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Development and assessment of a new dermal attachment for short-term tagging studies of baleen whales

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Summary

1. Current studies of fine-scale baleen whale diving and foraging behaviour rely on archival suction cup tags that remain attached over time scales of hours. However, skin irregularities can make suction cup attachment unreliable, and traditional pole deployment of suction cup tags is challenging in moderate sea conditions or when whales are evasive.

2. We developed a new tag attachment to overcome these limitations. The attachment features a short (6·5–7·5 cm) needle that anchors in the whale's dermis (epidermis and blubber) to which a free-floating tag is attached via a severable tethered link. The needle, tag and a detachable 'carrier rocket' with fletching are fitted together to form a projectile that can be deployed at distances of up to 20 m using a compressed-air launcher. A corrosive release mechanism allows the tag to separate from the needle after a specified period of time so that the tag can be recovered.

3. The dermal attachment was evaluated during a study of humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine and then subsequently deployed on bowhead whales (*Balaena mysticetus*) near Barrow, Alaska. Monitoring of tagged humpback whales indicated that the needle was shed several days after deployment, the attachment site healed shortly thereafter, and there were no discernible behavioural or health effects over time scales of days to months after tagging. Bowhead whales showed little immediate reaction to tagging; the most common response was a prolonged dive right after tag deployment. On average, respiration rates of tagged bowhead whales were elevated after tag attachment, but returned to the same rate as undisturbed bowheads within 1–1·5 h.

4. When compared to suction cups, the dermal anchor provided a more reliable attachment and it can be applied from greater distances and in rougher sea conditions; it is therefore a useful alternative in circumstances where suction cup tags cannot be easily deployed.

Key-words: behaviour, bowhead whale, foraging, humpback whale, mysticete, suction cup

Introduction

Our understanding of baleen whale diving and movement behaviour has greatly expanded in the last two decades with the advent of short-term archival tags that measure a variety of behavioural parameters (e.g. depth, pitch, roll and heading) and allow fine-scale tracking over time scales of hours. Most modern tags rely on suction cups for attachment to the whale's skin (Malcolm & Duffus 2000; Baumgartner & Mate 2003; Calambokidis *et al.* 2007; Stimpert *et al.* 2007; Friedlaender *et al.* 2009). However, suction cup tagging has important drawbacks: (i) because of skin irregularities, attachments are not always reliable, and (ii) both evasive behaviours and sea conditions often make manoeuvering a small boat to within ~8 m of a whale for pole deployment of a suction cup tag quite difficult. Because of these limitations, much more time is spent at sea attempting to attach a tag than actually studying whale behaviour. To improve tagging efficiency (i.e. to increase both the number of tagging attempts and the number of successful tag attachments per tagging attempt), a new and more reliable method of attaching tags to whales is required.

William 'Bill' Watkins pioneered tag attachment methods to track the movements of baleen whales via radio telemetry (Watkins *et al.* 1980, 1981; Watkins 1981). His tag consisted of a stainless steel cylinder housing only a radio transmitter; the tag did not have a sensor to measure pressure (depth) and was not designed to be recovered. A cupped blade at the point, fashioned after that used by Canadian harpooners during the 1960s, facilitated penetration of the skin and blubber, particularly at oblique entry angles (Watkins 1979). Upon deployment via a shoulder gun, nearly the entire tag implanted

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in the skin and blubber with only the endcap and the antenna of the radio transmitter protruding from the skin. While active tracking lasted for days to a few weeks, the tag likely remained implanted in the whale for much longer. Watkins' design ultimately became the foundation for the long-term, implantable satellite-transmitting tags used by many researchers (Mate, Mesecar & Lagerquist 2007). More recently, small surface-mounted satellite tags have been used with success on odontocetes (Andrews, Pitman & Balance 2008) and some baleen whales (Ford *et al*. 2013). This design is characterized by a tag housing that is not implanted, but instead is externally mounted on the animal via short barbed darts that anchor in the dermis. Goodyear (1993) developed a trailing tag design where the tag housing is neither implanted nor fixed to the whale, but trails behind a dermal anchor via a loose tether. Unlike satellite-transmitting tags, the Goodyear (1993) tag was designed for short-term tracking, so it was outfitted with very high-frequency (VHF) radio and acoustic transmitters and had a galvanic release that detached the tag from the dermal anchor after a specified period of time so that the tag could be recovered and reused. The Goodyear (1993) dermal anchor had a sharp point with no cutting blades, and it included stiff stainless steel tines to provide holding power (similar to the later design of Andrews, Pitman & Balance 2008).

