Remote assessment of 'Type C' implantable satellite tag extrusion using light sensors

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ABSTRACT

Advances in engineering and long-term monitoring projects have greatly increased the sophistication of cetacean biologging methods and technology. While implantable cetacean tags naturally extrude and eventually fall off, satellite tag duration for large whales is still highly variable and often below expected longevity based on battery life alone. Causes of tag failure are difficult to determine and may include natural extrusion of the device, transmitter failure during deployment, or post-deployment damage. Tags deployed during a study designed to assess tag performance and impacts in humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine between 2011 and 2015 were equipped with a sensor designed to detect light exposure. Light sensor readings were evaluated based on follow-up photos of 30 whales in order to investigate whether recorded light levels could serve as a remote indicator of tag extrusion distance. There was a direct correlation between the amount of extrusion and daytime light levels; fully embedded tags recorded no light, while tags that had extruded enough to fully expose the light sensor recorded full light levels. Partially extruded tags recorded variable light levels throughout daylight hours, likely due to irregular or partial exposure of the light sensor. While the single-sensor design cannot describe the fine-scale rate of tag extrusion, additional light sensors placed along the length of the tag and a visible indicator of sensor orientation would greatly improve remote diagnostics. These results show that light levels may be used as an indicator of extrusion and highlight their potential value for understanding tag performance.

KEYWORDS: SATELLITE TAGGING; TELEMETRY; CONSERVATION; MANAGEMENT PROCEDURE; REGULATIONS

INTRODUCTION

The incorporation of biotelemetry and biologging devices (i.e., 'tags') into large whale research projects over the past few decades has yielded invaluable data on habitat-use, foraging, migration, population structure and individual movements. This information has been used to help protect and manage cetaceans worldwide (Andrews *et al*., 2019; see Reference List for a comprehensive list of cetacean biologging studies). While there

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have been significant technological advances in tag design, electronics, deployment methods and satellite network coverage in the past decade, many satellite tags used on cetaceans typically stop transmitting before their battery life ends. Premature tag cessation leads to widely varying datasets within and between study seasons, and can bias resulting behaviour prediction models, home range density estimates and fine-scale movement statistics (Mul *et al*., 2019; Sequeira *et al*., 2019).

Type C (‘consolidated’) cetacean tags are defined as biologging devices whose ‘electronics and retention elements are consolidated into a single implanted anchor’ (Andrews *et al*., 2019) and are commonly used in long-term cetacean biotelemetry projects worldwide. These tags are designed to be fully implantable and record location data for a period of weeks to several months. Type C tags are deployed remotely and intended to capture behaviour not otherwise observed. Thus, aside from projects that include an initial post-deployment follow-up period, tagged whales are rarely re-encountered during the transmission period of a telemetry study. Reasons for premature Type C tag failure in large whales are not fully understood but may include hardware damage (during or after deployment), natural biological rejection (i.e., extrusion), sensor interference from biological matter, internal migration or intrusion of the tag past the wet/dry sensor, or other unexpected causes (Hays *et al*., 2007; Mate *et al*., 2011; Moore *et al*., 2013; Norman *et al*., 2018; Gulland *et al*., 2024).

Battery voltage levels are relayed during transmission and can often be used as a performance diagnostic, as consistently low battery voltage readings often precede battery exhaustion. However, there are no dedicated diagnostic sensors in Type C tags that can describe the cause of premature tag cessation for a tag with adequate battery voltage. Visual confirmation has therefore been necessary to diagnose tag extrusion or breakage.

Type C tag extrusion has been observed during opportunistic re-sightings of tagged animals and is generally thought to begin over varying periods of time, from hours to days (Robbins *et al*., 2013; Best *et al*., 2015; Norman *et al*., 2018). Extrusion is the result of the natural physiological response to a foreign body within living tissue. The underlying reasons for premature or accelerated tag extrusion vary by individual but may include anchor malfunction and/or improper tag placement during deployment. Regardless of the reasons for tag extrusion, a Type C tag that is fully penetrated will experience less drag than a tag with only partial penetration (Fiore *et al*., 2017). The increased external surface area of an extruded tag will result in greater drag forces being applied to the tag body and enclosing tissue (Fiore *et al*., 2017) and could also increase the chance of contact with external objects or conspecifics, which may result in breakage and/or premature removal of the tag.

