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Using an Infrared Temperature Sensor to Study Microhabitat Selection in Captive California Sea Lions (*Zalophus californianus*)

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Abstract

We used the Professional Equipment T7350 Series Infrared Thermometer to measure the temperature of haulout areas and pool water available to three adult California sea lions (*Zalophus californianus*) at the Peoria Zoo. The handheld, battery-operated sensor was pointed at a surface, a red laser light indicated the location of the reading, and the temperature was read on the digital display. To test its reliability over distance, repeated measurements were taken on each sea lion held at station by a trainer in an indoor enclosure at 1 and 3 m away.

Ambient air temperature and the temperature of eight haulout areas, as well as the water temperature in the three pools, were taken at 15-min intervals during zoo operating hours each week over a 10-mo period; weather conditions ranged from cold winter (-2.8° C [27.0° F]) to hot summer (37.8° C [100.0° F]) days. At the same intervals, each of the sea lion's skin temperatures (at the dorsal torso, fore-flipper, and hind-flipper) were measured and their location in the exhibit was noted. In addition, each sea lion's behavior was scored into one of eight classes when the measurements were taken.

The sensor could not measure the body temperature of a submerged sea lion, only the water temperature. However, the infrared thermometer accurately measured the sea lion's skin temperature while on land, exposed skin when the animal was partially submerged, and the temperature of the substrate. Since the unit is inexpensive, noninvasive, portable, and takes readings at a reasonable distance, the infrared temperature sensor is a useful tool to help zookeepers monitor the temperatures of the microhabitats of the captive animals. In addition, the sensor could have applications for studies of thermoregulation or health in captive and wild pinnipeds. Some topics for further research are identified, which would help clarify the overall usefulness of this infrared sensor.

Key Words: thermoregulate, remote sensing, microhabitat, body temperature, California sea lion, *Zalophus californianus*

Introduction

A basic premise of mammalian thermoregulation is that individuals initially control body temperature through behavioral changes and then by more energetically costly physiological methods. Behavioral adaptations for thermoregulation often include simply moving to a cooler or warmer location. Thus, the ability of an animal to thermoregulate through behavioral means is somewhat limited by the range of available environmental temperatures. In a captive environment, the design and construction materials of an exhibit determine the range of temperatures available to an animal. As a result, zookeepers need to know the range of temperatures available to animals in the various microhabitats of an exhibit and how temperatures vary within a day and among seasons. Materials used to construct exhibits may vary in thermal properties, and shade or dampness may affect substrate temperatures.

For amphibious marine mammals, the husbandry staff also needs to know the relative temperature differences between land and water environments. Keeping records of the air, substrate, and water temperatures in a pinniped exhibit, along with the animal's preferred locations, would be useful husbandry information. Furthermore, examining how an animal's age, body size, health, reproductive status, and social standing affects its location in an exhibit would provide valuable insights on the influences of each on thermoregulatory behavior in captive animals.

Typically, collecting body temperature data involves the capture and handling of an animal. This limits how often body temperature data can be collected and, when collected, these measures could be skewed if collection reflects a stressed individual. Collecting body temperature data for pinnipeds is particularly challenging because they inhabit both land and water environments. A device for remotely measuring body temperature would prevent the need to handle animals, thus reducing potential stressors involved with this husbandry action. However, only a few studies have remotely collected body temperatures on marine mammals. Whittow et al. (1974) used a temperature-sensitive transmitter placed in a fish and fed to a captive male pilot whale (*Globicephala melaena*), a male killer whale (*Orcinus orca*), and a male false killer whale (*Pseudorca crassidens*). Core body temperatures were collected using a receiver for the short time the radio-pill was in the digestive tract with an accuracy of 0.1° C. Westgate et al. (2007) developed two types of thermal data loggers housed in a Trac-Pac dorsal-fin saddle placed on bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida, and on spotted dolphins (*Stenella attenuata*) in the Eastern Tropical Pacific. The saddle pack had compartments that housed electronics for measuring heat flux and skin temperature, along with a time-depth recorder that measured water depth, water temperature, and swim velocity. A VHS-radio in the pack was used to track the dolphin and to recover the instruments after they detached from the animal. The unit provided a remote body temperature sensor, but required handling of the animal and retrieval of the unit for downloading data.

Recently, Knizkova & Kunc (2007) reported that veterinarians use an infrared camera to identify "hot spots" because changes in vascular circulation result in an increase or decrease in tissue temperature. Such changes may indicate inflammation—especially in orthopedic diseases in mammals. They advocate using infrared technology for research into reproduction, thermoregulation, animal welfare, and milk production of livestock. Walsh & Thompson (1999) and Clippinger & Cook (1999) used a thermographic camera (EVS Diagnostic Thermal Imaging System 500) on cetaceans to show evidence of trauma, dental disease, and dermal conditions. These relatively expensive systems provide detailed, color, digital images that can be used by veterinarians to track animal health over time.

Few studies on wild or captive pinnipeds have measured both the body temperature and the temperature of the substrate (i.e., water, land, ice), concurrently. Langman et al. (1996) measured the shortwave absorption of the fur of a wet California sea lion (*Zalophus californianus*) and the temperatures of surfaces in the outdoor California sea lion exhibit at the Audubon Zoo. The system was a Swissteco micro-albedometer mounted on a tripod in an open area, 2 cm above the ground, and was designed to minimize shadows. They also measured two primary heat gain components of the surfaces in the exhibit: (1) shortwave radiation using three Li-cor pyrheliometers placed outside the exhibit to avoid reflected solar radiation and (2) total reflected solar radiation measured from inside the enclosure. Surface temperatures were measured using either thermocouple probes connected to a Yellow Springs Instruments thermometer or with an Omegascope (OS82-LS-LT) infrared digital thermometer with a sighting laser, which recorded 60 temperatures/min to a laptop computer.

Recently, an inexpensive, handheld, portable, digital-display infrared temperature sensor with a laser beam pointer (Professional Equipment T7350 Series Infrared Thermometer) has been used to remotely measure temperatures to regulate food safety, collect information on home heating/cooling systems, and as a diagnostic tool for automotive maintenance (*Professional Equipment T7350 Series Instruction Manual*, 2003). To our knowledge, there are no peer-reviewed studies on using this infrared sensor to record surface body temperature on a marine mammal.

We predicted that this infrared thermometer could remotely register the temperature of haulout areas and water in the pools of captive California sea lions, as well as their body surface temperatures. These temperature data were used to demonstrate how environmental temperatures are related to the microhabitat selection and behavior of captive California sea lions. Specifically, we tested the reliability of the infrared thermometer to remotely measure (1) temperatures in eight haulout areas and water in three pools and (2) dorsal body temperatures of three sea lions at the torso, fore-flippers, and hind-flippers. Using these data, we examined whether a sea lion's skin temperature (1) correlated with the ambient air temperature, haulout substrate temperature, and/or water temperature; (2) was related to the preferred locations in the exhibit; and (3) was related to its behavior. In addition, this information will establish the degree of choice that these captive California sea lions had for thermoregulation by moving among areas of the exhibit. The unit could provide keepers with an inexpensive, portable tool to quickly evaluate the temperatures in a given facility on a given day. In addition, the battery-operated, non-invasive infrared sensor could be used in the wild to examine microhabitat selection in the haulout areas of pinnipeds.

Materials and Methods

Study Site and California Sea Lion Subjects

One large female ("Rosa," #7001, weight 127 kg), one small female ("Bobber," #7002, weight 100 kg), and one large male ("Neptune," #7008, weight 304 kg) California sea lion were studied at the Peoria Zoo in Illinois. Both females were brought to the zoo in 1985, while the male arrived in 2000. Both females were 22 y old, and the male was 20 y old. All were born in captivity but were not related. They were fed herring 4×/day: the small female was fed 3 to 4 kg, the large female 4 to 5.5 kg, and the large male 9 to 11 kg per day. Body weights fluctuated depending on the season, with reduced food intake during the breeding season from August to November (R. D. Wolfram, pers. comm., 2005).