During the late summers of 2007 and 2008, we attempted to deploy suction cup attached archival tags to bowhead whales (*Balaena mysticetus*) near Barrow, Alaska, USA, to study their diving and foraging behaviour. We found the whales difficult to approach with skin so rough that tag attachment by suction cup was impossible. To overcome these challenges, we developed a new short-term dermal attachment during late 2008 and early 2009 that is similar in concept to that of Goodyear (1993) (although different in materials and design). The dermal attachment was tested on humpback whales (*Megaptera novaeangliae*) near Cape Cod, Massachusetts, during the spring of 2009 and was then used with success on bowhead whales during the fall seasons of 2009 and 2010. This paper describes the dermal attachment, reports on its effects on humpback whales over time scales of hours to months and demonstrates the attachment's efficacy during bowhead whale deployments.

Materials and methods

Our goal was to design a projectile tag that could be fired from a launcher at distances of up to 20 m (longer than is currently feasible for pole-deployed suction cup tags). The tag would attach via a dermal anchor at the tip of the projectile, which would (i) be able to pierce the skin and blubber at oblique entry angles (i.e. not just when launched perpendicular to the whale's skin), (ii) not penetrate beyond a desired depth during implantation, (iii) not migrate inward after implantation, (iv) have enough holding power to remain implanted for a few days at most and (v) have as little holding power as possible to facilitate outward migration and shedding once the tag detached from the anchor. The tag housing would (i) contain an archival time–depth recorder (TDR), a radio transmitter and an acoustic transmitter, (ii) be recoverable and (iii) be stable in flight prior to attachment. Finally, the tethered link connecting the dermal anchor and the tag housing needed to be severable, so that the tag could detach from the anchor after a known period of time and be recovered to access the archived TDR data.

Fig. 1. Needles used in humpback whale field trials. Needle at left features four tapered cupped rings rising 0·16 cm above the needle shaft, while the needle at right features four curved 316 stainless steel pins. Each needle is attached to a white hemispherical delrin 'stop'. Inset shows cross design of needle tip with four cutting blades and side vents.

The dermal attachment (anchor) consists of a single stainless steel needle and a hemispherical delrin 'stop' that prevents full implantation of the needle and subsequent inward migration (Fig. 1). The needles used in the studies described below were 6·5 cm (humpback and bowhead whales) or 7·5 cm (bowhead whales) long with a 0·635-cm-diameter shaft, and each was machined from 316 surgical stainless steel. The design of the needle tip was originally based on the cupped blade of Watkins (1979); however, after testing on a beached fin whale (*Balaenoptera physalus*) carcass, we found that this point removed a plug of skin upon entry and carried the plug into the blubber. The introduction of this skin and associated surface contaminants into the blubber created an unacceptable risk of infection, so we redesigned the point to prevent this. The new point consists of four cutting blades arranged as a cross with side vents to prevent any skin or surface contaminants from entering the wound (Fig. 1). Testing of this new point on a second beached fin whale carcass indicated that, unlike the Watkins-style point, the cross design preserves the skin initially cut during entry to presumably facilitate better healing of the wound after the anchor is shed. Moreover, the cross design allows penetration of the skin and blubber at more oblique entry angles than would be allowed by a point (Watkins 1979), such as that used by Goodyear (1993); consequently, the dermal anchor does not need to be implanted while perpendicular to the whale's flank, but instead can be launched while the tagging boat is slightly behind and to the side of the whale. Two needle designs were used as follows: (i) tapered cupped rings rising 0·16 cm above the needle shaft and (ii) curved 316 stainless steel pins pulled through the needle shaft and blunted (Fig. 1). Prior to use, the anchor (i.e. the assembled needle and 'stop') is steam sterilized in an autoclave; the anchor can remain in the sterile autoclave bag until just before the tag is loaded into the launcher in the field. The needle is not touched during this process, and it is subsequently protected from incidental contact and sea spray while inside the barrel of the launcher.

The tag housing is a 40·6-cm-long-by-3·2-cm-diameter hollow cylinder constructed of polyethylene, and the TDR (Lotek LAT1500), VHF radio transmitter (Telonics MOD-050) and acoustic transmitter (VEMCO V22P) are imbedded in a buoyant PVC foam core (DIAB Global Divinycell HCP060) that inserts into the polyethylene housing (Fig. 2). Small venting holes are drilled into the housing to allow it to freely flood as well as to allow the signal produced by the acoustic transmitter

