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COMPARISON OF REMOTELY DEPLOYED SATELLITE RADIO TRANSMITTERS ON WALRUSES

CHADWICK V. JAY
U.S. Geological Survey, Alaska Science Center,
4230 University Drive, Suite 201, Anchorage, Alaska 99508, U.S.A.
E-mail: chad_jay@usgs.gov

MADS PETER HEIDE-JØRGENSEN
Greenland Institute of Natural Resources,
c/o Danish Polar Center, Strandgade 100H,
DK-1401 Copenhagen K. Denmark

ANTHONY S. FISCHBACH
U.S. Geological Survey, Alaska Science Center,
4230 University Drive, Suite 201, Anchorage, Alaska 99508, U.S.A.

MIKKEL V. JENSEN
Mikkels Værksted, Gislingevej 2, DK-4571 Grevinge, Denmark

DAVID F. TESSLER[1]
U.S. Geological Survey, Alaska Science Center,
4230 University Drive, Suite 201, Anchorage, Alaska 99508, U.S.A.

ANDERS V. JENSEN
Mikkels Værksted, Gislingevej 2, DK-4571 Grevinge, Denmark

Walruses spend most of their lives at sea, but frequently haul out on land or ice to rest (Fay 1982). Past aerial surveys of the Pacific walrus (*Odobenus rosmarus divergens*) were designed to count hauled-out animals, but did not adequately account for animals in the water (Gilbert 1999). This availability bias might be estimated in future surveys by simultaneously sampling walrus haul-out behavior with satellite radio telemetry. However, current techniques for attaching transmitters to walruses involve chemical immobilization (Born and Knutsen 1992, Wiig *et al.* 1996, Jay and Hills 2005). This is time-consuming and dangerous because darted walruses can enter the water and drown when the immobilizing drug takes effect.

Remotely attaching tags on walruses would eliminate the need for capture, and make it possible to deploy a large number of transmitters quickly and safely. Tags that anchor subdermally into the animal's blubber have been remotely deployed on cetaceans (Mate *et al.* 2000; Heide-Jørgensen *et al.* 2001*a*, *b*, 2003). Similar tag designs may be suitable for walruses. Subdermal tagging of walruses was attempted in the 1950s–1960s, but was largely ineffective (Appendix). However, the combined

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[1] Current address: Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska 99518, U.S.A.

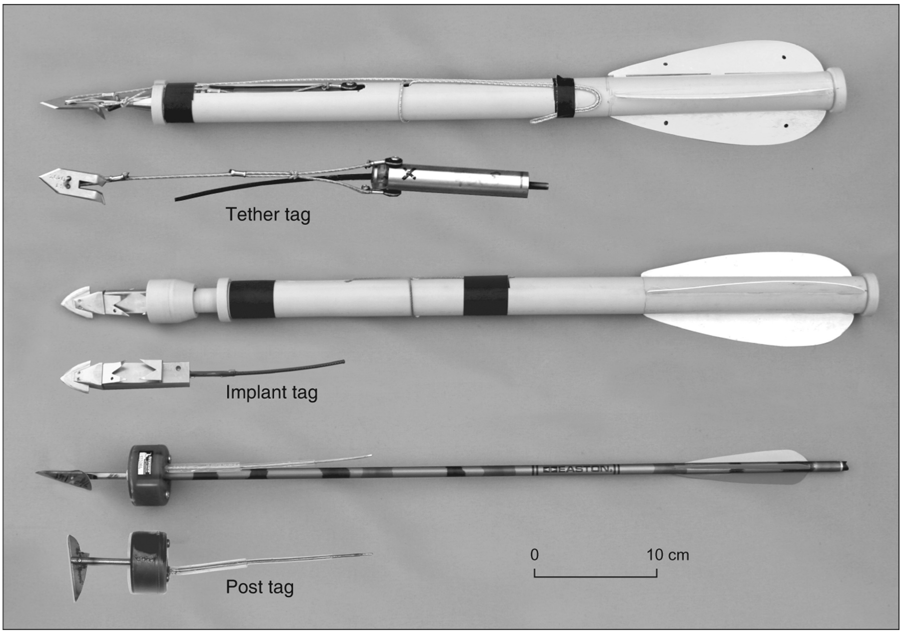

Figure 1. Three remotely deployed walrus tag designs—tag pictured alone and fitted in its projectile.

thickness of walrus skin and blubber (roughly 6 cm at the dorsal shoulder region of adults) should be sufficient for subdermal anchoring of small tags. We compared the functional longevity and transmission performance of three tag designs (tether, implant, and post tag) that were remotely deployed on free ranging Pacific walruses in the southeastern Bering Sea in spring of 2004.

