

Visual assessment of LIMPET tag site healing in Cuvier's beaked whales and fin whales

ERIN L. KEENE¹, ERIN A. FALCONE¹, GREGORY S. SCHORR¹, BRENDA K. RONE¹,
GUSTAVO CÁRDENAS-HINOJOSA^{2,3}, RODRIGO HUERTA-PATIÑO³ AND RUSSEL D. ANDREWS¹

Contact email: ekeene@marecotel.org

ABSTRACT

Implanted or anchored telemetry devices are valuable tools in cetacean research, especially for species whose habitats and ranging patterns limit the collection of movement and behavioural data by less invasive methods. In this study, 130 Low-Impact Minimally Percutaneous External Transmitter (LIMPET) tags were deployed on Cuvier's beaked whales and fin whales. LIMPET tags are small Type A (anchored) tags which are remotely deployed and secured on or near the dorsal fin using medical-grade titanium darts. They transmitted data via satellite for weeks to months (mean = 34 days, range 1–239 days). Most of these tagged whales (n = 123) were photo-identified at deployment. Sixty-one were photographed after tag loss, with the proportion of the resighted tagged whales meeting or exceeding the inter-annual resighting rates of their populations. Thirty-seven resighted whales (16 fin and 21 beaked) had adequate quality photos of the attachment site for visual assessment of healing on at least one day, over periods from 1–4,779 days (13.1 years) after the end of tag transmission. Most tag sites had resolved as one or two small (< 2 cm) marks or shallow depressions within 2–3 years. LIMPET tags placed outside the dorsal fin (n = 34) had significantly shorter transmission durations but were not associated with larger residual marks. Swelling, a notable concern in other tag follow-up studies, was observed in five whales, three of which were sighted with retained darts that had separated from the external tag package. It took 2–4 years to shed these retained darts. In two cases, the darts appear to have migrated through the fin and exited on the contralateral side. Retention petals from LIMPET tag darts may be left behind; if so, results suggest they are likely encapsulated or ejected without leaving a visible mark. These findings suggest that LIMPET tags are generally a safe and effective option for collecting extended movement and behavioral data from these and similar species.

KEYWORDS: ZIPHIUS CAVIROSTRIS; BALAENOPTERA PHYSALUS; SATELLITE TAGS; TELEMETRY; PHOTO-ID; MARKING; PACIFIC OCEAN

INTRODUCTION

Invasive tags have become an invaluable tool in cetacean research, enabling remote data collection from species whose distribution or behaviour limits visual observation of individuals (Andrews *et al.*, 2019). The earliest of these devices were relatively large, and, as such, took two forms depending on the intended target species: implantable tags with electronics consolidated into a single piercing anchor and remotely deployed on large baleen whales (e.g., Mate *et al.*, 2007: hereafter referred to as 'Type C' [consolidated]; see Andrews *et al.*, 2019 for complete descriptions of invasive tag types), and external packages with one or more piercing anchors that

¹ Marine Ecology and Telemetry Research, 2468 Camp McKenzie Tr NW, Seabeck, WA 98380

² Comisión Nacional de Áreas Naturales Protegidas, Ensenada, Baja California, México

³ Proyecto de Investigación de Zifido de Cuvier y Otros Cetáceos de Isla Guadalupe, Ensenada, Baja California, México

were bolted to the dorsal fin or dorsal ridge of smaller cetaceans under restraint (hereafter referred to as 'Type B' [bolt-on], e.g., Geertsen *et al.*, 2004; Heide-Jørgensen *et al.*, 2017; Burek-Huntington *et al.*, 2022). Despite some controversy (Hammerschlag *et al.*, 2014; Félix & Van Waerebeek, 2021; Papastavrou & Ryan, 2023), these tags provided critical data from challenging populations, driving demand for devices suitable for species that are too small to safely deploy Type C tags on but too large to be restrained for Type B tags. The solution was a version of an anchored tag (hereafter referred to as 'Type A'), consisting of a small electronics package that is attached to the exterior body surface via one or two barbed darts, which penetrate the dermis and anchor in the blubber layer (Andrews *et al.*, 2008). Perhaps the most widely used cetacean Type A tag has been the Low-Impact Minimally Percutaneous External Transmitter (LIMPET) tag (Wildlife Computers, Redmond, WA.). The LIMPET tag, designed to minimise drag and tissue disruption while maximising data collection, can be remotely deployed on the dorsal fin or dorsal ridge of a wide range of cetacean species using a crossbow or air rifle, obviating the need for capture (Andrews *et al.*, 2015). First commercially available in 2006, the LIMPET tag has been continuously improved and deployed on individuals from at least 30 cetacean species, ranging in size from common dolphins (*Delphinus spp.*) (Baird *et al.*, 2015) to blue (*Balaenoptera musculus musculus*) (Lesage *et al.*, 2017) and fin whales (*Balaenoptera physalus*) (Keen *et al.*, 2019). LIMPET tags are shed either by being dislodged through contact with other whales or inanimate objects, or by the gradual out-migration of the darts due to water flow forces and the immune system's foreign body response (Andrews *et al.*, 2015). This single-use tag transmits the entirety of its data via satellite and is not recovered.

The Best Practice Guidelines for Cetacean Tagging (Andrews *et al.*, 2019) emphasises that post-tagging monitoring is an essential element of responsible tag use, especially for invasive tags that may pose greater risk, and that the effect of tagging on individual health should be evaluated post-deployment whenever possible. Several studies have characterised the effects of Type B (e.g., Geertsen *et al.*, 2004; Sonne *et al.*, 2012; Wells, 2012; Heide-Jørgensen *et al.*, 2017; Burek-Huntington *et al.*, 2022) and Type C tags (e.g., Robbins *et al.*, 2013, 2016; Best *et al.*, 2015; Gendron *et al.*, 2015; Guzman & Capella, 2017; Norman *et al.*, 2017a; Gulland *et al.*, 2024) through photographic assessment or post-mortem examination of previously tagged individuals. These studies have reported tissue damage, swelling and depressions over timescales ranging from days to years after tag loss, particularly with some earlier tag designs. A primary impetus in developing the LIMPET tag was to minimise impacts on the animal (Andrews *et al.*, 2005). However, despite extensive use, follow-up studies of LIMPET tag attachments are limited to date (Hanson *et al.*, 2008; Andrews *et al.*, 2015). LIMPET tag deployments generally do not cause significant tissue damage, swelling or depressions (Hanson *et al.*, 2008), and the value of the data collected likely outweighs potential risks, particularly in populations exposed to intense levels of anthropogenic pressures. However, any device that penetrates the skin carries inherent risk. A fatal systemic infection in a killer whale was linked to LIMPET tagging, likely due to the transference of fungal spores from the skin to the blood vessels by the implanted tag darts (Raverty & Ford, 2016; Huggins *et al.*, 2020). Although this is the only documented case of a direct LIMPET tag-associated mortality, it highlights the need for thorough post-deployment monitoring via resighting photos and videos whenever feasible.

Since 2008, we have deployed LIMPET tags on fin whales and Cuvier's beaked whales (*Ziphius cavirostris*) off the west coast of the United States, and on Cuvier's beaked whales at Isla Guadalupe, México, since 2018. These tagging projects are part of a long-term, comprehensive marine mammal monitoring programme to describe the local populations, understand ranging patterns and behaviour, and assess the impacts of military exercises on cetaceans in and around the US Navy's Southern California Offshore Range area (e.g., Schorr *et al.*, 2014; Scales *et al.*, 2017; Falcone *et al.*, 2017, 2022; Curtis *et al.*, 2020). Beaked whale research at Isla Guadalupe, a biosphere reserve within Mexico with very limited anthropogenic activity, was established as a comparative study site for the heavily impacted population off Southern California (Cárdenas-Hinojosa *et al.*, 2015). Individuals in these populations have predominantly offshore distributions, and, though they may range broadly, they often occur within inaccessible areas where, in the case of Southern California, they are exposed to elevated levels of anthropogenic activity (Schorr *et al.*, 2022). Invasive tags are the only viable method for medium to long-term tracking of individual whales in these studies, which are regularly exposed to stressors, such as military sonar and shipping traffic, in their preferred habitat. These tracking data can be used for assessing behavioural

responses to these stressors, data that are essential for determining potential population-level impacts of recurrent exposure (Falcone *et al.*, 2017; Keen *et al.*, 2019). Here we use long-term photographic resighting data from these research programmes to visually evaluate the effects of LIMPET tag deployments on these two species over time.

