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# Physiological and behavioral response to intra-abdominal transmitter implantation in Steller sea lions

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## Abstract

The absence of a direct, long-term measure of individual Steller sea lion survival led to the development of implanted, delayed transmission satellite tags specifically for this species (Life History Transmitter, LHX). To assess possible effects of implant procedures and LHX tags, we undertook a two-stage approach to monitor: 1) immediate physiological response under controlled conditions in temporary captivity, and 2) post-release movement and dive behavior via externally mounted satellite data recorders (SDR). Six juvenile sea lions were monitored up to 8 weeks post-implant for physiological indications of post-surgical effects. Overall, mass, body condition and blood parameters did not change during the study period. There was limited white blood cell elevation and acute-phase reaction in the first 2 weeks post-implant. During the 3 months of post-release tracking, all sea lions returned to their respective capture haul-outs. Shorter and shallower dives during the first week post-release suggested a possible recovery period similar to other non-LHX individuals released from temporary captivity. For all subsequent weeks, dive depth, duration, frequency and dispersal distances of LHX animals were comparable to free-ranging individuals. All physiological and behavioral responses noted were temporary in nature, supporting LHX implantation as a viable alternative for long-term survival monitoring of free-ranging sea lions.

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*Keywords:* Acute-phase reaction; Dive behavior; *Eumetopias jubatus*; Intra-abdominal implant; Satellite telemetry; Steller sea lion

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## 1. Introduction

Advances in wildlife tracking technology have provided biologists with the tools to monitor animal dispersal, foraging patterns and to document mortality events in

animals ranging in size from mice to bears (Smith, 1980; Philo et al., 1981; Wheatley, 1997; Monnett and Rotterman, 2000; Ågren et al., 2000). External tracking devices are now routinely utilized to collect data from free-ranging pinnipeds (e.g., Lander et al., 2001; Raum-Suryan et al., 2002; Loughlin et al., 2003). Technological advances have improved the quality and quantity of transmitted data, however, tag longevity continues to be limited by transmitter battery life and attachment techniques. In pinnipeds, abrasion, pelage breakdown and the annual

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molt limit the tracking period for externally attached devices to several months. For species of particular concern, such as the endangered stock of Steller sea lions (*Eumetopias jubatus*), longer-term monitoring is crucial to accurately define vital rates and life history parameters, and constraints faced by the population.

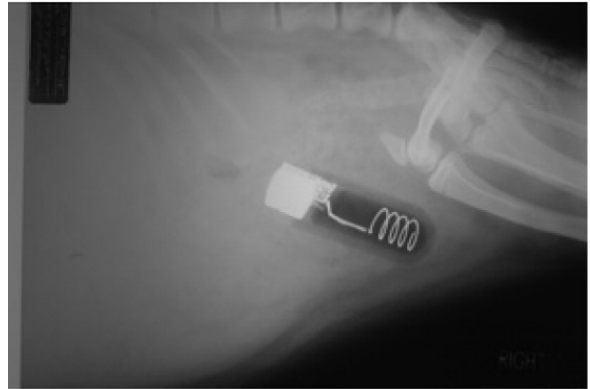
Steller sea lions were listed as endangered through the western portion of their range in 1997 (62 Federal Register 24345). Only limited knowledge of their life history traits are available due to the difficulty in initial capture and extremely low recapture rate of this species which spends a large proportion of its life at sea. Critical information on annual survivorship for the various age classes are limited, relying primarily on mathematical models for estimating age specific vital rates (e.g., York, 1994; Holmes and York, 2003; Winship and Trites, 2006). Brand based mark-resight studies may provide detailed data, but require very large sample sizes and yield no information on individual causes of mortality (Gerrodette, 1987; Link and Barker, 2005). Intraperitoneal implanted tags such as those used successfully in other highly aquatic mammals (e.g., *Enhydra lutris*, Williams and Siniff, 1983; Monnett and Rotterman, 2000) can provide the required long term data, and yield information on causes of mortality. However, conventional implanted tracking devices are limited by range of VHF transmissions, and battery life. The specifically developed Life History Transmitter (LHX) overcomes this limitation through the collection and archiving of dive behavior data throughout the life of the host animal, transmitting only after the host has died and the tag is extruded from the carcass. The absence of any transmissions throughout the life of the host extends battery life beyond ten years, and allows use of the Argos satellite-based data recovery system (Horning and Hill, 2005).

The substantial constraints of working with large pinnipeds in remote locations are multiplied when working with an endangered species. All procedures must follow strict guidelines, endure rigorous review and testing, as well as strive to provide maximal data with minimal impact. However, intra-abdominal implantation had not yet been attempted in this species for which every mortality must be prevented. Surrogate species can provide a wealth of information on basics of the procedure (e.g., *Zalophus californianus*, M. Haulena, M. Horning and J. Mellish, unpublished data), but eventually the method must be tested on the target population to accurately assess the feasibility of the procedure.

We evaluated the immediate post surgical physiological response (up to 8 weeks) and longer-term post release behavioral response (up to 3 months) to LHX implantation in six juvenile Steller sea lions brought into

temporary captivity for research purposes (e.g., Mellish et al., 2006). The technical specifications of the tag (Horning and Hill, 2005) and the surgical procedure (M.

a)



b)



c)



Fig. 1. a) X-ray radiographic image of an LHX device implanted into a 66 kg female California sea lion (*Zalophus californianus*) under NMFS permit #1034-1685 for an earlier trial. On the larger, juvenile Steller sea lions (*Eumetopias jubatus*), the LHX device has a length of about two vertebrae. b) Ventral location of incision site 2 weeks post-procedure in a juvenile Steller sea lion. c) Resight of LHX animal 15 weeks post-implant and 10 weeks post-release.

