Wildlife Society Bulletin 36(1):6 15; 2012; DOI: 10.1002/wsb.113

Original Article

Washing Oiled Sea Otters

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ABSTRACT The 1989 Exxon Valdez oil spill resulted in the death of 3,000–6,000 sea otters (*Enhydra lutris*) from exposure to Alaska North Slope crude oil, and the cleaning and rehabilitation of hundreds. The washing and care methods developed during that experience provided standard protocols for treatment of oiled sea otters, largely still in use 20 years later. From 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA), we experimentally manipulated water type (salt–fresh) and temperature, and we monitored otter physiology, behavior, and thermal properties to evaluate recovery from washing in the absence of oil. We also dipped otters in canola oil, and were able to wash one otter naturally oiled with Monterey formation crude oil, using the same methods. Providing soft freshwater in recovery pools reduced recovery time substantially. Warming the freshwater appeared to offer additional benefits in some cases. Infrared thermography and subcutaneous temperature-sensitive passive integrated transponder tags were 2 new technologies that enhanced this research. The improved washing and care methods developed have the potential to reduce the time required for recovery of water repellency of sea otter pelage.

KEY WORDS *Enhydra lutris*, Exxon Valdez, petroleum, recovery, sea otter, washing.

The historic fur trade of the late 1700s and early 1800s resulted in severe depletion and local extinction of sea otter populations throughout their historic range. The current range of the northern sea otter (*Enhydra lutris kenyoni*) arcs across the Aleutian Islands and southern Alaska (USA), the British Columbia coastal islands (Canada), and the northern coastal portions of Washington State (USA). The southern sea otter (*E. l. nereis*) is found only along California's central coast (USA).

The sea otter, due to its unique anatomy and physiology, is the marine mammal most susceptible to the detrimental effects of external oil contamination. Sea otters live in waters that are typically 21.0–38.0° C (50.0–70.0° F) below their core body temperature of 37.5–39.5° C (99.5–103.1° F). The thermal conductivity of water is approximately 25 times that of air of the same temperature (Denny 1993). The smallest of marine mammals in North America, sea otters have a high metabolic rate as compared to terrestrial mammals of similar size (Iverson 1972, Morrison et al. 1974, Costa 1978, Costa and Kooyman 1982), a high surface area:volume ratio, relatively little body fat, and no subcutaneous blubber layer (Williams et al. 1992). They generally must consume 20–25% of their body weight in shellfish daily (Kenyon 1969) to maintain their weight and core temperature (Costa and Kooyman 1982, Yeates 2006). Sea otter fur is the densest of any mammal, composed of stout guard-hairs and shorter, finer under-hairs varying from 26,000 hairs/cm^2 to 164,700 hairs/cm^2 (Tarasoff 1974, Williams et al. 1992, Davis and Hunter 1995). The interlocking of under-fur hair shafts to form aligned sheets, combined with surface tension, traps a layer of air next to the skin (Weisel et al. 2005). The void space (normally air space) in the coat is approximately 80% of the pelt's volume (Williams et al. 1988). The hydrophobic nature of the cuticle and the surface tension allow this air to remain trapped and provide an insulating "dry suit" like that used by divers in cold oceans (Tarasoff 1974, Swift 1977, Williams et al. 1988, Williams et al. 1992). When oil penetrates the fur, air is displaced and interlocking of the underfur hair shafts is disrupted, reducing the pelage-insulating properties by approximately 70% (Williams et al. 1988, Davis and Hunter 1995), which leads to potentially lethal hypothermia. Grooming also leads to ingestion of, and mucous membrane exposure to, toxic constituents of petroleum. Once the fur is compromised by oil, otters must 1) increase their already high metabolic rate, 2) increase food consumption, and/or 3) leave the water in order to offset heat loss.

Received: 15 November 2010; Accepted: 14 October 2011;
Published: 24 February 2012

Additional supporting information may be found in the online version of this article.

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The first alternative is only marginally possible and takes many days to occur. The latter 2 alternatives directly conflict, and reduced foraging resulting from leaving the water rapidly leads to starvation and potentially lethal hypoglycemia and hypothermia.

The grounding of the Exxon Valdez on Bligh Reef in the spring of 1989 in Prince William Sound, Alaska resulted in the release of approximately 11-million gallons of crude oil. The timing and nature of both spill and response resulted in the oil spreading a distance of over 900 km (560 miles), causing severe negative effects on marine mammals, birds, and ecosystems. In 1989, there were no facilities for the care of oiled wildlife in Alaska. Some otters had to wait days or weeks for care and died as a result. Three hundred sixty-one sea otters were cared for by contractors working for Exxon, of which 123 (34%) died, 196 (54%) were cleaned and released to the wild, and 37 (10%; many of them pups) were judged to be unlikely to survive if released and were sent to public display facilities (Hofman 1994). Additional information on the washing methods used in 1989 at the Exxon Valdez oil spill is presented in Addendum A.

River otter (*Lontra canadensis*) and American mink (*Neovison vison*) have been used as models for sea otters, at least in part because they have very similar hair-coat characteristics and hair-shaft microanatomy (Weisel et al. 2005). In river otter experiments, rinsing-water temperatures of 24.0° C (75.2° F) depressed body temperature more severely than rinsing at 38.0° C (100.4° F), but researchers were unable to reproduce loss of waterproofing in 8 of 10 river otters using a 1:16 dilution of dishwashing liquid (Stoskopf et al. 1997). Mink have been experimentally exposed to both acute external and chronic internal doses of Alaska North Slope (ANS) crude oil and Bunker C fuel oil (Mazet et al. 2000, 2001). This research was done under winter conditions in the Pacific Northwest that duplicated many of the physiologic stresses and some of the pathologies seen in sea otters in Alaska in 1989 (Mazet et al. 2000).

Washing trials on pelts of mink, river otter, and sea otter showed that washing procedures similar to those used in Alaska in 1989 were likely to have left residual soap and salts on the under-fur hair shafts (Dunkin 2001) that could disrupt their realignment into sheets, inhibit the restoration of critical microanatomy, and retard the waterproofing process.