Tether tags were cylindrical transmitters attached to the walrus with a flat 1.8 × 6.0 cm harpoon head and 15-cm long braided nylon line (Fig. 1, Table 1). They were delivered in a cylindrical projectile shot from a modified air gun (Air Rocket Transmitter System, Heide-Jørgensen *et al.* 2001*a*). The harpoon head was driven into the blubber of the walrus by a detachable post on the projectile and was designed to toggle into a lateral position when flanges on its distal end were engaged by the hydrodynamic drag of the transmitter. The projectile fell away from the tag upon impact and floated so it could be recovered and reused.

Implant tags were flat, rectangular transmitters held in the blubber and skin of the walrus by broad, flexible, backward-projecting stainless steel fins (Fig. 1, Table 1). They were delivered the same way as the tether tags. The tag had a cutting blade at the tip that facilitated its entry, and broad flexible forward-projecting fins near its distal end to prevent over penetration. Upon attachment, only the distal 2 cm of the tag remained exposed to the outside of the animal.

Post tags were puck-shaped transmitters attached to the walrus with a pivoting harpoon head mounted on a 6.0 cm × 0.6 cm stainless steel post (Fig. 1, Table 1).

Table 1. Characteristics of transmitters used in three different remotely deloyed walrus radio tags.

	Tag design		
	Tether	Implant	Post
Model, Manufacturer	Spot 3.0, Wildlife Computers, Redmond, WA	Spot 3.0, Wildlife Computers, Redmond, WA	ST-24, Telonics Inc., Mesa, AZ
Transmitter dimensions (excluding antenna)	2.0 × 10.5 cm cylinder	2.0 × 1.0 × 9.6 cm rectangular bar	5.2 × 2.8 cm puck-shaped disc
Approximate transmitter weight in air	122 g	74 g	91 g
Transmission duty cycle	18 h on 6 h off	none	none
Transmission output power	0.50 W	0.50 W	0.25 W
Transmission repetition interval	45 s	45 s	60 s
Message length	16 bytes	16 bytes	31 bytes
Delivery system	air gun[a]	air gun[a]	crossbow

[a] Air Rocket Transmitter System (Heide-Jørgensen *et al.* 2001*a*).

They were delivered with an arrow (2315 Lite Easton aluminum shaft filled with a solid fiberglass rod) that fit loosely into the rear of the transmitter and was shot from a recurve (Excalibur, Exocet model, ~1.06 J work, 19 tags) or compound crossbow (Barnett, Revolution, ~1.72 J work, 1 tag). The harpoon head was driven into the blubber of the walrus and was designed to pivot into position from the hydrodynamic drag of the transmitter.

All tags had a conductivity sensor that detected whether or not the transmitter was submerged in seawater to infer whether the animal was in water or hauled out. Transmissions were suspended whenever the tag was submerged to conserve battery life. All tags had battery capacities that would allow transmissions for at least 3–4 wk.

Alaskan hunters and government resource personnel were asked to provide details of the status of the tagging wound and condition of the tag if they encountered a tagged walrus.

The tether tags measured conductivity every 10 s. The percentage of dry measurements that occurred during a given 60-min interval was recorded using one of 13 percentage classes (0%, 0%–5%, 5%–15%, . . . , 85%–95%, 95%–100%, and 100%). Information on the most recent 24 60-min intervals was encoded into 12 bytes of data and stored, with four additional bytes of ancillary data, in one of 12 memory buffers. Data buffers were transmitted sequentially. After all 12 buffers were transmitted, a 13th transmission reported the transmitter's status (battery voltage, temperature, and number of previous transmissions) and the transmission process started over again. The tags were duty cycled 18 h on and 6 h off to conserve battery life.

The software configuration of the implant tags were identical to the tether tags, except the transmissions were not duty cycled.

The post tags measured conductivity every second. The percentage of dry measurements that occurred during a given 20-min interval was recorded using one of two percentage classes (0%–90%, and ≥90%). Each satellite transmission contained data of the most recent 240 20-min intervals (1-bit per interval plus one additional byte of ancillary data). The post tag did not report battery voltage, nor were the transmissions duty cycled. Ice charts (http://www.natice.noaa.gov/products/alaska/index.htm, Dedrick *et al.* 2001) and tracking data from two walruses that moved into Bristol Bay were used to determine times when the animals were far offshore and in supposed ice-free waters and compared to the haul-out status indicated by the conductivity data. Similar comparisons for times when the animals were known to be hauled out were not possible because, even though locations near land could be identified, errors associated with Argos location estimates (Service Argos 1996) made it impossible to identify haul-out episodes with certainty.