Table 1  
Selected hematology and blood chemistry parameters in juvenile Steller sea lions (*Eumetopias jubatus*) pre-and post-LHX implantation

	Capture	Pre-LHX	1–2 weeks	3–4 weeks	5–8 weeks
RBC (m/mm <sup>3</sup> )	3.9±0.11	4.1±0.06	4.5±0.20	4.1±0.16	3.9±0.11
Hematocrit (%)	43.0±0.79	44.9±0.52	48.4±2.29	42.2±1.60	39.9±0.84
Albumin (g/dl)	4.1±0.11	4.3±0.07	4.3±0.12	4.0±0.12	3.9±0.24
ALP (U/l)	76±11.5	64±5.8	65±6.5	50±6.2	49±5.1
ALT (U/l)	31±1.30	47±11.0	41±2.2	46±4.0	57±7.8
Amylase (U/l)	150±27.9	53±10.2	46±11.0	44±11.0	59±11.4
BUN (mg/dl)	19±2.1	23±1.0	28±2.2	26±2.0	25±1.9
Calcium (mg/dl)	10.2±0.19	9.8±0.09	9.8±0.11	9.7±0.14	9.9±0.14
Glucose (mg/dl)	142±4.5	133±1.7	135±2.3	123±2.4	132±4.2
Globulins (g/dl)	3.7±0.10	4.5±0.10	5.1±0.13	5.5±0.22	5.2±0.35

Haulena, M. Horning and J. Mellish, unpublished data) are described separately.

## 2. Materials and methods

### 2.1. Study area

We collected 6 juvenile (ranging from 15–20 months of age) Steller sea lions in Prince William Sound, Alaska (60° N 148° W), as part of an ongoing study of health and condition (Mellish et al., 2006). Animals (5 m, 1 f) were

held in a specialized quarantine habitat with four outdoor pools at the Alaska SeaLife Center (ASLC), Seward, Alaska. Additional capture, transport, holding and husbandry details are outlined in Mellish et al. (2006).

### 2.2. Animal husbandry and physiological sampling

Age was estimated by tooth eruption patterns (King et al., 2007), corrected for time of year based on a local mean pupping date of 10 June (Maniscalco et al., 2006). Animals were acclimated to the enclosure for 2–4 weeks

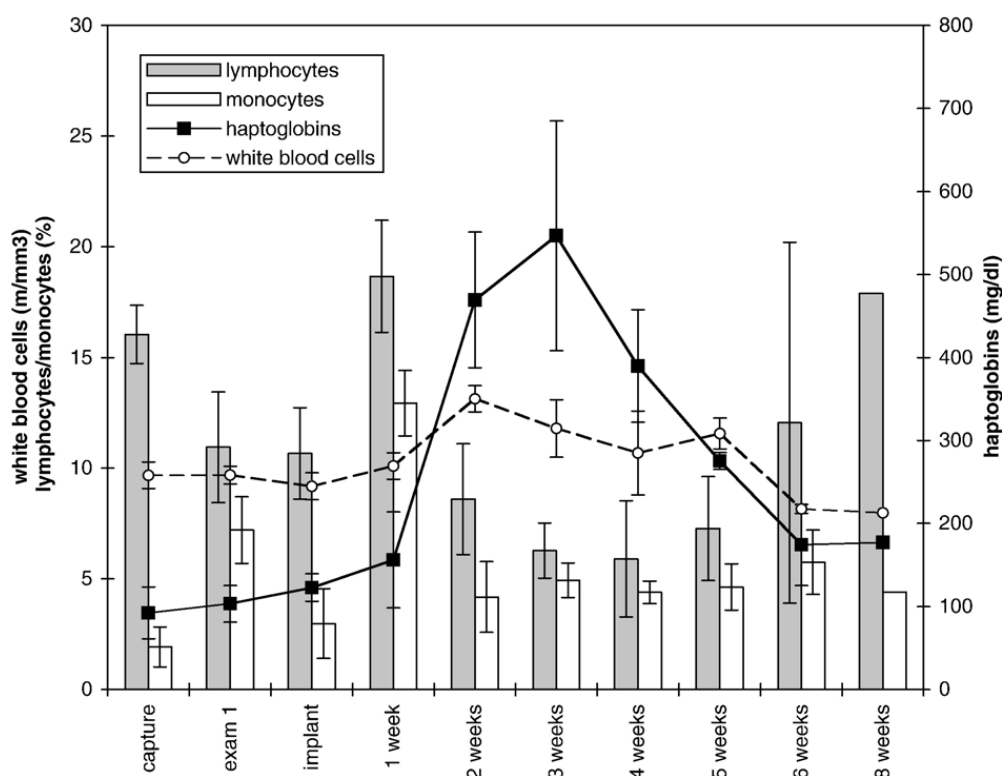


Fig. 2. White blood cell count, lymphocyte and monocyte percent and haptoglobin levels in 6 juvenile Steller sea lions (*Eumetopias jubatus*) with single ( $n=2$ ) or dual ( $n=4$ ) LHX transmitter implants.

prior to implantation. Individuals were fed *ad libitum* daily with a base percentage of body mass (e.g., 5–7%) adjusted for appetite level.

Throughout the captivity period ( $66 \pm 3$  days), sea lions were sampled up to 10 times each, including a health screen at capture and 2 weeks prior to release. Blood samples were collected during isoflurane gas anesthesia to ensure the safety of both the animals and the handlers. Sample collection included blood via the caudal plexus or hind flipper vein for complete blood count (CBC), serum chemistry and haptoglobin analysis. Mass was measured to the nearest 0.5 kg on a platform scale.

We performed single ( $n=2$ ) or dual ( $n=4$ ) LHX free-floating abdominal implants between 2 and 4 weeks post-capture (M. Haulena, M. Horning and J. Mellish, unpublished data, Fig. 1). The LHX device is an archival

data transmitter designed to monitor up to five parameters including pressure and temperature (Horning and Hill, 2005). The tag detects and stores time of death. Following carcass disintegration, the tag is extruded and if at sea, will float on the ocean surface. Previously collected data is then transmitted via the ARGOS system aboard NOAA satellites. Dual implants are used to increase data recovery and contribute to the assessment of tag failure rates through the calculation of dual to single return ratios.

The post-surgical monitoring period lasted up to 8 weeks. We were not able to sample all animals at all times due to handling restrictions. Sample sizes were as follows: capture ( $n=6$ ), pre-implant ( $n=5$ ), LHX implant ( $n=6$ ), and at weeks one ( $n=3$ ), two ( $n=6$ ), three ( $n=4$ ), four ( $n=5$ ), five ( $n=4$ ), six ( $n=2$ ), and eight ( $n=1$ ) post-implant.