During the day, the sea lions had access to an outside pool and haulout area viewed by the public. At night or in very cold or very hot weather, the sea lions were housed indoors. The unheated freshwater pools (maximum depth 2 m) were drained, cleaned, and refilled once per month. Each day, the water quality was tested, and the physical condition of each sea lion was noted. A regular salt bath was given to maintain osmoregulation, fur/skin quality, and ocular health in the sea lions.

Before the study, the investigators conducted some empirical tests on the performance of the Professional Equipment T7350 Series Infrared Thermometer (Figure 1) to verify its accuracy in air, in water, and by distance to a surface. According to the manufacturer's specifications, the targeting laser takes the temperature of the first surface it contacts with a response time of 0.5 s, a resolution of 0.5° C or 1.0° F, and an accuracy of ± 2% (± 3.0° F). The sensor is capable of taking temperature measurements in Celsius or Fahrenheit and values ranging from -4.0 to +932.0° F. It has an 8:1 distance-to-spot ratio and has a conical sensing beam pattern. The unit can operate on a "scan" mode, so it continues to update readings, or a "hold" mode when it reaches a stable value.

Figure 1. Professional Equipment T7350 Series Infrared Thermometer used to take surface temperatures of the torso and flippers of the California sea lions and of the water and land substrate on- and off-exhibit at the Peoria Zoo

A series of temperatures of land, snow, and concrete substrates were measured with the infrared thermometer and compared with readings from a thermistor connected to a digital voltmeter. In addition, the temperature from the infrared thermometer pointed at the water surface of a Jacuzzi was compared to the digital display on the Jacuzzi and to the thermistor readings at a variety of water temperatures. The researchers measured surface water temperature directly above a submerged human in the Jacuzzi, varying the depth of a limb and height of the sensor above the water.

Indoor Data Collection

To examine temperature variations among body locations, skin temperatures were recorded on each California sea lion at four torso locations and at three locations on all four flippers. The temperatures were taken while the sea lions were inside a heated holding area and held at station by a trainer. Ten consecutive readings at each body location were taken on each sea lion twice a day for 10 d opportunistically throughout the 10-mo study. The manufacturer does not list adverse health effects, but we kept the laser beam away from the sea lions' heads and eyes to ensure their safety.

To examine whether the distance between the sea lion and the sensor affected temperatures, readings were taken from about 1 and 3 m away from each sea lion, approximating the range of distances at which temperatures would be collected in the exhibit. The indoor ambient air temperature was taken with the Acurite 00888 series digital thermometer.

Outdoor Data Collection

Temperatures in the outdoor exhibit and of the sea lions were taken while the researcher stood on a stepladder outside the pool and reached over the acrylic wall surrounding the exhibit to aim the sensor (see Figure 2). The outdoor display was visualized as 11 areas, including three water areas (1-3) and eight haulout areas (4-11) as shown in Figure 2. Single temperature readings of each sea lion's torso, the right fore-flipper, and the right hind-flipper were taken at 15-min intervals between 1000 and 1645 h (2,469 readings over a 10-mo period on each sea lion). Immediately afterward, the air temperature and temperatures of all 11 areas were recorded, and the location of each sea lion was noted. The ambient air temperature was collected using an Acurite 00888 series digital thermometer.

After creating an ethogram for these California sea lions, mutually exclusive behaviors related to thermoregulation were divided into behaviors in water and those on land (Table 1). Behavioral data were collected for each sea lion using

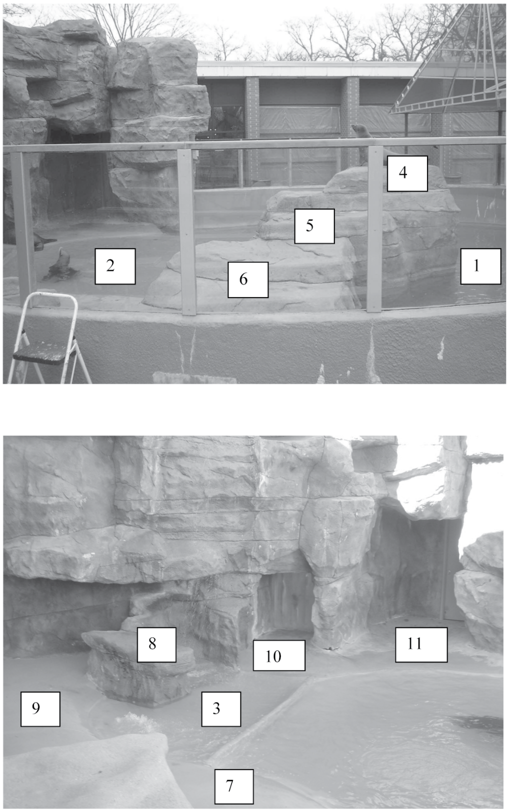

Figure 2. Eleven substrate areas of the California sea lion outdoor display at the Peoria Zoo

instantaneous scan-sampling at the same 15-min intervals between 1000 and 1645 h. Data were taken over a 10-mo period to examine the performance of the temperature sensor over a wide variety of temperatures and to examine the manner in which the sea lions' behavior might change at extreme temperatures. No data were collected during times of precipitation.

Summary statistics, Pearson's correlations, paired *t*-tests, and a one-way analysis of variance (ANOVA) were conducted, depending on the objective. All statistical tests were run at alpha = 0.05 level of significance. *SYSTAT Grad Pack*, Version 11.0 for Windows (SYSTAT, 2006) was used for all analyses and graphs.

Results

Preliminary Tests

Empirical tests of the infrared sensor showed excellent agreement among water temperatures measured by three different temperature-sensing devices—certainly within the 1.0° F reported by the manufacturer. Neither the water depth nor the presence of a warm body below the surface influenced water temperature readings. We concluded that the infrared thermometer could not be used to measure the body temperature of a submerged mammal.

Indoor Body Temperature Data

A paired *t*-test was conducted to determine if distance between the sensor and the sea lion (1 m vs 3 m) made a significant difference in the readings (Table 2). The only significant difference occurred in the large female ($df = 17$, $p = 0.011$), in which the mean torso surface temperature at 1 m away was 17.8° C (64.1° F) and at 3 m away was 17.7° C (63.8° F). This variation was only 0.5° F, however, which was within measurement error of the unit.

Summary statistics of the surface body temperatures of the torso, fore-flippers, and hind-flippers of three California sea lions collected indoors vs

Table 1. Definitions of behavioral categories of the California sea lions observed in the outdoor display at the Peoria Zoo

Behavior	Substrate	Description
*Swim	Water	Move, propelled by fore-flippers, fully submerged
Swim at surface	Water	Move, propelled by fore-flippers at the surface of water
Float	Water	Lie stationary at or near surface of water; constant position
Bob	Water	Float stationary, head out of water, body submerged; vertical position
*Rest on bottom	Water	Lie stationary, belly down on the bottom of the pool
Haulout	Land	Lie stationary, belly down, flat on land, with head up; all flippers positioned outward from body
Haulout flat	Land	Lie stationary, belly down, flat on the land, with head down and flippers positioned outward from body
Sit on hind-flippers	Land	Use flippers to support body in upright, head up, stationary position; flippers outstretched from the body

*Cannot correlate these behaviors with air, substrate, or water temperatures since infrared sensor only measures temperature of the water when animal is submerged.

Table 2. Summary statistics of surface body temperature in °C (and °F) taken from the California sea lions at Peoria Zoo while indoors at 1 m and 3 m away from the infrared temperature sensor

Sea lion	Statistic	Temperature 1 m from torso	Temperature 3 m from torso
Large female	Mean	17.8 (64.1)	17.7 (63.8)
	SD	6.4 (43.0)	6.2 (43.0)
	Maximum	22.2 (72.0)	21.9 (71.5)
	Minimum	11.1 (52.0)	11.1 (52.0)
	Range	11.1 (20.0)	10.8 (19.5)
Small female	Mean	18.9 (66.0)	19.0 (66.2)
	SD	7.1 (45.0)	7.0 (45.0)
	Maximum	27.5 (81.5)	27.2 (81.0)
	Minimum	12.2 (54.0)	12.2 (54.0)
	Range	15.3 (27.5)	15.0 (27.0)
Large male	Mean	16.9 (62.4)	16.9 (62.4)
	SD	5.6 (43.0)	5.5 (42.0)
	Maximum	20.3 (68.5)	20.3 (68.5)
	Minimum	10.8 (51.5)	10.8 (51.5)
	Range	9.5 (17.0)	9.5 (17.0)

Table 3. Summary statistics of surface temperatures °C (°F) of the California sea lions by body region; data were collected in an indoors holding area and in an outdoor exhibit at the Peoria Zoo while sea lions were hauled out.