Suggested ‘best practice’ methods for cetacean biologging studies emphasise the importance of weighing the potential scientific gain against the potential negative impact to animal welfare for each proposed biotelemetry project (Gales *et al*., 2009; Andrews *et al*., 2019; Papastavrou & Ryan, 2023). The ability to remotely assess the performance of biologging devices would greatly improve our understanding of the underlying mechanisms of premature tag loss and could allow researchers to make short and long-term changes to deployment methods (e.g., tag placement), tag design (e.g., anchor configuration) and study design (e.g., animal selection criteria) based on real-time conditions. Here, we report the results of a novel approach using built-in light sensors for remotely quantifying the amount of Type C cetacean tag extrusion from days to weeks after deployment on humpback whales in the Gulf of Maine.

MATERIALS & METHODS

Study population

North Atlantic humpback whales are identified and catalogued by variations in ventral fluke pattern and by size, shape and scarring of the dorsal fin (Katona & Whitehead, 1981). The Gulf of Maine is host to a well-studied population of humpback whales that feed in local waters in spring, summer and autumn every year (Fig. 1). Due to a long-term dedicated research program and data collection programs aboard collaborating commercial whale-watching vessels, some individuals in this population have high re-sighting rates, both within a season and from year to year (e.g., Clapham *et al*., 1993; Robbins, 2007). Detailed knowledge of individuals and re-sighting rates were the basis for choosing Gulf of Maine humpbacks as the target population for a study aimed at assessing the behavioural, physical and physiological effects of tagging on large whales (Robbins *et al*., 2013, Gulland *et al*., 2024).