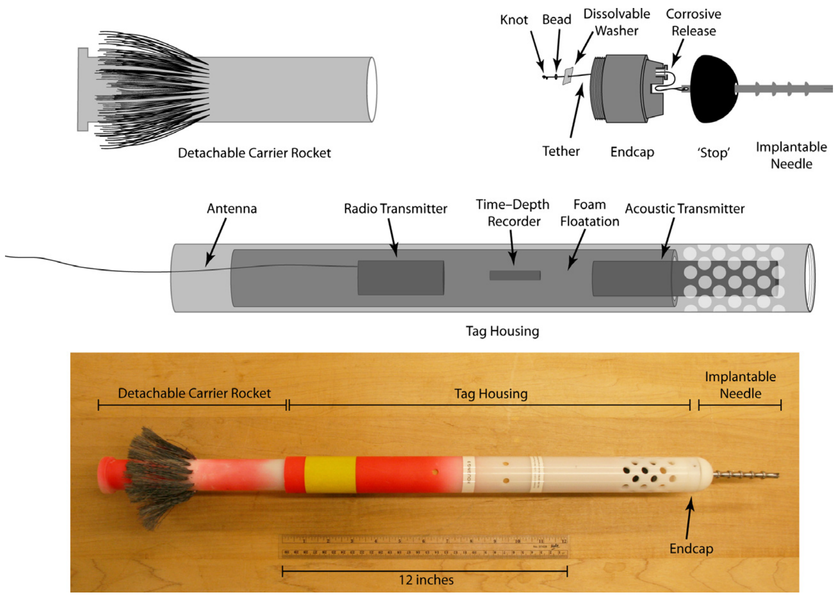

Fig. 2. Dermal attachment tag components, including tag housing, foam floatation, time–depth recorder, radio transmitter, acoustic transmitter, detachable carrier rocket with flu–flu fletching and endcap with needle, 'stop', and zinc foil corrosive release mechanism. Photograph shows tag assembled for launch with the carrier rocket fitted into the end of the tag housing at the left, endcap screwed into the tag housing at right and the sterilized needle fitted into the endcap.

to radiate outside of the housing. Attenuation of the acoustic pulse by the housing and foam core was tested by VEMCO and found to be negligible. The 'stop' of the dermal anchor is designed to fit into the endcap of the housing. The anchor and the tag housing are attached by a monofilament or braided polyethylene (Spectra) tether that passes through a piece of zinc foil in the endcap. This foil corrodes over several hours and weakens until a knot and bead at the end of the tether can be pulled through the foil; at that time, the tag housing parts from the dermal anchor, floats to the surface and is recovered (the anchor remains attached to the whale, but is shed within a few days; see below). During deployment, the force of initial recoil after anchor attachment can easily pull the knot and bead through the zinc foil; only 8 lbs of force is required to do this. A dissolvable washer made of a folded strip of Solvy (Sulky), a water-soluble stabilizer used in sewing applications, is used to absorb the force associated with the recoil. This dissolvable washer can withstand over 25 lbs of force when dry (i.e. upon initial deployment), but <2 lbs of force after being submerged in water for 5 min. Since the tag housing is not implanted, the dissolution of the Solvy occurs well away from the wound site.

The acoustic and radio transmitters were included in the tag design to facilitate tracking of the whale and recovery of the tag, respectively. The acoustic transmitter is particularly useful for continuously tracking submerged whales within approximately 1 km, and unlike tags that rely on radio transmissions for tracking, a tag with an acoustic transmitter can be attached below the water line. The acoustic transmitter emits a 36-kHz pulse roughly once a second that is likely inaudible to right, humpback and bowhead whales [see Baumgartner *et al.* (2008) for a description of the transmitter and a review of baleen whale hearing relative to the 36-kHz pulse, and Baumgartner & Mate (2003) for an evaluation of the diving behaviour of North Atlantic right whales (*Eubalaena glacialis*) tagged with and without the acoustic transmitter].

The anchor and tag housing fit together to make a single projectile (Fig. 2) that is deployed using a compressed-air launcher called the Air Rocket Transmission System (ARTS; Heide-Jørgensen *et al.* 2001), which is a modified line thrower (Restech, Inc., Bodø, Norway). To provide stability in flight, a 'carrier rocket' is inserted into the end of the tag housing opposite the dermal anchor (Fig. 2). Several designs of this carrier rocket were tested, including many with traditional vanes. Because we needed vanes that could be compressed in the barrel of the launcher, but would resume their shape upon exiting the barrel, we used flu–flu fletching borrowed from a style of arrow used to hunt birds. Flu–flu arrows have excessive fletching that provides greater stability in flight and slows the speed of the arrow. The carrier rocket is made of a hollow polyethylene cylinder with a buoyant PVC foam insert and fletching made of plastic strands; it is recoverable and reusable.

Results

Our objective in developing the dermal attachment and associated tag was to study the diving and foraging behaviour of bowhead whales. Prior to use, however, we thought it extremely important to examine the effects of the dermal attachment on both the health and behaviour of the whales over time scales of hours to months to insure that the tag was sufficiently benign. Because there is no systematic effort to monitor individual bowhead whales off Barrow, Alaska, a longitudinal study of tagging effects on this species was not feasible. Instead, we examined the effects of the dermal attachment in a much better monitored population: Gulf of Maine humpback whales. This population was chosen because (i) individuals in this population have been tracked and studied for more than three decades, (ii) animals can be individually identified from fluke and dorsal fin photographs, and (iii) follow-up photographs after tagging can be obtained by researchers and naturalists aboard whale watching boats from spring through early fall.