METHODS

Type A LIMPET tags were deployed on fin and Cuvier's beaked whales from 2008–2022, using four tag types (each representing different sensor configurations) and 15 different tag models (Table 1), with most of the variation between models consisting of small changes in shape and size of the external electronics package. The retention dart designs also evolved over time, including minor changes to the threaded connection between the dart and tag, making this connection more robust, and to the manufacturing process. In all cases, the portion of the dart shaft extending below the electronics package was approximately 6.7 cm long x 0.04 cm in diameter at the shaft, with six welded retention petals that radiated out near the distal end of the shaft to a total diameter of 2.4 cm. All parts of the darts and petals were constructed from titanium Ti-6Al-4V (Grade 5, or 'medical-grade'). Upon insertion into the target tissue, the petals compress against the dart shaft, resulting in an entry wound approximately 1 cm in diameter for each of the two darts.

Table 1
Summary of 130 LIMPET tag deployments in the study, detailing combinations of tag type, tag model, data type, and years deployed. All tags were manufactured by Wildlife Computers (Redmond, WA, USA).

Tag type	Model	Data types	First year	Last year	Tags deployed
SPOT5	AM-S240A-2		2008	2009	5
SPOT5	AM-S240A-3		2009	2010	14
SPOT5	AM-S240A-4		2009	2009	3
SPOT5	AM-S240A-5		2010	2010	1
SPOT5	AM-S240B-1	Location-Argos Doppler	2010	2011	5
SPOT5	AM-S240B-2		2011	2012	3
SPOT5	AM-S240C-1		2011	2019	27
SPOT6	AM-S240C-1		2016	2016	1
SPLASH10A	AM-369A-A-00		2019	2022	4
SPLASH10A	AM-A266A-A	Location-Argos Doppler, Dive	2010	2012	10
SPLASH10A	AM-A266A-D	Behaviour	2011	2011	1
SPLASH10A	AM-A266A-D-1		2012	2013	2
SPLASH10A	AM-A292B-A		2012	2019	37
SPLASH10F	AM-A333A-AF-00-2	Location-GPS, Dive	2016	2016	1
SPLASH10F	AM-A333B-AF-00	Behaviour	2016	2022	16

The target for LIMPET tag placement was on or near the dorsal fin, where anchoring in dense connective tissue improves tag retention (Fig. 1). All deployments adhered to the Best Practice Guidelines for Cetacean Tagging (Andrews *et al.*, 2019), with the exception of early modifications to dart disinfection and sterilisation procedures implemented during this study (Andrews *et al.*, 2019). Between 2008–2010, the darts were thoroughly cleaned and then disinfected by soaking in 70% isopropyl alcohol for a minimum of 12 hours. Disinfection with 70% isopropanol is bactericidal, tuberculocidal, fungicidal and virucidal, but it does not destroy bacterial spores (Rutala *et al.*, 2008). Therefore, after 2010, we switched to full sterilisation of the darts via gas sterilisation with ethylene oxide. All tags were deployed remotely from 6–7 m long research vessels using a 13 mm bore Dan-Inject CO₂ rifle at 25 bars pressure, from distances of 4–22 m (mean = 10 m). Still photographs and videos from cameras mounted on the rifle barrel and/or the tagger's helmet were taken during deployment with few exceptions. Additional still photos of each side of the whale were also taken post-deployment, when possible, to thoroughly document tag attachment.

Following each field effort during which tags were deployed, all imagery was reviewed to select the best representative images of each tagged whale before, during and immediately after deployment. These images were reviewed to document tag placement (Fig. 2, roughly following zones in Moore & Zerbini [2017]), flushness,

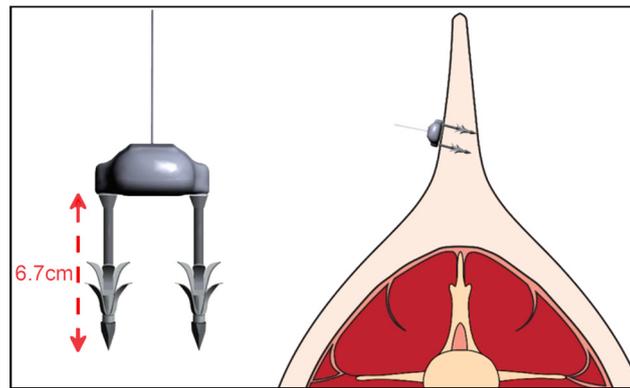


Figure 1. Illustration of the basic LIMPET tag design with dart dimensions (left), and ideal placement with respect to underlying tissues as seen in the sagittal section of a generalised odontocete whale at the level of the dorsal fin (right; modified from Andrews *et al.* [2019] with assistance from Uko Gorter).

and the number of darts implanted. For dorsal fin deployments, the number of darts that fully penetrated the fin and were visible from the contralateral side was also documented when possible. With respect to tag placement, if a tag straddled the line separating zones 1 and 3, it was assigned to zone 1; where a tag straddled a vertical zone divisor, the tag was assigned to the zone that was not under the dorsal fin; and where a tag straddled the lower horizontal divisor, it was assigned to the more ventral zone. Transmission duration was calculated as the number of days from the tag deployment to the date when the final transmission was received. A generalised linear model (GLM) with Gaussian distribution (R Core Team, 2024) was used to compare transmission durations (log transformed to adjust for right skewness in the data, Fig. 3A) as a function of species, number of darts implanted and attachment zone.

The best identifying images of each tagged whale were then aggregated with a collection of identification photos from the same species and region each year to determine the whale’s identity, following processes described in Falcone *et al.* (2022) for fin whales and in Falcone *et al.* (2009) and Curtis *et al.* (2020) for Cuvier’s beaked whales. Following each complete year of identification image processing, all sightings of concurrently or previously tagged individuals were reviewed to select a suite of representative photos of the tag site for follow-up assessment. Each image was scored for three quality factors (Table 2).

Throughout this study, the same two experienced analysts reviewed the suite of images for each whale on each date to assess the condition of the tag attachment (if present), or the dart insertion sites (if shed). The tissue surrounding the attachment site on both the tagged and the contralateral sides were scored for up to six tag site characteristics (Tables 3–5). This was adapted from tag follow-up assessment recommendations in the Best Practice Guidelines for Cetacean Tagging (Andrews *et al.*, 2019).

Table 2
Image quality factors used to evaluate the suitability of images for follow-up assessments.

Factor	Definition	Score	Description
Angle	Angle of whale body to the photographer	ND	Not Determinable
		1	0–30 degrees
		2	30–60 degrees
		3	60–90 degrees
Sharpness	Clarity of image details	ND	Not Determinable
		1	Very crisp, even fine details are clear
		2	Soft, subtle marks may not be visible
		3	Blurry, only very obvious marks visible
Exposure	Lighting and contrast	ND	Not Determinable
		1	Well-lit, good contrast, subtle marks visible
		2	Lighting/contrast obscures subtle marks
		3	Lighting/contrast obscures all but obvious marks

Table 3
Tag site condition factors used to assess marks at the attachment site following tag loss.

Condition factor	Score	Description
Mark Count	Number	Count of discrete visible marks
Mark shape	ND	Not determined
	Focal	Round/ovoid, centred on dart insertion
	Linear	Straight or curvilinear
	Hole	Fin perforation
	Notch	Loss of dorsal fin edge tissue
Complex	Multiple shapes or not as above	
Mark size	ND	Not determined
	0	None
	1	< 2cm diameter
	2	2–5cm diameter
Swelling	3	> 5cm diameter
	ND	Not determined
	0	None
	1	< 2cm diameter
Depression	2	2–5cm diameter
	3	> 5cm diameter
	ND	Not determined
	0	None
Tissue	1	Epithelium not intact
	2	Tissue extrusion
	ND	Not determined
Exudate	0	None
	1	Clear
	2	Blood
	3	Purulent

Skin lesions, i.e., areas of the skin at and near the tag site that visibly differed from the surrounding skin, were referred to as ‘marks’ and include both wounds and residual scarring or defects likely to have been associated with the tag (as opposed to other types of common natural marks). Photographic examples of the mark types found in this study can be found in Table 4.

‘Mark Count’ refers to the total number of visible marks associated with the tag attachment. For example, a typical LIMPET tag deployment with both darts attached leaves two discrete visible marks spaced approximately 4.2 cm apart. Marks were categorised into a set of common ‘Mark Shapes’; if there were multiple shape types or shapes not represented by the common categories, marks were scored as ‘Complex’. ‘Mark Size’ was based on the largest visible mark and could usually be visually estimated and assigned to one of three size categories based on the known distance between the dart insertion points. However, in cases where a more precise measurement was necessary and marks were visible at both dart sites, the distance between the centres of both insertion points was measured in ImageJ (Rasband, 1997) and used as a reference to measure other features of interest in the image. Regions of swelling or depression at the tag site were categorised using the same method as the Mark Size. ‘Tissue’ condition scores reflected whether tagging wounds were closed or not, and the presence or absence of ‘Exudate’ was recorded, with the understanding that this would be difficult to detect in free-ranging cetaceans due to constant water flushing and photographic distances. Finally, tag breakage is possible if a tagged whale makes forceful contact with another individual, the substrate or objects in the environment. This creates the potential for darts, petals or tag fragments to remain attached to the whale beyond the transmission period, and any observations of retained hardware at the tag site were noted. If an analyst did not

Table 4
Representative photos for Mark Types.