No empirical research to improve washing techniques for sea otters had occurred in the 15 years since the Exxon Valdez spill; therefore, in 2004, the California Department of Fish and Game (CDFG)—Office of Spill Prevention and Response established and funded a program to explore the physiology of washing sea otters with the goal of reducing the total time spent in the rehabilitation process through reducing the time required for them to recover their waterproofing and ability to thermoregulate.

METHODS

Animals, Care, and Facilities

Between 2004 and 2008 we used 2 adult male sea otters (referred to as otters A and B) in a washing research program conducted at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA). After repeated attempts at rehabilitation and release, both had been declared "unreleasable" by U.S. Fish and Wildlife Service due to maladaptive or aggressive behaviors toward humans and other animals. All procedures were approved by U.S. Fish and Wildlife Service (permit no. MA095276-1) and the Institutional Animal Care and Use Committee (U.S. Department of Agriculture—Animal and Plant Health Inspection Service Registration Certificate 93-R-0471) of the CDFG Marine Wildlife Veterinary Care and Research Center, Santa Cruz, California. Two adult male otters were acclimated to presence of people and trained using positive reinforcement techniques to enter and leave the water on command, station in various positions on deck, and to cooperate in simple handling and examination procedures including voluntary weighing. Additional comment on training methods can be found in Addendum B.

The sea otters were ages 12 and 2 at the beginning of these studies. Both exhibited normal behaviors, were in excellent health (based on multiple veterinary examinations and complete blood counts and serum chemistries), and had been in captivity for a minimum of 1 year prior to training and experimental measurements. We maintained animals in outdoor fiberglass holding pools (4.2 m × 1.2 m or 6 m × 1.5 m; diam × depth) and fed them a daily mixed diet of commercially obtained frozen squid (*Loligo opalescens*), surf clam (*Spisula solidissima*), cod (*Macruronus novaezelandiae*), and tiger prawns (*Panaeus vannamei*) presented in 4–7 meals/day. We weighed animals weekly to the nearest 0.1 kg using a platform scale (Arlyn, Rockaway, NY). Under nonexperimental conditions, pools were maintained on an open-loop system with fresh seawater from Monterey Bay continuously added at a minimum of 227 L/minute. Under this configuration, water temperatures varied with ambient coastal ocean temperature (approx. 10.0–17.0° C [50.0°–62.6° F]). A closed-loop configuration was used during trials in which the pool water was heated or freshwater was used. For these trials, salt water or freshwater was circulated through filters and a water heater and returned to the pool.

Instrumentation

We surgically implanted temperature-sensitive, very high frequency (VHF) radiotransmitters (7.6 cm × 10.2 cm × 2.5 cm, approx. 120 g; Advanced Telemetry Systems Incorporated, Isanti, MN) into the peritoneal cavity following previously published procedures (Lander et al. 2001) and used them to continuously monitor core body temperatures. The frequency of the pulsed signal was correlated to temperature and calibrated by the manufacturer over the range of expected body temperatures (Yeates 2006).

We subcutaneously implanted temperature-sensitive 14 mm × 2 mm-diameter passive integrative transponder (PIT) tags (IPTT-300; Bio Medic Data Systems, Seaford, DE) using a sterile 14-gauge needle at 3 sites along the dorsal midline: over the seventh cervical vertebra, the last thoracic vertebra, and at the first sacral vertebra. We read tags using a scanner (WRS-6007; Bio Medic Data Systems).

Figure 1. Subcutaneous temperatures of sea otters were read by scanning temperature sensitive passive integrated transponder tags 3 times daily at 3 locations on the body while the otter was voluntarily stationed for food. Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

Baseline Body Temperatures

We recorded core body temperatures from the VHF radio every 60 seconds using an integrated radio-receiver data logger (R4500S; Advanced Telemetry Systems). The data logger continuously recorded the time interval between radio pulses from individual transmitters. This signal was translated into core body temperature using a second-order linear equation for pulse frequency versus temperature developed during the calibration tests, and was unique to each transmitter.

We scanned PIT tags 3 times/day (Fig. 1): once in the morning (between the hr of 0800 and 1000), once in the afternoon (between the hr of 1100 and 1300), and once in the evening (between the hr of 1600 and 1800). We recorded body temperatures (core and subcutaneous) for 3 days prior to washing procedures. These body temperatures were used as baseline temperatures for comparison with those recorded after washing trials.

We averaged 24-hour mean core body temperature (T_b) over the 3-day pretrial period and compared it to daily T_b for each day following every washing trial. Otters were considered to have returned to pretrial T_b values once the daily mean T_b was within pretrial values (±SD) for 3 consecutive days. We always recorded core body temperatures for ≥3 days prior to, during, and 21 days following each experimental trial.

Infrared Thermal Imaging and Visual Inspection of Fur

We assessed general pelage quality (water repellency, presence of matting) and water saturation of fur visually by inspection several times daily during feeding or training sessions. Otters voluntarily positioned themselves on deck for up to 5 minutes; we then took thermal images and digital photographs 3 times/day (0800 hr, 1300 hr, 1700 hr). We assessed patterns of heat gain or loss using an infrared thermal imaging camera (S65; FLIR Systems, Boston, MA; Fig. 2).

Handling and Anesthesia for Washing

For each washing, rinsing, and recovery trial, we netted the captive sea otters out of their regular holding tanks and injected them intramuscularly (IM) with 0.22 mg/kg fentanyl citrate (Fentanyl Citrate for injection; Central Avenue Pharmacy, Pacific Grove, CA) and 0.07 mg/kg midazolam (Ben Venue Laboratories, Incorporated, Bedford, OH) to induce anesthesia. We recorded the following data: vital signs, photographs, and weight; blood samples for complete blood count; serum chemistry panel; and cortisol. We then intubated otters with a 5.0–6.0-mm endotracheal tube. Isoflurane to effect, typically 0.5–1.0%, was used to maintain anesthesia for the 2 hours of each trial. We monitored oxygen saturation and carbon dioxide levels continuously using a pulse oximeter and capnograph (V9204 SurgiVet Advisor Vital Signs Monitor; Smiths Medical PM Incorporated, Waukesha, WI). At the end of each trial, we gave 0.66 mg/kg naltrexone (ZooPharm, Fort Collins, CO) IM to reverse the effects of the fentanyl.