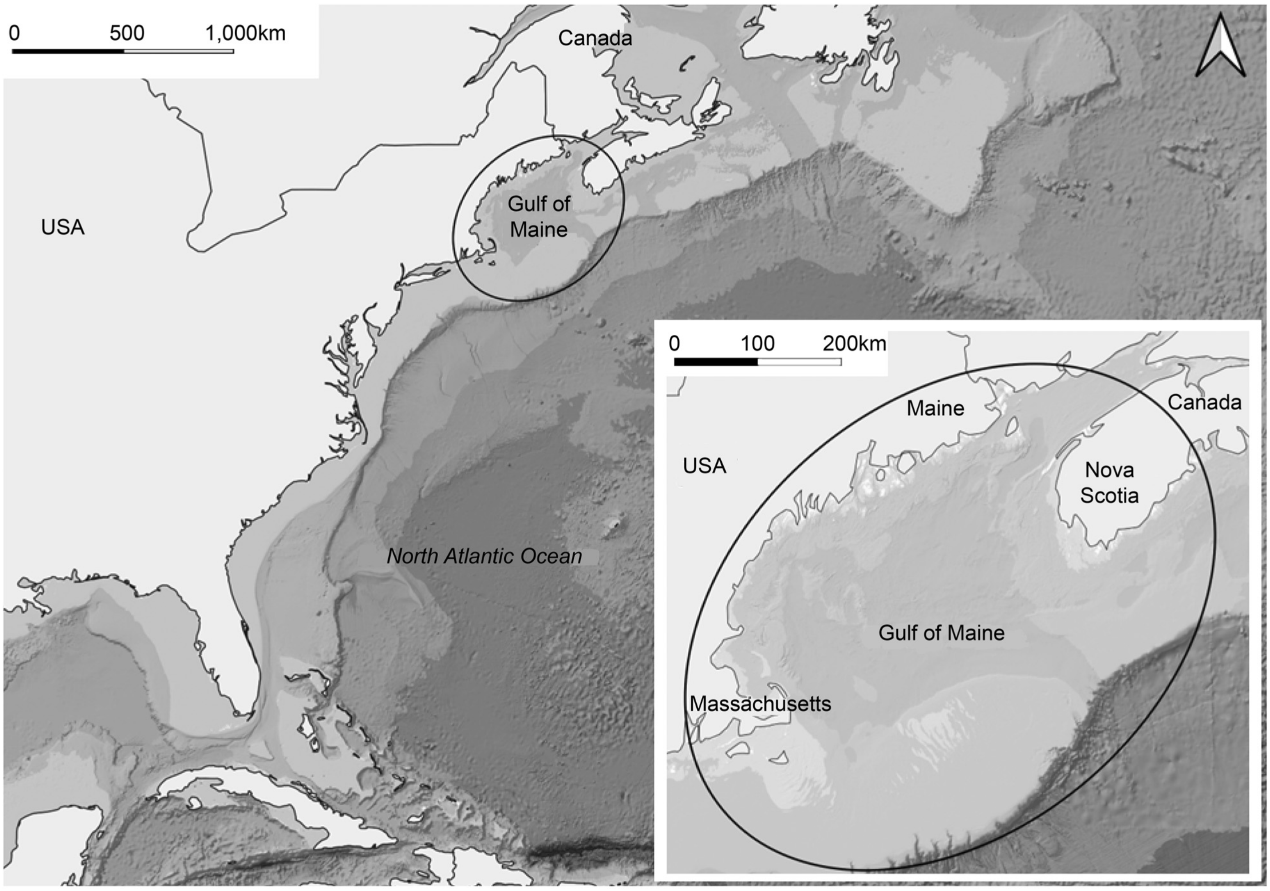

Figure 1. Location of Gulf of Maine study area. Light level recordings and resight images fell within the black ellipse shown here.

Tag and sensor specifications

The implantable (Type C) cetacean tags used in this study consisted of an electronics package manufactured by Wildlife Computers, Redmond, WA, USA, coupled with an attached anchoring system (Gales *et al*., 2009). The electronics package contained a SPOT-5 transmitter and light level sensor custom designed by Wildlife Computers, housed in a stainless-steel cylinder. The tags are designed with a triangular stopper and temporary deployment ring at the distal end of the electronics housing to prevent significant internal migration (or intrusion) of the tag. The tags were designed to penetrate beneath the hypodermis and anchor in the fascia between the blubber and muscle of the animal. Maximum penetration depth for all tags was 270 mm. Lines or bands were etched into the transmitter cylinder at predefined intervals to aid in extrusion estimates (Fig. 2; Table 1).

The light sensor, located in the communications port (COM port) at 4.75 cm or 5.75 cm from the distal-end stopper (depending on year; Fig. 2) recorded the level of irradiance from 300 nm to 1100 nm wavelength light as integers between 1 (no detectable daylight, 300 nm) and 255 (maximum daylight reading, 1100 nm). The tag recorded light levels immediately before positioning information was transmitted to the satellite, only when the wet/dry sensor indicated that the tag was out of the water. A single tag positioned on land in direct sunlight recorded light levels from mid-afternoon to mid-morning and reliably recorded full light levels during daytime hours and zero light levels during the night (Fig. 3, Top). An additional test of three tags showed that the light sensor's sensitivity was high enough to reliably detect dawn and dusk events (Fig. 3, Bottom). Each tag was tested briefly on land during daylight hours to check sensor accuracy before deployment.

Post-deployment follow-up

Tagged individuals were intentionally re-encountered either by travelling to transmitted positions while the tag was active or by later visiting historically used and high-density feeding areas. In order to evaluate the condition of the tag and the overall health of the whale during both the initial focal-follow and the subsequent re-sightings, high-resolution images were collected of the tag site from multiple angles to ensure detailed documentation of

