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The First Satellite Flipper Tag Deployments on Steller Sea Lions Allow Tracking Beyond the Annual Molt

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ABSTRACT

Entanglement in marine debris and fishing gear is increasingly recognized as a serious source of human-caused mortality for pinniped population world-wide and has been shown to contribute to Steller sea lion injury and mortality. As such, our primary goal in testing these location-only satellite flipper tags was to track post-entanglement response survival of Steller sea lions in Southeast Alaska, USA. The minimum data set necessary to determine post-release survival included: (a) location data sufficient to demonstrate movement indicating the tag was still attached to a live sea lion, and (b) tag endurance sufficient to track a dis-entangled sea lion beyond the molt (most entanglement response occurs during the summer in conjunction with other Steller sea lion research so tags glued to the pelage typically only last two to three months before falling off). For this study, we tested Wildlife Computers (Redmond, Washington, USA) Smart Position and Temperature (SPOT) 6 Model 371B inline satellite tags (SPOT 6 tags) on Steller sea lions. This first application of attaching SPOT 6 satellite flipper tags on otariids was a success with tags transmitting up to 2.05 years. Overall, the benefits of these tags outweighed their limitations and for the first time, allowed us to track Steller sea lions beyond the annual molt.

Advances in satellite technology have yielded valuable information on movements, dive behavior, and foraging range of the Steller sea lion (*Eumetopias jubatus*) (Lander et al. 2009; Pitcher et al. 2005; Raum-Suryan et al. 2004; Rehberg et al. 2018, 2009; Rehberg and Burns 2008). However, most satellite tags are secured to the hair of pinnipeds using fast-curing adhesives (epoxies, urethanes, cyanoacrylates) (Horning et al. 2019), which, if not recoverable after deployment, limit data collection because tags detach during the late summer/early fall molting period (Raum-Suryan et al. 2004). To combat this issue, we tested a satellite transmitter attached to the webbing of the foreflipper of the Steller sea lion. These tags have been successfully used on the webbing of the rear flipper of phocids (London et al. 2024) but this was the first application of these tags on an otariid. Because otariids have rotatable rear flippers allowing quadrupedal locomotion on land, tags attached to rear flippers would have greater potential for damage or loss. Rear flipper attachment on phocids, by comparison, has been successful because phocids move on land by undulating their bodies with no use of their hind flippers. Otariid front flippers are used for stability during on-land locomotion, and these larger front flippers allow for a durable tag attachment site below the armpit but above the surface of the flipper that makes contact with land.

We tested the efficacy of these flipper tags on Steller sea lions that we disentangled from marine debris and fishing gear in Southeast Alaska, USA. Entanglement in marine debris and fishing gear is increasingly recognized as a serious source of human-caused mortality for pinniped population worldwide (Kühn and van Franeker 2020) and entanglement in marine

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debris and fishing gear has been shown to contribute to Steller sea lion injury and mortality (De la Barcenas- Cruz et al. 2018; Perez 2006; Raum-Suryan et al. 2009; Raum-Suryan and Suryan 2022). As such, our primary goal in using satellite tags was to track the survival of Steller sea lions after they had been disentangled. The minimum data set necessary to determine post-release survival included: (a) location data sufficient to demonstrate movement indicating the tag was still attached to a live sea lion, and (b) tag endurance sufficient to track a disentangled sea lion beyond the molt (most entanglement response occurs during the summer in conjunction with other Steller sea lion research so tags glued to the pelage typically only last 2 to 3 months before falling off). For this study, we tested Wildlife Computers (Redmond, Washington, USA) Smart Position and Temperature (SPOT) 6 Model 371B inline satellite tags (SPOT 6 tags) on Steller sea lions. SPOT 6 tags weigh approximately 50 g and are 73 mm long, 17 mm wide, and 42 mm high. Tag posts are 21 mm long and 7 mm wide (Figure 1).

Tags were required to: (a) transmit location data and tag operational status, only while on land (we disabled data uplink while in at-sea mode to extend battery life and because the flipper-mounted tags would be usually submerged while at-sea), (b) transmit at low rates to conserve battery life but sufficient to provide sea lion locations once per 7–14 days at minimum, and (c) provide location accuracy of the Argos satellite system of class 0 or better (approximate accuracy plus or minus 1000 m or better Easting and Northing) sufficient to identify clusters of sea lion locations at one of the known sea lion haulouts in the study area.