Trial Design and Inter-Trial Intervals

The research was divided into 3 phases, with ≥1 trial in each phase (Table 1). Inter-trial intervals (Phases I–III inclusive) varied, but were never <60 days following complete recovery

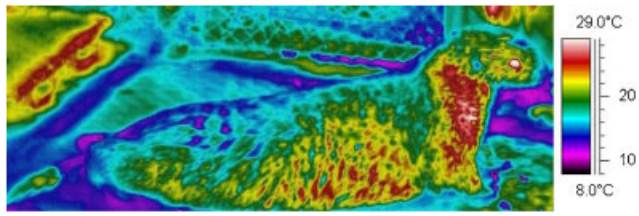

Figure 2. Sea otter A: prewashing image using a FLIR S65 on "rain" spectrum, temperature in centigrade. The heat signature on the neck and abdomen results from basking in the sun. The texture of the fur and its color change when water repellency is lost. Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

Table 1. Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA): phases and trials, length of anesthesia for washing, serum cortisol levels before and after washing, and decline for otters A and B.

				Serum cortisol (μg/dL)		
Procedure	**Variable**	**Length of time (hr)**	**Otter**	**Before**	**After**	**Decline**
Phase I	Trial 1: anesthesia only	2	A	1.3	1.3	0.0
			B	1.0	0.4	0.6
	Trial 2: rinse at 26.7° C (80° F) only	2	A	2.7	0.3	2.4
			B	1.4	0.3	1.1
	Trial 3: rinse at 32.2° C (90° F) only	2	A	3.3	0.4	2.9
			B	2.4	0.3	2.1
Phase II	Trial 4: standard wash; recovery in ambient seawater	2	A	0.4	0.4	0.0
			B	2.1	0.3	1.8
	Trial 5: standard wash; recovery in softened warm freshwater	2	A	2.4	0.4	2.0
			B	1.4	0.3	1.1
	Trial 6: standard wash; recovery in softened ambient freshwater	2	A	2.4	0.4	2.0
			B	3.7	0.3	3.4
	Trial 7: repeat of trial 4	2	A	2.1	0.3	1.8
			B	2.1	0.3	1.8
	Trial 8: standard wash; recovery in warm seawater	2	A	1.8	0.3	1.5
			B	2.1	0.3	1.8
Phase III	Trial 9: canola oiled, then washed; reduced rinse; recovery in softened warm freshwater	2	A	3.9	0.4	3.5
			B	2.1	0.4	1.7

of waterproofing and thermoregulatory ability and, in some cases, were as long as 120–180 days. We carried out each washing trial separately with approximately 3–4 weeks between the same numbered trial on different otters, such that only one animal was being closely monitored at any one time. To the maximum extent possible, we used the same equipment, personnel, methods, handling, and sampling protocols in every trial.

Phase I: Anesthesia and Rinsing

To establish the thermal effects of 2 hours of anesthesia alone, and to verify the observations made on river otters rinsed at 24.0° C and 38.0° C (75.2° F and 100.4° F), the first phase of this research consisted of a series of 3 initial trials with each otter. During trial 1, we placed anesthetized otters on a stainless-steel grate mounted in a stainless-steel basin (specifically designed for washing sea otters; Williams and Davis 1995), for 2 hours, and took temperature readings, with no other treatment. Room temperatures ranged between 10.0° C and 16.7° C (50.0° F and 62.0° F).

During trial 2, we anesthetized each otter for 1 hour and then rinsed it at 26.7° C (80.0° F) for 1 hour. During trial 3, a rinse-water temperature of 32.2° C (90.0° F) was used. We rinsed otters in softened freshwater for 60 minutes, using a repeating pattern of 15 minutes of rinsing ventrally and then 15 minutes rinsing dorsally. We recorded core body temperature and plotted it for each otter. Rinsing-water temperature was monitored using a thermocouple (PhysiTemp, Clifton, NJ) and hardness was maintained at 4 grains using a commercial water softener (Culligan Hi-Flo3; Culligan International Company, Rosemont, IL). We measured water hardness using a water-quality test kit (Hach 5-EP; Hach Company, Loveland, CO).

We monitored the core body temperature continuously using both the VHF radiotransmitter and a flexible rectal thermocouple probe (PhysiTemp). During rinsing procedures, we monitored subcutaneous PIT tag temperatures at 15-minute intervals. Following rinsing, we initially dried otters by vigorously rubbing the fur using clean cotton towels. We then dried fur using a commercial pet dryer (Oster Hi-Velocity Adjustable Table-Cage Dryer no. 78304-010-000; Sunbeam Products, Incorporated, McMinnville, TN) for approximately 6 minutes. After completion of each trial, we placed otters in a clean, dry Vari-kennel® (Extra-large; Doskocil Manufacturing Company Incorporated, Arlington, TX) and gave reversal drugs. We held otters in the kennel for approximately 1 hour and returned them to the ambient-temperature seawater pools once they were alert and responsive.

Phase II: Washing

The same procedures used in Phase I, trials 2 and 3, were utilized during Phase II, trials 4–8, with the additional procedures as follows. Following anesthesia, we placed each otter on the stainless-steel grate and basin and washed it for 15 minutes (7.5 min ventrally and 7.5 min dorsally) from the axilla (armpits) down, using 6% Dawn® (Procter & Gamble, Cincinnati, OH) dishwashing solution warmed to 26.7° C (80.0° F; Davis et al. 1988, Williams et al. 1988). Washing consisted of saturating the pelage with dilute detergent followed by continuous active digital massage of the soapy areas by 2 people.