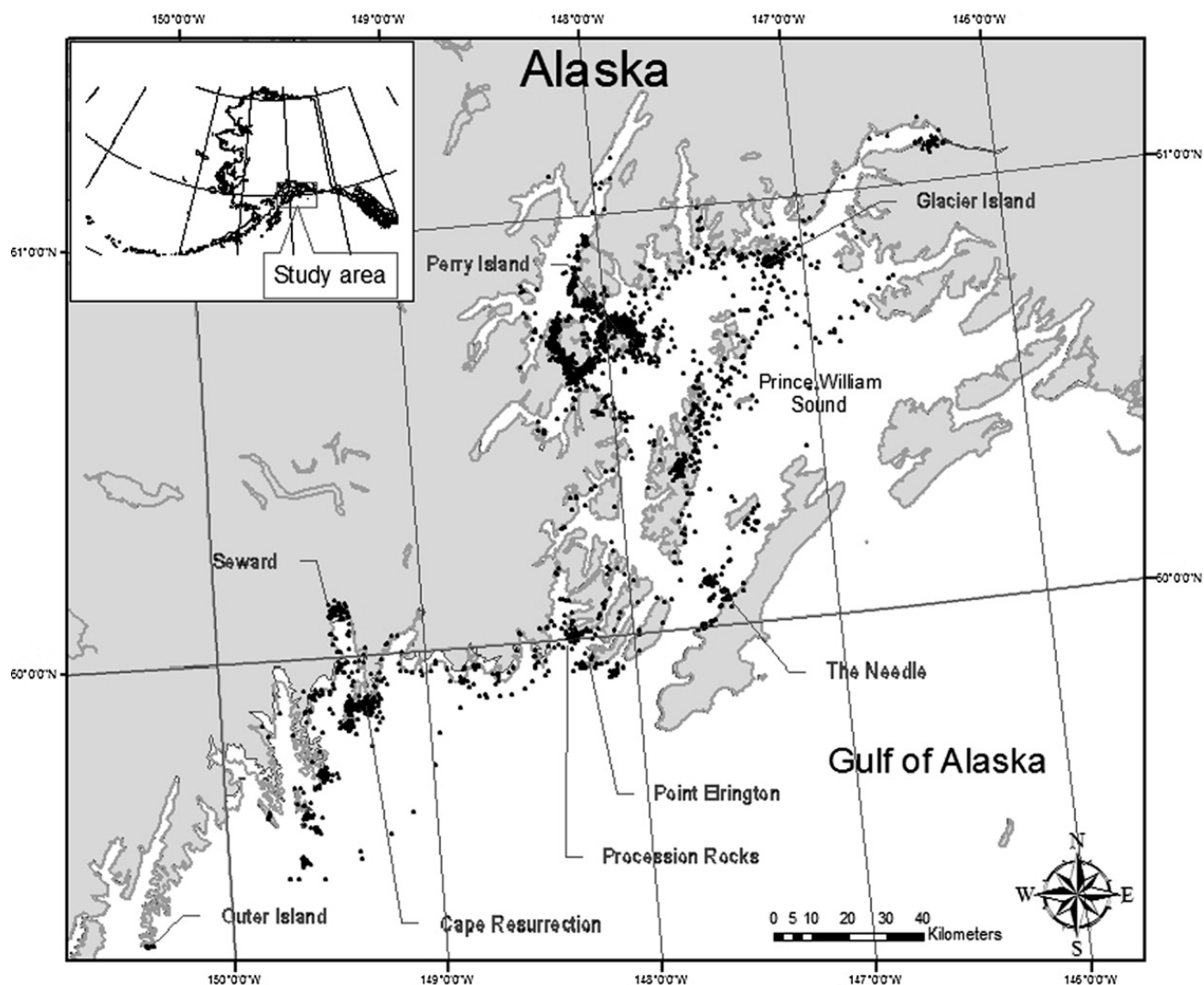


Fig. 3. Steller sea lion LHX implant recipients were released from temporary captivity in Seward. Subsequent dispersal and movement patterns (black dots represent locations) ranged between Outer Island and Prince William Sound.

We analyzed CBC and clinical chemistry panels immediately post-collection with the automated VetScan® HMTII and VetScan® Diagnostic Profile Plus analysis rotor systems (Abaxis, Union City, CA). Results were typically obtained while the individual was still under isofluorane anesthesia in the event that veterinary intervention or preventative measures were required. Sera samples were frozen at  $-80^{\circ}\text{C}$  until haptoglobin analysis via a colorimetric assay kit (Phase™ Range Haptoglobin assay, Tridelta Diagnostics, Morris Plains, NJ) as described in [Thomton and Mellish \(2007\)](#).

Total body water was estimated at capture and pre-release by the dilution method of an intramuscular injection of a precisely weighed dose of deuterium oxide dilution (averaging  $10.4 \pm 0.19$  g of 99.9% Sigma Aldrich, St. Louis, MO, USA). We were unable to obtain pre-release dilution samples from TJ25. Blood samples (10 ml) taken via the caudal plexus or hind flipper vein after equilibration (2 and 2.25 h post-injection) were analyzed by mass spectrometry at Metabolic Solutions (Nashua, NH, USA). Total body water sera and dose samples analyzed in triplicate for Delta D versus V-SMOW ([Scrimgeour et al., 1993](#)) were corrected for total body water (TBW) as per [Bowen and Iverson \(1998\)](#). In the absence of empirical equations for Steller sea lions, total body fat and protein were calculated with the equations derived by [Arnould et al. \(1996\)](#) for adult Antarctic fur seals (*Arctocephalus gazella*).

All animals were marked 2 weeks prior to release with a unique permanent hot-brand as per [Mellish et al.](#)

(2007). TJ25 was not branded but instead received dual fore-flipper tags. Additional monitoring occurred with opportunistic visual re-sight or pre-existing remote video systems ([Fig. 1](#)).