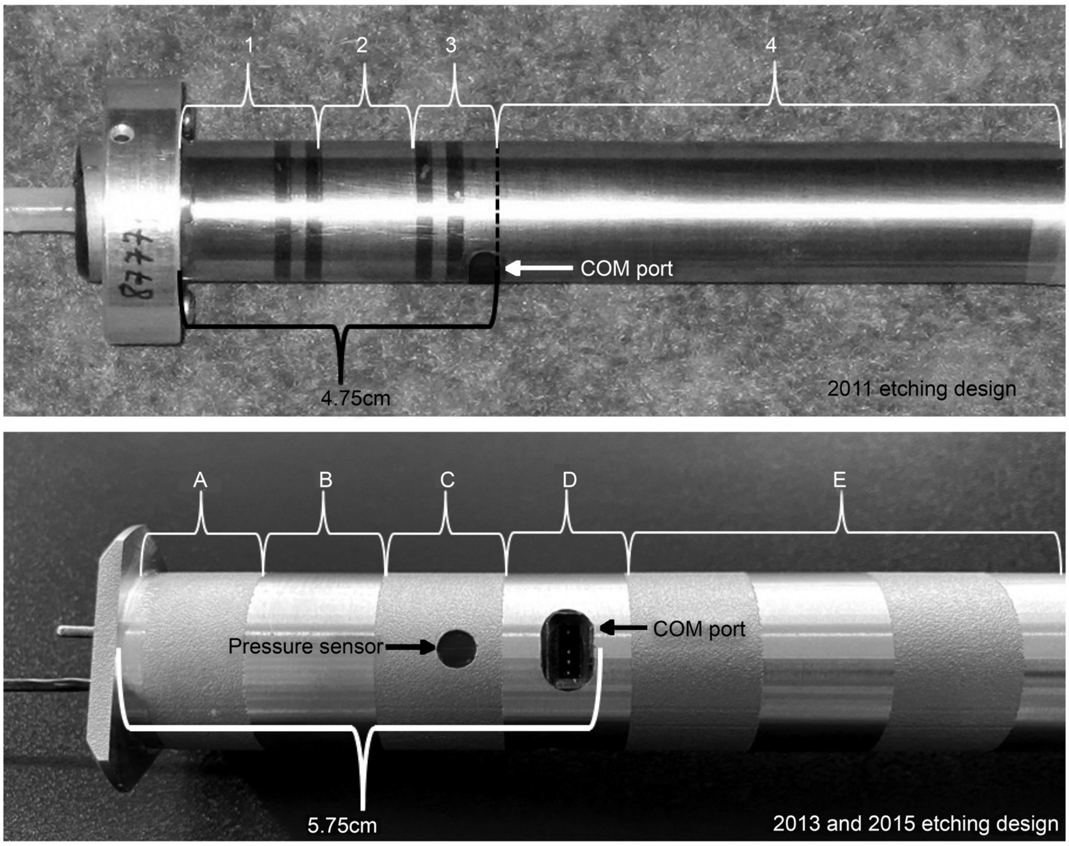

Figure 2. A photograph of the etch marks and associated zones used to describe extrusion distance in 2011 (Top) and 2013–15 (Bottom). The light sensor is located within the communications port (COM port) of the tags in all years. See Table 1 for measurements and zone descriptions.

Table 1
Extrusion distance per zone and description.
(See Figure 2 for a visual representation of zones)

Zone	Extrusion amount (cm)	Description
	2011	
1	0 to 1.75	Stopper to bottom of the first etch marks
2	1.75 to 3.75	Bottom of the first to top of the second etch marks
3	3.75 to 4.75	Top of the second etch marks to bottom of light sensor
4	4.75 to end	Fully exposed light sensor
	2013 + 2015	
A	0 to 1.5	Stopper to bottom of first etched band
B	1.5 to 3.0	Bottom of second etched band
C	3.0 to 4.5	Bottom of third etched band
D	4.5 to 6.0	Bottom of fourth etched band (contains light sensor)
E	6.0 to end	Fully exposed light sensor

tag extrusion. Opportunistic photographs taken by naturalists aboard commercial whale-watching vessels were also used if they were of sufficient quality to assess the level of tag extrusion. Photographs were rejected if the extrusion level could not be determined. The most common reasons for photo rejection were inadequate angle to the tag or poor focus, resolution or exposure. All photographs and light levels evaluated in this study were collected within the Gulf of Maine from mid-July to mid-November (Fig. 1).

Data analysis

Tag extrusion was described by zones which were based on the lines etched into the transmitter cylinder (Fig. 2). Multiple photographs taken on the same day were assessed whenever possible to ensure accurate zone