Walruses were tagged while they were hauled out on ice floes. Most were tagged from distances of 10–15 m from shooters in 7-m skiffs. We targeted the animal's mid-dorsal line, slightly forward of the shoulders. Ten, five, and twenty of the tether, implant, and post tags were deployed on about an equal number of adult males and females.

The functional longevity of the tags was defined as the time between tag deployment and the last transmission received, provided that the transmission occurred within 10 d of a previously received transmission. Changes in battery voltage from the tether and implant tags were examined for evidence of battery exhaustion.

Transmission performance was compared among tag designs by contrasting mean satellite reception rates, locations per day, ratio of in-water to out-of-water reception rates, signal strengths, and percentage of high-quality locations. For these comparisons we used all data from the tether tags and data from the implant and post tags that corresponded to the on-period of the tether tags' duty cycle (0600–2300 UTC). Of note, the duty cycle of the tether tags was inadvertently set incorrectly. To maximize the view of multiple satellites in our study area, the on-period should have been set for 1600–0900 UTC. Nevertheless, this oversight does not affect these comparisons.

Satellite reception rates were calculated from the number of transmissions received (from Service Argos dispose files) per scheduled transmission (calculated from transmission duty cycle and repetition rate, Table 1). This accounted for differences in repetition rates between transmitters. Locations per day were calculated from locations with a Service Argos location quality of ≥B. The ratio of in-water to out-of-water reception rates was the ratio of the rate of satellite receptions achieved when the walrus was determined to be in water to the reception rate when the walrus was determined to be out of water. In-water and out-of-water determinations were made from the conductivity data.

Software written in SAS (SAS Inc., Cary, NC) and by Wildlife Computers (Redmond, WA) was used to decode the downloaded data and reconstruct the haul-out chronology of each animal based on the conductivity summaries. For the tether and implant tags, each chronology was a string of 60-min intervals. If the percentage of dry time for a given interval was ≥85% then the animal was considered to be hauled out during that interval. For the post tags, each chronology was a string of 20-min intervals. If the percentage of dry time during a given interval was ≥90% then the animal was considered to be hauled out during the interval.

The extent of missing data from the haul-out chronologies was summarized from the data collected during the first 14 d of tag deployment from tags that were functional for at least this long.

Haul-out chronologies from two walruses equipped with tether tags and tracked into Bristol Bay suggest that the tags accurately measured in-water status. The tracking data contained one day of offshore (>85 km) locations from one walrus, and nine days of offshore (>21 km) locations from the other walrus during ice-free conditions in the bay. The haul-out chronologies correctly indicated in-water status during these times.

The median functional longevity of the tether tags was about twice that of the implant and post tags (Fig. 2). The tether and implant tags were active on walruses for at least 14 d, whereas almost half of the post tags failed within that time. Functional longevity of both tether and post tags was quite variable.

A precipitous drop in battery voltage was observed from all five implant tags approximately 1–6 d before they failed, suggesting the failures were caused by battery exhaustion. The tether tags provided too few battery voltage measures to determine their voltage trends.

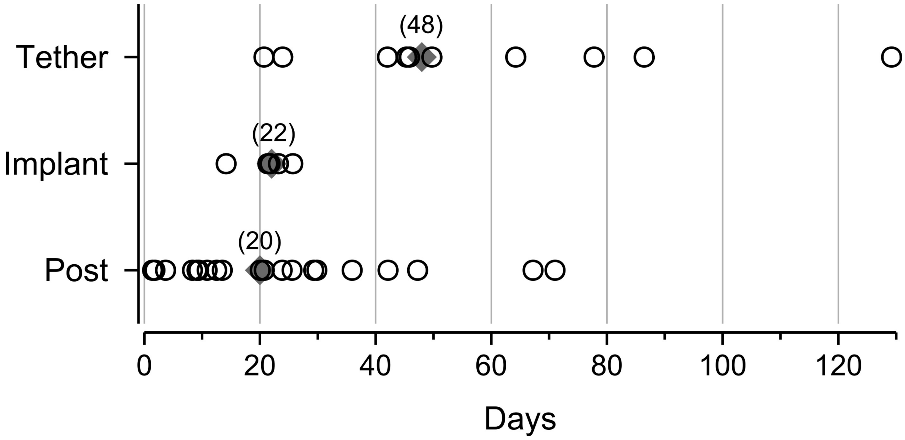

Figure 2. Functional longevity of remotely deployed walrus tags of three designs (circle = time from deployment to last transmission received from an individual tag, filled diamond = sample median).