Tag photo	Example	Mark shape
		None
		Focal
		Linear
		Hole
		Notch
<p data-bbox="459 1933 580 1962">No tag photo</p>		Complex

Table 5
 Representative examples of depression, swelling, and tissue condition scores seen in this study.
 Definitions of these scores are provided in Table 3.

Score	1	2	3
Depressions			No depressions found in this range
Swellings			No swellings found in this range
Tissue			N/A

feel a factor could be scored accurately with the available images, they assigned the factor a ‘ND’ (Not Determinable) score for that date.

After reviewing images from all sighting dates, analysts compared scores to identify any disagreements. The analysts then reviewed these scores together to reach a consensus. The final dataset included all daily tag site factor scores that were not assigned a ‘ND’ and both agreed on the score. Daily tag site factor scores were associated with the days since the last transmission, serving as a proxy for time since tag release, with the understanding that in some cases this might be an overestimate (e.g., if the tag ceased transmitting prior to being shed). Tag site scores where the days since the last transmission was > 0 were used to assess healing progression. The final tag deployments considered for follow-up occurred in 2022, while resightings were considered through 2023.

RESULTS

A total of 130 LIMPET tags were deployed from 2008–2022 (Table 1), of which 124 transmitted for at least one day. Of these 124 tags, there were 76 tags deployed on fin whales with transmission durations ranging from 1–239 days (median 19.7, mean 35.4, st. dev. 48.0) and 48 tags deployed on Cuvier’s beaked whales with transmission duration ranging from 2–121 days (median 24.5, mean 32.7, st. dev. 25.7) (Fig. 3A). Ninety-three tags were placed on the dorsal fin (Zone 1, 92% of fin whale and 48% of beaked whale deployments), 16 placed immediately below the dorsal fin (Zone 3, 7% of fin whale and 23% of beaked whale deployments), and 15 tags in Zones 2, 4, 6 or 7 (1% of fin whales and 29% of beaked whales) (Fig. 2). No tags were placed within Zone 5 (Fig. 2). A GLM analysis showed that transmission duration was significantly longer for Cuvier’s beaked whales than fin whales (estimated coefficient 2.332, std. error 0.211, $p = 0.008$), for tags attached to the dorsal fin (Zone 1) versus the body (Zones 2–7; estimated coefficient -0.741 , std. error 0.239, $p = 0.002$), and for tags with two darts implanted versus one (estimated coefficient 0.726, std. error 0.304, $p = 0.018$) (Fig. 3B).

Of the 130 tags deployed, seven were placed on whales with insufficient quality identification photographs to be assigned a catalog ID (either via match to a known individual in the catalogue or being added as a new

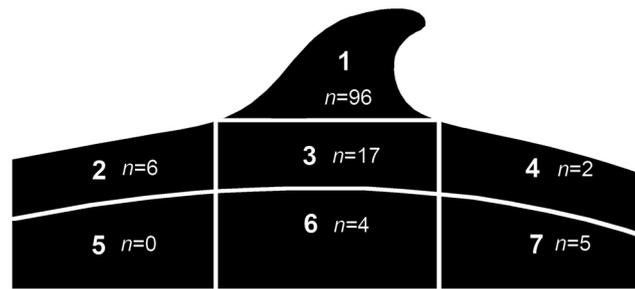


Figure 2. Tag placement zones, with number of deployments per zone indicated.

individual in the tagging year) and therefore could not be resighted, leaving 123 tagged whales that could be identified post-deployment. Of these, 61 whales were photographed one or more times following tag loss, resulting in 284 sightings of 32 tagged fin whales (43% of tags on this species) and 238 sightings of 29 Cuvier's beaked whales (59% of tags on this species). Individual whales were photographed on up to 75 different dates post tag loss (mean = 9, median = 3) with follow-up spans up to 4,779 days (13.1 years) since the last transmission was received from the tag (mean = 1,649 days or 4.5 years, median = 1,522 days or 4.2 years).

Residual marks were typically very small, which limited the sample of resightings for follow-up assessment to those with sufficient quality images to reliably see subtle marks. Only 37 tagged whales (16 fin and 21 beaked whales) could be reliably evaluated on at least one date post tag loss; of these, 34 (92%) had at least one residual mark at the tag site (14 fin and 19 Cuvier's beaked whales). Most tag sites had focal marks at the dart insertions ($n = 24$, 65%), followed by complex marks ($n = 9$, 24%), notches ($n = 2$, 5%), holes ($n = 1$, 3%) and linear marks ($n = 1$, 3%). Complex marks typically consisted of a focal mark plus a notch or a hole for dorsal fin attachments near the leading or trailing edges. Five deployments (11%), two on fin whales and three on beaked whales, displayed no visible marks as of the most recent sighting of the whale. Examples of all mark types are in Table 4. The shortest period from the last tag transmission to a resighting with no visible marks was 706 days (1.9 years). Two of these cases were sighted with residual marks prior to visibly resolving. These were both beaked whales: one was first sighted with focal marks at 1,080 days (3.0 years), then without visible marks at 2,549 days (7.0 years); the second with focal marks five days post tag release, a complex mark at 693 days (1.9 years) post tag release, and apparent resolution of marks by 1,864 days (5.1 years). It should be noted that both beaked whales experienced natural pigmentation loss as they matured, potentially rendering residual depigmented marks from the tag indistinguishable against their paling skin, rather than completely resolving. In addition, two fin whale deployments changed from one mark type to another over time. One had a complex mark at 55 days consisting of an irregular, oblong depigmented area surrounding a retained dart in the dorsal fin, which became a single focal mark at 856 days (2.3 years). Another fin whale had a complex mark at 337 days consisting of a focal mark combined with a hole, which resolved to a single hole in the fin at 1,407 days (3.9 years).

In the majority of the 37 deployments with follow-up assessments, there were two or fewer discrete marks at the tag site in at least one post-deployment sighting ($n = 34$, 92%). Three (8%) deployments were observed with three marks at the tag site, all of which were beaked whales. In 21 (57%) of these deployments, the largest dimension of any mark was < 2 cm. In 15 (41%), at least one mark was 2–5 cm, and three deployments (8%) were observed with at least one mark > 5 cm. Beaked whales were more likely to be observed with marks > 2 cm than fin whales (62% versus 19%). In general, mark size decreased as a function of the number of days since the last transmission (Fig. 4A). However, two deployments were observed with 2–5 cm marks within two weeks of tag loss (at 5 and 13 days after transmissions ceased), which increased to > 5 cm marks (at 693 and 314 days, respectively). However, at 1,028 days (2.8 years), the marks were reduced to < 2 cm for one of the whales.

Swellings and open wounds were uncommon regardless of how long after the end of transmission the whale was observed (Fig. 4). These reactions were observed in five whales each (less than 15% of resighted individuals), with swellings observed in three fin and two beaked whales, and open wounds in one fin and four beaked whales. Depressions were observed in 50% of cases, with equal frequency in fin and beaked whales. Swellings and

