The effects of oil contamination and cleaning on sea otters (*Enhydra lutris*). I. Thermoregulatory implications based on pelt studies

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The contamination of sea otter (*Enhydra lutris*) fur with crude oil or dispersants reduces its insulation and could subject the animal to hypothermia. This study tested methods for removing crude oil from sea otter pelts, and measured changes in insulation caused by oil contamination and subsequent cleaning. Four detergents and two pretreatments were tested on sea otter pelts soiled with fresh crude, 5-day weathered crude, and an oil–dispersant (COREXIT 9527) solution. To examine the effects of oiling and cleaning on the thermal properties of the fur, the thermal conductance of untreated, oiled, and cleaned pelt samples was determined with a heat-flow transducer. Changes in lipid concentration in the fur resulting from contamination and cleaning were also assessed. The results demonstrated that Dawn dishwashing detergent was the most effective agent in removing crude oil from sea otter fur. This detergent removed similar amounts of oil with 15 or 40°C rinse water, and was less effective when used in conjunction with mineral oil or soap pretreatments. Oil contamination caused a two- to four-fold increase in thermal conductance over base-line levels (7.64 ± 1.30 W/(m^2 · °C)). Following cleaning, the thermal conductance of the pelt was not significantly different from that of untreated fur. However, mean lipid weight decreased from 7.4 mg lipid/g fur in untreated pelts to 2.0 mg lipid/g fur in cleaned pelts. This study demonstrated that even though natural oils may be lost during the cleaning process, proper cleaning and rinsing restores the water repellency of the sea otter pelt after exposure to crude oil.

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La présence de pétrole brut ou d'agents dispersants du pétrole sur la fourrure de la Loutre de mer (*Enhydra lutris*) peut en réduire les propriétés isolantes, ce qui risque d'exposer l'animal à une hypothermie. Nous avons mis à l'épreuve diverses méthodes d'élimination du pétrole sur des peaux de Loutres de mer et nous avons mesuré l'amplitude de la diminution des propriétés isolantes causée par la contamination et par le nettoyage qui a suivi. Quatre détergents et deux pré-traitements ont été éprouvés sur des peaux de loutres enduites de petrole brut frais, des peaux enduites depuis 5 jours et des peaux enduites d'une solution pétrole – agent dispersant (COREXIT 9527). Pour évaluer les effets de ces traitements sur les propriétés thermiques de la fourrure, nous avons mesuré, au moyen d'un transducteur, la conductance thermique de peaux saines, de peaux enduites de pétrole et de peaux nettoyées. Les changements des concentrations de lipides dans les fourrures à la suite de la contamination et du nettoyage ont également été mesurés. Le détergent à vaisselle Dawn s'est avéré l'agent nettoyant le plus efficace; ce détergent a réussi à enlever les mêmes quantités d'huile à des eaux de rinçage de 15 ou de 40°C, et a été moins efficace lorsque combiné à de l'huile minérale ou lorsqu'utilisé après un pré-traitement au savon. La contamination par l'huile a doublé ou même quadruplé les valeurs initiales de la conductance thermique ($7{,}64 \pm 1{,}30$ W/(m^2 · °C)). Après le nettoyage, la conductance thermique de la peau ne différait pas significativement de celle d'une peau non traitée. Cependant, la masse lipidique moyenne avait diminué de 7,4 mg lipide/g de fourrure (peau témoin) à 2,0 mg lipide/g de fourrure (peaux nettoyées). Ces résultats démontrent que, bien que les huiles naturelles puissent disparaître au cours du nettoyage, un nettoyage et un rinçage adéquats restaurent les propriétés hydrofuges de la peau des Loutres de mer après exposition à du pétrole brut.

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Introduction

Sea otters that have been cleaned following contamination with crude oil have difficulty thermoregulating (Costa and Kooyman 1982; Siniff *et al.* 1982). Because these animals depend on an air layer trapped within their dense fur for insulation (Tarasoff 1974), the water-repellent quality of the pelt must be maintained for thermal balance to occur. Crude oil, detergents, and solvents can decrease the natural water repellency of the pelt and cause the fur to saturate when immersed. As a result, insulation decreases, and the otters are subject to hypothermia (Costa and Kooyman 1982).