HUMPBACK WHALES IN THE GULF OF MAINE

Dermal attachment tags were deployed on humpback whales during late May 2009 from the bow of the 18·3 m oceanographic research vessel *Tioga*. Five attempts were made to tag four whales near Cape Cod, Massachusetts (Table 1); this sample size was deliberately small to be precautionary. Tag attachment durations were variable: 0 min (events 1–3; owing to early problems with the tether that were solved during

Table 1. Summary of humpback whale field trials in the south-western Gulf of Maine (times are local). Note that during event 2, the tag was not launched with sufficient force, so the dermal anchor only partly implanted and was shed 5 min after attachment; hence the retagging of 'Ventisca' with a new tag during event 3

Event	Date, time and position	Needle	Individual ID	Reaction	Tag attachment duration (min)	Anchor retention time (days)
1	5/25/09 15:00 42°N 03·8′ 69°W 53·0′	Cupped rings	'Clothesline'	None	0	Unknown
2	5/27/09 11:58 42°N 05·7′ 70°W 16·3′	Cupped rings	'Ventisca'	None	0	<0·01
3	5/27/00 12:35 42°N 05·4′ 70°W 16·3′	Cupped rings	'Ventisca'	None	0	2
4	5/27/09 13:23 42°N 05·3′ 70°W 17·3′	Pins	'Ragweed'	Tail flick	84	Unknown
5	5/29/09 13:08 42°N 07·9′ 70°W 12·3′	Cupped rings	'Whisk'	None	197	5

subsequent deployments), 84 min (event 4) and 197 min (event 5). In all but one of the five tagging events, the whales showed no immediate reaction to being tagged (Table 1). The first whale tagged (event 1) was observed feeding at the surface prior to tagging and continued feeding without interruption during and after tag deployment. This animal also tolerated close boat approaches to obtain follow-up photographs of the tag site for one hour after tagging. Only during event 4 was a reaction to tagging observed. The tag was launched from behind the animal and attached at an oblique angle forward of the dorsal fin on the left flank. The animal reacted with a strong tail flick (similar to those reported for biopsying; Weinrich *et al.* 1992; Clapham & Mattila 1993). On rare occasions, we have observed similar tail flicks when approaching humpback whales in a 4·5-m rigid hulled inflatable boat for suction cup tagging.

All of the whales were monitored for at least 30 min after tagging to obtain photographs of the attachment site and to observe both behaviour and swim speeds. Swim speeds were assessed using the ship's track (derived from a global positioning receiver; GPS) and the times of photographs of the whales taken in proximity to the ship (the camera's clock was synchronized with GPS time prior to use). The whales tagged with the dermal attachment travelled at speeds comparable to humpback whales that were suction cup-tagged in the same area during July and August of 2005 and 2006 (Baumgartner *et al.* 2008): the mean swimming speed of the dermal attachment-tagged whales was 0·55 m s^{-1} (n = 5, SD = 0·17 m s^{-1}, 95% CI: 0·34–0·76 m s^{-1}) and the mean swimming speed of the suction cup-tagged whales was 0·74 m s^{-1} (n = 6, SD = 0·22 m s^{-1}, 95% CI: 0·51–0·96 m s^{-1}). On average, suction cup-tagged whales swam slightly faster than dermal attachment-tagged whales, but not significantly so (two-sample two-tailed t-test, t = 1·57, P = 0·1517). During events 4 and 5, the tag housings were mechanically detached when the whales breached (1·5 and 3·5 h after tagging, respectively) and the tether was forcibly pulled through the zinc foil upon impact with the sea surface. From examination of follow-up photographs of one of these whales, there was no evidence that the anchor was dislodged during breaching.

Photographs were obtained of the attachment site immediately after tagging in four of the five events (the exception was event 2 where the attachment site was well below the water line). During the hours after tag attachment, these photographs showed that the delrin 'stop' rested snugly against the skin with no sign of swelling, bruising, protruding tissue or damage to nearby skin. Over the week following tagging, additional photographs were taken of two of the four tagged whales (events 3 and 5). The whale tagged during event 3 shed the anchor within 2 days of tagging (Fig. 3), and the wound at the attachment site appeared to be healing well at that time with no signs of trauma. Follow-up photographs over the course of the next 3 months indicated complete healing with no long-term swelling or depression at the wound site (Fig. 3d). The whale tagged during event 5 was photographed 4, 5 and 9 days after tagging (Fig. 4). The anchor was migrating cleanly out of the skin on day 4 and was completely shed by day 5. By day 9, the wound site was virtually undetectable (Fig. 4e), and follow-up photographs collected over the next 2 months indicated complete healing (Fig. 4f).

All of the whales were re-sighted over the 3 months following tagging within 30 km of the location at which they were originally tagged, and sightings of three persisted within this radius for nearly 5 months after tagging. All were re-sighted in the same area the following year (2010). Two of the tagged whales were reproductively mature females, and both produced calves in years following the tagging. One of these females calved during 2010 and was therefore pregnant when tagged.