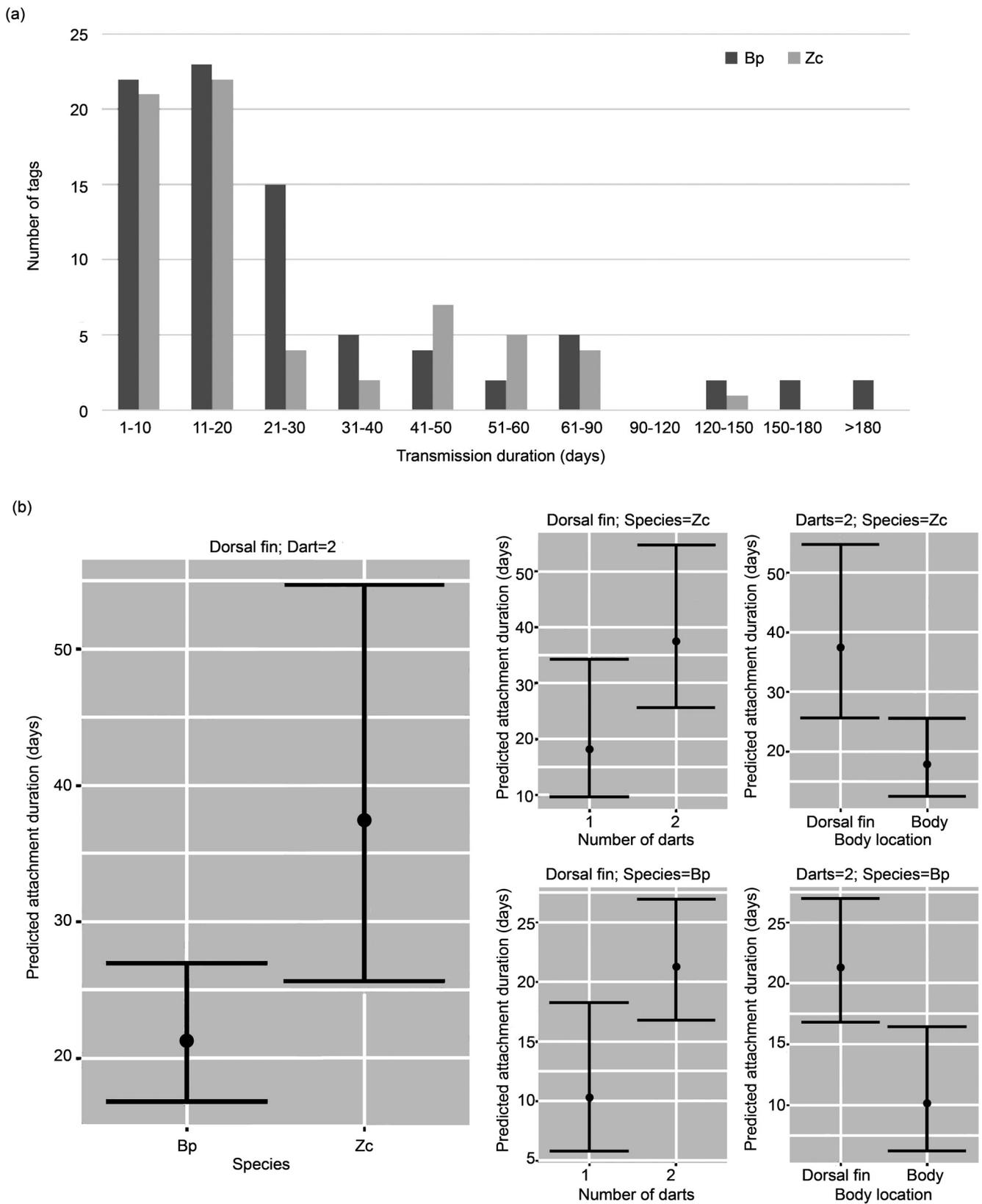


Figure 3. Tag transmission durations: (A) The distribution of transmission duration for 123 LIMPET tags that transmitted for at least one day, 2008–2022, by species; (B) Prediction plots based on a GLM, with the mean and 95% confidence intervals of transmission duration, as a function of species (Bp = fin whale, Zc = Cuvier’s beaked whale), number of darts implanted, and attachment location. For the creation of these plots, values of other significant predictors were fixed as described at the top of each plot.

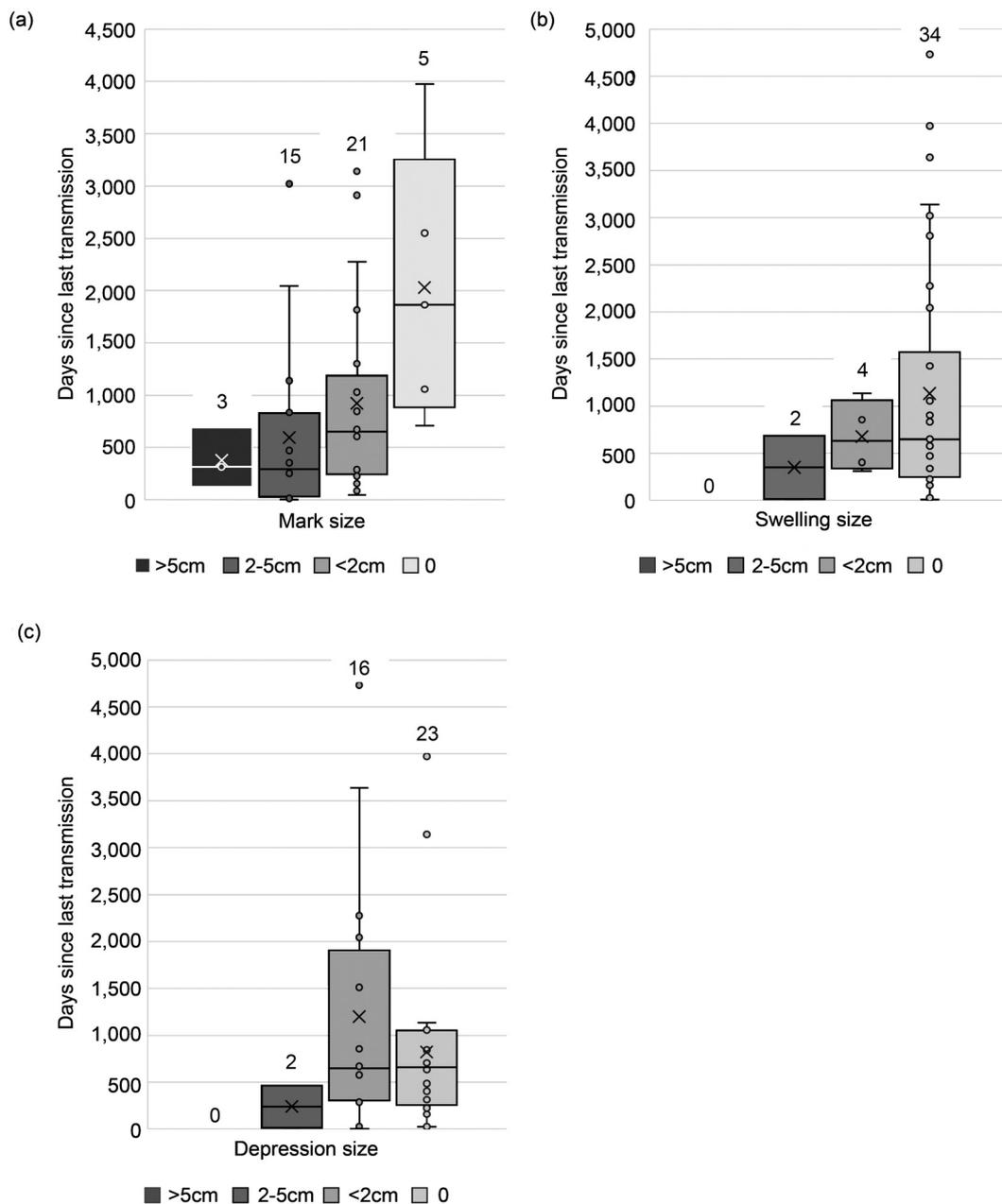


Figure 4. The size classes of (A) marks, (B) swellings and (C) depressions at the tag site as a function of days since the last transmission was received from the tag. Larger marks, swellings and depressions were uncommon and tended to be observed earlier in the post-tag history. Boxes represent median and interquartile range, with the median as a line and the mean marked with 'x'. Numbers are sample sizes of observations in each class size. Number of days is the first post-transmission observation in the given size class for tags with multiple resightings. Individual whales may be counted in more than one class if their mark changed size over the sighting history.

depressions were rarely > 2 cm in diameter if present, and none exceeded 5 cm (Figs. 4B and 4C). Representative examples of the swellings, depressions and tissue scores found in this study are in Table 5. The size distributions of marks, swellings and depressions at the final resighting did not differ between tags attached to the dorsal fin and those attached to the dorsal body surface, though small sample sizes may limit our statistical power to detect a difference (Table 6). Five whales were observed with small open wounds that had not re-epithelialised when observed at 5, 13, 29, 55 and 1,137 days after the last tag transmission. All five of those whales were later photographed with re-epithelialised wounds at 171, 902, 487, 856 and 3,638 days, respectively. No whales were resighted with visible exudate at the tag site.

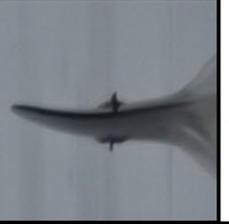
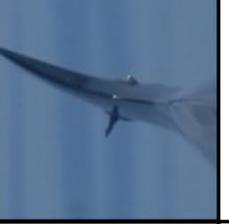
Table 6
The observed number of marks, swellings, and depressions, by size, at the final sighting, as a function of tag placement. Results of a Chi-square test are provided, though sample sizes were small, and this result may be inaccurate.