We rinsed otters in warm softened freshwater for 60 minutes, as in trials 2 and 3, with rinsing-water temperatures ranging between 32.2° C and 33.0° C (90.0° F and 91.4° F). On several occasions toward the end of a 2-hour period when core body temperature of otters approached 35.0° C (95.0° F), we increased rinse-water temperatures to 35.0–35.5° C (95.0–95.9° F) to maintain a safe, stable core body temperature. Following rinsing, we dried otters and allowed them to recover as previously described.

The only variables manipulated in Phase II, trials 4–8, were water temperature and salinity of the recovery pool in the following order: 4) ambient seawater (water temp range = 10.0–14.5° C [50.0–58.1° F]), 5) warmed softened fresh water (water temp range = 17.0–20.6° C [62.6–69.1° F]), 6) ambient-temperature (cool) softened fresh water (water temp range = 11.6–12.9° C [52.9–55.2° F]), and 8) warmed seawater (water temp range = 17.0–19.0° C [62.6–66.2° F]). Trial 7 was a duplicate of trial 4 (ambient seawater) in an attempt to determine whether results were repeatable and whether reduced recovery times seen in trials 5 and 6 might be the result of learned behavior. Trial 8, release into warmed sea water, completed the Latin Square design of this phase of the trials. We controlled water temperature of heated recovery pools via a hot-water heater (D3T9-208-30X-3-PI-X60; Process Technology, Mentor, OH).

Phase III: Washing Oiled Sea Otters

In Phase III (trial 9), after anesthesia, we dipped each otter into a 190-L container of seawater at 13.8° C (56.8° F), to which 120 mL of canola oil had been added to produce a 2-mm slick, and we stirred the mixture for 3 minutes. We submersed each otter 3 times to the level of the umbilicus and then elevated it until the tip of the tail emerged. We then placed the otters on the stainless-steel rinsing grates and massaged the oil–seawater mixture into the fur distal to the umbilicus for 10 minutes to mimic grooming behavior. We then washed otters in the same manner as in previous trials 4–8, except we reduced rinse times slightly to 10 minutes per side, front, then back, and repeated (total rinse time 40 min instead of 60 min). Following rinsing, we dried otters, allowed them to recover as previously described, and returned them to a pool of warmed fresh softened water (water temp range = 17.0–20.6° C [62.6–69.1° F]). With the exception of the initial oiling and a 20-minute (33%) reduction in rinsing time, this trial was the same as trial 5.

Determination of Recovery

Recovery of normal water-repellant properties of the fur was based on 1) visual observation of normal fur characteristics on close inspection by the trainer, 2) return to prewash patterns of infrared heat loss, 3) return to normal prewash behavior patterns, and 4) return of subcutaneous temperatures to pretrial values. We considered an otter recovered from the washing when all 4 criteria were met. We deemed metabolic recovery, or return to a normal metabolic rate, to have occurred when VHF-radiomonitored T_b returned to baseline level following a washing trial.

Statistical Analyses

We compared recovery time for waterproofing and mean core body temperature between fresh and softwater methods using repeated-measures analysis of variance (ANOVA) with trial as the within-subject factor and water type the between-subject factor. We did all analyses using appropriate statistical software (PASW Statistics 18.0; SPSS, Inc., Chicago, IL) and considered a P-value of <0.05 significant.

RESULTS

Phase I

In trial 1, 2 hours of anesthesia at ambient room temperature resulted in a slight initial decrease followed by a steady increase of 0.5° C/hour (0.9° F/hr) in core body temperature. No significant effect on any other monitored parameter was noted. Trials 2 and 3, rinsing each otter at 26.7° C (80.1° F) and 32.2° C (90.0° F) for 1 hour, resulted in a steady decline of 1.0° C/hour (1.8° F/hr) in core body temperature. No significant effect on any other parameter was noted.

Results of complete blood counts and 24-value serum chemistry panels taken immediately before and after all trials (a period of approx. 2 hr) did not reveal any significant departure from baseline levels established for otters A and B before experimental trials, or from establish sea otter normal ranges. For most trials, serum cortisol (μg/dL) taken immediately before and after trials showed an order-of-magnitude decline over the approximately 2 hours of the procedures (Table 1).

Phase II

The time required for the fur to return to normal water repellency (trials 4–9 of Phases II and III) was significantly influenced by whether recovery water provided was softened freshwater or seawater (repeated-measures ANOVA; $P = 0.003$ [Fig. 3]). When released into freshwater (either warmed or ambient temp—trials 5, 6, and 9), recovery times based on 4 criteria for both otters, whether oiled or not, averaged 2 days. When released into either warm or cold seawater (trials 4, 7, and 8), recovery by all 4 criteria averaged 7 days. Note: trial 4 with cold seawater came first sequentially and was repeated a year after the research started (as trial 7). Results were very similar (repeatable) and showed that experience with repeated washings had not altered time required for recovery.

Phases II and III

The time required for T_b to return to baseline for sea otters A and B following 6 washing trials was clearly influenced by

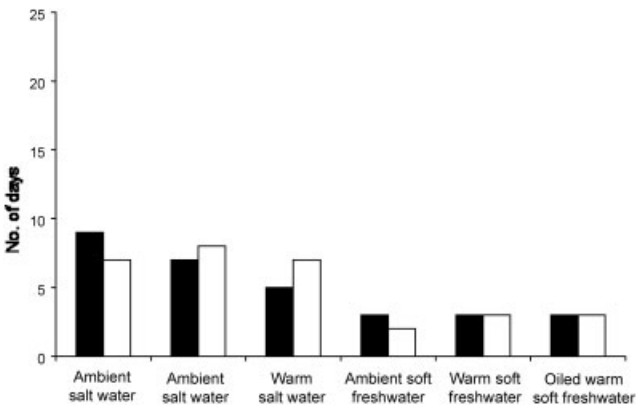

Figure 3. The number of days required for the sea otter's fur to return to full water repellency, as determined by 4 criteria following a washing trial, for each recovery water regime for otter A (white bars) and otter B (black bars). Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