		Temperatures taken indoors °C (°F)			Temperatures taken outdoors °C (°F)		
Sea lion	Statistic	Torso temperature	Fore-flipper temperature	Hind-flipper temperature	Torso temperature	Fore-flipper temperature	Hind-flipper temperature
Large female	Mean	18.3 (65.0)	16.7 (62.1)	17.3 (63.2)	15.9 (60.6)	14.7 (58.5)	13.2 (55.8)
	SD	8.1 (47.0)	7.2 (45.0)	7.3 (45.0)	17.8 (64.0)	17.8 (64.0)	19.8 (67.6)
	Maximum	25.8 (78.5)	22.5 (72.5)	24.2 (75.5)	34.0 (93.0)	30.8 (87.5)	30.3 (86.5)
	Minimum	10.3 (50.5)	8.1 (46.5)	8.6 (47.5)	1.4 (34.5)	0.3 (32.5)	-3.6 (25.5)
	Range	15.5 (28.0)	14.4 (26.0)	15.6 (28.0)	14.7 (58.5)	13.0 (55.0)	16.0 (61.0)
Small female	Mean	19.6 (67.3)	18.7 (65.6)	17.4 (63.3)	15.9 (60.7)	14.6 (58.2)	*18.2 (64.8)
	SD	9.2 (48.6)	8.3 (46.9)	7.2 (45.0)	17.1(62.8)	18.3(64.9)	*18.1(64.6)
	Maximum	29.7 (85.5)	29.2 (84.5)	26.1 (79.0)	33.1 (91.5)	33.0 (92.0)	*28.3 (83.0)
	Minimum	10.0 (50.0)	8.3 (47.0)	8.3 (47.0)	0.8 (33.5)	0.0 (32.0)	*3.0 (38.0)
	Range	19.7 (35.5)	20.9 (37.5)	17.8 (32.0)	14.0 (58.0)	14.6 (58.2)	*6.9 (44.5)
Large male	Mean	17.3 (63.2)	17.1 (62.8)	17.2 (62.9)	17.3 (63.2)	15.9 (60.7)	15.3 (59.5)
	SD	6.1 (42.9)	6.3 (43.4)	6.5 (43.7)	15.6 (60.1)	15.3 (59.5)	15.7 (60.3)
	Maximum	23.1 (73.5)	24.4 (76.0)	23.3 (74.0)	32.5 (90.5)	33.0 (92.0)	34.0 (93.0)
	Minimum	11.4 (52.5)	10.0 (50.0)	9.4 (49.0)	3.0 (38.0)	2.0 (36.0)	3.0 (37.0)
	Range	11.7 (21.0)	14.4 (26.0)	13.9 (25.0)	11.4 (52.5)	13.0 (56.0)	15.3 (59.5)

* Sample size of only 9

outdoors while they were hauled out are compared in Table 3.

A comparison of the readings repeated on the same animal at the same time, but at different body regions—torso, right fore-flipper, right hind-flipper, left fore-flipper, and left hind-flipper—is shown for each sea lion in Table 4. In the male sea lion, surface temperatures at all body locations was positively correlated with air temperature. However, in the large female, the temperature of the right and left hind-flippers was not correlated with air temperature. In the small female, only the temperature of the left fore-flipper was correlated with air temperature.

Paired *t*-tests were conducted to examine bilateral differences in body temperature for the fore- and hind-flippers (Table 5). Both females had significant temperature differences between the right and left fore-flippers and between the right and left hind-flippers. The adult male only had a significant temperature difference between the right and left hind-flippers.

Table 4. Values of r from a Pearson's correlation analysis comparing torso temperature or flipper temperature with air temperature of three California sea lions; data were collected indoors at the Peoria Zoo. Bold values indicate a significant correlation; torso comparisons had df = 72 and all flipper comparisons had df = 54, critical r = 0.27.

Sea lion	Torso	Right fore-flipper	Right hind-flipper	Left fore-flipper	Left hind-flipper
Large female	**0.38**	**0.32**	0.25	**0.37**	**0.27**
Small female	0.17	0.23	0.12	**0.32**	0.22
Large male	**0.37**	**0.38**	**0.33**	**0.34**	**0.29**

Table 5. Values of *p* from a paired *t*-test comparing torso vs flipper surface temperatures of three California sea lions; data were collected indoors at the Peoria Zoo. Bold values indicate significant differences; df = 53 in all comparisons.

Sea lion	Right fore-flipper & torso	Right hind-flipper & torso	Left fore-flipper & torso	Left hind-flipper & torso	Right fore & right hind-flippers	Left fore- & left hind-flippers	Right fore- & left hind-flippers	Left fore- & right hind-flippers
Large female	**0.000**	**0.000**	**0.000**	**0.001**	**0.007**	**0.004**	**0.000**	**0.000**
Small female	**0.014**	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**	**0.001**	**0.001**
Large male	0.634	**0.000**	0.152	0.193	**0.002**	0.057	0.071	0.097

Paired *t*-tests were run to examine whether right vs left flipper temperatures were different from torso temperatures and whether fore-flipper vs hind-flipper temperatures were different from torso temperatures (Table 5). In both females, surface temperatures of the right and left hind- and fore-flippers were significantly different from each other and from torso temperatures. In the male sea lion, only the temperatures of the right hind-flipper and the right fore-flipper were significantly different (Table 5).

Outdoor Body Temperature Data

Summary statistics of the surface temperatures of the torso, fore-flipper, and hind-flipper of the sea lions taken in their indoor and outdoor exhibits are listed in Table 3. Surface body temperatures of all sea lions were on average lower when taken outdoors, except for the small female whose hind-flippers were warmer when she was outside. Minimum surface body temperatures ranged from about -3.9 to +17.0° C (25.0 to 35.0° F), while maximum surface body temperatures were from 30.6 to 33.9° C (87.0 to 93.0° F). When outdoors, the sea lions' torso temperatures varied only slightly among individuals, with means ranging from 15.9° C (60.6° F) to 17.3° C (63.2° F). The temperature of fore-flippers taken from sea lions outdoors changed very little, with mean values ranging between 14.7 to 15.9° C (58.5 to 60.7° F). Ranges of the hind-flipper temperatures varied among the subjects; the means were from 13.2 to 18.3° C (55.8 to 64.8° F).

Variability in Outdoor Air, Water, and Substrate Temperatures

Over the 10-mo study, air temperatures (Figure 4a) collected between 1000 and 1645 h ranged from -2.8° C (27.0° F) to 37.8° C (100.0° F), with an average of 19.4° C (67.0° F). As might be expected, there was a very significant correlation (r = 0.919, df = 2,467) between the ambient air and substrate temperature. Figure 4a shows the variety of haulout temperatures available to sea lions on days at a given air temperature.

Figure 4b shows the variety of water temperatures available to a sea lion at a given air temperature. Over the 10-mo study, water temperatures ranged from -2.5° C (27.5° F) in winter to 31.7° C (89.0° F) in summer. Figure 4b shows there was very little difference in water temperature on days at any given air temperature; however, water temperature and air temperature both were positively correlated (r = 0.992, df = 2,086).

Paired *t*-tests were conducted and showed that when sea lions were in the water, there were significant differences among water temperatures in the three pools. For the large female and large male, temperature differences were significantly different among the three pools by an average of 1.4° F. For the small female, the average water temperature difference among pools was slightly smaller, 1.25° F.

Preferred Outdoor Locations of Sea Lions

When outdoors, the most preferred locations among the sea lions were areas 1, 2, and 4 (see Figure 2 for site location & Figure 3d). That is, they tended to prefer the water overall, but when on land, the peak of the center rock was the most frequented location followed by area 10, a haulout cave. Both the large and small female sea lions preferred areas 1, 2, and 4 (Figures 3a & b). The male preferred areas 1, 2, and 10 (Figure 3c). No sea lion was ever in area 8, and there was little or no preference for areas 5, 6, or 7.