### 2.3. Satellite dive recorder parameters and post-release monitoring

Prior to release, external Splash satellite dive recorders (SDR, Wildlife Computers, Inc., Redmond, WA) were mounted with 5 min epoxy to the midline dorsal pelage between the fore-flippers of each animal. Splash tags were programmed to record dive data in four histogram periods of six hour duration each, between 10:00–15:59 (mid-day), 16:00–21:59 (evening), 22:00–03:59 (mid-night), and 04:00–09:59 (early morning) AST. Depth was sampled every 5 s ( $\pm 0.5$  m) and maximum depth of individual dives recorded in the 14 following dive depth bins: 4–8, 9–16, 17–24, 25–32, 33–40, 41–50, 51–60, 61–70, 71–80, 81–100, 101–120, 121–160, 161–200, and  $>201$  m. Dive duration was determined in 5 s increments and recorded in 14 duration bins (30 s increments). Time at depth (TAD) was calculated and recorded as the percent time spent in a given depth range within the 6 h periods described above. Time at depth bins included: 0, 1–4, 5–8, 9–16, 17–24, 25–32, 33–40, 41–50, 51–60, 61–70, 71–80 and  $>81$  m. Timeline data reported time wet versus dry for each hour (%). Maximum daily dive depth was determined via histogram depth data, which underestimates dives greater than 201 m. Data for non-LHX

Table 2

Summarized dive data from six LHX implanted and 21 non-implanted ([Thomton et al., in review](#)) juvenile Steller sea lions

ID	Age (mos)	Mass (kg)	Sex	Mean max dive depth (m)	Number of periods (n)	Max depth (m)	Mean depth (m)	Number of dives in depth bins (n)	Mean duration (s)	Number of dives in duration bins (N)	Max duration (s)	Dive rate (dives $\text{h}^{-1}$ )	Mean CVD (m)
TJ22	17	131	F	121	418	201	41	29797	102	33130	331	10.9	19932
TJ23	17	137	M	91	202	161	48	11552	131	11448	391	6.8	13474
TJ24	22	180	M	90	222	161	22	21761	67	21788	361	12.8	12725
TJ25	22	140	M	75	182	161	17	15518	68	15288	301	9.7	8202
TJ26	22	172	M	68	301	201	17	21254	81	21467	391	9.1	7801
TJ27	22	149	M	96	191	201	21	19833	69	19042	331	11.6	12196
Mean	20	152		90		181	28		86		351	10.1	12388
SE	1	8		8		9	5		10		15	0.9	1796
<i>Non-implanted temporarily captive summary (TJ 1-21)</i>													
Mean	19	137		117		275	26		83		372	10.1	12251
SE	1	6		24		45	4		7		19	0.5	3531

Mean maximum dive depth and duration represents the mean of all deepest and longest, respectively, dives recorded during all 6 h sampling periods. Maximum dive depth and duration achieved during the entire recording period is reported for all dives as maximum depth (n) and duration (N). Mean depth represents the average of all dives (N). Counts in overflow bins differ for depths (n) and durations (N), resulting in unequal samples sizes (see Materials and methods). Dive rate and CVD characterize 6 h histogram periods for all animals.

implanted animals was similarly recorded as described in Thomson et al. (in review).

Summarized dive data was calculated using the midpoint of each dive depth or duration bin and the lower limit of the largest bin. Cumulative vertical displacement (CVD) was calculated as an index for dive effort that is independent of the dive rate (e.g. one 20 m dive=40 m CVD). Movement data was received from the Argos system, which provides location information for multiple received transmissions, classified by quality and projected accuracy of location (Sorna and Tsutsumi, 1986). Maximum distance (shortest water route) from capture haul-out location and release location were measured using ArcMap™ 9.1 software (ESRI®, Redlands, CA). Trip distances were not calculated due to low resolution of location data. After filtering location data (Loughlin et al., 2003) and retaining positions with swim speed  $\leq 3 \text{ m s}^{-1}$ , Argos location quality  $\geq 0$  and removing locations on land, an average of 3 positions per round-trip remained which precluded an accurate assessment of trip distances.

#### 2.4. Statistical analyses

All data are presented as means with standard error. Data were analyzed with Sigmasat 3.11 (Systat Software Inc., Richmond, CA) using ANOVA, *t*-test, Holm-Sidak post-test and linear regression. All research was conducted under National Marine Fisheries Service permit #881-1668 and ASLC Institutional Animal Care and Use Protocol #05-002.

### 3. Results

#### 3.1. Body condition and health assessments

Mean body mass did not differ throughout the experimental period ( $147 \pm 3.3 \text{ kg}$ ,  $p=0.531$ ). However, single implant recipients were lighter ( $120 \pm 3.0 \text{ kg}$ ) than dual implant recipients ( $158 \pm 2.4 \text{ kg}$ ,  $p<0.001$ ). Body condition at capture ( $28 \pm 1.9 \text{ d pre-LHX}$ ) and 2 weeks prior to release ( $26 \pm 3.6 \text{ d post-LHX}$ ), did not differ ( $p>0.4$ ). Animals averaged  $18.3 \pm 1.19\%$  total body fat,