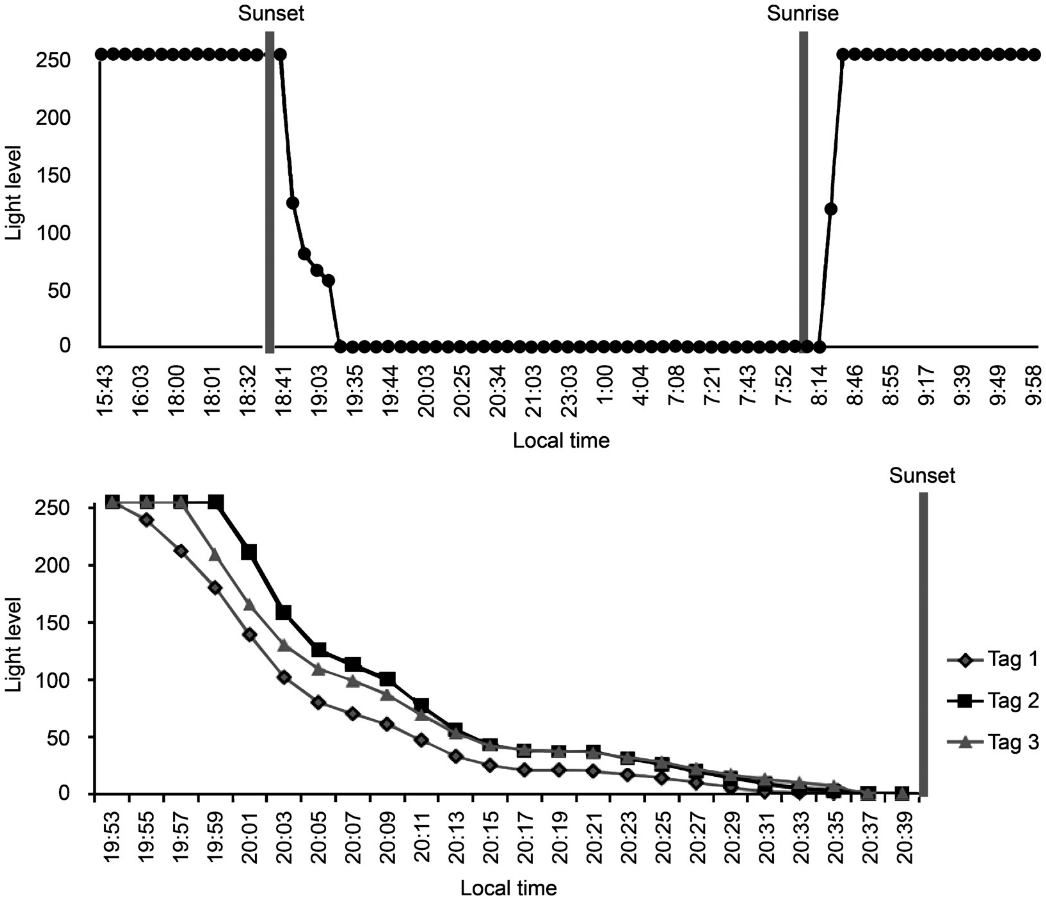

Figure 3. Top: Light level readings from one tag positioned on land in full sunlight exposed throughout an entire pre-sunset to post-sunrise period. Bottom: A comparison of light level sensor values from three tags exposed to full sun during dusk. Readings from the single tag (above) were collected on a different date from the readings below.

determination. If the extrusion zone remained constant throughout the day, one zone value was assigned to the day for each whale, regardless of the number of resights. If the tag had extruded or intruded between single-day resights, multiple zone values were assigned to that day. Daytime light level readings, from at least 30 mins after sunrise to at least 30 mins before sunset based on daylight hours for the tag location on the day of the reading, were averaged and used to represent the daily average light level. This standardised time period was chosen specifically to exclude dawn and dusk periods and only include full daylight hours throughout the study. Light sensor data from the day of deployment were also excluded to avoid the inclusion of pre-deployment light levels.

RESULTS

High-quality photographs and/or light sensor readings were obtained from 37 whales tagged in the summer of 2011, 2013 and 2015. Of these, 30 whales had adequate images for at least one zone determination plus associated daytime light level readings (Table 2). Photographic resight coverage was highly variable between whales, with some animals having many relevant resight days and some only having one (mean resight days per whale: 4.6 ± 3.8, range = 1–15). Because of this, it was not possible to document the full tag extrusion process for individual whales.

On days where there was sufficient photographic coverage and daytime light level readings (excluding deployment day, n = 134 d), measured light levels were highly correlated with the amount of tag extrusion (Fig. 4). Average light levels from multiple-zone days were excluded from daily comparisons shown in Table 2 and Figure 3, since the exact time of extrusion could not be determined. However, a qualitative comparison of

Table 2
A summary of post-deployment resighting days where: (a) follow-up images were acceptable for zone measurements (Zone); and (b) light level (LL) measurements were collected during corresponding daylight hours. *One whale was tagged in 2013 with the 2011 tag etching design, so it was included in the 2011 data.