BOWHEAD WHALES IN THE WESTERN BEAUFORT SEA

Dermal attachment tags were deployed on bowhead whales from late August to mid-September during 2009 and 2010 near

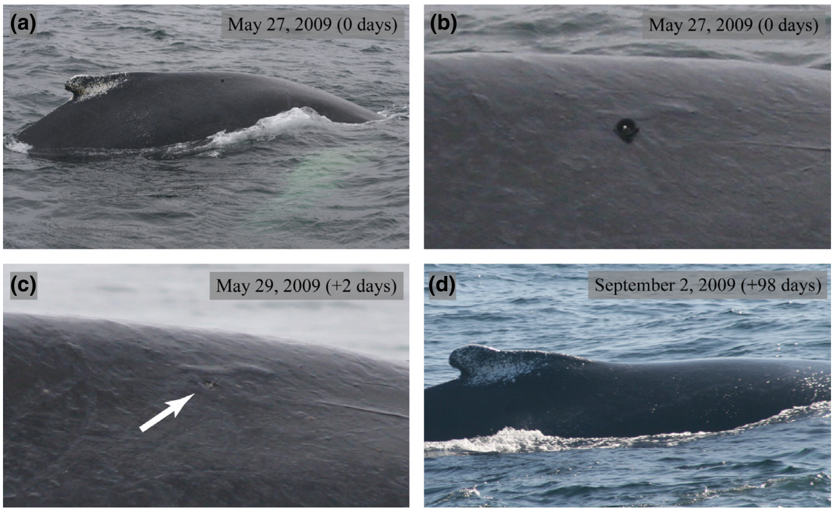

Fig. 3. Photographs of humpback whale tagged during event 3. Arrow in (c) points to wound. Photo credits: (a–c) Woods Hole Oceanographic Institution, and (d) Whale and Dolphin Conservation Society. Note that the delrin 'stop' used in event 3 was black.

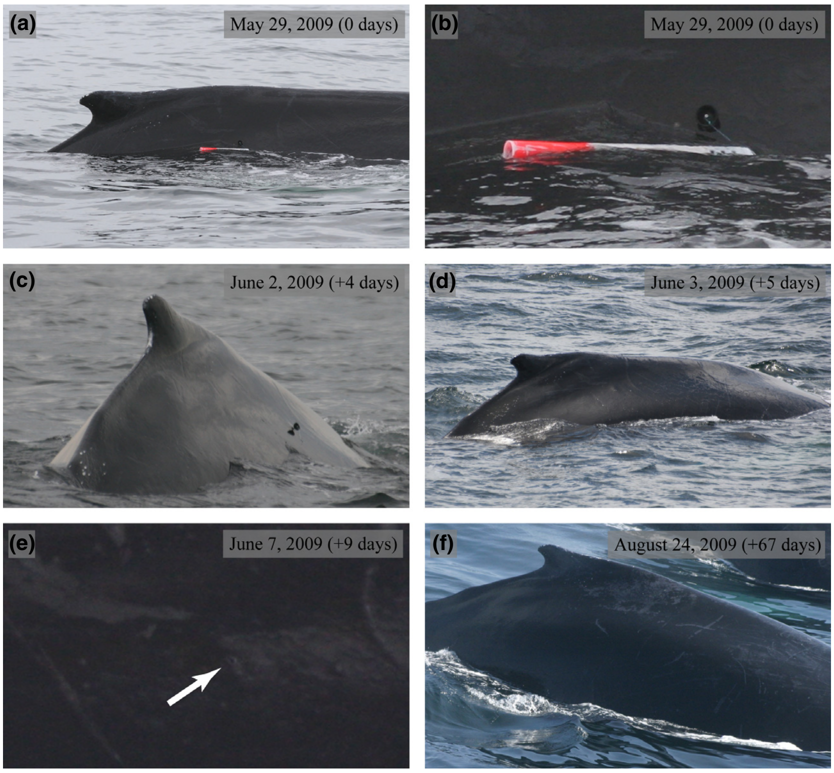

Fig. 4. Photographs of humpback whale tagged during event 5. Arrow in (e) points to wound. Photo credits: (a,b) Woods Hole Oceanographic Institution, (c,d) Whale Center of New England, (e) Provincetown Center for Coastal Studies and (f) Dolphin Fleet. Note that the delrin 'stop' used in event 5 was black.

Barrow, Alaska. During 2009 and the first half of the 2010 field season, needles with cupped rings in lengths of either 6·5 or 7·5 cm were used with variable, but generally quite poor, results (Table 2, Fig. 5a–f). During some deployments, this needle was observed to fully penetrate, but then immediately exit the skin and blubber (note that this same needle was used on humpbacks with far better anchor retention times). Six bowheads whales were tagged with the cupped ring needle design, and the tag housing detached from these whales after 11–291 min (median = 24 min, Table 2). In all of these cases, detachment was caused by shedding of the dermal anchor such that the tag was recovered with the dermal anchor still tethered to the tag housing. During the latter half of the 2010 field season, we switched to 7·5-cm needles with stainless steel pins, and retention improved significantly (Table 2, Fig. 5g–l). Six whales were tagged with the needle featuring the stainless steel pins, and the tag housing detached from these whales after 45–137 min (median = 116 min, Table 2). In all of these cases, the tag housing separated from the dermal anchor via the corrosive release as planned, and the dermal anchor remained implanted in the whale after detachment of the tag housing. The original study design called for tag attachments of 1–2 h (after Baumgartner & Mate 2003), so these deployments were considered successful. All tag deployments were made at faster approach speeds or longer distances than that which is feasible for pole deployment of suction cup tags.