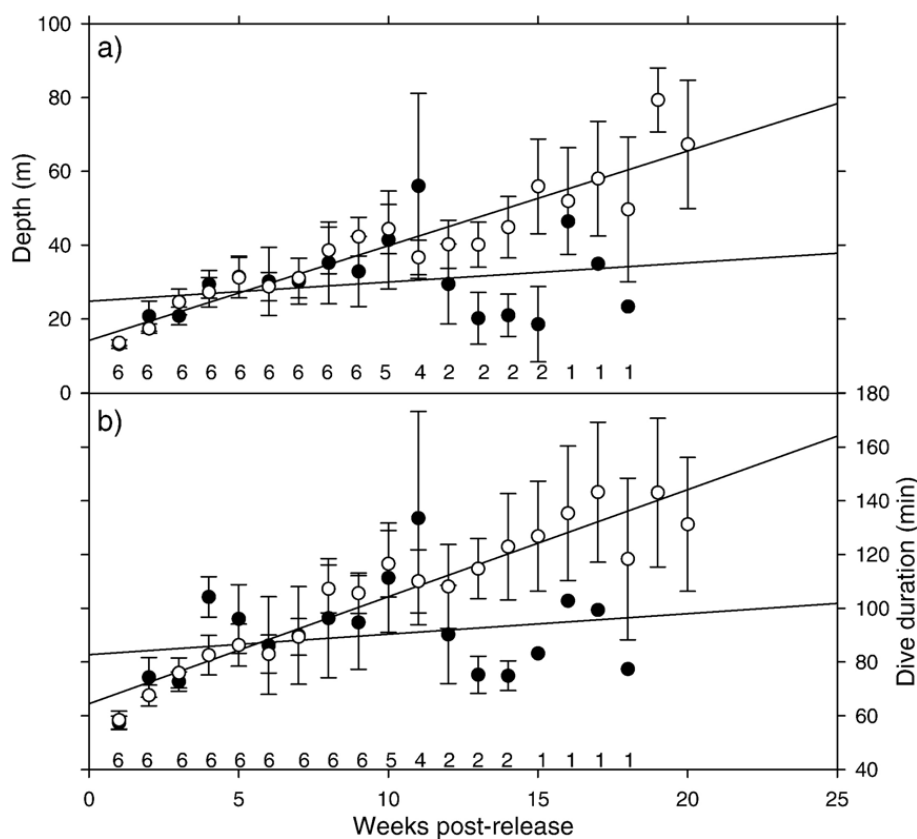


Fig. 4. Dive depth (a) and duration (b) increased linearly for both non-LHX implant animals (○) and LHX animals (●) during the first 11 weeks post-release (Non-LHX depth:  $r^2=0.822$ ,  $p<0.001$ . Non-LHX duration:  $r^2=0.733$ ,  $p<0.001$ . LHX depth:  $r^2=0.834$ ,  $p<0.001$ . LHX duration:  $r^2=0.709$ ,  $p=0.001$ ). After week 11, non-LHX dive depths and durations continue to increase, however LHX dives decrease in depth and duration due to small sample size and seasonal changes in dive behavior. Data for non-LHX implant animals from Thomson et al. (in review). Sample size per week for LHX animals is presented above the x-axis.

$18.60 \pm 0.22\%$  total body protein and  $57.9 \pm 1.00\%$  total body water.

CBC and clinical chemistry panels were performed up to ten times per individual during the study period. Parameters with significant change during the study period are shown in Table 1 and Fig. 2. Red blood cell counts ( $p=0.001$ ) and hematocrit ( $p<0.001$ ) were highest during the first two weeks post-implant. Although WBC appeared to rise temporarily post-implantation, the trend was not significant ( $p=0.39$ , Fig. 2). Platelets ( $389 \pm 12.3$   $m/mm^3$ ,  $p=0.39$ ), granulocytes ( $82 \pm 2.3\%$ ,  $p=0.69$ ) and hemoglobin ( $16.7 \pm 0.26$  g/dl,  $p=0.08$ ) levels also did not fluctuate significantly. In contrast, lymphocytes were elevated at capture and one week post-implant ( $p=0.002$ , Fig. 2). Monocytes were likewise elevated at one week post-implant ( $p<0.001$ , Fig. 2).

Total bilirubin ( $0.3 \pm 0.01$  mg/dl,  $p=0.28$ ), phosphorous ( $6.7 \pm 0.14$  mg/dl,  $p=0.28$ ), creatinine ( $0.9 \pm 0.03$  mg/dl,  $p=0.45$ ),  $Na^+$  ( $144 \pm 0.8$  mmol/l,  $p=0.28$ ) and  $K^+$  ( $4.0 \pm 0.07$  mmol/l,  $p=0.07$ ) values did not change. Albumin ( $p<0.001$ ), alkaline phosphatase ( $p=0.02$ ), blood urea nitrogen ( $p=0.04$ ) and calcium ( $p<0.001$ ) varied from capture to release (Table 1). Alanine amino transferase ( $p<0.001$ ) and total protein

( $p<0.001$ ) was lowest at capture, whereas amylase was highest at capture ( $p<0.001$ ; Table 1). Glucose levels were highest at pre-implant and late stages of the study ( $p=0.02$ ).

Haptoglobin and globulin levels increased post-implantation ( $p<0.001$ , Table 1, Fig. 2). Haptoglobin levels were correlated to total WBC ( $r=0.58$ ,  $p<0.001$ ), globulins ( $r=0.58$ ,  $p<0.001$ ), and platelet counts ( $r=0.31$ ,  $p=0.04$ ). There was a negative correlation between haptoglobin levels and %lymphocytes ( $r=-0.51$ ,  $p=0.001$ ), but not %monocytes ( $p=0.81$ ) or % granulocytes ( $p=0.78$ ).

### 3.2. Post-release movement and dive behavior

LHX implant recipients were released in late November ( $n=2$ ) or mid-April ( $n=4$ ), with external Splash tag transmission lengths of  $91.5 \pm 8.6$  days. Two animals were initially captured at the Needle and four at Glacier Island, Prince William Sound (PWS), AK. Animals were released in Resurrection Bay, AK (Seward) and returned to their respective capture haul-outs. During the tracking period, movement was typically restricted to PWS, but ranged as far west as Outer Island ( $59.4^\circ$  N  $150.4^\circ$  W,

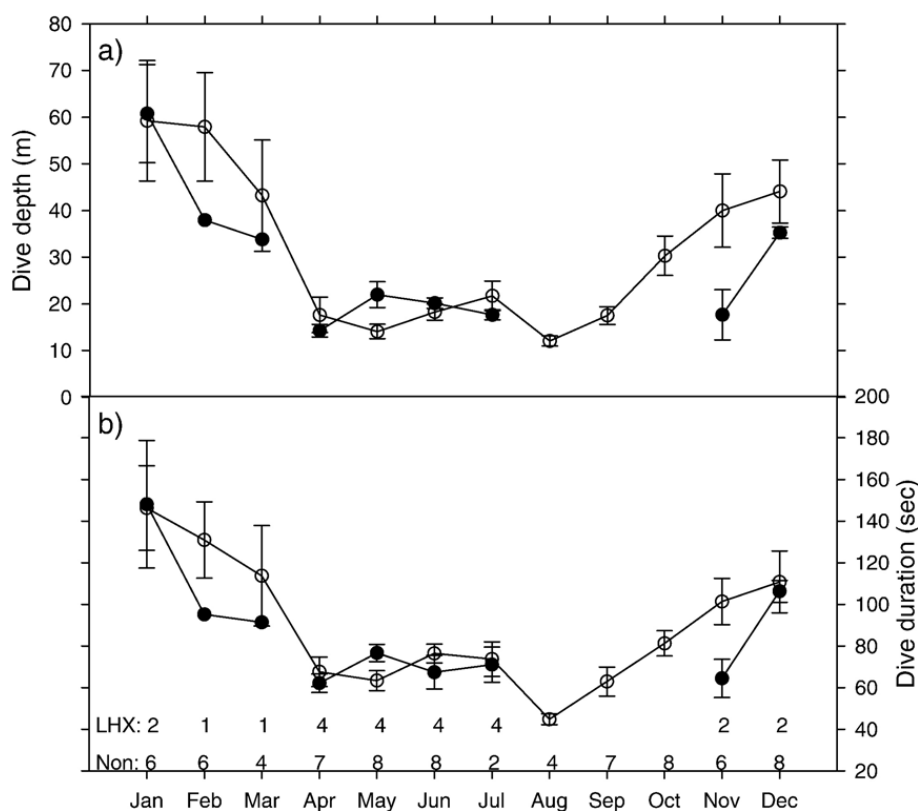


Fig. 5. Seasonal (a) dive depth and (b) duration in both non-LHX (○) and LHX (●) recipient Steller sea lion juveniles after temporary captivity. Data for non-LHX implant animals from Thomson et al. (in review). Sample sizes for per month for LHX and non-LHX (Non) are indicated above the x-axis and represent both panels.