Despite past attempts to clean animals contaminated with crude oil, standard protocols for cleaning oiled fur have not been established for marine mammals. Only brief descriptions of cleaning methods have been reported (Kooyman *et al.* 1977; Costa and Kooyman 1982; Siniff *et al.* 1982). Because of the risk of an oil spill, as well as the proposed oil exploration and development within the range of the California sea otter, further investigation concerning the thermal consequences of oil contamination and cleaning was warranted. The present study tested methods for cleaning oiled sea otter pelts, and measured the changes in insulation caused by oil contamination and subsequent cleaning. Different cleaning methods were evaluated for effectiveness in removing oil and the ability to restore the insulation of pelts to preoiling levels. Based on results from these tests, we developed a method for cleaning oiled sea otter fur that had a low impact on thermal insulation.

Methods

Tests were conducted on samples of adult sea otter (*Enhydra lutris*) pelts obtained from the California Department of Fish and Game. Samples (25 × 25 cm) were cut from the dorsal surface of fresh otter pelts and mounted on 23 × 23 cm square plywood frames. Extreme cranial or caudal areas that are more variable in fur length and quality (T. M. Williams, personal observation) were avoided. Depending on pelt size, one to three test squares were obtained from each pelt. Mounted pelts were frozen in plastic bags until the thermal conductance experiments were conducted. Remnants of the pelts were cut into swatches, mounted on 5 cm diameter hoops, and used in detergent tests.

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Fresh and 5-day weathered crude oil (ARCO 3120-9, Holly platform, Monterey Zone; a "sour crude" containing highly volatile sulfur) were tested. Oil was weathered by layering 100 mL on the surface of 100 L of 3.5% NaCl in tap water (details of the weathering process and analysis of fresh and weathered crude oils are presented in Fry and Lowenstine, 1985). To avoid compositional changes, crude oils were stored frozen and were warmed to 20°C before experimentation.

Cleaning procedure

Determination of the most effective procedure for cleaning oiled sea otter fur was based on four criteria: (*i*) the ability to remove oil, (*ii*) restoration of hair loft following cleaning, (*iii*) level of saturation of the pelt after cleaning, and (*iv*) practical considerations for application on a live animal. The first criterion was determined quantitatively, while the latter three were assessed qualitatively.

Detergents

Fresh crude oil (0.8 mL per swatch) was rubbed into the dried fur of 5-cm diameter pelt swatches. Because this volume of oil saturated the fur sample, it was considered a "worst case" situation. One millilitre of the test detergent was then applied and rubbed into the fur. An additional 1 mL of detergent was applied during tests examining pretreatment products.

Four detergents, representing commercially available industrial and domestic products, were each tested on 10 pelt swatches: Dawn (Proctor & Gamble Inc.), household dishwashing detergent: recommended for cleaning oiled wildlife (A. Berkner, personal communication). Polycomplex A-II (Guardian Chemical), an oil dispersant: previously used for cleaning oiled sea otters (Siniff *et al.* 1982). Basic I (Shaklee): recommended for cleaning oiled birds (Berkner *et al.* 1977). This product is similar to the Shaklee product used for cleaning oiled sea otters (Kooyman *et al.* 1977). Boat Zoap (Sudbury Laboratory), a marine grease cleaner: selected by the authors based on its marine application.

Following the application of detergent, fur samples were rinsed in a series of four beakers, each containing 500 mL of sea water at 40°C. Pelt swatches were dipped 10 times in each of the beakers with the fourth rinse supplemented by manual washing. The amount of oil removed was determined colorimetrically from water samples taken from the four rinsing beakers. These samples were compared visually to 10 standard solutions of crude oil, detergent, and sea water ranging in concentration from 0.010 to 0.100 vol.% (oil to sea water).

The effect of rinse water temperature on detergent performance was also assessed by comparing results for oiled pelt swatches rinsed in 40 or 15°C sea water. The two rinse water temperatures were tested on fresh crude oil and on 5-day weathered crude oil. Ten pelt swatches were tested for each detergent–temperature–oil combination. Only the most effective detergent identified in the above tests was used in this portion of the study.