2011 (n = 11 tags, 56 days)

Zone	# Tags	Resight days w/LL	LL Range	LL Mean/SD	Median
1	2	2	1–4.9	3.0/2.0	3.0
2	6	10	1–196.5	26.0/58.0	1.0
3	8	19	1–255	128.6/100.5	126.9
4	6	25	255	n/a	255.0

2013 + 2015 (19 tags, 78 days)

Zone	# Tags	Resight days w/LL	LL Range	LL Mean/SD	Median
A	9	18	1–255	22.8/57.5	5.4
B	8	14	1–41.3	9.7/8.2	9.8
C	12	21	1–255	103.2/107.7	47.0
D	6	13	1.6-–55	185.7/102.7	255.0
E	6	12	255	n/a	255.0

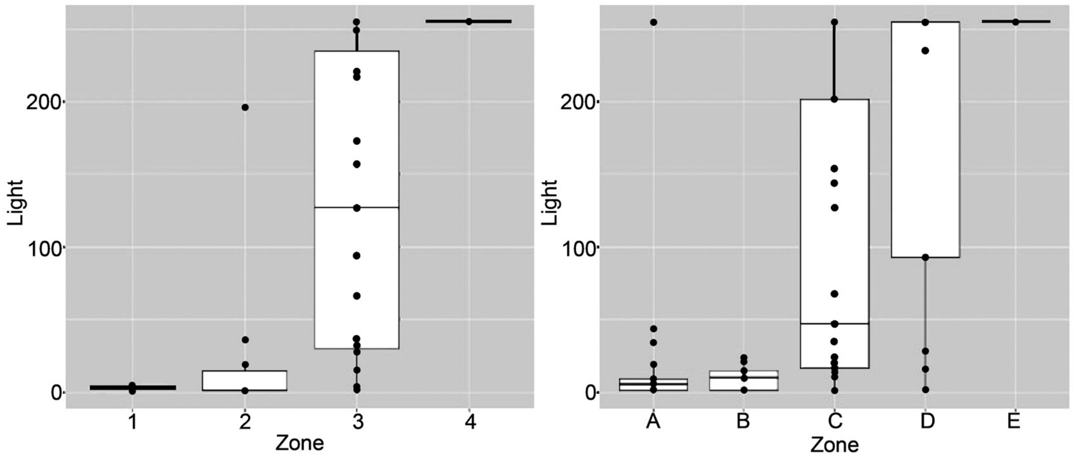

Figure 4. A box and whisker plot showing average daily light levels versus observed extrusion zones. The light level sensor was located in Zone 3 in 2011 (Left) and Zone D in 2013–15 (Right). Box plots show median values (solid horizontal line), 50th percentile values (box outline), 90th percentile values (whiskers) and outlier values (black dots).

extrusion zone to light level readings on the rare multi-zone days showed a correlation between extrusion amount and measured light.

There was sufficient imagery to validate that tags described as 'flush' (e.g., penetrated to the stopper located on the distal end of the tag) after deployment date (n = 2 d) recorded the extremely low light levels (< 10), while fully exposed sensors (Zones 3–4 (2011) or D–E (2013–15), n = 69 d) invariably recorded maximum daytime light levels (Table 1; Fig. 4). Tags extruded to Zones 1 or A recorded very low daily average light levels (n = 20 d, light level mean ± SD = 30.4 ± 65). The most variable average light level readings occurred when tags were observed extruded to the middle zones (i.e., zones between the bottom of the first etched band and the COM port, or zones 2, 3, B, C and D; Fig. 1). While light levels recorded in the middle zones were, on average, lower than those recorded in zones containing and past the light sensor, there was considerable variation in all zones distal to and containing the COM port.