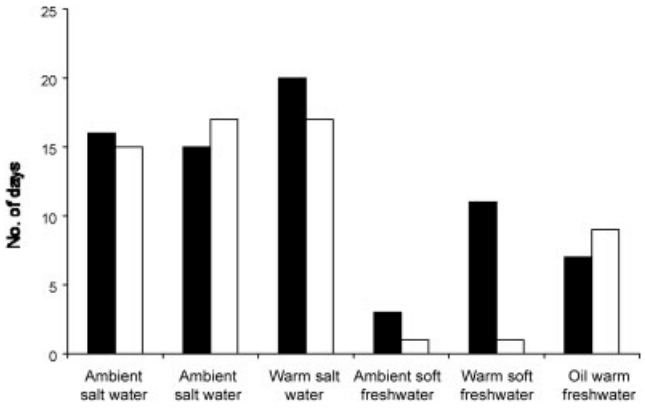

Figure 4. The number of days required for mean core body temperature of sea otters to return to pretrial values for otter A (white bars) and otter B (black bars) for each washing trial. Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

whether softened fresh- or seawater was provided for bathing during recovery (repeated-measures ANOVA; $P = 0.027$ [Fig. 4]). Recovery of T_b in either warm or ambient-temperature seawater took longer (trials 4, 7, and 8; $\overline{x} = 17$ days) than in any trials where recovery occurred in freshwater (trials 5, 6, and 9; $\overline{x} = 5$ days). Some individual variations in T_b recovery times in freshwater were evident. When oiled and released into warm freshwater (trial 9) both otters appeared to require slightly more time for T_b recovery than when not oiled. Although trial 9 was very similar to trial 5, they were not identical.

The overall pattern of T_b elevation and return to baseline was significantly influenced by the type of water in which they recovered (Fig. 5A, B). Body temperature recovery in freshwater (warmed or ambient temp) was $\geq$50% faster than when core body temperature was more seriously disrupted, as occurred in all seawater trials. Return to T_b was believed to reflect recovery to a normal metabolic rate.

Phase II: Comparison of Core Body to Subcutaneous Temperatures

Core body temperatures and subcutaneous temperatures derived from PIT tags before, during, and after a typical washing trial revealed clear evidence of a relationship between time required for coat recovery and water type provided (Fig. 6A, B). For example, in trial 4 (ambient-temp seawater) with otter A, subcutaneous temperatures in washed areas took 5 days to return to baseline temperature conditions (Fig. 6A). During this time, and for some days following, core temperature trended upward at a rate of 0.3° C/day. The temporary increases of subcutaneous temperatures during the first 4 days (Fig. 6A) reflect basking and haul-out behaviors that provided only temporary relief until water repellency of the fur coat returned. In trial 6 (ambient-temp soft freshwater) otter A required just over 24 hours for subcutaneous temperatures to return to baseline and core temperature did not significantly increase (Fig. 6B). Comparison of trials 4 and 6 (Fig. 6A, B) for this same animal shows the difference in subcutaneous temperature

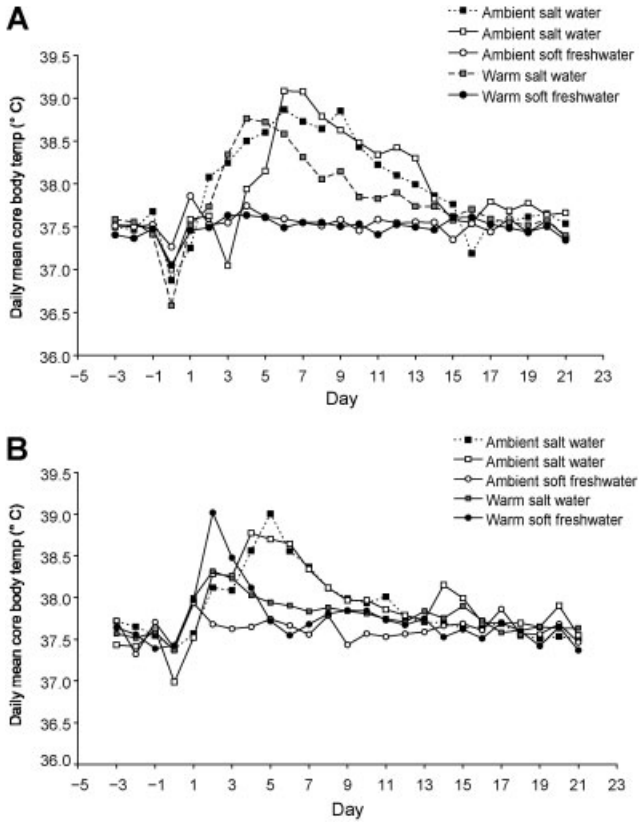

Figure 5. Daily sea otter mean core body temperature for otter A (top panel) and otter B (bottom panel) following washing trials while recovering in ambient salt water (closed and open squares), soft freshwater (open circles), warm salt water (gray squares), and warm soft freshwater (closed circles). Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

recovery time in ambient-temperature salt water versus ambient-temperature soft freshwater. Similar patterns were observed for otter B, and for other trials.

Comparison of Digital and Infrared Images

Paired digital photographic and infrared images were effective in identifying areas with poor waterproofing (Fig. 7). Infrared "thermograms" clearly showed extensive heat loss from areas where water repellency had been lost. For example, an infrared photo of otter B 24 hours after washing trial 4, taken with a FLIR S65 camera in the "rain" infra-red spectrum, showed essentially all washed portions of the body radiating heat (from 22° C to >28° C; Fig. 7A). A digital image, taken 3 minutes later, showed the slick, soaked appearance of the hair coat (Fig. 7B). During the recovery of otter C (a naturally oiled subad F), using a "rain" spectrum thermogram, a persistent wet spot (28.0–32.0° C) was evident (Fig. 7C). A matching digital photo taken minutes earlier showed the wet spot as it appeared to the human eye (Fig. 7D).