Pretreatment assessment

Organic solvents and mineral oil have been recommended for solubilizing crude oil before cleaning soiled animals (Berkner *et al.* 1977; Tangredi 1980). To determine if pretreatments improve the cleaning efficiency of a detergent (i.e., quantity of oil removed and speed of removal), three products were examined. Pretreatment products were mechanic's hand soap (Goop, Critzas Industries), an organic solvent (Shelsol 70, Shell Oil Inc.), and 70-viscosity mineral oil. Two millilitres of each pretreatment were applied to pelt swatches oiled with fresh or weathered crude. Cleaning, rinsing (40°C), and colorimetric analysis were performed as previously described.

Thermal conductance of immersed pelts

To examine the effects of oiling and cleaning on the thermal properties of sea otter fur, the thermal conductance of pelts was determined using methods described by Kooyman *et al.* (1977). Heat flux was measured with a calibrated heat-flow transducer (Beckman-Whiteley, model T200-3). The transducer consisted of a silver–constantan thermopile sandwiched between thin bakelite plates. Heat flow through the thermopile generates an electromotive force resulting from the difference in temperature between the thermocouple junctions of the thermopile. Output from the heat-flow transducer was measured with a potentiometer (Leads and Northrup, model 8686). A brass chamber insulated with Styrofoam was mounted on the underside of the transducer. Fresh water at 37°C (simulating the body temperature of sea otters) was circulated through this chamber with a constant temperature bath (Lauda-Brinkman, model MS-3). A 30 × 30 × 6 cm water bath with a bottom of thin plastic (thickness, 0.02 mm) was placed on top of the heat-flow transducer; calibration tests demonstrated that thermal insulation of the thin plastic sheet was negligible. Pelt squares mounted on wooden frames were bonded to the plastic with a thin film of grease and secured in position with clamps. Sea water at 5°C was circulated above the pelt square with a constant temperature bath (Lauda-Brinkman, model RCS-6D). To minimize convective heat losses, and to evenly distribute flow across the pelt, sea water was slowly circulated (925 mL/min) through the chamber via two manifolds. Water temperature measurements above and below the transducer plate were measured with thermocouple probes referenced against a slush of distilled water and ice. The entire apparatus was housed in a constant-temperature refrigerator that maintained air temperature at 5°C (Thermistemp, model 71A). A small electric fan insured an even temperature distribution throughout the refrigerator. A fluorescent light and a Plexiglas window permitted observation of the pelt during the conductance measurements without disturbing air or water temperatures.

Thermal conductance was calculated from the following equation:

$$C = \frac{H}{A\ (T_s - T_w)}$$

where C = conductance (W/(m$^2\cdot$°C)), H = heat flux (W), A = area (m^2), T_s = skin temperature (°C), and T_w = water temperature (°C) (Tracy 1972). Thermal conductance of each pelt square was measured under three conditions: untreated, oiled, and cleaned after oiling. Independent tests on untreated pelts demonstrated that thermal conductance was unaltered by three repeated measurements.

Untreated pelts

Twenty-four untreated pelt squares were divided into three test groups to examine the effects of fresh crude oil, 5-day weathered crude oil, and fresh crude oil treated with a dispersant. Pelt squares from individual animals were placed into different oil treatment groups. Before measuring thermal conductance, frozen pelt squares were thawed, dried with a blow dryer, brushed to maximum loft, and placed in the water bath. The presence of an air layer (as indicated by silver coloration of the pelt) and fur loft were noted. Heat flux and plate and water temperatures were recorded hourly following a 0.5-h equilibration period. Measurements were continued until thermal conductance varied by less than 10% over a 1-h period. Following the conductance measurements, the pelts were removed from the water bath and the level of water penetration into the fur was assessed visually.

Oiled pelts

Ten millilitres of oil (fresh or 5-day weathered crude) were applied with a syringe and rubbed into each dry pelt square. Oiled pelts were placed in the water bath and thermal conductance was determined using the methods described previously.

A third treatment group of eight pelt squares was exposed to a mixture of fresh crude oil, dispersant, and sea water. The dispersant mixture contained 0.5 mL COREXIT 9527 and 10 mL of fresh crude oil in a 50-L tub (61 × 42 × 21 cm) filled with sea water at 15°C. Dried pelt squares were mounted on a dipping rack that prevented the underside of the hide from becoming contaminated. To simulate the swimming and grooming behavior of live otters, pelts ware dipped for 10 min and the mixture was rubbed into the fur.