An unidentified implant tag was observed on an animal on a beach in Bristol Bay, 102 d after the last implant tag was deployed. The tag was still implanted to its original depth, but its antenna was broken off. The surrounding skin did not appear swollen, but was stained with a serosanguinous exudate.

There were large differences in transmission performance among tag designs (Table 2). Satellite receptions per scheduled transmission, locations per day, and the ratio of in-water to out-of-water transmission rates were highest from the implant tags, followed by the post, then the tether tags. This was coincident with higher signal strengths from the implant tags than from the other two tag designs. Overall, transmission performance from the tether tags was poor.

The mean proportion of high-quality locations (Service Argos LC $\geq$ 1) did not differ significantly among tag designs (Table 2). The mean of the mean proportion of high quality locations across designs was 32%.

Walruses were tracked for distances up to 1,500 km. Up to 78 d of haul-out behavior data were collected from each animal (mean = 29 d), including periods of uninterrupted chronologies of up to 66 d (Fig. 3). Most of the gaps that occurred in the chronologies came from the tether tags. For example, during the first 14 d of tag deployment, gaps in haul-out chronologies occurred from 8 of 9 tether tags, but from only 1 of 11 post tags, and 0 of 4 implant tags (Table 3). During the same period, the mean proportion of unrecovered chronology data from the tether tags (18%) was orders of magnitude higher than that from the implant and post tags.

Several decades ago, researchers used three types of subdermally anchored tags and hand-held harpoons to mark several hundred walruses for resighting studies (Appendix). During those studies only three tags were ever resighted. Those efforts were apparently ineffective, and no further attempts to remotely apply tags on walruses have since been reported.

Table 2. Transmission performance of three remotely deployed walrus tag designs. For comparative purposes, all measures from the implant and post tags were derived from data corresponding to the on-period of the duty cycle of the tether tags (0600–2300 UTC).

Tag design		Satellite receptions per scheduled transmission (10^{-3})	Locations per day[a]	Ratio in-water to out-of-water reception rates	Signal strength (dB)[b]	Percent high quality locations[c]
Tether	Mean ± 2 SE	3	1.2	0.102	−133.0	34
($n = 10$)		2–4	0.9–1.5	0.014–0.019	−133.2–132.7	27–39
Implant	Mean ± 2 SE	44	17.3	0.406	−128.3	26
($n = 5$)		26–62	9.6–25	0.090–0.722	−128.9–127.8	16–36
Post	Mean ± 2SE	23	6.9	0.223	−132.2	37
($n = 20$)		17–29	4.9–8.9	0.133–0.313	−132.7–131.7	29–45

[a] Locations per day for the post and implant tags without the imposed artificial duty cycle were about 1.5 times these values.

[b] Strongest signal strength received as reported in the Service Argos diagnostic files (Service Argos 1996).

[c] High quality = Service Argos location classes ≥ 1.