	Mark size				Swelling			Depression		
	None	< 2cm	2–5cm	> 5cm	None	< 2cm	2–5cm	None	< 2cm	2–5cm
Zone 1	3	13	6	0	20	1	1	12	9	0
Zones 2–7	2	6	6	1	13	1	1	8	4	1
	Chi-square: 2.55 DF: 3 P: 0.47				Chi-square: 0.16 DF: 2 P: 0.92			Chi-square: 1.95 DF: 2 P: 0.38		

Two of the five whales with open wounds were among three cases where mechanical failure post-deployment caused the tag body to separate from the darts, leaving one or more darts visibly protruding at a later sighting without the tag attached (Table 7). This included the first Cuvier’s beaked whale tagged in 2008 (20080803-Zc), one of five early deployments using the initial LIMPET tag and dart model, and the longest beaked whale deployment at 121 days. Tagged in Zone 3, immediately below the dorsal fin, this whale was first resighted 1,137 days (3.1 years) after transmissions ceased, with the tag shed, but the proximal ends of both darts still visibly protruding. The more dorsal of the two darts was barely visible above the skin, suggesting either the dart shaft had broken off near skin level or the intact dart had migrated into the whale after it separated from the tag body. The other dart was protruding approximately 3.2 cm above the skin (1.4 cm of threads and 1.8 cm of visible shaft) with the tips of the retention petals likely within 1 cm of the skin surface (Table 7). There was localised swelling (score of ‘1’) and loss of epithelial tissue (score of ‘2’), particularly surrounding the protruding dart. The next sighting occurred 1,759 days later (7.9 years after transmissions ceased). While the images were of insufficient quality to confidently assess tissue condition or swelling (Table 7) neither dart was visible. A faint, depigmented area < 2 cm in diameter was visible at the dorsal dart site and there was a 2–5 cm depigmented area at the ventral dart site. The final sighting of this whale occurred 3,638 days (10.0 years) after transmissions ceased, and while the images were also suboptimal for assessment of tissue condition and the size of swellings or depressions, no darts were visible, the upper mark was less evident than in the previous sighting, and the lower mark was partially repigmented (Table 7).

The other two whales sighted with retained darts were both cases where a single dart remained in the dorsal fin after the loss of the tag electronics package. In both cases, the retained dart fully penetrated the dorsal fin on deployment and was visible on both sides. The first of these cases was a 23-day deployment on a fin whale in 2013 (20130116-Bp in Table 7). The whale was sighted three days after the tag ceased transmitting with the dart tip, and possibly retention petals, protruding from the contralateral side, but the tagged side was not observed (Table 7). The whale was next photographed 55 days after transmission ceased, this time from the tag attachment side only, with the dart shaft visibly protruding. The final sighting 20130116-Bp was 856 days (2.3 years) post-transmission; the whale was only photographed from the tag side, and the dart was no longer visible, but there was a small, repigmented swelling (score of ‘1’) at the dart insertion site (Table 7). The last case with a retained dart was a 60-day deployment on a Cuvier’s beaked whale from Isla Guadalupe in 2019 (20190916-Zc, Table 7). This whale was first resighted 342 days after the end of transmission. Photographs on the tagged side were very low quality but suggested slight swelling, less pronounced on the contralateral side, which had a confirmed swelling score of ‘2’, along with depigmentation at both dart sites on both sides of the fin, particularly at the more dorsal dart site. The next sighting, at 644 days (1.8 years), provided better quality images and revealed that the more dorsal of the darts was embedded in the fin, with roughly equal lengths of the dart protruding from both sides, as documented from behind. 20190916-Zc was then sighted 44 days later, the dart now clearly protruding further from the contralateral side than the tag side, suggesting it was migrating forward along its trajectory across the fin, rather than backing out. The dart was shed, and the whale was sighted five times from 919 to 1,366 days (2.5–3.7 years) post transmission. Although images were predominantly low quality during this period, the dart wound appeared to be present but with reduced swelling on the tagged side and a depigmented depression of similar size on the contralateral side at its final sighting, although confirmation was limited by image quality.

Table 7
 Healing progression of three whales documented with retained darts after tag loss. Abbreviations: Zc: Cuvier's beaked whales; Bp: fin whale.
 The numbers under each photo are the number of days since the last tag transmission on the date the photo was taken; negative numbers indicate the number of days before presumed tag loss, i.e. the total transmission duration.

Tag Date-Species	Deployment Tag side	Tag off, darts retained		Darts out		Last photograph	
		Tag side	Contralateral side	Tag side	Contralateral side	Tag side	Contralateral side
20080803-Zc			N/A		N/A		N/A
Days since last Tx	-122	1,137	1,137	2,896	-	3,638	-
20130116-Bp				N/A	N/A		N/A
Days since last Tx	-23	55	3	-	-	856	-
20190916-Zc							
Days since last Tx	-61	644	688	1,008	1,008	1,366	1,366

Twenty-seven whales had at least one post-tag release resighting with adequate quality images to evaluate the contralateral tag site. Twelve whales had at least one residual mark on the contralateral side; all of these were dorsal fin attachments. In all but two of these cases, one or both darts were known to have fully penetrated the fin at the time of deployment, the others were not photographed from the contralateral side to confirm the level of dart penetration. The remaining 15 of these tags had no residual marks on the contralateral side of the deployment, including three tags attached to the dorsal fin and twelve that were attached below the fin. Most residual marks on the contralateral side were small (< 2 cm) focal marks. However, three of these deployments resulted in notches in the leading or trailing edge of the fin, one of which began as a hole very near the trailing edge that ultimately evolved into a notch. One tag left a visible hole through the fin at the whale's most recent sighting 3,097 days (8.5 years) after the last transmission.

DISCUSSION

Implanted or anchored telemetry devices are increasingly important cetacean research tools, particularly for species like the beaked and fin whales in this study whose preferred habitat or ranging patterns limit data collection by other means. In these populations, limited opportunities to collect individual sighting histories necessitate the use of tags capable of remaining attached for days to months to help define conservation units, identify critical habitat and estimate impacts, such as exposure to MFA sonar and risk of vessel collision (e.g., Falcone *et al.*, 2017; Scales *et al.*, 2017; Keen *et al.*, 2019). But the same sparse sighting histories complicate the follow-up assessments that should be conducted after the use of anchored or implantable tags. Despite this challenge, with conscious effort to photo-identify whales upon deployment (89% of fin whales and 100% of beaked whales in this study were photo-identified and could be reliably identified in the future), 43% of fin whales tagged off Southern California, 35% of beaked whales tagged off Southern California, and 95% of beaked whales tagged at Isla Guadalupe were resighted in a subsequent year. Many factors affect the likelihood of tagging and resighting an individual in a given year (e.g., all of these populations represent a varying mix of transient and resident individuals [Curtis *et al.*, 2020; Falcone *et al.*, 2022]), and the relatively small sample sizes here preclude a statistical assessment of resighting probability as a function of having been tagged, which could be used as a potential measure of tagging effect on survival. However, these data suggest that, as a cohort, these tagged whales both survived and returned to these study areas at rates similar to or exceeding the rates for the populations they are a part of. As a coarse metric of comparison of the rates of resighted tagged whales (above) to the resighting rates of all individuals photographed at the same locations, 28% of fin whales and 35% of beaked whales identified off Southern California, and 61% of beaked whales identified at Isla Guadalupe, were identified in a subsequent year during the same time period (Unpublished data, current study). It was expected that LIMPET tags would not adversely affect resighting rates: follow-up studies of humpback and right whales tagged with Type C tags, which are mostly designed to penetrate the subdermal sheath layer, versus the Type A tags described in this study, detected neither increased mortality nor an obvious reduction in pregnancy rates in previously tagged whales (Mizroch *et al.*, 2011; Robbins *et al.*, 2013; Best *et al.*, 2015; Gulland *et al.*, 2024). However, with the documented mortality of a killer whale following an infection linked to a Type A tag (Raverty & Ford, 2016; Huggins *et al.*, 2020), a lower resighting rate among tagged whales would have raised concern, but this was not observed.

As has been the case in other tag follow-up studies, image quality is often a limiting factor in visual assessment of attachment sites. In this study, only 27% of the tagged whales had adequate quality resighting photos for a reliable visual assessment of the tag site. In the case of this study, the subtlety of many residual marks meant they were only visible in the very highest quality images. Most of these tag deployments resulted in depigmented focal marks and/or repigmented depressions at the dart entry sites, seldom more than 2 cm in diameter, within two to three years of the final tag transmission. Swellings were rare and always less than 5 cm in diameter when observed. Where larger or complex marks were observed, including holes or notches in the dorsal fin or linear depigmented marks, these generally appeared superficial, re-epithelialised, and minor within the scope of natural marks routinely acquired by these species (Rosso *et al.*, 2011; Herr *et al.*, 2020, 2022; Onofre-Díaz *et al.*, 2022).