Table 2. Summary of bowhead whale tagging events near Barrow, Alaska (times are local)

Year	Event	Date, Time & Position	Needle	Reaction	Tag attachment duration (min)	Anchor retention time (days)	Figure 5 panel
2009	1	09/02/09 15:21 71°N 21·7′ 155°W 21·9′	Cupped rings	None	31	0·02	a
2009	2	09/07/09 12:48 71°N 22·3′ 155°W 29·0′	Cupped rings	None	24	0·02	b
2009	4	09/13/09 13:49 71°N 24·8′ 156°W 01·3′	Cupped rings	None	11	<0·01	c
2009	5	09/13/09 18:34 71°N 24·2′ 156°W 18·5′	Cupped rings	None	291	0·2	f
2010	3	09/09/10 13:20 71°N 30·2′ 155°W 18·2′	Cupped rings	None	12	<0·01	d
2010	4	09/16/10 09:12 71°N 22·90′ 156°W 00·4′	Cupped rings	None	11	<0·01	e
2010	5	09/16/10 10:48 71°N 20·7′ 155°W 47·8′	Pins	Tail flick	65	Unknown	j
2010	6	09/17/10 13:56 71°N 22·3′ 156°W 15·0′	Pins	None	137	Unknown	h
2010	7	09/17/10 17:09 71°N 24·0′ 155°W 55·6′	Pins	None	45	Unknown	g
2010	8	09/18/10 12:23 71°N 24·5′ 156°W 08·2′	Pins	None	88	Unknown	k
2010	9	09/18/10 14:53 71°N 22·4′ 155°W 48·9′	Pins	Fluke slap	129	Unknown	i
2010	10	09/19/10 15:28 71°N 18·8′ 155°W 13·1′	Pins	None	116	Unknown	l

There were very few reactions to the tagging process; on one occasion, the tagged whale made a tail flick in response to the carrier rocket falling on its peduncle, and on another occasion the tagged whale resurfaced within a minute of tagging and slapped the sea surface with a pectoral fin. In all other cases, the whales showed no overt reaction to tag deployment. However, many whales made a long dive immediately after tagging. Of the eight whales that carried the tag for 30 min or more, five spent 4·0–10·0 min submerged immediately after tagging, whereas the remaining three whales had first dive times of only 0·3–1·2 min. Of the five whales that had long first dives, three of these first dives were significantly longer than subsequent dives observed over the course of the first hour. These results suggest that the immediate reaction to small boat approach and tagging is relatively mild and varies among individuals.

To assess the response to tagging over the first few hours of attachment, respiration rates were measured for each tagged whale using surfacing data from the TDR. These rates were then compared between the first and second hour of attachment. The surfacing during which the tag was attached was not included in these calculations. Respiration rates for the tagged animals were also compared to the respiration rates of undisturbed bowheads. Undisturbed rates were observed for four bowheads on 10 September 2010 over the course of an hour from a stationary small boat whose engine was shutdown for 30 min prior to respirations being recorded. Undisturbed individuals were each monitored for 5·5–22 min. For the five whales tagged for roughly 1·5 h or more, respiration rates for the first hour of attachment were significantly higher than for the second hour of attachment (paired one-sample two-sided *t*-test: $n = 5$, average difference = 0·39 blows min^{-1}, $t = 5{\cdot}55$, $P = 0{\cdot}0052$). Respiration rates for the tagged whales averaged 1·79 blows min^{-1} during the first hour ($n = 5$, SD = 0·336 blows min^{-1}) and 1·41 blows min^{-1} during the second hour ($n = 5$, SD = 0·327), whereas undisturbed bowheads averaged 1·29 blows min^{-1} ($n = 4$, SD = 0·191 blows min^{-1}). Respiration rates during the first hour of tag attachment were significantly higher than those of the undisturbed whales (two-sample two-tailed *t*-test: $t = 2{\cdot}65$, $P = 0{\cdot}0328$), but there was no significant difference between respiration rates for the undisturbed animals and those observed during the second hour of tag attachment (two-sample two-tailed *t*-test: $t = -0{\cdot}633$,