Fig. 3). The mean maximum distance traveled was  $217 \pm 8$  km from the original capture haul-outs. Average duration of individual foraging trips, as determined by the wet/dry sensor timeline, was  $11.6 \pm 0.5$  h with a haul-out duration of  $18.8 \pm 1.2$  h, however these ranged as long as 58 h and 134 h, respectively. Overall, animals spent  $43.1 \pm 4.1\%$  of their time in the water.

Summarized dive depth, duration, dive rate, and CVD are reported for each individual in Table 2. Dive depth averaged  $27.7 \pm 5.4$  m, but increased with time post-release from  $13.1 \pm 1.2$  m in week 1 to  $56.0 \pm 25.1$  m in week 11 (Fig. 4,  $r^2 = 0.834$ ,  $p < 0.001$ ). This effect decreased in weeks 12–18, however these data represent  $\leq 2$  sea lions ( $n = 2$  weeks 12–16;  $n = 1$  weeks 16–18). Weeks 16–18 represent a single sea lion during the spring season when dives become seasonally shallower and shorter (Fig. 5). Time at depth data revealed that the majority of dives were within 9 to 16 m bin regardless of the time of day. The mean dive duration during the tracking period was  $87 \pm 11$  s. The greatest proportion of dives was 0 to 1 minute in duration (45%) followed by a proportional decrease in longer duration bins (Fig. 4). Similar to overall depth, dive duration increased from  $57 \pm 2$  s in week 1 to  $134 \pm 40$  s in week 11 (Fig. 4) post-release ( $r^2 = 0.709$ ,  $p = 0.001$ ), followed by a decreased duration trend (due to small sample size and seasonal effects). As expected, dive duration increased with dive depth ( $r^2 = 0.885$ ,  $p < 0.001$ ).

LHX juveniles averaged  $10.1 \pm 0.9$  dives  $\text{h}^{-1}$ , with the highest ( $14.6 \pm 2.6$  dives  $\text{h}^{-1}$ ) at midnight and lowest ( $7.9 \pm 1.1$  dives  $\text{h}^{-1}$ ) at mid-day, a non-significant difference ( $p = 0.117$ ). Similar to non-implanted animals, LHX recipients dived deeper and longer overall, compared to free-ranging animals, with greater CVD in winter months and higher dive rate in summer months (Thomton et al., in review).

## 4. Discussion

### 4.1. General physiological response to implantation

Little to no variation in protein, enzymes and electrolytes indicated that kidney, liver and pancreatic functions were not adversely influenced by the introduction of implants to the abdominal cavity, or in response to the surgical procedure itself. Red blood cell counts and hematocrit levels were highest 2 weeks post-surgery, but remained within the typical range for this population and age class (3.4–4.7 mg/dl and 37–54%, respectively, Mellish et al., 2006). Nutritional indicators (e.g., body composition, blood urea nitrogen and total protein) also were not altered after the surgical

procedure or in the presence of the implant device. Combined with a lack of change in behavior, appetite or waste excretion, these findings suggest that surgery and implants did not interfere with digestion.

A generalized immune reaction of WBC and platelet increases was not evident, as counts for both parameters were within the expected normal variation for western stock Steller sea lions throughout the study period (Bossart et al., 2001; Mellish et al., 2006). The temporary elevation of lymphocytes and monocytes at one week post-implantation indicated a minor response to implants, with limited amounts of phagocytosis and perhaps some cell necrosis (Latimer and Prasse, 2003). In contrast, the implant procedure and/or the presence of LHX devices did result in an acute-phase reaction, marked by elevation of globulins and haptoglobins (Table 1, Fig. 2).

### 4.2. Differential response to acute events

Physiological monitoring of sea lions post-trauma is limited, however data do exist in conjunction with other acute events such as branding (Mellish et al., 2007), and with parasitized and infected California sea lions undergoing rehabilitation (*Z. californianus*, Roletto, 1993). Hot-branding in Steller sea lions resulted in increased WBC ( $18 \text{ m/mm}^3$ ), platelets ( $1100 \text{ m/mm}^3$ ), globulins and haptoglobins by 2 weeks but returned to baseline within 8 weeks (Mellish et al., 2007). Elevated WBC have been found previously in California sea lions with peritonitis or septicemia (average  $18 \text{ m/mm}^3$ , Roletto, 1993) and an abscessed Steller sea lion ( $25 \text{ m/mm}^3$ , Thomton and Mellish, 2007). Maximal output of WBC ( $15 \text{ m/mm}^3$ ) and platelets ( $550 \text{ m/mm}^3$ ) in response to intra-abdominal LHX implantation were below the trend for hot-branding, and below values for California sea lions with peritonitis, septicemia, or abscess, but above normal for the local population ( $10 \text{ m/mm}^3$  and  $316\text{--}425 \text{ m/mm}^3$ , respectively; Mellish et al., 2006).

The general response to LHX implantation was limited with significant changes only in haptoglobin levels. A range of 0–300 mg/dl was considered baseline for temporarily captive animals from the same population, with highest reported levels of 500 and  $> 1000$  mg/dl in a branded and severely infected/abscessed sea lion (Mellish et al., 2007; Thomton and Mellish, 2007). Over 60% of the post-operative haptoglobin values were below the 300 mg/dl threshold, and all values had returned to baseline by five weeks.