Within this study, we were able to coarsely assess whether the attachment location on the body affected healing outcomes. Previous follow-up studies on baleen whales tagged with Type C tags (Norman *et al.*, 2017; Gulland *et al.*, 2024), and post-mortem experiments using 1/7th-scale dummy tags in dolphins (Moore & Zerbini, 2017), have demonstrated differential tissue trauma associated with tag placement, even when dart size and shape are similar to LIMPET tags. Both of these studies found that devices implanted lower on the sides of the body and further back along the body had more pronounced effects, including larger and more persistent swellings and depressions (Type C tags) and increased subdermal tissue damage (dummy tags). It should be noted that both these studies assessed the effects of implants that were assumed or known to have fully penetrated the blubber layer. For tags deployed on the body surface (as opposed to the dorsal fin), anchoring below the blubber layer is thought to be necessary to achieve long deployments (Mate *et al.*, 2007); but, particularly when tags are placed further from the dorsal midline, increased shearing at or below the blubber-muscle interface may result in increased damage to surrounding tissue (Moore *et al.*, 2013; Moore & Zerbini, 2017; Norman *et al.*, 2017). LIMPET tags maximise attachment duration through placement in the fibrous connective tissue of the dorsal fin or sheath, and even when deployed on the body, darts of this length should not penetrate the blubber-muscle interface in healthy, non-calf individuals of either species. While the sample of tags placed on the body surface in this study was relatively small (34 tags), these tags did have significantly shorter transmission durations than tags attached to the dorsal fin. This is more likely because it takes much less force to pull a retention dart out of blubber than the dorsal fin. There was no significant difference in the visible tag site assessments of LIMPET tag deployments in the fin versus the body within the limited sample assessed here. Thus, while LIMPET tag deployments that miss the fin are likely to result in reduced data collection through both shorter attachment durations and poorer data transmission (tags placed lower on the body don't clear the water to transmit data as consistently as fin-mounted tags), they do not appear to cause more significant injury.

Swellings have been among the most concerning post-deployment effects in other tag follow-up studies. Some Type C tag deployments have been associated with swellings much larger than the diameter of the tags themselves, some of which have persisted for years before finally resolving, often as depressions of varying size (Mizroch *et al.*, 2011; Gendron *et al.*, 2015; Guzman & Capella, 2017; Norman *et al.*, 2017; Minton *et al.*, 2022; Gulland *et al.*, 2024). The most severe swellings were associated with tags believed to have broken, leaving some portion of the tag invisibly embedded in the body of the whale with nothing protruding above the skin surface to create drag and help pull the tag from the body. In some cases, these orphaned pieces of hardware were documented to have been ejected gradually via a foreign body response (Gulland *et al.*, 2024). In at least one case where a broken part of a Type C tag was retained for an extensive period, a previously reproductively successful female blue whale with an extensive sighting history pre and post-tagging failed to reproduce during an eight-year period of swelling at the tag site but was sighted with a calf five years after a foreign body response ejected hardware, suggesting retained hardware for extended periods of time (e.g., years) may have systemic health consequences for some whales (Gendron *et al.*, 2015).

Three of the five whales observed with swellings in this study were cases where the tag body separated from one or both darts, leaving darts visibly protruding from the whale at a post-transmission sighting (Table 7). All three of these whales were ultimately sighted without visible darts and with their wounds re-epithelialised; however, the timeframe of shedding these retained darts was long, estimated at 2–4 years for the two whales that had adequate sighting history to assess the loss of broken darts. It is also worth noting that for one case where the darts were left in the dorsal fin, there is strong evidence to suggest the dart migrated forward along its trajectory through the fin and out the contralateral side, rather than backing out through the entry hole as would occur if the darts had remained attached to the tag body, as intended. This raises concerns for the first whale with retained darts, since the tag was attached below the fin, and thus a retained dart would not likely exit the contralateral side and could remain in the body for some time. Although, it is possible that the foreign body response may eventually push the dart out through the entry hole, as was observed for some humpback whales with retained tag anchors (Gulland *et al.*, 2024). Nearly 3.5 years after the tag was deployed on the first whale with retained darts (20080803-Zc), the more ventral dart was partially ejected and a localised tissue response was evident, with swelling and loss of epithelium at the site. The more dorsal dart, however, was nearly fully embedded with very little apparent tissue response. The whale was left with considerably less residual

scarring at this dart site than at the site of the partially ejected dart, and also less scarring than at the sites of the retained darts that were ultimately ejected from dorsal fins of the other two whales with swelling associated with retained darts. This suggests the more dorsal dart may not have been ejected but was instead encapsulated and remained in the body of this whale as of its last sighting, 10 years after the tag was deployed. This whale did not visibly exhibit a protracted subdermal foreign body response resulting in large swellings, similar to those associated with broken Type C tags that persist for years; however, it is also possible that a foreign body response occurred between resightings and resulted in the ejection of the hardware and subsequent healing of the epidermis. While overall body and skin conditions were not formally analysed in this study, using criteria defined by Wachtendonk *et al.* (2022) and Boileau *et al.* (2024) for photographic health assessments, this whale would have been considered generally healthy at its most recent sighting. However, we await further sightings of this individual to inform us of the long-term outcome of this deployment.

Finally, while retained darts appeared to be uncommon in this study, it is possible that retention petals were left behind more frequently. LIMPET tags are not recovered, and thus the condition of the darts when a tag is shed is unknown. LIMPET dart petals were found embedded at the dart penetration sites in the post-mortem examination of the previously tagged killer whale (Raverty & Ford, 2016; Huggins *et al.*, 2020) as well as in a right whale (Moore *et al.*, 2013). The titanium petals used in this study are known to be more brittle than a stainless-steel alternative and have been associated with a higher rate of petal loss in a study where darts were used to anchor archival tags in baleen whales and subsequently recovered and examined (Szesciorka *et al.*, 2016). Despite this, titanium remains the preferred material for LIMPET tag darts due to its substantially lighter weight (improving the ballistic profile of the tag and thus placement accuracy), as well as its superior biocompatibility, which is important given that LIMPET tags are designed to remain attached for months, and that retained darts can take years to eject if they occur. The fact that we rarely observed more than two visible marks following a LIMPET tag deployment suggests that, if petals are routinely left behind, they are either encapsulated through the combination of stability (tags are typically placed in fibrous tissue that does not move much) and biocompatibility (the titanium used in these darts is approved for surgical implantation in humans), or the ejection wounds are too small to be detectable even in high quality photographs.

CONCLUSION

Type A LIMPET tag deployments typically result in favorable long-term outcomes for Cuvier's beaked whales and fin whales. Tagged whales of both species were resighted at similar rates to un-tagged whales in their study areas. Unhealed wounds were only observed while darts were still present and shortly after darts were shed, and most whales in this study were ultimately left with one or two small (< 2 cm), superficial marks at the tag attachment site within three years after the tag ceased transmitting. Our findings suggest LIMPET tags are a safe and effective option for collecting extended movement and behaviour records from a wide range of cetacean species and are uniquely suited for smaller and medium-sized cetacean species with a dorsal fin, for which Type B and Type C tags may not be feasible or appropriate.

ACKNOWLEDGEMENTS

Funding for preparation of this manuscript was provided by the US Navy Pacific Fleet. Funding for the fieldwork was provided by numerous agencies, including the US Navy (N45, Office of Naval Research, Living Marine Resources, and US Pacific Fleet) and the NOAA National Marine Fisheries Service (Southwest Fisheries Science Center, Northwest Fisheries Science Center, and Alaska Fisheries Science Center). Work was conducted under National Marine Fisheries permits No. 540-1811, 1611, 15330, 20605 and 21163, and the Mexican Secretaría de Medio Ambiente y Recursos Naturales permits No. SGPA/DGVS/00451/18, SGPA/DGVS/00374/20 and SGPA/DGVS/005955/21. Tagging was approved by the Institutional Animal Care and Use committees of the respective permit holders. We thank Cascadia Research Collective and the NOAA Marine Mammal Lab. Numerous people were involved in the field efforts, but we'd like to specifically acknowledge the entire team at the Naval Undersea Warfare Center's Marine Mammal Monitoring on Ranges group, and the personnel at the San Clemente Island Range Complex, particularly the Watercraft Group. We thank the crew of the M/V Storm and M/V Azteca,

the fishers of Isla Guadalupe, and the team from the Comisión Nacional de Áreas Naturales Protegidas at Isla Guadalupe. We thank the numerous individuals and organisations who have contributed opportunistic photographs of fin whales to our research, particularly the staff at the Aquarium of the Pacific, Laura Lopez and the naturalists at Dana Wharf Whale Watch, and Alisa Schulman-Janiger. We thank David Sweeney for assistance with analysis.