Because SPOT 6 tags were designed by Wildlife Computers for ice-obligate pinnipeds, for which a 20,000+ transmission longevity was expected, we first needed to test the efficacy of the tags on an ice-free substrate before testing on our species of interest, the Steller sea lion, as battery life was expected to be affected by substrate. Battery exhaustion prior to 7000 transmissions was expected because these tags draw more current per transmission on a rocky substrate than over an ice substrate. Therefore, Wildlife Computers requested we test SPOT 6 tags on a rocky substrate similar to that of Steller sea lion haulouts, providing test data to help improve transmission efficiency for our subsequent live animal tagging effort. To do this, we attached a SPOT 6 tag to a flipper from a sea lion carcass. We used a measuring tape perpendicular to the water line to place the flipper with the operational tag on the rocky substrate at various distances from the water's edge (i.e., 0, 3, 8, 14, and 45 m) and in various orientations (flipper lying flat on the ground or positioned vertically with the transmitter approximately 30–38 cm from the ground). We shared the 4 h of transmission data with Wildlife Computers engineers to help improve the tag transmission efficiency for our live animal deployments.

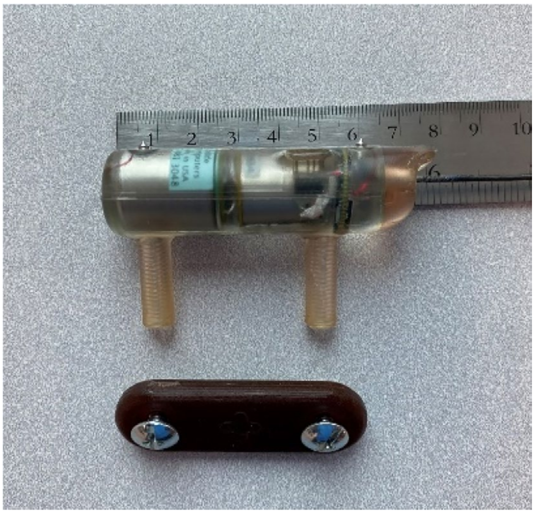

FIGURE 1 | Smart Position and Temperature (SPOT) 6 Model 371B inline satellite tag.

Planning for tag attachment to the sea lion, we found limited information about otariid flipper vasculature. Thus, we dissected a flipper collected from a sea lion carcass to locate major and minor vessels to ensure tag placement would not interfere with major blood vessels or nerves. To determine the best tools to use and develop proficiency in deploying the SPOT 6 tag, we practiced making holes and inserting the tag posts of these satellite tags through the flipper of a sea lion carcass. We used calipers to measure the thickness of the flipper at various distances from the outer edge of the flipper to determine the best tag placement to accommodate the height of the tag post so that when the tag was applied, it would not pinch the flipper.

When handling live animals, we first used the calipers to measure the distance from the flipper edge to ensure proper tag placement. For subadult and adult males, this was approximately 2 to 4 cm from the flipper edge. After cleaning the top and bottom of the flipper tag location with alcohol, we then used a sterilized forged steel leather punch (10 mm for subadult males) to make holes through the flipper for the tag posts (Figure 2). We inserted the top half of a cotton swab inside each post hole prior to sliding the tag posts through the flipper to keep the inside of the posts clean (Figure 2). Once the tag posts were inserted, we removed the cotton swabs, lined up the bottom plate to the base of the tag posts, and used a screwdriver to secure galvanized crosshead screws to the plate (Figure 2). We chose galvanized screws rather than stainless steel screws in the hope that they would degrade faster in saltwater, allowing the tag to eventually fall off; however, we did not test this idea prior to deployment. We determined the best placement was parallel to the outer edge of the foreflipper, with the antennae pointing dorsally to minimize any interference with the animal's movements (Figure 2).

We initially tested the SPOT 6 tags on subadult and adult male Steller sea lions that we had handled as part of entanglement response and research studies. To capture free-ranging Steller sea lions entangled in marine debris or fishing gear, we darted each animal with a combination of medetomidine (0.04 mg/kg), midazolam (0.15 mg/kg), and butorphanol (0.15 mg/kg) (Frankfurter et al. 2016; Haulena 2014; Melin et al. 2013) using a Daninject JM.DB 13 Standard CO_2 dart projector (NOAA permit #932-1905-01/MA-009526-1 and #18786). Induction time varied from approximately 10 to 20 min. Once the sea lion was fully sedated, the veterinarian administered oxygen and monitored the animal's heart and respiration rates, oxygen saturation, capillary refill time, and temperature. Simultaneously, we disentangled the sea lion, took morphometric measurements, collected samples (i.e., whisker, hair, skin), attached the SPOT 6 flipper