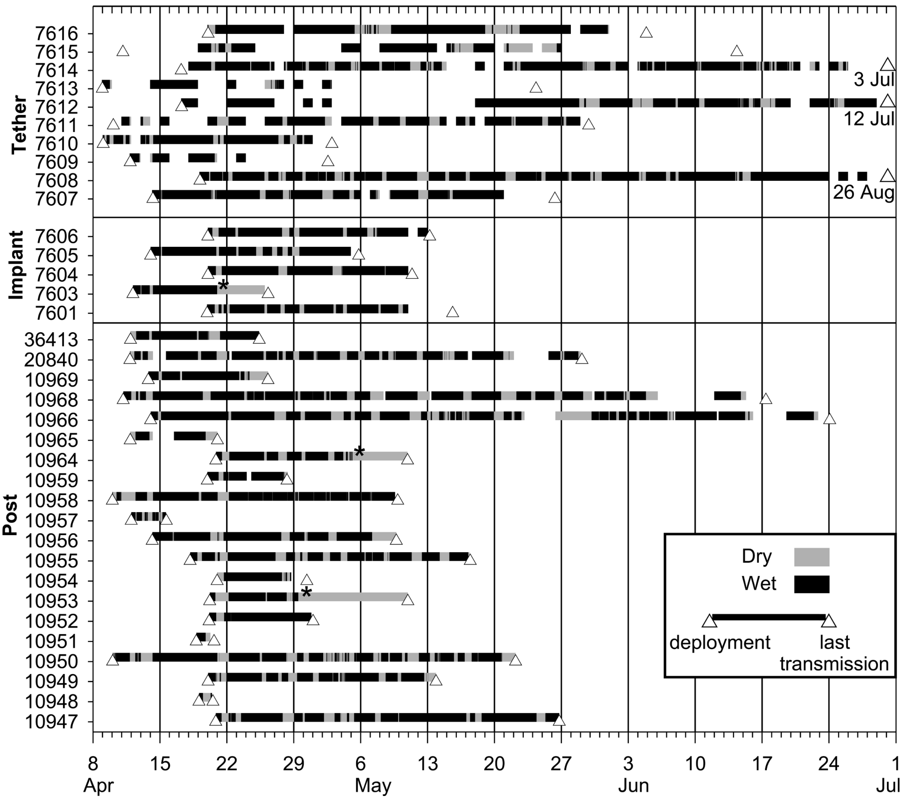

Figure 3. Haul-out chronologies from 35 tagged walruses based on conductivity data from spring 2004, southeast Bering Sea (* = anomalously long dry period at the end of the haul-out chronology, which suggests the tag may have malfunctioned or became detached from the animal on land or ice).

It was not possible to fully determine the causes of tag failures in the current study, partly because the tagged animals were in very remote areas, and except for one animal, they were never resighted. The implant tags apparently failed from battery exhaustion. The wide range in functional longevity of the tether and post tags suggest that battery exhaustion was not the principal cause of failures in these

Table 3. Summary of gaps in haul-out chronologies from sensor data during the first 14 d of tag deployment.

Tag design	*n*	Average % missing chronology (mean, minimum–maximum)
Tether	9 (8 with gaps)	18, 0–50
Implant	4 (0 with gaps)	0, —
Post	11 (1 with gaps)	1, 0–11

tags; however, beyond this, we could not distinguish between failures that may have been caused by antenna breakage, transmitter damage, or tag loss.

The missing antenna from the resighted implant tag (>102 d post-deployment) suggests that antenna breakage may be a problem for these and other tags. The condition of the animal's wound from the same tag indicates that the tag was not abscessed, and that it was in the process of being extruded from the skin. This resighting suggests that retention of the implant tags may have far exceeded their battery lifespan and perhaps antenna integrity.

The flexible attachment of the tether tag may alleviate damage to the tag's antenna, but is probably responsible for the tag's poor transmission performance from antenna misalignment. In contrast, the antenna of the post and implant tags were directed almost perpendicular from the surface of the animal (as observed upon initial deployment). The higher signal strength and superior transmission performance from the implant tags compared to the post tags may have been partially due to their higher output power (0.50 W compared to 0.25 W from the post tags) and warmer operating environment afforded by the animal's surrounding tissues.

Tracking observations from the two walruses with tether tags in Bristol Bay suggest that in-water determinations from the conductivity sensor were accurate. However, similar data were not available to determine the concordance between out-of-water determinations from the conductivity sensor with times when the animal was known to be hauled out. We expect that these errors occurred infrequently because a "false" in-water determination for a given sampling interval could occur only if the tag lay in saltwater on the haul-out for >9 min of the 60-min sampling intervals in the case of the tether and implant tags, or >2 min of the 20-min sampling intervals in the case of the post tags.

The amount of haul-out chronology data that was obtained from all three tag designs was encouraging. Although there were considerable gaps in chronologies from some of the tags (primarily the tether tags), it is likely that changes in data storage and transmission protocols can alleviate these gaps. For the tether tags, these might include storage and transmission of longer periods of haul-out information. Duty cycling the transmissions from the implant tags would increase their battery life and may increase their functional longevity in future deployments.

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Appendix. Tags with subdermal anchors used in past walrus studies. All were visual tags and deployed with a pole.

Tagging date	Tag type	Where	Number deployed	Number resighted	Maximum retention duration	Reference
July–August 1954–1956	pyramid-shaped anchor head with shaft and external numbered disc	Coats Island, Canada	115	0	unknown	Mansfield (1958)
August–September 1954	toggle harpoon head with numbered disc attached by short chain	Bencas, Coats, and Southhampton islands, Canada	32	3 (from hunt)	~1.5 mo	Loughrey (1959)
July 1963	2-edged anchor head with shaft and external numbered disc	Rudder Spit, Russia	500	0	unknown	Krylov (1965)