Cleaned pelts

After thermal conductance was measured for the oiled pelts, all pelts were cleaned and dried, and thermal conductance was measured again. To clean the pelts, detergent was rubbed into the oiled fur; swatches were then rinsed for a minimum of 10 min with warm

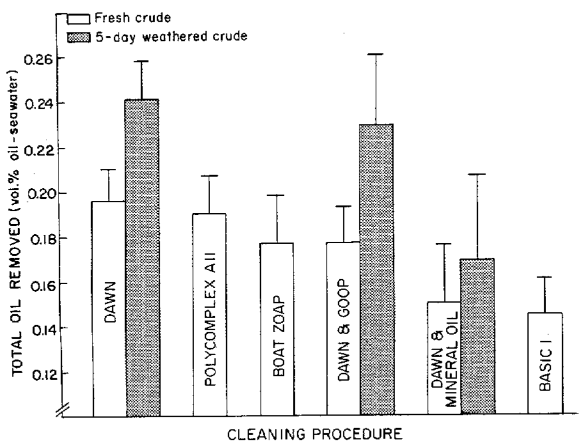

FIG. 1. Comparison of the amount of oil removed from sea otter pelts by four detergents and two pretreatments. Pelts were rinsed in 40°C sea water. $n = 10$ for each procedure. Bars represent mean values, and vertical lines are 95% confidence intervals. Results for 5-day weathered oil (shaded bars) are compared for three cleaning procedures.

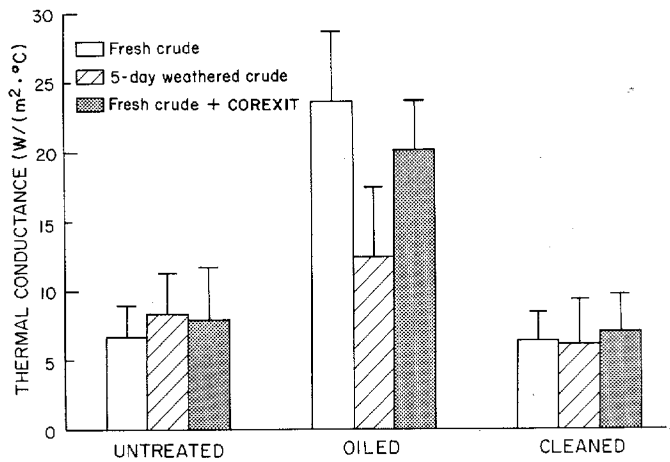

FIG. 2. Thermal conductance of untreated, oiled, and cleaned sea otter pelts. Three oil treatments are compared. Bars represent mean values for eight pelts, and vertical lines are 95% confidence intervals.

(40°C), fresh water at normal tap pressure (30–40 psi; 1 psi = 6.89 kPa). The procedure was repeated until the hairs had a normal appearance and the fur regained loft and water repellency.

Squalene analysis

Squalene is a major component of the sebaceous oil in the fur of semiaquatic mammals (Lindholm and Downing 1981), including sea otters (Williams *et al.* 1988). To determine the effect of fresh crude oil and detergents on the squalene concentration in sea otter pelage we extracted lipids from the fur and hide of pelt swatches. Squalene concentration was measured in two untreated pelt samples, two pelt samples washed with detergent, and two samples contaminated with fresh crude oil and subsequently washed. Lipid contents were determined by thin layer chromatography as described in Williams *et al.* (1988).

Statistical analysis

Detergent effectiveness was analyzed using a one-way analysis of variance with Tukey's pairwise procedure at $p < 0.05$ for posterior comparisons (Stoline 1981). The experimental design of the thermal conductance tests was a mixed two-factor within subjects design, with oil type being the independent group and the cleaning procedure being the repeated measures (Keppel 1982). The effects of oil type and cleaning procedure on thermal conductance were tested with a repeated measures analysis of variance. Because the interaction term was significant, the effect of oil type was calculated at each step of the cleaning procedure with a one-way analysis of variance and posterior comparisons using the Student–Newman–Keuls procedure at $p < 0.05$. The effect of the cleaning procedure was calculated for each oil type using a repeated measures analysis of variance and posterior comparisons using a Bonferroni adjustment of $p < 0.05$. Results are presented as means ± 95% confidence intervals.