While it is difficult to discern if the physiological changes measured were due to the surgical procedure, the presence of implanted devices, or both, we can

speculate based on the response observed. An immediate response (i.e., 1 week) might be expected as a result of the surgical procedure alone, as appears to be the case with hot-branding (Mellish et al., 2007). A delayed response sustained beyond 2–3 weeks may indicate a rejection of the implant device, or necrosis around the implant site. Neither pattern was evident, with only temporary elevations in acute-phase proteins. Given the observed overall lack of physiological reaction to both the procedure and the implant device itself, there is substantial potential for the use of this method for free-ranging applications in which the post-surgery monitoring is limited.

#### 4.3. Impact on post-release movement and behavior patterns

Steller sea lions with intra-abdominal LHX implants displayed movement and dive behavior similar to both non-implanted temporarily captive juveniles (Thomton et al., in review) and free ranging animals of the same population. The movement of free ranging juveniles in Alaska increases from  $\leq 500$  km as pups to 1785 km as juveniles (Raum-Suryan et al., 2002). In this geographic region, at-sea trip durations are typically  $8.9 \pm 10.2$  h SD with haul-out lengths of  $10.2 \pm 8.7$  h SD (Call et al., 2007). Mean percentage time wet for juveniles ranges from 39% for females to 50% for males (Rehberg, 2005). Dive rates increase during pup development to juvenile rates between 5 and 21 dives  $h^{-1}$  (Fadely et al.,

2005). Typical juvenile Steller sea lion mean dive depths and dive durations in Alaska range from 16.6 m for 1.1 min (Loughlin et al., 2003) to 22.9 m for 1.7 min (Rehberg, 2005).

For temporarily captive non-implanted individuals, dive behavior variables (Table 2) were within the above described published ranges according to sex, mass and time of year (Thomton et al., in review). The only exceptions to this comparison were slightly shallower and shorter dives for the initial week post-release, for all temporarily captive animals. Overall, temporary captivity alone had minimal effect on dive behavior and dispersal following release (Thomton et al., in review).

The dive behavior of sea lions that received LHX implants did not differ from non-implanted temporarily captive animals (Table 2). A respective comparison between implanted and non-implanted animals revealed no significant differences in: 1) movement ( $217 \pm 8$  km and  $190.0 \pm 31.9$  km), 2) trip duration ( $11.6 \pm 0.5$  h and  $14.1 \pm 2.1$  h), 3) haul-out duration ( $18.8 \pm 1.2$  h and  $14.1 \pm 1.3$  h) and 4) time wet ( $43.1 \pm 4.1\%$  and  $46.6 \pm 2.3\%$ ). Mean dive depth and duration did not differ between implanted and non-implanted animals ( $27.7 \pm 5.4$  m for  $1.5 \pm 0.2$  min and  $26.2 \pm 4.0$  m for  $1.4 \pm 0.4$  min respectively). The apparently uninhibited development of diving ability in LHX recipients is evident with consistently increasing dive depth and duration post-release (Fig. 4), as has been shown in non-implanted juveniles (Thomton et al., in review). The LHX sea lions however, display a decrease in mean dive depths and

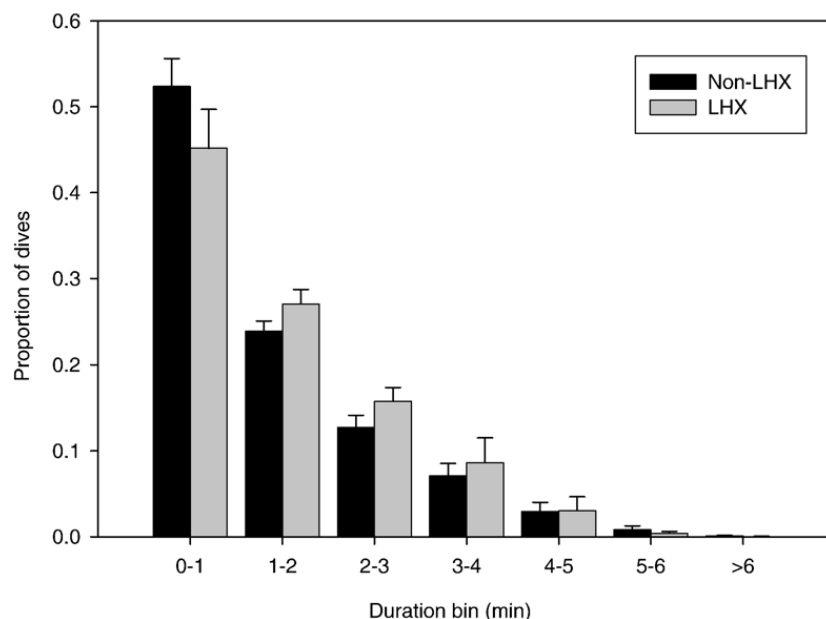


Fig. 6. The proportion of Steller sea lion dives per duration bin for both non-LHX and LHX recipient juveniles after temporary captivity. Data for non-LHX implant animals from Thomton et al. (in review).

durations in weeks 12 to 18, however this is most likely an artifact of the small sample size ( $n \leq 2$ ) and seasonal changes in diving behavior (Fig. 5). The distribution of dive duration was similar between the two groups, with most dive durations less than two minutes (Fig. 6). The diving behavior (depth, duration, dive rate and CVD) of the two groups were similar when adjusted to time of year (Fig. 5). The greater variance in LHX recipients was likely due to the small sample size.

#### 4.4. Management implications

Minimal to no change in health and condition parameters following LHX implantation suggests no major immune response or impediment to feeding or digestive capacity. Brief elevations in haptoglobin levels indicate an acute-phase response to the first few weeks of implantation. However, this response was temporary suggesting that body does not consider implanted LHX devices as a long-term sublethal threat. In addition, dive behavior and movement patterns post-release were not altered compared to individuals of the same population. The lack of substantive physiological response combined with no observed behavioral effects post-release suggest that LHX implantation is a viable method for the long-term monitoring of Steller sea lions, with potential for future modification and use in other marine mammal species.