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FIGURE 2 | Attaching a SPOT 6 satellite tag to the right foreflipper of a subadult male Steller sea lion: (a) 10 mm forged steel leather punch; (b) using calipers to measure the correct location to attach the SPOT 6 tag; (c) cotton swabs cut and placed inside tag posts to keep the inside of tag posts clean; (d) using a screwdriver to secure the bottom plate with galvanized screws; (e) final placement of the SPOT 6 tag; and (f) subadult male Steller sea lion disentangled, tagged, released, and temporarily dye marked with hair dye for easier identification. All photos were taken under NOAA permit #18786-05.

tag to one foreflipper and a plastic Allflex tag to the other foreflipper, glued a GPS satellite transmitter to the top of the head, and temporarily marked the sea lion with hair dye. Afterwards, the veterinarian hand-injected the sea lion with reversal drugs containing a combination of atipamezole (0.2 mg/kg), naltrexone (0.5 mg/kg), and flumazenil (0.0002 mg/kg).

From 2018 to 2019, we successfully deployed tags on six live subadult and adult male Steller sea lions in Southeast Alaska as part of entanglement response and research studies. All location data were calculated by the Argos satellite system and provided as spreadsheets via the Wildlife Computers Inc. data portal. Although haul-out transmissions in Argos Class 0 or better were sparse given the programming to extend battery life, haul-out location data were sufficient to show that the sea lions were alive and moving among haul-out locations. Comparisons of SPOT 6 flipper tags to epoxy-affixed head-mount GPS tags will be described in much greater detail in a subsequent paper as our goal here is to show the efficacy of SPOT 6 tags deployed on Steller sea lions. Tag operational status messages were also transmitted to monitor battery life and transmission counts. Longevity of the SPOT 6 tags on male Steller sea lions ranged from 68 to 500 days ($\bar{x} = 134$, SD = 168), and the total number of transmissions ranged from 2582 to 17,742 ($\bar{x} = 9135$, SD = 5293) (Table 1).

Following this success, in October 2019, we deployed seven tags on endangered adult female Steller sea lions in the Gulf of Alaska with even greater efficacy. Tag duration for adult female Steller sea lions ranged from 160 to 745 days ($\bar{x} = 552$ days, SD = 185) and transmissions ranged from 2728 to 28,454 ($\bar{x} = 15{,}639$, SD = 8729) (Table 2).

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TABLE 1 | Performance of six SPOT 6 flipper tags deployed on subadult male Steller sea lion flippers (2018–2019).

Animal ID	Tag longevity (day)	Tag longevity (year)	Transmits made	Transmits day^{-1}	Days with transmits (%)	Battery voltage on first day	Battery voltage on last day
2018_772	68	0.2	7737	113	78	3.275	2.025
2018_773	299	0.8	17,742	59	35	3.525	2.65
2018_205	95	0.3	11,874	119	24	3.475	3.175
2019_778	174	0.5	5173	29	24	3.475	3.2
2019_779	93	0.3	2582	28	23	3.45	3.3
2019_780[a]	500	1.4	10,710	21	13	3.475	3.225

Note: Tag longevity (from date of attachment to animal to day of final transmission received), total number of transmissions made (from date of attachment to final transmission), overall transmission count per day, percentage of days over the tag longevity that the tag transmitted > 1 transmission, and change in battery voltage from date of attachment to final battery status are reported. Where tagging sites were visible, observations of tag condition subsequent to release are described as footnotes. Flipper tags were programmed to only transmit while animals were hauled-out on land and to not collect non-location data (e.g., temperature, on-land/at-sea status). Battery endurance manufacturer estimates were 20,000 transmissions on ice substrate and ≤ 7000 on ice-free substrate. Manufacturer indicated that generally, when battery voltage falls below 3 v, the battery is anticipated to deplete soon.
[a]Tag was observed attached on Day 767.

TABLE 2 | Performance of seven SPOT 6 flipper tags deployed on adult female Steller sea lion flippers (2019).

Animal ID	Tag longevity (day)	Tag longevity (year)	Transmits made	Transmits day^{-1}	Days with transmits (%)	Battery voltage on first day	Battery voltage on last day
2019_781[a]	745	2.0	15,902	21	18	3.4	2.65
2019_782[b]	655	1.8	28,631	43	15	3.425	2.225
2019_783[c]	561	1.5	12,800	23	15	3.425	1.9
2019_784	160	0.4	2860	17	12	3.375	3.3
2019_785	527	1.4	25,136	47	15	3.425	2.675
2019_786	465	1.3	10,162	22	17	3.375	1.675
2019_788[d]	552	1.5	15,034	27	13	3.475	1.95