Effects of Air, Water, and Substrate Temperature on Sea Lions' Chosen Location

Outdoor Air Temperature and Body Temperature—For all sea lions, outdoor air temperature and body region temperature, separated into torso, fore-flippers, and hind-flippers, were all significantly correlated (Table 6). When air temperature increased, body temperature increased. Figure 5 shows the relationship between available air temperature and the temperature at the location chosen by each sea lion. The diagonal line represents the situation where the sea lion chose a location that matched the air temperature. In general, for air temperatures between 40.0 and 80.0° F, all sea lions chose locations slightly warmer than the air temperature. Above air temperatures of 80.0° F, sea lions chose locations with a lower temperature. At air temperatures near freezing, sea lions chose a temperature slightly below the air temperature, perhaps spending time in the water.

Outdoor Water and Body Temperature Data—For all sea lions, outdoor water temperature and body region temperature, separated into torso, fore-flippers, and hind-flippers, were all significantly correlated (Table 6). Figure 6 shows the relationship between available water temperature and the temperature at the location chosen by each sea lion. At any given air temperature, the sea lions had little choice in available water temperatures.

Outdoor Substrate and Body Temperature Data—When substrate temperatures increased, so did surface body temperatures. When sea lions were on land, there were significant differences in the substrate temperatures from which the sea lions could choose; the average temperature differences among substrate areas on a given day was about 12.4° F. Haulout substrate temperatures ranged from -7.2° C (+19.0° F) in winter to 44.2° C (111.5° F) in summer. Figure 7 shows the relationship between available substrate temperature and

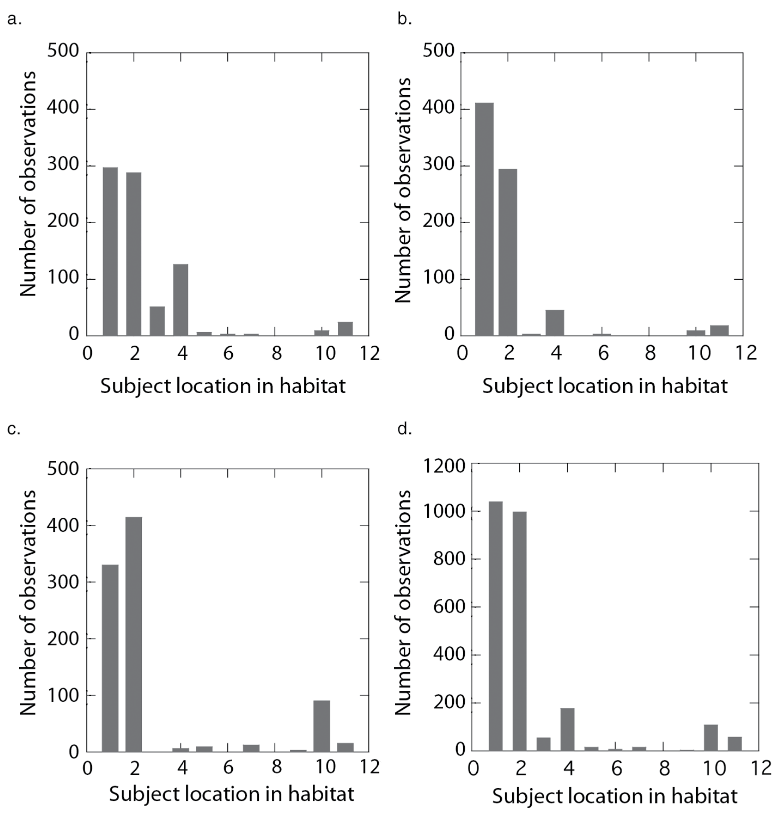

Figure 3. Preferred areas in the outdoor exhibit at the Peoria Zoo by the a. large female, b. small female, c. large male, and d. all California sea lions combined over 10-mo period; areas 4 through 11 are haulout substrates, and areas 1, 2, and 3 are water in pools.

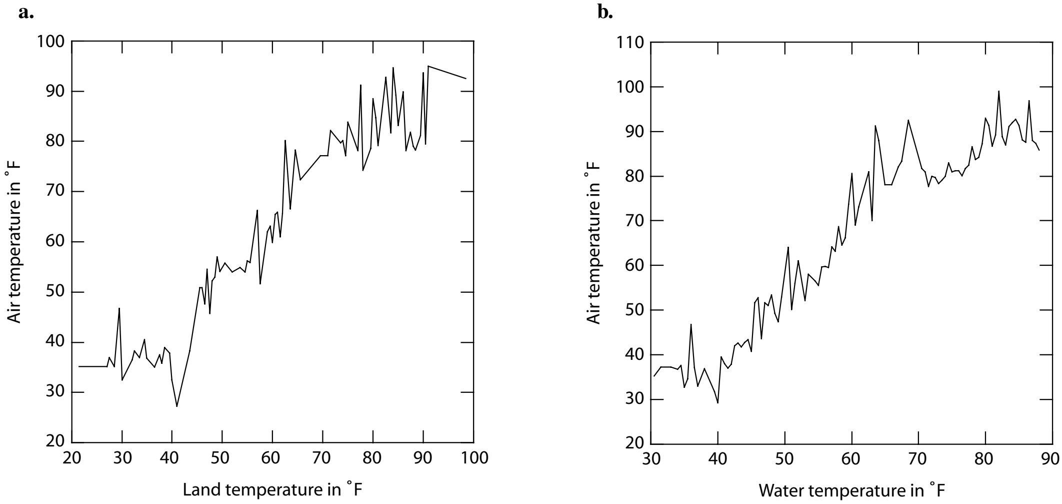

Figure 4. a. Comparison of air temperature and haulout temperature and b. air temperature and water temperature in the California sea lion outdoor exhibit at the Peoria Zoo; values averaged over all areas of the exhibit.

Table 6. Values of r from a Pearson's correlation of surface temperature by body region for three California sea lions with air and water temperatures; data were collected outdoors at the Peoria Zoo. Bold values indicate significant correlation; (*n*) is sample size.

Body region	Torso temperature and		Fore-flipper temperature and		Hind-flipper temperature and	
Sea lion	Air temperature (*n*)	Water temperature (*n*)	Air temperature (*n*)	Water temperature (*n*)	Air temperature (*n*)	Water temperature (*n*)
Large female	**0.912** (265)	**0.995** (211)	**0.919** (253)	**0.996** (206)	**0.920** (231)	**0.996** (203)
Small female	**0.914** (259)	**0.996** (236)	**0.914** (254)	**0.996** (235)	**0.920** (244)	**0.997** (235)
Large male	**0.920** (291)	**0.995** (248)	**0.926** (281)	**0.992** (245)	**0.925** (277)	**0.996** (245)

the temperature at the location chosen by each sea lion. The diagonal line represents the preferred temperature for a haulout site. In most cases, each animal chose a haulout location between the maximum and minimum temperature available.

Maximum Temperatures Available to Sea Lions—Over the 10-mo study, the substrate temperatures ranged from approximately -6.7 to +46.1° C (20.0 to 115.0° F) on land and from -1.1 to +32.2° C (30.0 to 90.0° F) in water. The mean substrate temperature chosen by sea lions when on land was 18.3° C (65.0° F), and when in the water was 15.6° C (60.0° F). Figure 8 shows the substrate temperatures available to the sea lions in their exhibit. The maximum temperature difference on a given day was 42.0 °F. Water in the pools did not freeze, so it was never significantly below 32.0° F.

Interestingly, the average preferred temperature for both land and water was about 15.6° C (60.0° F). The sea lions occupied a wide variety of substrate temperatures; they were observed on land with substrate temperatures ranging from -6.7 to +37.8° C (20.0 to 100.0° F) and were observed in water temperatures ranging from -1.1 to +32.3° C (30.0 to 90.0° F). The sea lions tended to choose a location between 7.2 to 26.7° C (45.0 and 80.0° F) on both land and water, but the range of preferred water temperatures was slightly smaller.