Of the 30 tags examined in this study, 19 were observed progressively extruding from a low to high zone over time, as expected. No resight photos showed the tags intruding past the distal end stopper in any year. However, 12 tags were observed intruding from a previous extrusion distance during the study period. For example, one

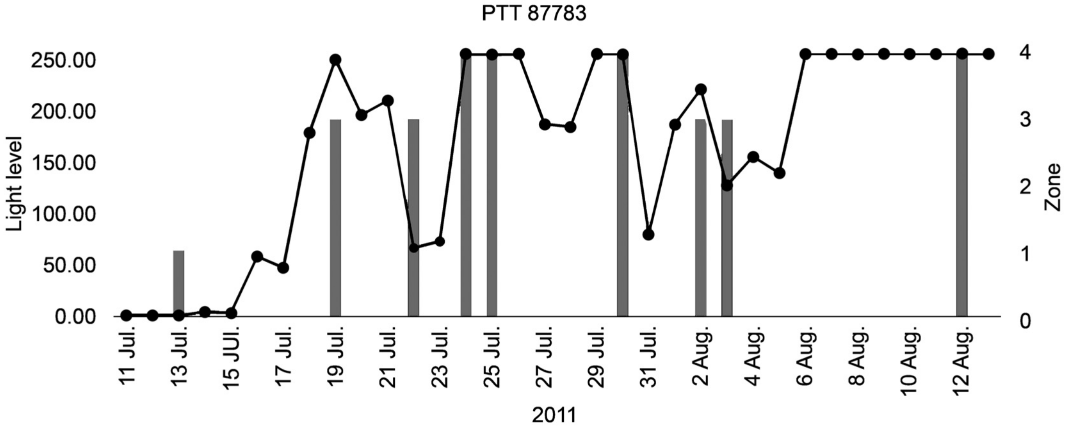

Figure 5. Typical examples of average daily light levels (solid black line) and extrusion zones (grey bar) for PTT 87783 in 2011 and PTT 87634 in 2015.

tag was observed both intruding and extruding between 10 July (deployment date) and 13 August. Three days after deployment, the tag was observed fully flush against the skin (Zone 1). The tag was later observed in Zone 3 (nine days post-deployment), Zone 2 (12 and 13 days post-deployment), Zone 4 (14, 15 and 16 days post-deployment), Zone 2 again (23 and 24 days post-deployment) and finally Zone 4 again (33 days post-deployment). Intrusion and extrusion events were reflected in the average daily light levels recorded, with lower light levels corresponding with lower extrusion zones (see Fig. 5 for two examples).

DISCUSSION

The goal of this study was to assess the ability of a built-in light sensor in Type C cetacean tags to remotely describe tag extrusion. Understanding the real-time tag extrusion distance can help researchers remotely diagnose tag performance and can then be used to inform future survey design, biologging field methods and technological advancements. Results from this study validate that light level readings roughly corresponded with observed extrusion levels and confirm that tag-mounted sensors could be used to describe tag extrusion. Examination of remote light level data from the Type C cetacean tag configuration discussed here should allow researchers to predict when a tag is either: (a) almost completely penetrated, as average daily light levels readings were consistently very low (less than 100); or (b) extruded past the COM port when daily light levels consistently read 255. While differentiating extrusion distances in the 'middle zones' would be more difficult without visual confirmation, our results suggest that light level readings that are consistently variable most likely reflect tag extrusion to somewhere between 1.5 cm and the location of the COM port, but not further. With the single light sensor configuration, it would be impossible to determine the extrusion distance past the COM port without visual verification.

This study reinforces findings that Type C cetacean tags do not generally undergo significant or long-term inward migration past the wet/dry sensor during a routine deployment (Robbins *et al.*, 2013; Best *et al.*, 2015; Norman *et al.*, 2018). However, the light sensors were able to capture other intrusion events (between the distal-end stopper and the anchor) that were validated by follow-up photographs. These deviations from the presumed natural progression of low to high extrusion provide further validation of the sensitivity of light sensor readings for remote tag diagnostics.

Potential error

While tags extruded within the lowest zone (i.e., A and 1, respectively for tags used in 2011 and 2013–15) normally recorded very low light levels, the fact that any light was recorded by some sensors is surprising and suggests some level of inaccuracy. There are two main situations that could cause inaccurate light level or zone readings, and thus bias the extrusion analyses: inaccurate light level readings due to sensor malfunction, or incorrect zone determinations due to angled tag orientation and/or wound healing processes (i.e., biofouling).

Since it is standard protocol to check each tag's sensors before deployment, it is assumed that errors encountered during this study are not due to sensor malfunction.