REFERENCES

- Andrews, R.D., Baird, R.W., Calambokidis, J., Goertz, C.E.C., Gulland, F.M.D., Heide-Jørgensen, M.P., Hooker, S.K., Johnson, M., Mate, B., Mitani, Y., Nowacek, D.P., Owen, K., Quakenbush, L.T., Raverty, S., Robbins, J., Schorr, G.S., Shpak, O.V., Townsend, F.I., Uhart, M., Wells, R.S., & Zerbini, A.N. (2019). Best practice guidelines for cetacean tagging. *J. Cetacean Res. Manage.* 20: 27–66. [Available at: <https://doi.org/10.47536/jcrm.v20i1.237>]
- Andrews, R.D., Baird, R.W., Schorr, G.S., Mittal, R., Howle, L.E., & Hanson, M.B. (2015). Improving attachments of remotely-deployed dorsal fin-mounted tags: Tissue structure, hydrodynamics, in situ performance, and tagged-animal follow-up. Final Report. ONR Report Award Number: N000141010686.
- Andrews, R.D., Mazzuca, L., & Matkin, C.O. (2005). Satellite tracking of killer whales. In: T.R. Loughlin, S. Atkinson, D.G. Calkins, Alaska SeaLife Center (Eds.). *Synopsis of Research on Steller Sea Lions: 2001 – 2005* (pp.238–248). Alaska SeaLife Center.
- Andrews, R.D., Pitman, R., & Ballance, L. (2008). Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. *Polar Biol.* 31(12): 1461–1468. [Available at: <https://doi.org/10.1007/s00300-008-0487-z>]
- Baird, R.W., Webster, D.L., Swaim, Z.T., Foley, H.J., Anderson, D.B., & Read, A.J. (2015). Spatial use by Cuvier’s beaked whales, short-finned pilot whales, common bottlenose dolphins and short-beaked common dolphins satellite tagged off Cape Hatteras, North Carolina, in 2014. Draft Report Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, Contract No. N62470-10-3011, Task Orders 14 and 21.
- Best, P., Mate, B., & Lagerquist, B. (2015). Tag retention, wound healing, and subsequent reproductive history of southern right whales following satellite-tagging. *Mar. Mammal Sci.* 31(2): 520–539. [Available at: <https://doi.org/10.1111/mms.12168>]
- Boileau, A., Blais, J., Van Bresseem, M.-F., Hunt, K.E., & Ahloy-Dallaire, J. (2024). Physical measures of welfare in fin (Balaenoptera physalus) and humpback whales (*Megaptera novangliae*) found in an anthropized environment: Validation of a first animal-based indicator in mysticetes. *Animals* 14(3519): 1–27. [Available at: <https://doi.org/doi.org/10.3390/ani14233519>]
- Burek-Huntington, K.A., Shelden, K.E.W., Andrews, R.D., Goertz, C.E.C., McGuire, T.L., & Dennison, S. (2022). Postmortem pathology investigation of the wounds from invasive tagging in belugas (*Delphinapterus leucas*) from Cook Inlet and Bristol Bay, Alaska. *Mar. Mammal Sci.* 39(2): 492–514 [Available at: <https://doi.org/10.1111/mms.12981>]
- Cárdenas-Hinojosa, G., Hoyos-Padilla, M., & Rojas-Bracho, L. (2015). Occurrence of Cuvier’s beaked whales (*Ziphius cavirostris*) at Guadalupe Island, Mexico, from 2006 to 2009. *Lat. Am. J. Aquat. Mamm.* 10(1): 38–47. [Available at: <https://doi.org/10.5597/lajam00192>]
- Curtis, K.A., Moore, J.E., Falcone, E.A., Moretti, D.J., Schorr, G.S., Barlow, J., & Keene, E. (2020). Abundance, survival, and annual rate of change of Cuvier’s beaked whales (*Ziphius cavirostris*) on a Navy sonar range. *Mar. Mammal Sci.* 37(2): 399–419. [Available at: <https://doi.org/10.1111/mms.12747>]
- Falcone, E.A., Keene, E.L., Keen, E.M., Barlow, J., Stewart, J., Cheeseman, T., Hayslip, C., & Palacios, D.M. (2022). Movements and residency of fin whales (*Balaenoptera physalus*) in the California Current System. *Mamm. Biol.* 102: 1445–1462. [Available at: <https://doi.org/10.1007/s42991-022-00298-4>]
- Falcone, E.A., Schorr, G.S., Douglas, A.B., Webster, D.L., Calambokidis, J., Hildebrand, J.A., Andrews, R.D., Hanson, M.B., Baird, R.W., & Moretti, D.J. (2009). Movements of Cuvier’s beaked whales in a region of frequent naval activity: Insights from sighting, photo-identification, and satellite tag data [Oral Presentation]. 18th Biennial Conference on the Biology of Marine Mammals, Quebec City, Canada.
- Falcone, E.A., Schorr, G.S., Watwood, S.L., DeRuiter, S.L., Zerbini, A.N., Andrews, R.D., Morrissey, R.P., & Moretti, D.J. (2017). Diving behaviour of Cuvier’s beaked whales exposed to two types of military sonar. *Royal Soc. Open Sci.* 4(8): 170629. [Available at: <https://doi.org/10.1098/rsos.170629>]
- Félix, F., & Van Waerebeek, K. (2021). Towards an aquatic mammal research code of conduct in Latin America: Ethical before technical considerations. *Lat. Am. J. Aquat. Res.* 16(1): 61–65 [Available at: <https://doi.org/10.5597/lajam00274>]
- Geertsen, B.M., Teilmann, J., Kastelein, R.A., Vlemmix, H.N.J., & Miller, L.A. (2004). Behaviour and physiological effects of transmitter attachments on a captive harbour porpoise (*Phocoena phocoena*). *J. Cetacean Res. Manage.* 6(2): 139–146. [Available at: <https://doi.org/10.47536/jcrm.v6i2.777>]
- Gendron, D., Serrano, I.M., Cruz, A.U., Calambokidis, J., & Mate, B. (2015). Long-term individual sighting history database: An effective tool to monitor satellite tag effects on cetaceans. *Endanger. Species Res.* 26(3): 235–241. [Available at: <https://doi.org/10.3354/esr00644>]
- Gulland, F.M.D., Robbins, J., Zerbini, Alexandre N., Andrews-Goff, V., Bérubé, M., Clapham, Phillip J., Double, M.C., Gales, N., Kennedy, A.S., Landry, S., Mattila, D.K., Sandilands, D., Tackaberry, J.E., Uhart, M.M., & Vanstreels, R.E.T. (2024). Effects of satellite-linked telemetry tags on humpback whales in the Gulf of Maine: Photographic assessment of tag sites. *J. Cetacean Res. Manage.* Special Issue 5: 1–33. [Available at: <https://doi.org/2024.02.07.579298>]
- Guzman, H.M., & Capella, J.J. (2017). Short-term recovery of humpback whales after percutaneous satellite tagging: Recovery of satellite-tagged humpback whales. *J. Wildl. Manage.* 81(4): 728–733. [Available at: <https://doi.org/10.1002/jwmg.21235>]
- Hammerschlag, N., Cooke, S.J., Gallagher, A.J., & Godley, B.J. (2014). Considering the fate of electronic tags: Interactions with stakeholders and user responsibility when encountering tagged aquatic animals. *Methods Ecol. Evol.* 5(11): 1147–1153. [Available at: <https://doi.org/10.1111/2041-210X.12248>]