Results

Cleaning procedure determination

A one-way ANOVA of six cleaning procedures demonstrated that significantly different ($F_{5,54} = 6.08$, $p < 0.0016$) amounts of oil were removed by the tested agents when rinse water at 40°C was used (Fig. 1). Dawn detergent was the most effective and Basic I the least effective in removing fresh crude oil from the pelts. Posterior comparisons of the total oil removed by the different cleaning procedures revealed three broad categories: (*i*) most effective cleansers: Dawn, Polycomplex A-II; (*ii*) partially effective cleansers: Boat Zoap, Dawn with Goop; and (*iii*) least effective cleansers: Dawn with mineral oil, Basic I. For 10 pelts washed with Dawn and rinsed in 40°C water, mean total oil removed was 0.196 ± 0.016 (95% confidence interval) vol.% for fresh crude and 0.241 ±0.017 vol.% for 5-day weathered crude. No significant difference was found between the total amount of oil removed by this detergent with 15 or with 40°C rinse water ($t = 0.04$, df = 18, $p = 0.48$ for fresh crude; $t = 1.12$, df = 18, $p = 0.14$ for weathered crude).

Pretreatment assessment

For both fresh and weathered crude, 70-viscosity mineral oil pretreatment with Dawn detergent removed less oil than the detergent alone (Fig. 1). In comparison, the amount of oil removed by a mechanic's hand soap (Goop) pretreatment and this detergent was not statistically different from the amount of oil removed by detergent alone. A detrimental effect of these pretreatments was increased penetration of the crude oil into the fur. In some cases, pretreatment resulted in patches of crude oil remaining on the fur after cleaning. Similar problems were encountered with spot tests of organic solvents, such as Shelsol 70. Because of its toxicity and limited effectiveness, this solvent was eliminated from the study.

Thermal conductance of immersed pelts

Untreated pelts

The thermal conductance of sea otter pelts depended on the presence or absence of a layer of air in the fur. Twenty-four good quality pelts were identified in which an air layer was retained and only the tips of the fur became wet when immersed. These pelts had a mean thermal conductance of 7.64 ± 1.30 W/(m^2 · °C) (Table 1, Fig. 2). Old or soiled pelts, which saturated on immersion, had high thermal conductance values. The mean thermal conductance of seven pelts that saturated during immersion was 25.21 ± 2.28 W/(m^2 · °C).

Oiled pelts

The thermal conductance of oiled sea otter pelts depended on oil treatment (Fig. 2; $F_{4,42} = 8.48$, $p < 0.001$). Rubbing fresh crude oil into the pelts coated the entire hair shaft and matted the fur. When immersed, many areas of these pelts saturated to the epidermis. Thermal conductance measurements of the pelts

TABLE 1. Thermal conductance measurements (W/(m$^2 \cdot$ °C)) of California sea otter pelts, expressed as mean ± 95% confidence interval

	Untreated,	Oiled		Oiled and cleaned	
	$\bar{x}$ ± 95% CI	$\bar{x}$ ± 95% CI	F	$\bar{x}$ ± 95% CI	F
Fresh crude oil	6.68±1.99	23.60±4.91	103.92*	6.41±2.14	0.11
5-day weathered crude oil	8.36±2.46	12.45±4.68	5.78	6.14±3.11	1.78
Fresh crude and COREXIT	7.88±3.27	20.54±3.63	95.54*	7.12±2.20	0.28

*Significant difference from untreated values at α = 0.05 with Bonferroni adjustment in the posterior comparisons of pelt treatment within each oil type; df = 1,7 and n = 8.

reflected this saturation and were similar to values obtained for the poor quality, unoiled pelts discussed above. The application of fresh crude oil resulted in a 3.5-fold increase in thermal conductance over values for untreated pelts (Table 1).

Because of its high viscosity, 5-day weathered crude oil did not penetrate as deeply into the fur as fresh crude. This resulted in pockets of air being retained in the fur during immersion. Consequently, the thermal conductance for these pelts was more variable than for other oil treatments. Like fresh crude, 5-day weathered crude had a significant effect on thermal conductance (Fig. 2; $F_{2,14}$ = 5.217, 0.01 < p < 0.025), but the mean was less than two times the value for untreated pelts.