Tissue swelling, scarring or other wound-healing processes vary among deployments (Gulland *et al*., 2024). Whales in this study were occasionally observed with small amounts of tissue extruding from the tag insertion point. This tissue may shift to cover the light sensor during surface readings at any time, and the overall effect of these temporary obstructions on the average light level readings is unknown. In addition, the damage to or displacement of tissue surrounding the tag (Moore *et al*., 2013; Best *et al*., 2015; Norman *et al*., 2018) may create a 'light channel' around the sensor, and the natural flexion and extension of the whale's muscles may influence the data by either pulling tissue away from or pushing tissue into the light sensor at different extrusion levels. The effects of flexion/extension and swelling/subsidence seem to be the most likely contributors to the unexpected light readings recorded in Zone A/1 and the highly variable sensor readings observed in the middle extrusion zones.

Finally, researchers have no control over the orientation of the light sensor after deployment, and the sensor's responsiveness to changing light levels at different orientations to the sun may affect the readings. An unknown number of tags deployed in 2011 exhibited breakage at the interface between the anchor and electronics cylinder (Robbins *et al*., 2013, Gulland *et al*., 2024), yet their light sensor data were still used for extrusion assessment during this study. Any structural damage could alter the tag extrusion/intrusion process in unpredictable ways and cause the orientation of the light sensor to change more rapidly than expected.

Suggested modifications

Future biologging technology designs should consider incorporating sensors that would facilitate the assessment of tag extrusion rate in relation to tag placement and compare the differences between species. In the meantime, in lieu of costly and extremely time-consuming large-scale tag modifications, some simple adjustments could improve our ability to interpret light level readings remotely. The addition of more etched horizontal measurement lines, such as those implemented for the 2013 and 2015 field seasons in this study, could refine extrusion estimates. A vertical line etched along the length of the transmitter cylinder (from the distal end to the anchor) to indicate the location of the light sensor would also help quantify the effects of sensor orientation on light level recordings. Also, as tag extrusion can occur rapidly and can easily be missed during long non-transmitting periods, tags should be programmed to record and transmit daily in order to increase the likelihood of recording significant changes.

Moving forward, more complex tag modifications need to be considered to effectively perform tag diagnostics remotely. With the current single-sensor tag design, describing extrusion distances past the COM port would not be possible without visual confirmation. The light sensor used in this study was located 4.75 cm and 5.57 cm from the stopper, leaving more than 22 cm to extrude before complete tag removal. The addition of more light sensors along the length of the transmitter body, especially near the full-extrusion depth, would allow for fine-scale extrusion rate calculations.

CONCLUSIONS

There have been several attempts to assess the effects of tagging on the overall health and behaviour of large whales (Watkins, 1981; Kraus *et al*., 2000; Mate *et al*., 2007; Mizroch *et al*., 2011; Walker *et al*., 2012; Moore *et al*., 2013; Robbins *et al*., 2013; Best *et al*., 2015; Gendron *et al*., 2015; Norman *et al*., 2018, Gulland *et al*., 2024), but this is the first attempt to use a built-in light level sensor for remote Type C cetacean tag diagnostics. While the results reported here show that it is possible to analyse certain aspects of implantable biologging device performance, it is clear that additional tag design and instrument modifications are needed to increase the effectiveness of remote tag diagnostics. Additional light sensors could allow researchers to remotely assess tag extrusion rate, and subsequently assess the effects of tag design and placement on that rate. Dedicated long-term monitoring studies of the effects of tag placement on tag longevity, such as those undertaken for humpback whales in the Gulf of Maine, should allow for more confidence when translating light sensor readings into extrusion estimates remotely.

As tag electronics become more sophisticated and researchers gain insight into the complexities of wound healing and tag placement, tag-mounted sensors will allow for more informed assumptions about the causes of premature cessation. Cetacean tagging projects are invasive (Andrews *et al*., 2019), potentially dangerous to both humans (Hassel *et al*., 2022) and whales (Moore & Zerbini, 2017; Norman *et al*., 2018, Gulland *et al*., 2024), require highly trained personnel (Andrews *et al*., 2019) and customised equipment (Klevaine *et al*., 2022), and are often used in the study of endangered animals. Therefore, proposed projects and technological improvements that include the evaluation of tag performance should be considered a high priority in the future.

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