Changes in Behavior and Body Mass

Generally there was no significant change in the proportion of time spent in water and on deck before and after washing. For example, otter B spent 89% of time in water and 11% out of water before trial 5, and 90% in water and 10% out of water

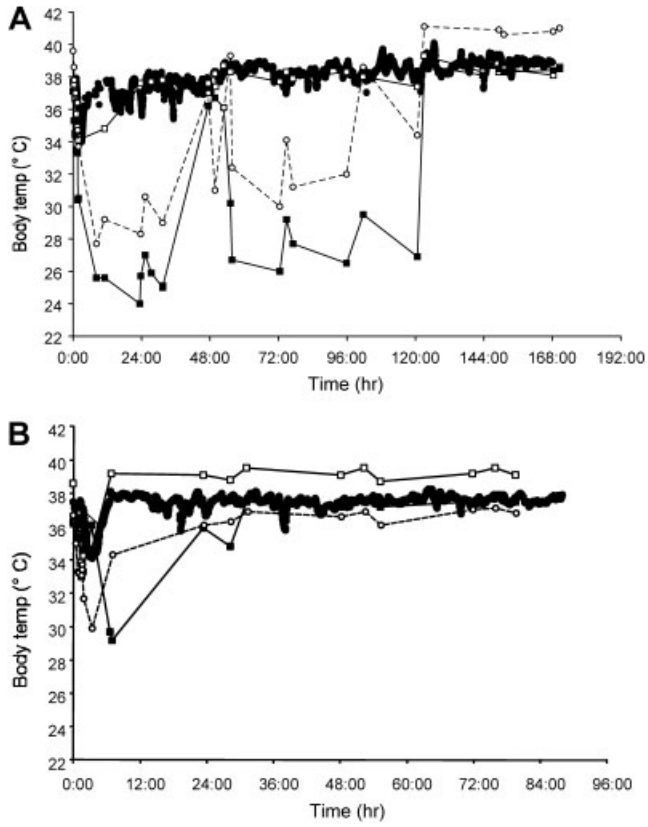

Figure 6. (A) Core temperature (closed circles) and subcutaneous PIT temperatures of sea otters at the neck (open squares), the mid back (closed squares), and the lower back (open circles) over a 96 hour period for otter A recovering in ambient salt water (trial 4), and (B) core and subcutaneous temperatures for otter A recovering in warm freshwater (trial 6). Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

afterward. However, the time spent grooming in and out of water increased dramatically during the first 24–48 hours after washings. Increasing time was spent at various specialized forms of in-water grooming like "log rolling" and "somersaulting" (Packard and Ribic 1982) as recovery progressed.

For essentially all trials, daily caloric content of food was held at the same level prior to and following any wash. Changes in body mass, even when obtained by voluntary weighing prior to, during, and after washing trials, proved unreliable as a measure of recovery following washing. Immediate weight gains of up to several kg occurred after washing trials due to water entrapped in the fur. Otter A, the older of the two, showed a tendency for weight loss in the week or two following trials that required longer recovery times.

The Real Thing

In February 2009, after the research trials on otters A and B were completed, a subadult female southern sea otter (otter C) heavily (50%) tarred with Monterey formation crude oil was rescued and treated using the procedures described for our experimental animals (Fig. 8A–D). The washing was conducted approximately 24 hours after otter C stranded and following administration of parenteral fluids, glucose, and provision of warmth and food. It is impossible to wash tar out of fur or feathers with detergent and water; therefore, a cup of olive oil was massaged into the coat of otter C to soften the tar and facilitate its displacement from the fur. After approximately 10 minutes of massaging in the olive oil, the oil and tar combination was reduced to the consistency of a thin paste (Fig. 8B). The entire body of otter C was washed and rinsed using procedures similar to those used on otters A and

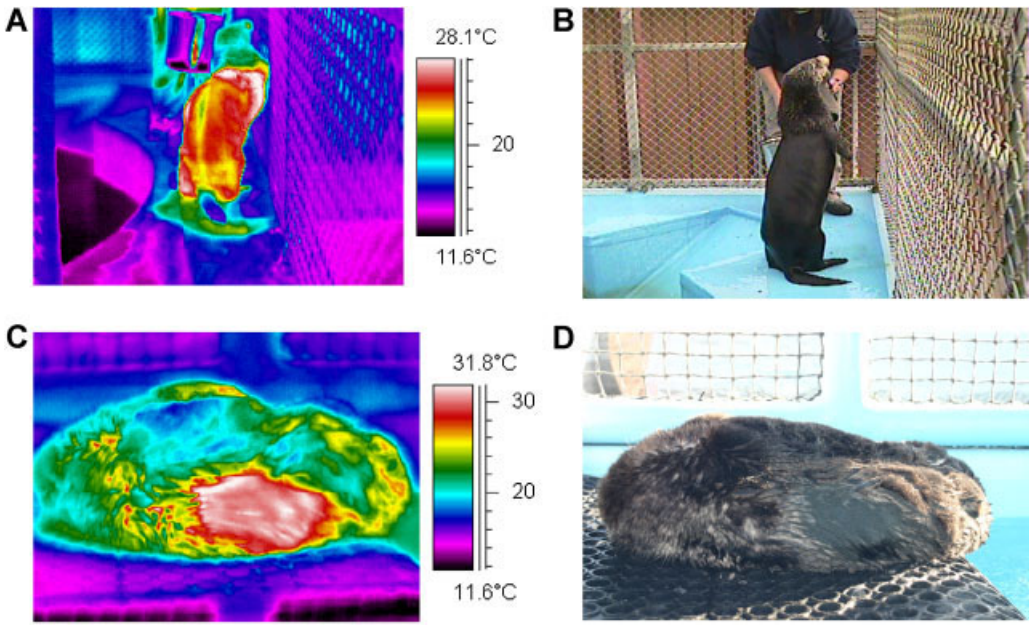

Figure 7. Infrared thermograms (A, C) and accompanying digital images (B, D) of washed sea otters. Surface temperatures (centigrade scale at right of A and C) are correlated to color white, red, and yellow representing relatively warmer temperatures and green, blue, and purple denoting the coolest temperatures. Thermogram A and Photo B both are of otter B 2 days postwashing trial 4. Thermogram C and photo D both are of otter C 4 days postwashing. Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