On the coldest day of the study (5 February at 1000 h), the lowest substrate temperature was measured as -6.9° C (19.5° F) at areas 4, 5, and 6. At that time, the sea lions could have chosen a terrestrial substrate temperature as warm as 7.8° C (46.0° F) or warmer water temperatures ranging from 0.3° C to 1.9° C (32.5 to 35.5° F). They chose the warmest location in the exhibit, the largest pool, which had a water temperature of 1.7° C (35.0 F). On the hottest day of the study (15 April at 1130 h), the warmest substrate temperature was 44.2° C (111.5° F) in area 9. At that time, the coolest haulout area available to the sea lions was area 11, which had a temperature of 25.6° C (78.0° F); however, all sea lions chose area 1, the

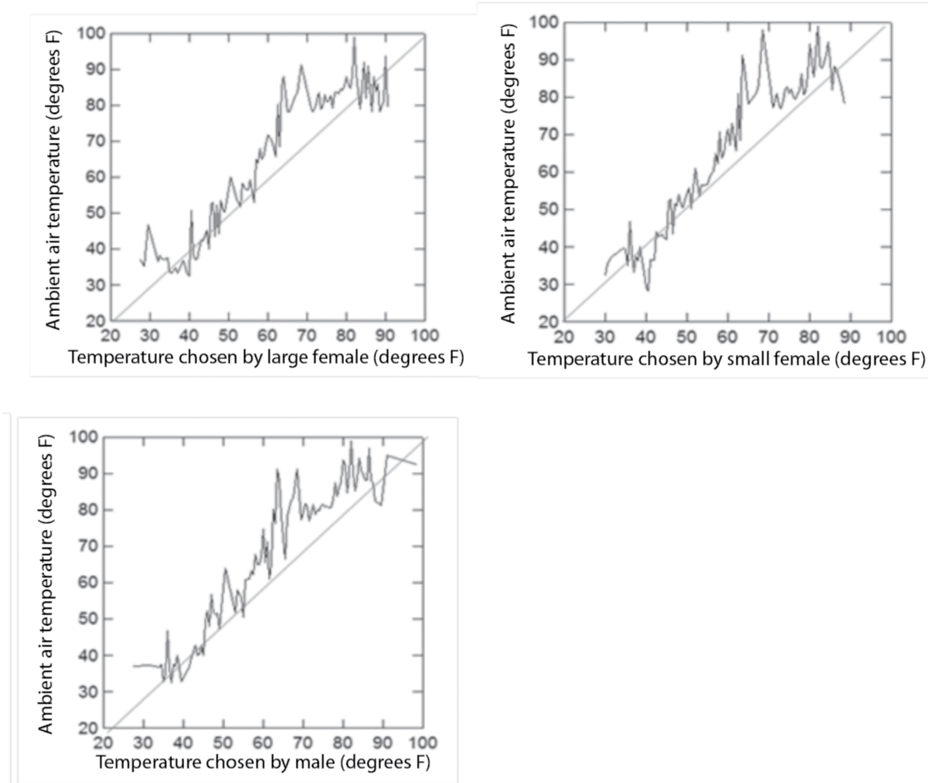

Figure 5. Temperatures chosen by three California sea lions at the Peoria Zoo vs air temperatures; diagonal line represents cases where animal chose to be in a location the same as the air temperature. Above diagonal line, sea lion chose location (haulout or water) higher than air temperature; below diagonal line, sea lion chose location below air temperature.

largest pool, with a slightly higher temperature of 25.8° C (78.5° F).

Outdoor Body Temperature and Behavioral Data

The most common sea lion behaviors included floating, resting at the pool bottom, and swimming fully submerged (Figure 9d). The large female frequently hauled out, rested on the bottom of the pool, and swam fully submerged (Figure 9a). The small female usually floated or swam at the surface of the water or swam fully submerged (Figure 9b). The male's most frequent behaviors were floating at the surface of the water, resting at the pool bottom, and swimming fully submerged (Figure 9c).

One-way ANOVA with Bonferroni adjusted p-values were used to compare the surface body temperatures of each sea lion by behaviors that occurred at the water surface (e.g., bob, float, and surface swim). Only the male sea lion showed a significant difference in body temperature when bobbing vs surface swimming (df = 182, $p = 0.04$).

Table 7 reports the summary statistics for the surface body temperature of each sea lion while exhibiting six different behaviors. Using a one-way ANOVA and Bonferroni adjusted p-values, we examined how surface body temperature might change with different behaviors (Table 8). Skin temperatures of the small female (df = 48, $p = 0.05$) and the large male (df = 105, $p = 0.00$) were significantly different when they were hauled out with a head-up posture vs when they sat on land on their hind-flippers. Also, skin surface temperatures were lower when they curled in and sat on their hind-flippers than when they were simply hauled out (lower by 4.5 to 9.7° F on average). When hauled out, the large male had significantly different torso temperatures ($F = 4.13$, df = 2, 38, $p = 0.024$), different fore-flipper temperatures ($F = 3.01$, df = 2, 32, $p = 0.06$), and different hind-flipper temperatures ($F = 4.916$, df = 2, 28, $p = 0.04$). On average, the body temperatures of both the torso and fore-flippers were lower when the male was hauled out with a head-up posture than when he hauled out

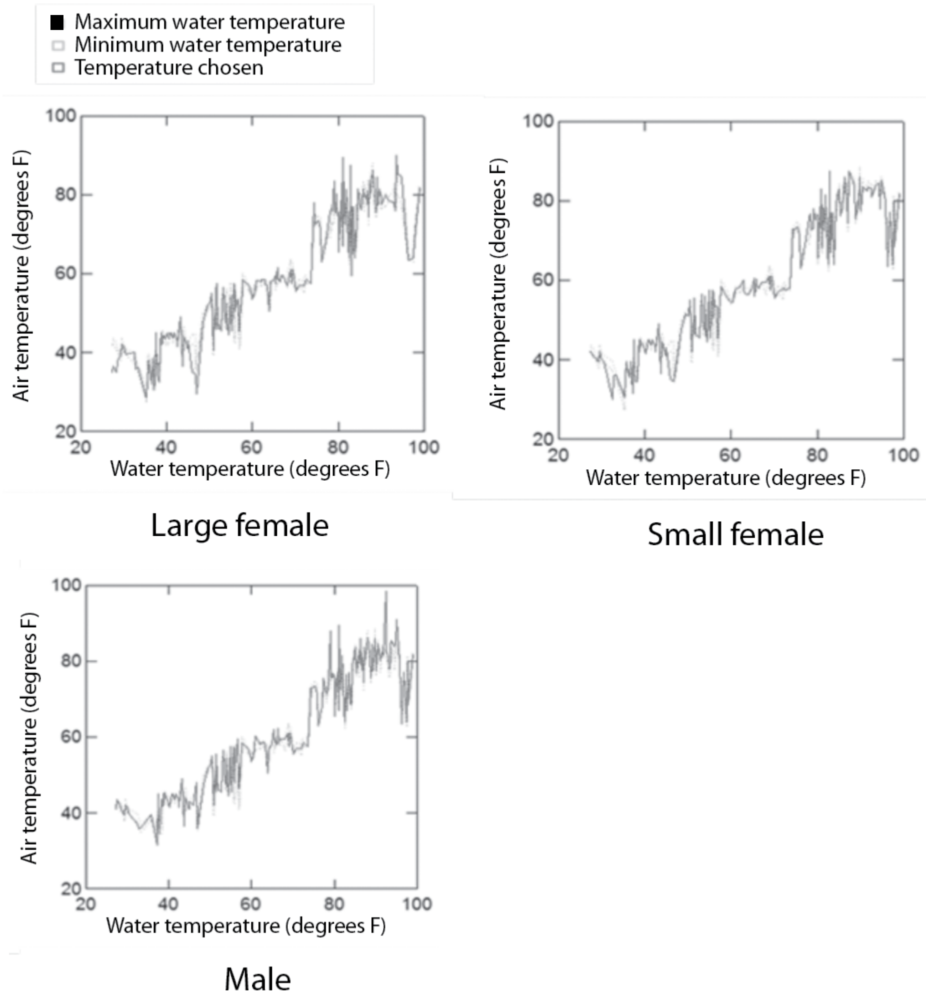

Figure 6. Temperatures chosen by three California sea lions at the outdoor exhibit of the Peoria Zoo vs available water temperatures; sea lions chose among water areas that varied by only 2.0° F.

lying flat on the concrete. However, when hauled out sitting on his hind-flippers, the skin temperature was higher than when he hauled out in a head-up posture or lay flat on the concrete.