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#### References

- Ågren, E.O., Nordenberg, L., Mörner, T., 2000. Surgical implantation of radiotelemetry transmitters in European badgers (*Meles meles*). *J. Zoo Wildl. Med.* 31, 52–55.
- Arnould, J.P.Y., Boyd, I.L., Speakman, J.R., 1996. Measuring the body composition of Antarctic fur seals (*Arctocephalus gazella*): validation of hydrogen isotope dilution. *Physiol. Zool.* 69, 93–116.
- Bowen, W.D., Iverson, S.J., 1998. Estimation of total body water in pinnipeds using hydrogen-isotope dilution. *Physiol. Zool.* 71, 329–332.
- Bossart, G.D., Reidarson, T.H., Dierauf, L.A., Duffield, D.A., 2001. Clinical pathology. In: Dierauf, L.A., Gulland, F.A. (Eds.), *Handbook of Marine Mammal Medicine*. CRC Press, New York, pp. 383–436.
- Call, K.A., Fadely, B.S., Greig, A., Rehberg, M.J., 2007. At-sea and on-shore cycles of juvenile Steller sea lions (*Eumetopias jubatus*) derived from satellite dive recorders: a comparison between declining and increasing populations. *Deep-Sea Res., Part 2, Top. Stud. Oceanogr.* 54, 298–310.
- Fadely, B.S., Robson, B.W., Sterling, J.T., Greig, A., Call, K.A., 2005. Immature Steller sea lion (*Eumetopias jubatus*) dive activity in relation to habitat features of the eastern Aleutian Islands. *Fish. Oceanogr.* 14 (1), 243–258.
- Gerrodette, T., 1987. A power analysis for detecting trends. *Ecology* 68, 1364–1372.
- Holmes, E.E., York, A.E., 2003. Using Age structure to detect impacts on threatened populations: a case study with Steller sea lions. *Cons. Biol.* 17, 1794–1806.
- Horning, M., Hill, R.D., 2005. Designing an archival satellite transmitter for life-long deployments on oceanic vertebrates: the life history transmitter. *IEEE J. Ocean. Eng.* 30, 807–817.
- King, J.C., Gelatt, T.S., Pitcher, K.W., Pendleton, G.W., 2007. A field-based method for estimating age in free-ranging Steller sea lions (*Eumetopias jubatus*) less than twenty-four months of age. *Mar. Mamm. Sci.* 23 (2), 262–271.
- Lander, M.E., Westgate, A.J., Bonde, R.K., Murray, M.J., 2001. Tagging and tracking. In: Dierauf, L.A., Gulland, F.A. (Eds.), *Handbook of Marine Mammal Medicine*. CRC Press, New York, pp. 851–880.
- Latimer, K.S., Prasse, K.W., 2003. Leukocytes. In: Latimer, K.S., Mahaffey, E.A., Prasse, K.W. (Eds.), *Duncan & Prasse's Veterinary Laboratory Medicine: Clinical Pathology*, 4th edition. Iowa State University Press, Ames, Iowa, pp. 46–79.
- Link, W.A., Barker, R.J., 2005. Modeling association among demographic parameters in analysis of open population capture-recapture data. *Biometrics* 61, 46–54.
- Loughlin, T.R., Sterling, J.T., Merrick, R.L., Sease, J.L., York, A.E., 2003. Diving behavior of immature Steller sea lions (*Eumetopias jubatus*). *Fish. Bull.* 101, 566–582.
- Maniscalco, J.M., Parker, P., Atkinson, S., 2006. Interseasonal and interannual measures of maternal care among individual Steller sea lions (*Eumetopias jubatus*). *J. Mammal.* 87 (2), 304–311.
- Mellish, J., Calkins, D., Christen, D., Horning, M., Rea, L., Atkinson, S., 2006. Temporary captivity as a research tool: comprehensive study of wild pinnipeds under controlled conditions. *Aquat. Mamm.* 32, 58–65.
- Mellish, J., Hennen, D., Thomson, J., Petrauskas, L., Atkinson, S., Calkins, D., 2007. Physiological response to hot-branding in juvenile Steller sea lions. *Wildl. Res.* 34, 1–6.
- Monnett, C., Rotterman, L.M., 2000. Survival rates of sea otter pups in Alaska and California. *Mar. Mamm. Sci.* 16, 794–810.
- Philo, L.M., Follmann, E.H., Reynolds, H.V., 1981. Field surgical techniques for implanting temperature-sensitive radio transmitters in grizzly bears. *J. Wildl. Manage.* 45, 772–775.
- Raum-Suryan, K.L., Pitcher, K.W., Calkins, D.G., Sease, J.L., Loughlin, T.R., 2002. Dispersal, rookery fidelity, and metapopulation structure of Steller sea lions (*Eumetopias jubatus*) in an increasing and a decreasing population in Alaska. *Mar. Mamm. Sci.* 18 (3), 746–764.
- Rehberg, M.J., 2005. Pattern matters: changes in the organization of swimming and diving behavior of Steller sea lion juveniles in Alaska. M. Sc. thesis, University of Alaska, Anchorage, AK.
- Roletto, J., 1993. Hematology and serum chemistry values for clinically healthy and sick pinnipeds. *J. Zoo Wildl. Med.* 24, 145–157.
- Scrimgeour, C.M., Rollo, M.M., Mudambo, M.K.T., Handley, L.L., Prosser, S.J., 1993. A simplified method for deuterium/hydrogen isotope ratio measurements on water samples of biological origin. *Biol. Mass Spectro.* 22, 383–387.

- Smith, H.R., 1980. Intraperitoneal transmitters in suckling white-footed mice, *Peromyscus leucopus*. Biotelem. Patient Monit. 7, 221–230.
- Sorna, M., Tsutsumi, M., 1986. Biological telemetry using the Argos system. Mesogee 46, 87–92.
- Thomton, J., Mellish, J., 2007. Haptoglobin concentrations in free-range and temporarily captive juvenile Steller sea lions. J. Wildl. Dis. 43 (2), 258–261.
- Thomton, J.D., Mellish, J.E., Hennen, D., Horning, M., in review. Juvenile Steller sea lion dive behavior following temporary captivity. Endangered Species Research.
- Wheatley, M., 1997. A new surgical technique for implanting radio transmitters in beavers, *Castor canadensis*. Can. Field-Nat. 111, 601–606.
- Winship, A.J., Trites, A.W., 2006. Risk of extirpation of Steller sea lions in the Gulf of Alaska and Aleutian Islands: a population viability analysis based on alternative hypotheses for why sea lions declined in western Alaska. Mar. Mamm. Sci. 22, 124–155.
- Williams, T.D., Siniff, D.B., 1983. Surgical implantation of radiotelemetry devices in the sea otter. J. Am. Vet. Med. Assoc. 183, 1290–1291.
- York, A., 1994. The population dynamics of Northern sea lions 1975–1985. Mar. Mamm. Sci. 10, 38–51.