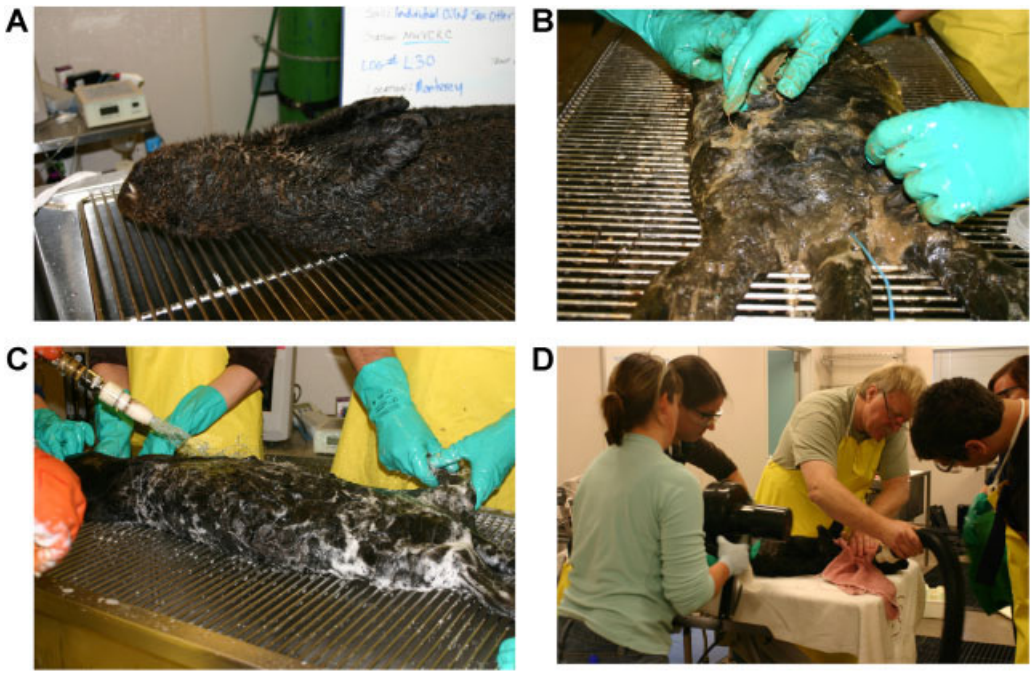

Figure 8. Composite picture showing (A) extent of tarring on anesthetized subadult female sea otter C, (B) beginning to rinse out olive oil and tar and detergent, (C) rinsing after most oil removed, and (D) drying. Sea otter washing study conducted from 2004 to 2008 at the Marine Wildlife Veterinary Care and Research Center (Santa Cruz, CA, USA).

B (Fig. 8C, D). Otter C was severely emaciated (approx. 20% underweight for age and length) and rapidly lost body heat, so the rinse-water temperature was increased to 37.8° C (100.0° F). Due to continuing depression, her low intake blood glucose (50), and periodic bouts of hypo- and hyperthermia, she was kept indoors under steady observation for 24 hours after washing.

We monitored core and subcutaneous temperatures regularly and provided chipped ice, which C regularly gnawed on. Starting about 18 hours postwash and when core temperatures began to rise above normal, she began resting on the bed of chipped ice. These behaviors continued periodically when otter C was caged indoors.

We fed otter C hourly to repletion on day 1 and then every 2 hours for the next 2 days. On day 2, after initial release into warm freshwater 15.6° C (60.0° F) proved insufficient to maintain thermal stability, the softwater pool temperature was increased to 31.1° C (88.0° F). Although otter C's condition rapidly improved, due to continued weakness, she was allowed to swim and groom outdoors only under close observation for approximately 8 hours/day for 2 days and then brought indoors at night. We gradually lowered water temperatures as otter C was able to tolerate them and maintain normal core and subcutaneous temperatures. For further discussion of otter C, see Addendum B.

DISCUSSION

Limitations

The capture, handling, washing, and care of hundreds of oiled sea otters during the Exxon Valdez oil spill response provided, even now, an unmatched opportunity to observe the effects of ANS crude oil on the health and pelage of sea otters and to improve and fine-tune washing and care procedures. The otter response was also organized in such a way that observations and results were well-documented (Geraci and St. Aubin 1990, Loughlin 1994, Williams and Davis 1995).

Our captive sea otter washing research was designed so results could be compared to those of the Exxon Valdez oil spill. However, several important differences were unavoidable. In our study, the captive trained adult male research otters were in excellent health and without known preexisting health problems. Thus, the potential contributions of fear and physical exertion engendered by capture on the endocrine-mediated stress response, as well as the effects of pre-existing injuries, infections or other health problems, or pregnancy or lactation were not duplicated. No toxic petroleum products were used in the research trials, so toxic insults to the respiratory, hematopoietic, central nervous system, kidneys, liver, and integument (and their consequences on physiologic homeostasis), were not present.