Discussion

Reliability of the Infrared Temperature Sensor

The Professional Equipment T7350 Series Infrared Thermometer was a reliable instrument for remotely measuring body surface temperature in California sea lions. At room temperature, the laser temperature sensor detected subtle differences in the surface body temperatures of the torso and all flippers in all California sea lions. The infrared thermometer showed further reliability in an outdoor environment. Readings of surface body temperature were reliable on land vs in water and at cold vs hot air temperatures.

The distance at which skin temperature was taken by the sensor did not affect the surface temperatures taken on the small female and large male, but it did affect measurements on the large female, perhaps due to excessive body movement by this individual during readings. Based on these results, surface temperature recordings should not be impacted if taken at a reasonable distance (approximately 3 m) from a stationary sea lion.

Regulation of Body Surface Temperatures

McGee (2006) reported that the blubber layer, fur, and vascular system of the California sea lion

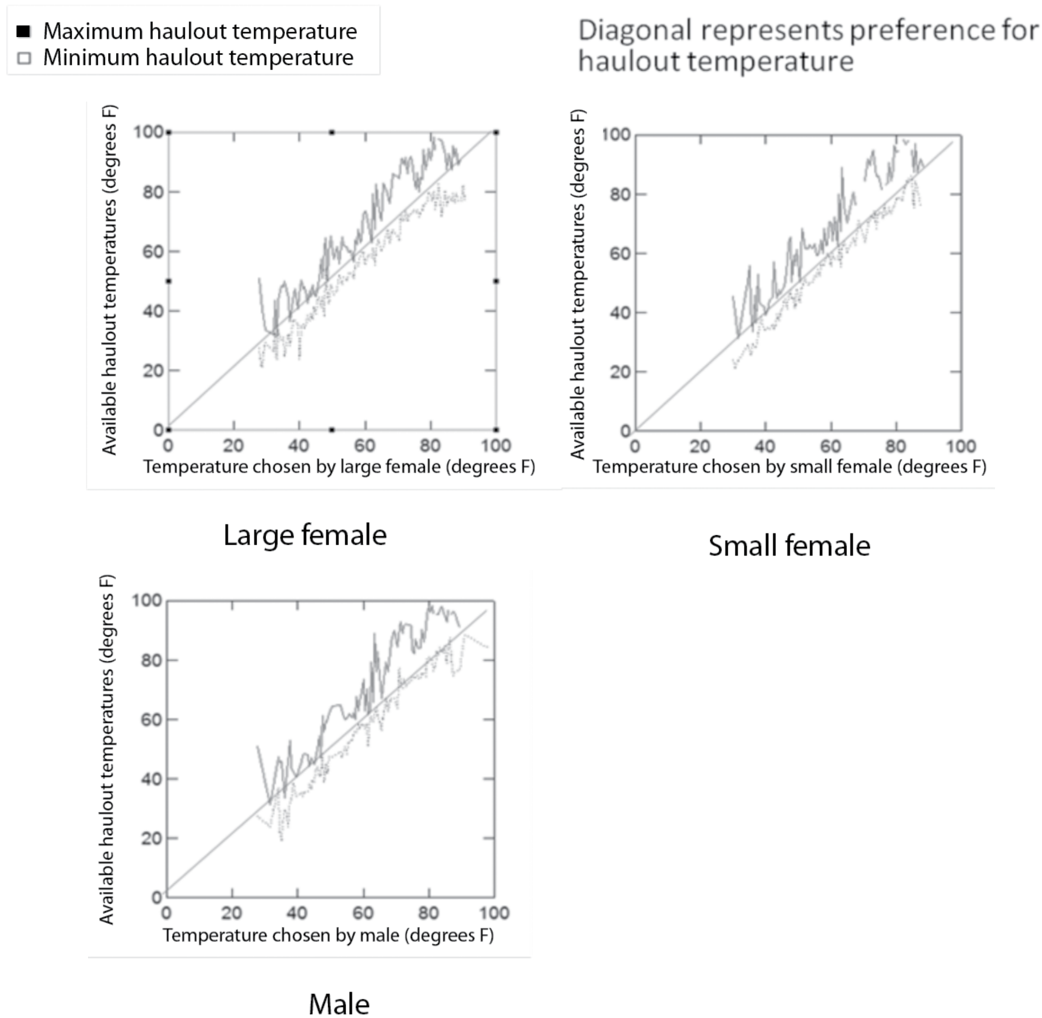

Figure 7. Temperatures chosen by three California sea lions at the outdoor exhibit at the Peoria Zoo vs available haulout temperatures; diagonal represents cases where sea lions preferred the temperature of the haulout substrate.

allow it to efficiently thermoregulate over a wide variety of ambient temperatures, which is adaptive considering its large geographic range. Langman et al. (1996) reported captive California sea lions with wet fur absorbed 91.6% of all types of shortwave radiation. As with most mammals, California sea lions can regulate body temperatures through behavioral and physiological changes, or both. In the short term, California sea lions can move in and out of the shade or in and out of the water. They can dissipate or acquire heat through vasodilatation or vasoconstriction of the flippers (Scholander & Schevill, 1955; Tarasoff & Fisher, 1970; Ridgway & McCormick, 1971; Sweeney & Ridgway, 1975; Hammond & Elsner, 1977; Innes et al., 1990; Worthy & Edwards, 1990; Kvadsheim et al., 1997). In the long-term, California sea lions are capable of shifting their thermal neutral zone through increased or decreased food intake, which alters the blubber layer and metabolic requirements. However, a significant long-term ambient temperature change is needed to resort to metabolic change for thermoregulation. Worthy (1990) noted that exposure to temperatures as low as 10.0° C (50.0° F) did not result in a metabolic change in a California sea lion.

According to our data, these sea lions regulated surface temperature in specific body regions relative to ambient air temperature. There were slight surface temperature differences among body regions taken at a given time on the same sea lion. Also, the larger sea lions exhibited more

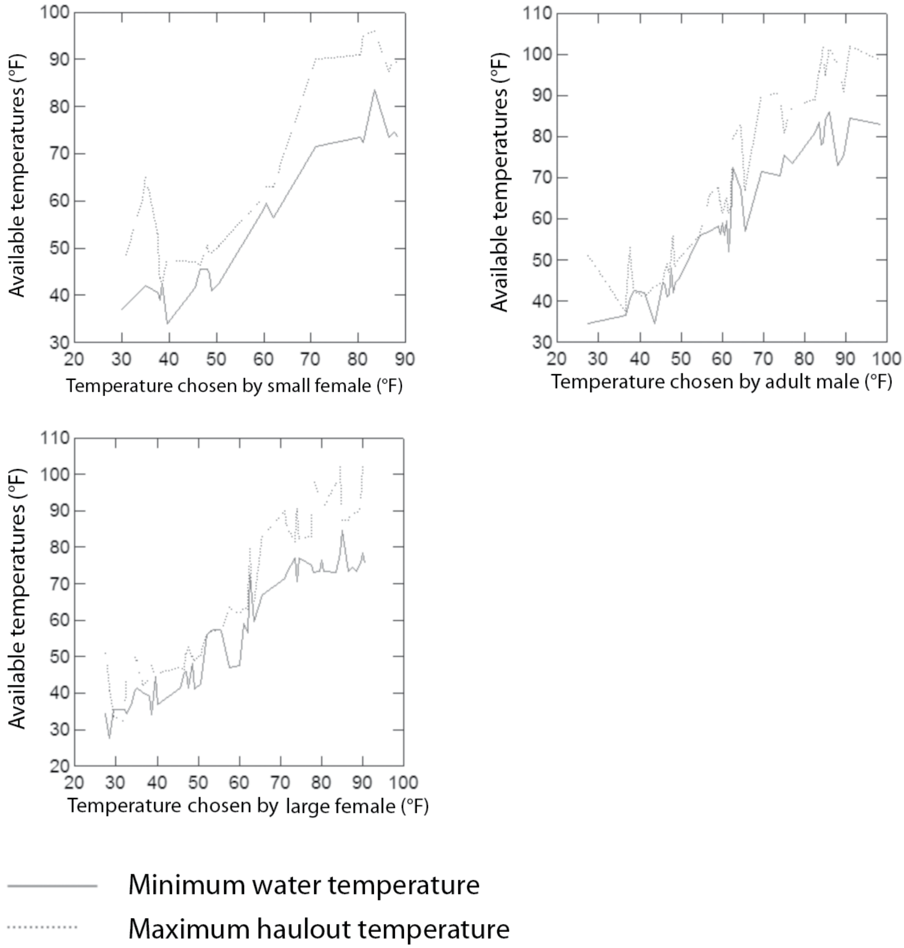

Figure 8. Average temperature chosen by three California sea lions in the outdoor exhibit at Peoria Zoo vs available temperatures, ranging from coolest water to warmest haulout temperatures