Oil–dispersant mixtures quickly penetrated the fur and caused sea otter pelts to saturate on immersion. This treatment significantly altered the thermal conductance of pelts ($F_{2,14}$ = 50.391, p < 0.001). Mean thermal conductance of the pelts treated with oil–dispersant was 20.54 ± 3.64 W/(m$^2 \cdot$ °C), 2.6 times greater than measured for untreated pelts.

Comparison between oil types showed that changes in thermal conductance resulting from 5-day weathered crude oil were significantly different from the effects observed for fresh crude and for dispersant and oil mixtures ($F_{2,21}$ = 9.386, 0.001 < p < 0.01, Student–Newman–Keuls posterior comparison at p = 0.05). The mean difference in thermal conductance between untreated pelts and those oiled with 5-day weathered crude was 4.1 W/(m$^2 \cdot$ °C). In contrast, the mean difference was 16.9 W/(m$^2 \cdot$ °C) for fresh crude and 12.6 W/(m$^2 \cdot$ °C) for oil–dispersant mixtures.

Cleaned pelts

Oiled pelt squares were cleaned with Dawn detergent and warm (40°C), pressurized water rinses. Four to six applications (10–20 mL) of full-strength Dawn were preferable to soaking or prolonged exposure of the pelt to detergent. Pelts that were rinsed and dried after soaking in detergent saturated when immersed in a water bath. Prolonged rinsing did not correct this problem. Therefore, full-strength Dawn was rubbed into the pelt and rinsed immediately. These steps were repeated until all traces of crude oil were removed.

After drying, the immersed cleaned pelts developed an air layer similar to that of untreated pelts, resulting in lower thermal conductances than recorded for oil-treated pelts. Regardless of oil treatment, thermal conductance of the cleaned pelt was not significantly different from base-line values (Table 1). Based on these data, the cleaning procedure developed in this study was found to return the insulation of oiled sea otter pelts to its original condition.

Squalene analysis

Lipid contents of untreated sea otter pelt samples were similar to values reported in Williams *et al.* (1988). Mean lipid weight for untreated sea otter fur was 7.4 (range = 5.2–9.7) mg lipid/g fur. The primary component of these lipids, as identified by thin layer chromatography, was squalene. Dawn detergent removed more than 70% of the lipids from the fur. Mean lipid weight for two cleaned pelts was 2.0 (range = 1.8–2.2) mg lipid/g fur. Similarly, two pelts that were oiled with fresh crude oil and subsequently cleaned were stripped of natural oils. The mean lipid weight of these pelts was 2.2 (range = 0.9–3.5) mg lipid/g fur. Lipid contents of the sea otter skins were unaffected by either treatment.

Discussion

Unlike the blubber of marine mammals, the primary insulating layer of sea otters is continuously exposed to the environment. Trapping a layer of air in the fur prevents excessive heat loss across the otter's body surface. Physical properties of the fur, such as kinks in the underfur hair (Sokolov 1962), cuticular scales (Tarasoff 1974), and high hair density (Tarasoff 1974) facilitate the maintenance of an air layer in sea otter pelage. The importance of this air layer is demonstrated by comparing the thermal conductance of normal and saturated pelts. Thermal conductance of an immersed pelt with an intact air layer averaged 7.64 W/(m$^2 \cdot$ °C), or one-quarter that of a saturated pelt.

Insulation based on an air layer in the fur is easily reduced by physical movements and pelage soiling (Williams 1986). When contaminated with oil (fresh, 5-day weathered, or oil–dispersant mixtures), thermal conductance of sea otter pelts increased two to four times over base-line values (Fig. 2). Mean thermal conductance of the oiled pelts was not different from that of poor quality, untreated pelts that saturated on immersion. Examination of the pelts demonstrated that fresh crude oil and oil–dispersant mixtures allowed water to penetrate the fur. The greater oil viscosity of weathered crude reduced oil and water penetration into some areas of the fur. As a result, the effect of weathered oil on the thermal conductance of sea otter fur was more variable than that of other oil treatments.