Otters A and B had been acclimated to handling and manipulation to facilitate this research, but also to remove stress of handling and captivity as a variable that might influence outcomes. Variations in behavior type or frequency were obvious to animal care personnel, making detection of trial effects clear. Multiple veterinary examinations, complete blood counts, and serum chemistry evaluations performed on each otter prior to beginning washing trials and to monitor health during washing and rinsing trials (data not shown), all of which were within normal limits for sea otters, clearly established that both animals were healthy. Serum cortisol, a

measure of acute stress widely used in human and animal medicine (Fowler 1995), unexpectedly decreased by roughly an order of magnitude in both otters during the 2-hour course of most washings (Table 1). If the washing and rinsing trials had caused stress, pain, or tissue injury, then an increase in serum cortisol might be expected. Our results suggest that the drugs used for anesthesia and the manner in which the research trials were conducted were not injurious or stressful. They also suggest that the stress-related pathology and clinical pathology observed in 1989 may have had more to do with capture and holding of wild otters, and the effects of crude oil on various organ systems, than the washing and rinsing procedures themselves. For further discussion of sea otter washing and behavior, see Addendum B.

Temperature Effects

Core body temperature in sea otters is not as stable as that of many other mammal species, regularly varying with behaviors by about 2.0° C (3.6° F) daily (Costa and Kooyman 1982). Core temperatures of wild oiled otters are usually taken via rectal thermometer; however, this method is stressful and thermometer misplacement can result in either high or low readings. The implantation of VHF radios may be contraindicated in very recently oiled and washed sea otters that would be encountered during oil spill events. Subcutaneous temperature-sensitive PIT tags proved to be an accurate and relatively noninvasive tool for determining local temperature, and challenges to core temperature. The baseline subcutaneous temperatures at various location differed by about 1.0° C (1.8° F), but they differed consistently by location under normal conditions. For further discussion of PIT-tag temperature, see Addendum B.

Oil Effects

Oiling with vegetable oil did not appear to change the recovery process. The canola oil–seawater mixture was massaged into the fur to mimic grooming behaviors of hypothermic otters. For further discussion of the effects of oil on recovery, see Addendum B. In 1989, "the otters' normal grooming behavior in water usually results in full restoration of the fur in seven to ten days" (Davis and Hunter 1995:100). When otters A and B were washed and allowed to recover in either warm or cold seawater (trials 4, 7, and 8) it took approximately 5–6 days for subcutaneous temperatures, and 7 days for behaviors and coat waterproofing and insulating properties, to return to baseline. It took approximately 17 days for the mean core body temperature to return to baseline. Thus, the responses of otters A and B during trials 4, 7, and 8 were quite comparable to those reported for wild sea otters in 1989 (Davis and Hunter 1995). Conversely, the responses of otters A and B during trials 5, 6, and 9 (with coat recovery complete in 2–3 days and little to no elevation in T_b) were much more rapid than the week to 10 days reported in 1989, representing at least a halving of recovery time, by all measures.

Coat Recovery and Water Type

The factor that clearly influenced time required for coat recovery was the type of water (softened fresh- vs. seawater) provided to recovering otters. See Addendum B for further discussion of wash water and coat recovery.

Recovery of Mean Core Temperature

The T_b of otters that remained cold or had unstable subcutaneous temperatures for >48 hours (trials 4, 6, and 7) generally increased for a period of a week or more (Fig. 6A, B). We have interpreted this as a sign of increased metabolic rate, probably thyroid-mediated, and we have termed the time interval for return to baseline as "metabolic recovery." Relatively little disturbance to T_b (and, we posit, metabolic rate) occurred when otters were allowed to recover in either warm- or ambient-temperature soft freshwater (Fig. 6A, B). See Addendum B for further discussion of metabolic response.

Applicability and Cost

These washing trials used healthy, tame, research-trained, male otters. Wild sea otters in poorer body condition, with various pre-existing health problems, may respond differently. Although trained captive sea otters do not suffer the many stresses and health problems of wild sea otters, anything that can be done to reduce washing- and captivity-related physiologic stress, caloric needs, time until metabolic recovery, and time required for the fur to recover its water repellency, should benefit wild oiled sea otters. These benefits should also reduce holding times and per-animal costs associated with them. Direct costs associated with these treatments (excluding facility construction–modification) were modest: the inclusive cost of care for otter C for 2 weeks until she was recovered was about US$5,000, considerably less than the US$40,000–$80,000 estimated for sea otters in 1989 (Estes 1991).

MANAGEMENT IMPLICATIONS

Washing and treating oiled sea otters has the potential to save the lives and reduce suffering of individual sea otters, but also to reduce the potential threat posed by a catastrophic oil spill to a small threatened population like that of the southern sea otter. Facilities for the care and washing of oiled sea otters should be available in any locations where a reasonable likelihood of oil spills exists, because oiled sea otters have considerably reduced potential for survival unless washed within hours to days of stranding. Effective response relies greatly on the availability of pretrained and experienced staff and appropriately designed and supplied facilities.

Better recovery times should shorten overall holding, improve the efficiency of oiled otter care, and increase the numbers of otters that can be cared for in a given time period at any given facility. In turn, this should considerably reduce personnel time and costs and, most importantly, improve the survival and recovery to normal behaviors of the oiled, washed, and released wild sea otters. This research is already being used to modify sea otter washing protocols, to make changes in the design and construction of some otter care facilities, and has caused a re-evaluation of opinions, thoughts, and concepts coming out of the Exxon Valdez experience.

ACKNOWLEDGMENTS

This work was supported by the California Department of Fish and Game, Office of Spill Prevention and Response, Scientific Studies and Evaluations Program, and the University of California-Davis School of Veterinary Medicine, Oiled Wildlife Care Network under the respective leadership of B. Joab and M. Ziccardi. K. Mayer advocated for this research and M. Sowby and J. Yamamoto supported it in later years. This work was made possible by cooperation and collaboration between the staff of the CDFG-Marine Wildlife Care and Research Center, the University of California—Santa Cruz (UCSC) Marine Mammal Physiology Project (MMPP) and the Monterey Bay Aquarium. We thank T. M. Williams and J. A. Estes; also B. Richter, T. Kendall, B. Long, M. Rohrer, and C. Doll of the UCSC MMPP; M. Viens and K. Mayer of the Monterey Bay Aquarium; and D. Brownstein, M. Reed, B. Weitzman, and F. Wilhelm of the MWVCRC for their contributions.

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Associate Editor: Rominger.