Note: Tag longevity (from date of attachment to animal to day of final transmission received), total number of transmissions made (from date of attachment to final transmission), overall transmission count per day, percentage of days over the tag longevity that the tag transmitted > 1 transmission, and change in battery voltage from the date of attachment to the final battery status are reported. Where tagging sites were visible, observations of tag condition subsequent to release are described as footnotes. Flipper tags were programmed to only transmit while animals were hauled out on land and to not collect nonlocation data (e.g., temperature, on-land/at-sea status). Battery endurance manufacturer estimates were 20,000 transmissions on ice and ≤ 7000 on ice-free substrate. The manufacturer indicated that generally, when battery voltage falls below 3 v, the battery is anticipated to deplete soon.
[a]Tag was observed attached to the intact antenna on Day 1014.
[b]Tag was observed attached on Day 649.
[c]Tag was observed attached "with at least a little antenna left" on Day 1382.
[d]Tag was observed attached on Day 641.

SPOT 6 tag programming allowed 100 transmissions per 48 h. period for 30 days post-deployment to provide relatively frequent data shortly after each disentanglement attempt. After 30 days, the transmission rate was reduced to 100 per every 96 h. to further reduce battery usage and favor the longevity of the tag. Transmissions were allowed at any hour of the day and made at 90 s intervals. Time-at-temperature and percent dry data collection were inhibited to conserve battery life. Tags entered haul-out mode (during which transmissions were allowed) after the tags were 100% dry for five consecutive minutes. Tags entered at-sea mode (during which transmissions were inhibited) once tags became 100% wet for five consecutive minutes. By favoring battery life over transmission rate, we were able to increase tag longevity from 68 to 500 days for subadult males and later up to 745 days for adult females. Ten of 13 tags exceeded the expected battery life of 7000 transmissions.

Our first three deployments (2018_772, 2018_773, and 2018_205, Table 1) rapidly burned through their battery life. This revealed a programming flaw relative to sea lion behavior: each time a sea lion entered the water, swam, and hauled out, the 48- or 96-h waiting period between transmission attempts was reset and allowed a fresh set of 100 transmissions ahead of schedule. Tags were transmitting 59–119 times per day, exceeding our maximum allotment of 100 per 4-day period. For the second set of three deployments (2019_778, 2019_779, and 2019_780, Table 1), we altered tag programs to shut down the transmitter for a full 2- or 4-day period after each set of 100 transmissions, irrespective of how many haulout cycles occurred. The improved

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program reduced the rate to a more sustainable 21–29 transmissions per day. We have resighted SPOT tags on five (one male, four female) of the 13 Steller sea lions from 641 to 1382 days after deployment, and there was no indication of infection or complications as a result of the tags. We have no resights of the other eight individuals, so we do not know the fate of those tags or animals once the tags stopped transmitting.

This first application of attaching SPOT 6 satellite flipper tags on otariids was a success. By adapting programming, these SPOT 6 flipper tags successfully transmitted up to 2.05 years. These flipper-mounted SPOT 6 tags provide essential new information not possible before: (a) comparison of individual Steller sea lions' seasonal choices of foraging and pup rearing locations from one year to the next; (b) tracking that may begin at any time of year irrespective of an individual sea lion's fur molting status; (c) durable and low-cost tracking of Steller sea lion multiple central place foraging choices (Raum-Suryan et al. 2002); (d) essential monitoring of individuals post-disentanglement, ensuring they are able to swim from haulout to haulout. Disadvantages of these SPOT 6 flipper tags observed include: (a) GPS receivers for higher-quality locations cannot be integrated into the small transmitter package; (b) size limits the battery capacity relative to the larger tags glued to the fur, which in turn limits the frequency and volume of data that may be collected; (c) placement on the flipper prevents at-sea location estimation because the antenna is usually submerged; (d) re-sighting flipper tag condition can be difficult because flippers are often tucked under the body; (e) the small battery is prone to passivation, and thus these tags, while in storage, must be activated and connected to a computer monthly to "exercise" the battery; and (f) tag attachment, while done carefully, is invasive relative to temporary tag applications using glue. Overall, we believe the benefits of these tags outweigh their limitations and, for the first time, allow us to track Steller sea lions beyond the annual molt.

Author Contributions

Kimberly L. Raum-Suryan: conceptualization, investigation, funding acquisition, writing – original draft, methodology, validation, visualization, writing – review and editing, project administration, data curation, supervision, resources. **Lauri A. Jemison:** conceptualization, investigation, funding acquisition, methodology, validation, writing – review and editing, project administration, data curation, supervision, resources. **Michael J. Rehberg:** conceptualization, investigation, funding acquisition, methodology, validation, writing – review and editing, software, data curation, resources, supervision. **Katharine N. Savage:** investigation, writing – review and editing, project administration, resources, methodology, supervision, validation.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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