variability among their flipper temperatures, so they may be able to adjust thermoregulation more exactly than a smaller sea lion. The large male's surface body temperatures were affected in all body areas by ambient air temperatures. Similarly, the large female's surface body temperatures at all body regions, except the hind-flippers, were affected by the air temperature. In contrast, the small female's surface body temperatures were not as affected by air temperature, perhaps because of her lesser body size. Both large sea lions exhibited significant temperature differences between flippers at a given time; however, the small female did not exhibit significant temperature differences between flippers. As a result, body size could affect the need or ability to thermoregulate by changing flipper temperatures. These results are counter-intuitive because a smaller animal should be more affected by ambient temperatures than a larger one. However, the weight difference between the two females was only 27 kg, so to categorize the smaller female as "small" may not be warranted.

The body surface temperature for all subjects at all body regions was significantly correlated with outdoor air temperature. Several authors report that outermost tissue layers of pinnipeds are close to the ambient air temperature (Irving, 1969; Folkow & Blix, 1989; Hokkanen, 1990; Worthy, 1991; Watts et al., 1993; Kvadsheim et al., 1997; Dehnhardt et al., 1998).

The thermal neutral zone for a California sea lion is the body temperature at which a resting California sea lion achieves equilibrium core temperature without resorting to physiological measures like shivering or spreading saliva over its fur. Worthy (1990) reported the thermal neutral zone of an immature California sea lion

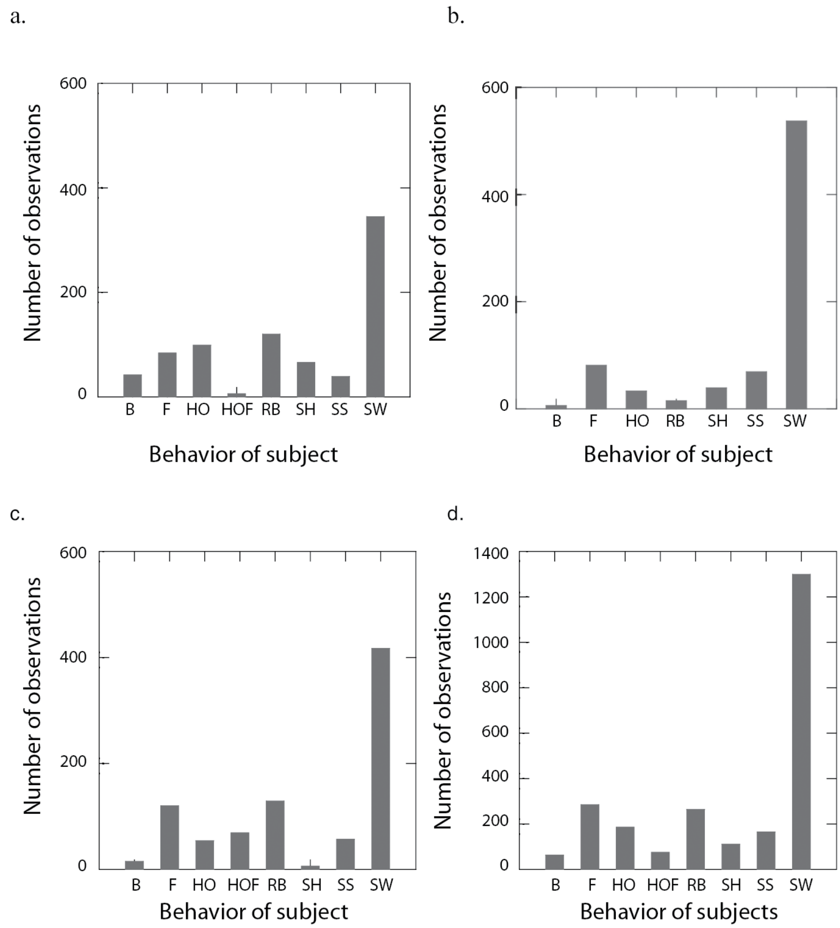

Figure 9. Number of observations by behavioral category over the 10-mo study while California sea lions were in the outdoor exhibit at the Peoria Zoo: a. large female, b. small female, c. large male, and d. all California sea lions combined; B = bob, F = float, HO = haulout, HOF = haulout flat, RB = rest on bottom, SH = sit on hind-flippers, SS = swim at surface, and SW = swim fully submerged. Body temperatures could not be taken during SS, SW, or RB.

as 11.0 to 25.0° C (51.8 to 77.0° F) and that a young animal typically had a lower tolerance for extremely warm or cold ambient temperatures. Langman et al. (1996) reported the upper critical temperature for the California sea lion is 22.0° C or 71.6° F, so the wide range of surface body temperatures in our study was expected.

Variability in Substrate Temperatures

In the wild, California sea lions experience air temperatures ranging from 0.0 to 24.0° C (32.0 to 75.2° F) and water temperatures ranging from 5.5 to 20.0° C (41.9 to 68.0° F) (NOAA, 2006).

Langman et al. (1996) concluded that the ambient conditions in the sea lion exhibit at the Audubon Zoo during the summer might have exceeded the upper critical temperature for this species (22.0° C or 71.6° F). This factor, combined with the high degree of shortwave absorbance by their wet coats, suggested that an alternate indoor habitat, air-conditioned to temperatures below the upper critical temperature, would provide a behavioral option for heat loss in this species. This set of equipment provided a comprehensive evaluation of the thermal properties of the sea lion exhibit and of the shortwave radiation absorption of the animal's fur; however, it was costly, required elaborate setup, and was not used to gather body temperature or behavior of the animals. The elaborate setup used by Langman et al. (1996) is not likely to be used by zookeepers on a regular basis.

In our study, the substrate temperatures of the haulout areas and water in pools changed with air temperature, so the sea lions had a variety

Table 7. Results of three, one-way ANOVA tests and Bonferroni adjusted *p*-values on torso temperature by behavioral category; data were collected from the sea lion exhibit at the Peoria Zoo. Bold values indicate significant differences.

Sea lion	Behavior	Bob	Float	Haulout	Haulout flat	Sit on hind-flippers	Swim at surface
Large female	Bob	1.000					
	Float	1.000	1.000				
	Haulout	**0.000**	**0.000**	1.000			
	Haulout flat	1.000	1.000	0.778	1.000		
	Sit on hind flippers	**0.000**	**0.000**	1.000	0.093	1.000	
	Swim at surface	1.000	1.000	**0.000**	1.000	**0.000**	1.000
Small female	Bob	1.000					
	Float	1.000	1.000				
	Haulout	**0.007**	**0.000**	1.000			
	Haulout flat	N/A	N/A	N/A	1.000		
	Sit on hind flippers	**0.000**	**0.000**	**0.000**	N/A	1.000	
	Swim at surface	1.000	1.000	**0.000**	N/A	**0.000**	1.000
Large male	Bob	1.000					
	Float	1.000	1.000				
	Haulout	**0.000**	**0.000**	1.000			
	Haulout flat	1.000	1.000	**0.000**	1.000		
	Sit on hind flippers	**0.037**	**0.006**	1.000	0.073	1.000	
	Swim at surface	1.000	1.000	**0.000**	1.000	**0.009**	1.000

N/A = Behavior never seen in that sea lion

of temperature choices over the 10-mo study. Haulout area temperatures were as low as -7.2° C (+19° F) and as high as +44.2° C (111.5° F). Water temperatures ranged from -2.5° C (27.5° F) in the winter to +31.7° C (89.0° F) in the summer. Within a single day, variation in land substrate temperatures was dramatic; water temperature was less resistant to change throughout a day. This is not surprising given that water has a high specific heat or ability to retain heat. Thus, the sea lions tended to stay in the water most of the time due to its more constant temperature readings. McGee (2006) reported that California sea lions "have been successfully maintained in outdoor exhibits through cold winters in temperate climates as long as the animal is allowed to acclimate and water temperature does not fall below 4° C (39.2° F)" (p. 4). According to McGee, excessive heat is more life threatening to California sea lions than excessive cold. Sea lions exposed to direct summer sun or ambient temperatures in excess of 30.0° C (86.0° F) (p. 4) without means of cooling themselves can suffer fatal heat prostration within 1 h. At the Peoria Zoo, animals had the option of going into the water or moving under a shaded area to avoid high ambient temperatures.