Increases in thermal conductance associated with oil contamination were greater in the present study than reported for sea otters by Kooyman *et al.* (1977). This difference is attributed to (*i*) the small sample size of the latter study, (*ii*) differences in methods, and (*iii*) the condition of the air layer in the fur at the time of the conductance measurement. The similarity of our saturated pelt measurements (25.2 W/(m$^2 \cdot$ °C)) to base-line values (23.3 W/(m$^2 \cdot$ °C)) reported by Kooyman *et al.* (1977) indicates that the pelts in the latter study may have been saturated at the time of the measurement. This would result in an elevated base line and a less pronounced effect from oil contamination in comparison to the present study.

Previous studies have examined the effects of oil contamination on waterfowl (Tangredi 1980; Lambert *et al.* 1982), pinnipeds (Kooyman *et al.* 1976; Geraci and Smith 1976; Kooyman *et al.* 1977), polar bears (Hurst and Oritsland 1982), rodents (McEwan *et al.* 1974; Wolfe and Esher 1981), cetaceans (Geraci and St. Aubin 1980), and sea otters (Kooyman *et al.* 1977; Costa and Kooyman 1982; Siniff *et al.* 1982). In aquatic species that rely primarily on fur or feathers for insulation, oiling has profound effects on thermoregulation. The thermal conductance of the oiled pelts of polar bears (Hurst and Oritsland 1982), sea otter pups and fur seals (Kooyman *et al.* 1977), and live adult sea otters (Costa and Kooyman 1982) is more than double the value for untreated pelts. A decrease in buoyancy associated with water infiltration of the fur and pelage matting have also been reported (McEwan *et al.* 1974; Costa and Kooyman 1982; Lambert *et al.* 1982). In contrast, animals that rely on blubber for insulation demonstrate little or no thermal response to oil contamination (Geraci and Smith 1976; Engelhardt 1978; Geraci and St. Aubin 1980).

Cleaning agents can be as damaging as crude oil or dispersants to the insulation of sea otter fur. Therefore, many criteria, including cleaning effectiveness, pH, commercial availability, toxicity, and ease of rinsing should be considered when employing a detergent. In the present study a household dishwashing detergent (Dawn) met these criteria. However, we found that natural oils in the fur were removed along with crude oil during the cleaning process. Although the loss of these oils did not affect the thermal conductance of pelt samples, the conductance of live otters is elevated after cleaning (Davis *et al.* 1988; Costa and Kooyman 1982).

Both Berkner *et al.* (1977) and Tangredi (1980) have used solvents and mineral oil pretreatments to clean birds heavily contaminated with fresh or weathered crude oil. We found that Shelsol 70 and mineral oil (70 viscosity) pretreatments hindered cleaning and prolonged the cleaning process by causing crude oil to penetrate farther into the fur. In view of these problems and the potential toxic effects of many solvents (Geraci and St. Aubin 1980), mineral oil and solvent pretreatments are not recommended for cleaning crude oil from sea otter fur.

The ability to remove oil and the residual effects of the cleaning procedure on insulation of the fur are the most important factors in evaluating a cleaning technique. Because detergents promote wetting of otherwise waterproof fur and feathers, inadequate cleaning procedures are as detrimental as oil contamination. With proper cleaning and rinsing, the water repellency of the sea otter pelt can be restored after exposure to fresh crude oil, 5-day weathered crude oil, or an oil treated with a dispersant, even though natural oils may be lost during the cleaning process. However, the application of this procedure to live sea otters requires further refinement. Complicating factors include the displacement of the insulating air layer by movements of the animal, the effects of grooming on soiled or cleaned fur, the length of time required to replace squalene to normal concentrations, and thermoregulatory adjustments by the animals. For example, although the thermal conductance of the sea otter pelt is 7.64 $W/(m^2 \cdot °C)$, whole animal conductances can range from 3.6 to 15.5 $W/(m^2 \cdot °C)$ depending on ambient water temperatures and activity level (Costa and Kooyman 1982; Davis *et al.* 1988). The following paper (Davis *et al.* 1988) addresses the problem of cleaning live sea otters contaminated with crude oil, and demonstrates the importance of behavioral thermoregulation and restoration of these natural oils for the rehabilitation of the animal.

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