- Hanson, M.B., Andrews, R.D., Schorr, G.S., Baird, R.W., Webster, D.L., & McSweeney, D.J. (2008). Re-sightings, healing and attachment performance of dorsal fin-mounted tags on Hawaiian odontocetes. Document PSRG-2008-10 submitted to the Pacific Scientific Review Group.
- Heide-Jørgensen, M.P., Nielsen, N.H., Teilmann, J., & Leifsson, P.S. (2017). Long-term tag retention on two species of small cetaceans. *Mar. Mammal Sci.* 33(3): 713–725. [Available at: <https://doi.org/10.1111/mms.12394>]
- Herr, H., Burkhardt-Holm, P., Heyer, K., Siebert, U., & Selling, J. (2020). Injuries, malformations, and epidermal conditions in cetaceans of the Strait of Gibraltar. *Aquat Mamm.* 46(2): 215–235. [Available at: <https://doi.org/10.1578/AM.46.2.2020.215>]
- Herr, H., Viquerat, S., Naujocks, T., Gregory, B., Lees, A., & Devas, F. (2022). Skin condition of fin whales at Antarctic feeding grounds reveals little evidence for anthropogenic impacts and high prevalence of cookiecutter shark bite lesions. *Mar. Mammal Sci.* 39: 299–310. [Available at: <https://doi.org/10.1111/mms.12966>]
- Huggins, J.L., Garner, M.M., Raverty, S.A., Lambourn, D.M., Norman, S.A., Rhodes, L.D., Gaydos, J.K., Olson, J.K., Haulena, M., & Hanson, M.B. (2020). The emergence of Mucormycosis in free-ranging marine mammals of the Pacific Northwest. *Front. Mar. Sci.* 7: 555. [Available at: <https://doi.org/10.3389/fmars.2020.00555>]
- Keen, E.M., Scales, K.L., Rone, B.K., Hazen, E.L., Falcone, E.A., & Schorr, G.S. (2019). Night and day: Diel differences in ship strike risk for fin whales (*Balaenoptera physalus*) in the California Current System. *Front. Mar. Sci.* 6: 730. [Available at: <https://doi.org/10.3389/fmars.2019.00730>]
- Lesage, V., Gavrilchuk, K., Andrews, R.D., & Sears, R. (2017). Foraging areas, migratory movements and winter destinations of blue whales from the western North Atlantic. *Endanger Species Res.* 34: 27–43. [Available at: <https://doi.org/10.3354/esr00838>]
- Mate, B., Mesecar, R., & Lagerquist, B. (2007). The evolution of satellite-monitored radio tags for large whales: One laboratory's experience. *Deep-Sea Res. II: Top. Stud. Oceanogr.* 54(3): 224–247. [Available at: <https://doi.org/10.1016/j.dsr2.2006.11.021>]
- Minton, G., Van Bresseem, M.F., Willson, A., Collins, T., Al Harthi, S., Sarrouf Willson, M., Baldwin, R., Leslie, M., & Van Waerebeek, K. (2022). Visual health assessment and evaluation of anthropogenic threats to Arabian Sea humpback whales in Oman. *J. Cetacean Res. Manage.* 23(1): 59–79. [Available at: <https://doi.org/10.47536/jcrm.v23i1.336>]
- Mizroch, S.A., Tillman, M.F., Jurasz, S., Straley, J.M., Von Ziegesar, O., Herman, L.M., Pack, A.A., Baker, S., Darling, J., Glockner-Ferrari, D., Ferrari, M., Salden, D.R., & Clapham, P.J. (2011). Long-term survival of humpback whales radio-tagged in Alaska from 1976 through 1978. *Mar. Mammal Sci.* 27(1): 217–229. [Available at: <https://doi.org/10.1111/j.1748-7692.2010.00391.x>]
- Moore, M., Andrews, R., Austin, T., Bailey, J., Costidis, A., George, C., Jackson, K., Pitchford, T., Landry, S., Ligon, A., McLellan, W., Morin, D., Smith, J., Rotstein, D., Rowles, T., Slay, C., & Walsh, M. (2013). Rope trauma, sedation, disentanglement, and monitoring-tag associated lesions in a terminally entangled North Atlantic right whale (*Eubalaena glacialis*). *Mar. Mammal Sci.* 29(2): E98–E113. [Available at: <https://doi.org/10.1111/j.1748-7692.2012.00591.x>]
- Moore, M.J., & Zerbini, A.N. (2017). Dolphin blubber/axial muscle shear: Implications for rigid trans-dermal intra-muscular tracking tag trauma in whales. *J. Exp. Biol.* 220(20): 3717–3723 [Available at: <https://doi.org/10.1242/jeb.165282>]
- Norman, S.A., Flynn, K.R., Zerbini, A.N., Gulland, F.M.D., Moore, M.J., Raverty, S., Rotstein, D.S., Mate, B.R., Hayslip, C., Gendron, D., Sears, R., Douglas, A.B., & Calambokidis, J. (2017). Assessment of wound healing of tagged gray (*Eschrichtius robustus*) and blue (*Balaenoptera musculus*) whales in the eastern North Pacific using long-term series of photographs. *Mar. Mammal Sci.* 34(1): 27–53 [Available at: <https://doi.org/10.1111/mms.12443>]
- Onofre-Díaz, M.A., Ortega-Ortiz, C.D., Cárdenas-Hinojosa, G., Huerta-Patiño, R., Falcone, E., Trickey, J.S., Van Waerebeek, K., & Van Bresseem, M.F. (2022). Cutaneous conditions and injuries in *Ziphius cavirostris* and *Mesoplodon peruvianus* from Mexican Pacific and Southern California waters. *Mamm. Biol.* 102(4): 1547–1564. [Available at: <https://doi.org/10.1007/s42991-022-00273-z>]
- Papastavrou, V., & Ryan, C. (2023). Ethical standards for research on marine mammals. *Res. Ethics*, 19(4): 390–408. [Available at: <https://doi.org/10.1177/17470161231182066>]
- R Core Team (2024). *R: A language and environment for statistical computing* (Version 4.4.2) [R]. R Foundation for Statistical Computing.
- Rasband, W.S. (1997). *ImageJ* [Computer software]. U.S. National Institutes of Health.
- Raverty, S., & Ford, J. (2016). Final Report AHC Case: 16-1760. Final Report AHC Case Nos. 16-1760: 1–7. Ministry of Agriculture of British Columbia, Abbotsford British Columbia.
- Robbins, J., Andrews-Goff, V., Clapham, P., Double, M., Gales, N., Gulland, N., Kennedy, A., Landry, S., Matilla, D., Sandilands, D., Tackaberry, J., & Zerbini, A. (2016). Evaluating potential effects of satellite tagging in large whales: A case study with Gulf of Maine humpback whales. Report to the National Fish and Wildlife Foundation Grant #23318.
- Robbins, J., Zerbini, A.N., Gales, N., Gulland, F.M.D., Double, M., Clapham, J., Andrews-Goff, V., Kennedy, A.S., Landry, S., & Mattila, D.K. (2013). Satellite tag effectiveness and impacts on large whales: Preliminary results of a case study with Gulf of Maine humpback whales. SC/65A/SH05 presented to the IWC Scientific Committee, South Korea, 2013. [Available from the IWC Publications Team]
- Rosso, M., Ballardini, M., Moulins, A., & Würtz, M. (2011). Natural markings of Cuvier's beaked whale *Ziphius cavirostris* in the Mediterranean Sea. *Afr. J. Mar. Sci.* 33(1): 45–57. [Available at: <https://doi.org/10.2989/1814232X.2011.572336>]
- Rutala, W.A., & Weber, D.J. (2008). Guideline for disinfection and sterilization in healthcare facilities. Centers for Disease Control and Prevention, Atlanta, GA.
- Scales, K.L., Schorr, G.S., Hazen, E.L., Bograd, S.J., Miller, P.I., Andrews, R.D., Zerbini, A.N., & Falcone, E.A. (2017). Should I stay or should I go? Modelling year-round habitat suitability and drivers of residency for fin whales in the California Current. *Divers. Distrib.* 23(10): 1204–1215. [Available at: <https://doi.org/10.1111/ddi.12611>]
- Schorr, G.S., Rone, B.K., Falcone, E.A., Keene, E.L., Cárdenas-Hinojosa, G., Huerta-Patiño, R., López-Arzate, D., Rojas Bracho, L., Baumann-Pickering, S., & Trickey, J.S. (2022). Demographics and diving behavior of Cuvier's beaked whales at Guadalupe Island, Mexico: A comparative study to better understand sonar impacts at SOAR and Cuvier's beaked whales at Guadalupe Island, Mexico: A comprehensive assessment of demographics and behavior in an undisturbed area. Final Report (Award No. N000141812777) and Interim Report (Award No. N000142012755) to the US Navy Office of Naval Research.

- Sonne, C., Teilmann, J., Wright, A.J., Dietz, R., & Leifsson, P.S. (2012). Tissue healing in two harbor porpoises (*Phocoena phocoena*) following long-term satellite transmitter attachment. *Mar. Mammal Sci.* 28(3): E316–E324. [Available at: <https://doi.org/10.1111/j.1748-7692.2011.00513.x>]
- Szesciorka, A.R., Calambokidis, J., & Harvey, J.T. (2016). Testing tag attachments to increase the attachment duration of archival tags on baleen whales. *Anim. Biotelemetry* 4(1): 1–12. [Available at: <https://doi.org/10.1186/s40317-016-0110-y>]
- Wachtendonk, R., Calambokidis, J., & Flynn, K. (2022). Blue whale body condition assessed over a 14-year period in the NE Pacific: Annual variation and connection to measures of ocean productivity. *Front. Mar. Sci.* 9: 847032. [Available at: <https://doi.org/10.3389/fmars.2022.847032>]
- Wells, R.S. (2012). *Evaluation of tag attachments on small cetaceans*. Report No. N000141210391 to the Office of Naval Research. Chicago Zoological Society and Mote Marine Laboratory.

©Authors. This is an open access article distributed under the terms of a *Creative Commons License CC-BY-NC 4.0*.