Zookeepers should monitor daily variations in land and water temperatures and provide the sea lions with the widest range of temperatures possible. If sea lions are housed outdoors, the pool water could be heated or cooled, depending upon the season. Voluntary access to an indoor, temperature-controlled habitat could be given to the sea lions during days with extreme ambient temperatures. Adequate shade over both haulout and pool areas should be provided (McGee, 2006). Langman et al. (1996) concluded that thermal properties of materials used in zoo enclosures are an important determinant of the animals' heat load and should be considered in the design of captive habitats. They reported that darkening the color of the Gunite surface in a sea lion enclosure at the Audubon Zoo reduced reflectance and decreased the shortwave heat load in an open haulout area. They also reported that by adding two effective shaded areas, the long-wave heat load was reduced in the California sea lion exhibit.

Influence of Substrate Temperature on California Sea Lions' Locations

We assumed that the California sea lions chose their location areas in the exhibit based on a preferred substrate or water temperature. The sea lions seemed to stay away from the hottest regions of the habitat when temperatures were warmest and away from the coldest areas when temperatures were coolest. The sea lions tended to stay in the water, especially during cold ambient temperatures. Similarly, Dehnhardt et al. (1998) observed that harbor seals (*Phoca vitulina*) seldom left the water in cold winter conditions presumably because of the more constant water

Table 8. Summary statistics for surface body temperature (in degrees F) for three California Sea lions in an outdoor exhibit at the Peoria Zoo by behavioral category

	Large female (7001)		Small female (7002)		Large male (7008)	
Behavioral category	Statistic	Surface body temperature	Statistic	Surface body temperature	Statistic	Surface body temperature
Bob	mean	56.0	mean	57.2	mean	51.9
	SD	10.0	SD	6.3	SD	9.6
	maximum	79.0	maximum	63.0	maximum	61.0
	minimum	37.5	minimum	51.5	minimum	37.5
Float	mean	54.5	mean	N/A	mean	58.8
	SD	13.7	SD	N/A	SD	14.0
	maximum	86.5	maximum	N/A	maximum	86.0
	minimum	34.5	minimum	N/A	minimum	41.5
Haulout	mean	60.5	mean	64.8	mean	70.7
	SD	18.7	SD	15.1	SD	12.0
	maximum	87.5	maximum	84.0	maximum	90.5
	minimum	32.0	minimum	43.5	minimum	45.5
Haulout flat	mean	57.5	mean	N/A	mean	N/A
	SD	21.4	SD	N/A	SD	N/A
	maximum	77.0	maximum	N/A	maximum	N/A
	minimum	38.0	minimum	N/A	minimum	N/A
Sit on hind-flipper	mean	56.5	mean	55.1	mean	65.1
	SD	17.1	SD	18.8	SD	15.9
	maximum	93.0	maximum	92.0	maximum	77.5
	minimum	25.5	minimum	32.0	minimum	46.0
Swim at surface	mean	54.4	mean	57.3	mean	63.3
	SD	12.7	SD	17.9	SD	14.6
	maximum	78.5	maximum	85.5	maximum	88.0
	minimum	38.0	minimum	35.5	minimum	35.0

Body temperatures could not be taken for submerged swimming or resting on bottom; N/A = animal never exhibited that behavior

temperature compared to the wide range of temperatures and quick temperature changes on the land. Swimming fully submerged was the most frequent behavior of the sea lions during cold air temperatures. That is, the water allowed warmth when air temperature was cold and coolness when ambient air temperatures were hot.

Other factors influenced the sea lions' location and behavior. For example, the male tended to follow the large female around the exhibit, particularly during the breeding season. The sea lions became more active in anticipation of going inside for the evening and of feeding times associated with shows conducted at 1100 and 1400 h.

Sea lions preferred the center rock of their habitat, the highest point in the exhibit. The hollow center rock (areas 4, 5, and 6) was made of Gunite and exhibited more temperature fluctuations than the cement substrates. Langman et al. (1996) reported that the surface of Gunite rocks reflected 41% of shortwave radiation, so it helps to reduce surface temperature. In our study, the variable temperatures of the Gunite rock could have allowed sea lions to choose substrate temperatures and thus resulted in the female sea lions' preference for the highest point of the center rock. Alternatively, the highest point in the exhibit could have been preferred by females because it provided an easy lookout over the entire area, was the farthest location away from the male, or indicated social dominance. Since a sea lion's location can be affected by social influences, zookeepers might consider whether subordinate sea lions have adequate location choices for thermoregulation.

In the wild, temperatures of rock and sand can vary greatly, depending on the latitude, cloud cover, and season. To our knowledge, surveys of temperatures available to wild California sea lions on a microhabitat level are not available but would be useful for examining behavior and how location is selected based on social vs thermoregulatory needs.

Influence of Behavior on Body Temperatures of California Sea Lions

Certain behaviors, such as hauling out with the head up and sitting on hind-flippers while hauled out, were directly related to the surface body temperatures of the sea lions. The head-up posture might help a sea lion dissipate heat, and the body temperatures were lowest when the sea lions were sitting on their hind-flippers or when hauled out in a prone position. These behaviors, therefore, may help the sea lions conserve heat.

When in the water, bobbing and floating at the surface were associated with a lower body temperature than on land. Since floating and bobbing were most frequent with lower water temperatures, these behaviors may aid in sea lion thermoregulation.

Future Research

In retrospect, there were several additional types of information that would help in evaluating the effectiveness of this temperature sensor that could not be addressed in this non-invasive study. Some of these topics for future research studies are cited below:

- The influences of rain and snow on sea lion behavior and locations were not examined and could have affected sea lion behavior or choice of location in the exhibit.
- Measurements of surface body temperature over time within a behavioral category would be valuable. For example, a series of measurements from the time the sea lion hauled out until it reentered the water would show the range of surface body temperatures and whether the sea lions were thermoregulating while hauled out.
- The male often sat on his hind-flippers with part of the hind-flippers submerged in the water; this was an unexpected behavior and could have affected his body temperatures. Our study design did not include the category of partially submerged, so we could not examine the effect.
- A careful comparison of simultaneous core body temperatures and surface body temperatures taken with the infrared sensor would verify the usefulness of the infrared sensor; however, to do this would be invasive.
- If the infrared sensor were used on wild sea lions, the effects of sand or dirt adhering to their skin on surface body temperature would need to be evaluated.
- Further investigations on the relationship between movement by the sea lion and surface body temperature are needed.

Application of the Laser Temperature Sensor

This is the first documented study using the Professional Equipment T7350 Series Infrared Thermometer to examine microhabitat selection, differences in surface temperature by body region, and behavioral adjustments to ambient temperature by captive California sea lions. This instrument could provide a real-time technique for the remote, non-invasive collection of body temperatures in a captive or a wild setting. Alternative methods for collecting environmental and body temperatures of a marine mammal would disturb the animal's behavior, perhaps require physical restraint, and might require retrieval of the data collection unit at another time. This non-invasive, remote-sensing device could be used on wild animals without being physically invasive, encroaching on their habitat, or interrupting their behavior. Detailed surveys of temperature variations within haulout sites could provide important information about microhabitat selection in California sea lions.

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