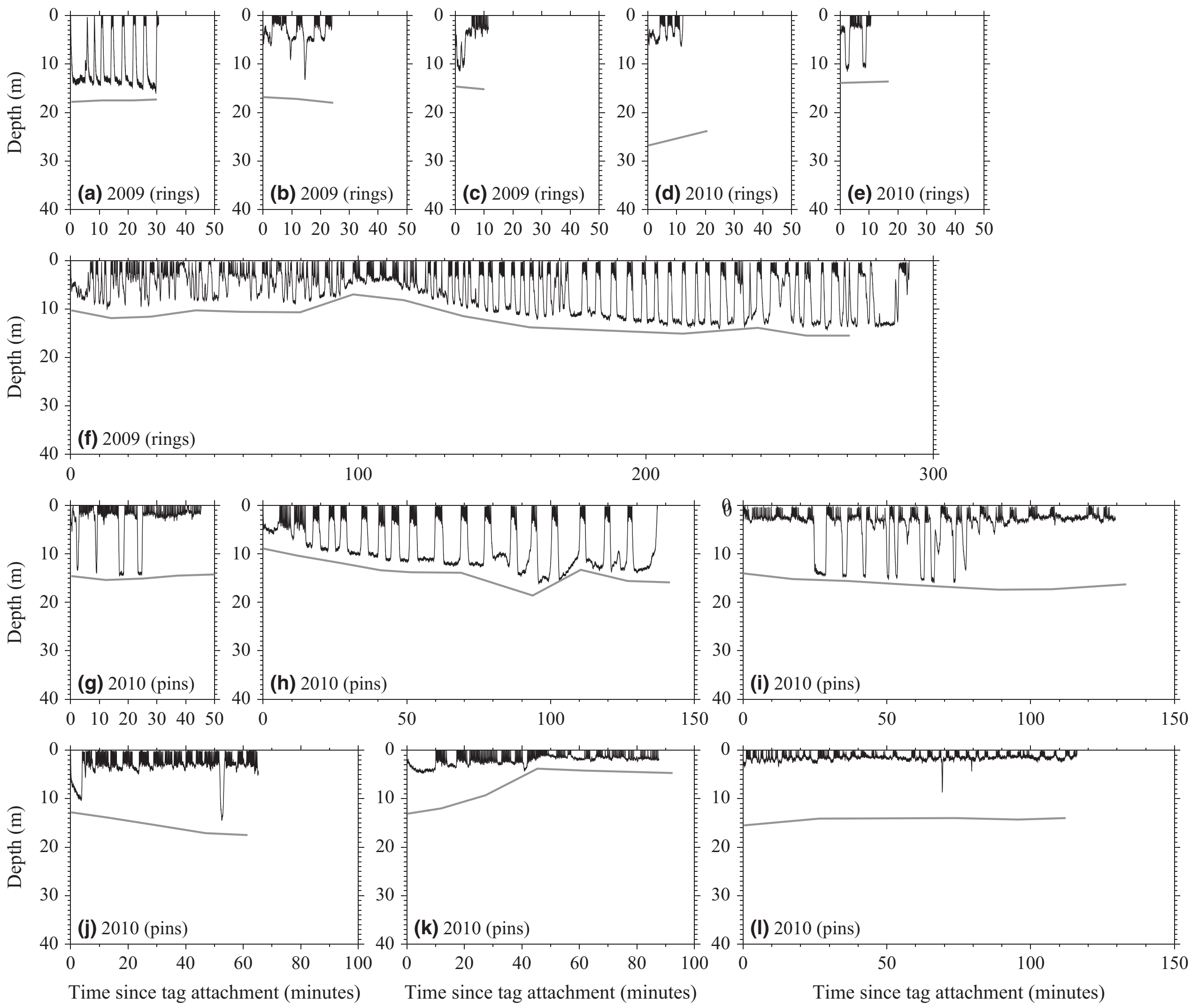

Fig. 5. Dive profiles for all bowhead whale deployments using (a–f) needles with cupped rings and (g–l) needles with stainless steel pins. Grey line indicates the sea floor. Tags using needles with cupped rings detached prematurely because the dermal anchor was shed from the whales' dermis. Tags using needles with stainless steel pins detached via the corrosive release.

$P = 0{\cdot}5470$; note low power of this test). After 1·5 h had elapsed since tag attachment, average respiration rates for the tagged whales and the undisturbed whales were nearly identical (tagged: $n = 4$, average = 1·24 blows min^{-1}, SD = 0·300; undisturbed: $n = 4$, average = 1·29 blows min^{-1}, SD = 0·191; two-sample two-tailed *t*-test: $t = 0{\cdot}310$, $P = 0{\cdot}7669$). These results suggest that the response of bowhead whales to close approach and tagging lasts for up to 1–1·5 h, but afterwards, the whales' surfacing behaviour is similar to undisturbed whales. This time scale of response appears to be longer than that observed for suction cup-tagged North Atlantic right whales, whose first feeding dive immediately after tagging was 15% shorter on average than subsequent dives (average duration is 12·2 min), but no response was apparent afterwards (Baumgartner & Mate 2003).

