags (Daunt et al., 2014) and razorbills *Alca torda* (St. John Glew et al., 2019).

During the 2019 breeding season, GLS loggers were removed from a black-legged kittiwake (hereafter 'kittiwake') at the Isle of May National Nature Reserve, Scotland (56°11'N, 02°33'W; Logger: Biotrack MK4083, weight: 1.9 g) and a common guillemot (hereafter 'guillemot') at Whinnyfold, Scotland (57°39'N, 01°87'W; Logger: Biotrack MK3006, weight: 2.5 g) and were observed to have barnacles attached. The logger removed from the Isle of May kittiwake had three barnacles attached, ranging from ca. 1.4 - 2.7 mm in diameter (Figure 1a), and the logger removed from the Whinnyfold guillemot had one barnacle attached (ca. 7.5 mm diameter; Figure 1b). Although the specimens were not collected for formal identification, they are assumed to be the acorn barnacle *Semibalanus balanoides*, the most common and widespread intertidal barnacle around the coastlines of north-west Europe (White, 2008). *Semibalanus balanoides* individuals are found across a range of wave exposure levels as well as rocky shore heights and can also colonise artificial substrates including marine debris (White, 2008).

Table 1. Number of global location sensing (GLS) loggers retrieved from 5 species of seabird by UK Centre for Ecology and Hydrology (UKCEH) between 2002 and 2020 at 11 colonies across the UK.

	Number of GLS loggers retrieved				
	Species				
	Atlantic puffin, *Fratercula arctica*	Black-legged kittiwake, *Rissa tridactyla*	Common guillemot, *Uria aalge*	European shag, *Phalacrocorax aristotelis*	Razorbill, *Alca torda*
Canna	-	-	103	-	31
Colonsay	-	-	43	-	1
East Caithness	-	-	77	-	22
Fair Isle	-	-	15	-	11
Farne Islands	-	-	1	-	4
Foula	-	-	13	-	1
Isle of May	145+	168	160+	444	50+
Orkney	-	-	-	-	31
Shiant Islands	-	-	-	-	13
Treshnish Isles	-	-	31	-	13
Whinnyfold	-	-	76	-	10



a) **b)**

Figure 1. The acorn barnacle *Semibalanus balanoides* found attached to global location sensing (GLS) loggers after removal from a) a black-legged kittiwake *Rissa tridactyla* at the Isle of May and b) a common guillemot *Uria aalge* at Whinnyfold in 2019.

The fouling of biologging devices has been observed previously in marine fishes, turtles, seals and cetaceans and measures to reduce this and avoid burdening the animals are encouraged (Hammerschlag et al., 2014). However, to the best of our knowledge, the attachment of barnacles to GLS loggers on seabirds is relatively uncommon. Previously, goose barnacles *Lepas* spp. have been found attached to self-amalgamating tape wrapped around loggers removed from Falkland skuas *Catharacta antarctica* at New Island, Falkland Islands (Phillips et al., 2007), as well as GLS loggers deployed on wandering albatrosses *Diomedea exulans* at Bird Island, South Georgia (R.A. Phillips pers. comm.). Goose barnacles attach to a variety of substrata, including the plumage of several species of penguins breeding at remote southern hemisphere islands (Reisinger, 2010). Due to the large sizes to which goose barnacles can grow, Phillips et al. (2007) recommended that self-amalgamating tape be avoided in future deployments of GLS devices on skuas so as not to burden birds with this additional load. The species of acorn barnacle that we observed is only able to reach a maximum of 15 mm in diameter (White, 2008) and therefore its mass is likely to have a negligible impact in terms of the load on the leg. However, barnacle attachment may increase hydrodynamic drag with the potential to reduce diving efficiency (Pennycuick et al., 2012). For example, the attachment of a single acorn barnacle with a height of 4 mm and a diameter of 7.5 mm would lead to a 15 mm^2 increase in frontal area of the logger. Depending on the location of barnacle attachment, the proportional increase in frontal area could be large (Table 2), increasing the drag coefficient (Pennycuick et al., 2012). Furthermore, there is a risk that if barnacle attachment occurred over the light sensor of a GLS logger, this could influence the light data recorded.

Table 2. The percentage increase in frontal area that a single acorn barnacle *Semibalanus balanoides* would cause to a GLS logger. The barnacle is assumed to be cone-shaped with a height of 4 mm and a diameter of 7.5 mm. The dimensions of Biotrack MK4083 and MK3006 loggers are 17 x 10 x 6.5 mm and 16 x 14 x 6 mm, respectively. Both loggers were assumed to be cuboid.

Logger	Percentage increase in frontal area caused by barnacle attachment	
Biotrack MK4083	Face/back + barnacle =	8.8%
	Side + barnacle =	13.6%
	Top/bottom + barnacle =	23.1%
Biotrack MK3006	Face/back + barnacle =	6.7%
	Side + barnacle =	15.6%
	Top/bottom + barnacle =	17.9%

The attachment of goose barnacles to loggers retrieved from Falkland skuas was attributed to the high proportion of time spent on water during winter increasing the opportunities for larvae settlement (Phillips et al., 2007). However, there is extensive variation in the non-breeding behaviour, including time spent on the water, of the five species of seabirds from which loggers have been retrieved in our studies (Table 1). Guillemots spend high proportions of time on water throughout their annual cycles (Dunn et al., 2020), whereas kittiwakes spend comparatively low proportions of time on water during the winter (McKnight et al., 2011), suggesting that immersion time may not be the sole driver of barnacle attachment to loggers on North Atlantic seabirds. One reason that successful attachment of *Semibalanus balanoides* to seabird loggers may be rare is that their larvae favour gregarious settlements on nearshore habitats that enable future mating opportunities with nearby conspecifics (White, 2008).

Due to the rarity of barnacle attachment, there is no reason to recommend that researchers avoid deployment of GLS loggers on seabirds. Additionally, we acknowledge that self-amalgamating tape is likely to reduce the risk of a GLS logger being lost from the ring, but recommend that it is trimmed along the cable tie to minimise the surface area that protrudes. Furthermore, we advise the documentation of future observations of marine biota found attached to seabird loggers.

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