We found that bowhead whales were difficult to approach after tag attachment without disturbing their behaviour, and because the goal of our study was to observe natural behaviour, no follow-up photographs of the attachment site were collected. Moreover, owing to the remoteness of their habitat, there is no concerted photographic monitoring of this population. Therefore, we were unable to conduct a follow-up study to determine the duration of anchor attachment (i.e. anchor retention time) or the condition of the wound site over time.

Discussion

From our field trials with humpback whales and the subsequent photographic documentation of the tag attachment site, the dermal anchor appears to be reasonably benign. Our selection of a well-studied humpback whale population off Massachusetts and the small sample size was by design, allowing us to proceed cautiously by closely monitoring the outcome of a few trials. In the two best-monitored cases, anchors were shed in 2 and 5 days, and the wound site appeared in very good condition over time scales of days to months after tagging. Re-sightings for all humpback whales and calving events for known mature females indicate that the dermal attachment has no discernible effect on long-term behaviour and reproduction. While it is nearly impossible to study the wound site in detail, we believe that the needle design (cutting blades with vents that may preserve epidermal tissue) and sterilization of the anchor prior to use may improve health outcomes for the tagged whales.

Reactions to boat approach and tagging varied widely among individuals and between species. Both humpbacks and bowheads appeared to tolerate tag deployment well; overt reactions were uncommon, and when observed, were mild. Immediately after tagging, we observed long dives and increased respiration rates in some bowhead whales, which suggests that the tagging process may be stressful for this species. However, respiration rates returned to levels observed in undisturbed animals within 1–1·5 h of tagging. In contrast to bowhead whales, no behavioural changes were observed in response to the tagging process for humpback whales. The differences in behaviour between the two species may be related more to the animals' experience with boats than to the attachment of the tag itself. In the Gulf of Maine, humpback whales are exposed to a wide variety of commercial and recreational vessels, and are regularly approached by commercial whale watch vessels and pleasure boats. In contrast, bowhead whales encounter significantly less vessel traffic. It is plausible, therefore, that bowheads could be more reactive to any close boat approach, so studies such as ours that seek to study natural behaviour must use tag attachments of sufficient duration to allow whales time to recover from the initial stress of the tagging process.

FUTURE DIRECTIONS

Our primary objective in tagging humpback whales was to study the effects of the dermal attachment over time scales of hours to months; however, we also observed behaviours during the time that the tag was attached that may limit the effectiveness of the tag design presented here. In particular, the tag was mechanically detached when the humpbacks tagged in events 4 and 5 breached. None of the tags affixed to bowhead whales were detached because of the whales' behaviour, and Goodyear (1993) similarly reported no overt response or removal of tethered tags by North Atlantic right whales. We do not know the specific cause of breaching in the humpback cases, but note that it is a well-documented behaviour in humpback, bowhead and right whales. Thus, any tag attached for more than a few hours is at risk of mechanical detachment.

The freely floating tag housing can easily come in contact with the whale's skin, and some species or individuals may be sensitive to this stimulus such that it alters their natural behaviour. To mitigate this potential irritation, a more rigid attachment similar to the Andrews, Pitman & Balance (2008) satellite tag would be useful. Such an attachment is challenging to engineer, however, because unlike satellite-transmitting tags, tags for short-term monitoring of diving and foraging behaviour must be recoverable (and therefore detachable) and equipped with instrumentation that allows tracking at high temporal and spatial resolution (e.g. tens to hundreds of seconds, tens to hundreds of metres), such as radio or acoustic transmitters. Future development of the dermal attachment tag should include efforts to minimize intermittent contact, either by rigidly holding the tag against the whale's skin, or by suspending the tag above the whale's skin.

The dermal attachment tag provides a suitable alternative to suction cup archival tags for short-term studies when whales have irregular skin, are particularly evasive, are rare or in situations where pole tagging is difficult (e.g. moderate seas or very fast approaches). Additionally, the dermal attachment appears capable of significantly longer deployment durations than is currently allowed by suction cups. Traditional tagging studies of cetaceans have focused primarily on two disparate time scales, short (hours) or long (weeks to months), by using suction cup and satellite tags, respectively. For species that can carry this tag for extended periods of time, the dermal attachment may provide access to a time scale that has been poorly addressed in baleen whale behavioural studies: daily. We envision tagging studies with simultaneous observations of conspecific behaviour, oceanographic conditions and prey distribution collected over 1–2 day periods that can address hypotheses about diel changes in behaviour, build much-needed activity budgets or simply inform us of important night-time behaviours. All short-term tagging studies of baleen whales are conducted primarily during daylight hours, but the bias this introduces into our understanding of behaviour or activity budgets is rarely discussed (some studies have tagging events that extend into night-time hours, but not reliably so, e.g. Friedlaender *et al.* 2009). The dermal attachment tag could enable studies that specifically address this important gap in our understanding of baleen whale ecology.

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Data accessibility

No data are archived because all of the data used in this article are present in the article.

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