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Movements of Male California Sea Lions Captured in the Columbia River

Abstract

There is growing concern in the Pacific Northwest over predation by migratory male California sea lions (*Zalophus californianus*) on threatened and endangered salmonid (*Onchorynchus* spp.) stocks. We compared movements of 14 male California sea lions known to have previously consumed salmonids at Bonneville Dam on the Columbia River or Willamette Falls on the Willamette River ("river"-types), with 12 animals of unknown foraging history ("unknown"-types). We captured sea lions in the Columbia River and instrumented them with satellite-linked transmitters during 2003-2004, 2004-2005, and 2006-2007. Transmitters operated for an average of 87.9 d (range 23-200 d) resulting in 14,539 location fixes. All 14 river-type animals returned to either Bonneville Dam or Willamette Falls whereas none of the 12 unknown-types exhibited this behavior. Minimum upstream and downstream transit times between the mouth of the Columbia River and Bonneville Dam (210 rkm) were 1.9 d and 1 d. Duration at the dam ranged from 2 d to 43 d. The median start dates of the southbound migration from the Columbia River to the breeding grounds for river-type and unknown-type sea lions were 20 May and 15 June, respectively. The maximum travel speed during migration was approximately 130 km d⁻¹ (5.4 km h⁻¹). Our results clearly show that not all California sea lions in the Columbia River prey on salmonids at Bonneville Dam or Willamette Falls. However, factors influencing recruitment into the upriver salmonid-foraging subpopulation are unknown.

Introduction

The California sea lion (*Zalophus californianus* [Lesson 1828]) is distributed seasonally in North Pacific waters from central Mexico to southeast Alaska, with breeding areas restricted primarily to island rookeries off southern California (the Channel Islands), Baja California, and in the Gulf of California (Peterson and Bartholomew 1967, Odell 1981). For management purposes, the U.S. National Marine Fisheries Service (NMFS) divides the population into three stocks: the U.S. stock, the western Baja California stock, and the Gulf of California stock (Carretta et al. 2007). In general, subadult and adult males undergo a northward migration following the summer breeding season, whereas females, pups, and juveniles stay near the rookeries (Peterson and Bartholomew 1967, Odell 1981; but see Maniscalco et al. 2004). Although the California sea lion population was severely reduced due to commercial harvest and predator control during the 19th and 20th centuries (Cass 1985, Zavala-Gonzalez and Mellink 2000), it

has largely recovered. The total population now numbers approximately 344,000 to 359,000 individuals, of which over two-thirds is from the U.S. stock (Lowry and Maravilla-Chavez 2005).

While regarded as a conservation success story, the apparent recovery of California sea lions has not been without negative consequences. For example, in Monterey Bay, California, sea lions have been responsible for thousands of dollars in lost fishing gear and depredated catch in the commercial and recreational salmonid (*Onchorynchus* spp.) fisheries (Weise and Harvey 2005). In the Pacific Northwest, the primary concern over the increasing California sea lion population has been their impact on threatened and endangered salmonid stocks (NMFS 1997). This concern first arose in the 1980s and 1990s at the Chittenden (Ballard) Locks, Washington, where California sea lion predation contributed to the functional extinction of Lake Washington winter steelhead (*O. mykiss*) (Jeffries and Scordino 1997, Fraker and Mate 1999). More recently, a similar situation on the Columbia River led the states of Oregon, Washington, and Idaho to apply for, and receive, limited authority under Section 120 of the Marine Mammal Protection Act (MMPA; 16 United States Code §1361 et

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seq.) to permanently remove California sea lions consuming threatened and endangered salmonids at Bonneville Dam (NMFS 2008).

Despite their observed and perceived impact in the Pacific Northwest, the literature on male California sea lions in this region is limited. Mate (1975) presented information on California sea lion migration along the Oregon coast based on aerial and shoreside observations. Bigg (1988) reviewed the species' status in British Columbia, Canada, and Maniscalco et al. (2004) reported on the 52 documented cases of California sea lions in Alaska (including several females). To the best of our knowledge there has been only one other study of male California sea lions movements in the Pacific Northwest. In that study, the migration and movements of nine adult male sea lions captured in Puget Sound, Washington, were monitored with VHF radio tags and satellite linked time-depth recorders (Patrick J. Gearin, NMFS National Marine Mammal Laboratory, personal communication).

We describe the movements of 26 satellite-tagged sea lions captured in the Columbia River during three non-breeding seasons (2003-2004, 2004-2005, and 2006-2007). This is the first description of male California sea lion movements from animals caught outside of California or Puget Sound, Washington, and is based on one of the largest samples of instrumented males of this species yet reported. Our objective was to gain insight into the foraging behavior of these animals with particular emphasis on individuals that foraged in the lower Columbia River and its tributaries where they might potentially consume threatened and endangered salmonids.

Study Area

We captured California sea lions at two locations on the Columbia River (Figure 1): at Bonneville Dam near North Bonneville, Washington (~rkm 235; Figure 1b), and at the East Mooring Basin (EMB) in Astoria, Oregon (~rkm 25; Figure 1c). Bonneville Dam is the first dam on the mainstem Columbia River and has been the site of intensive pinniped-salmonid research and management since 2002 (NMFS 2008, Tackley et al. 2008). The EMB is a mooring facility for commercial and recreational vessels and is the primary California sea lion haul-out site inside the Columbia River estuary; it is regularly occupied by 10s-100s of

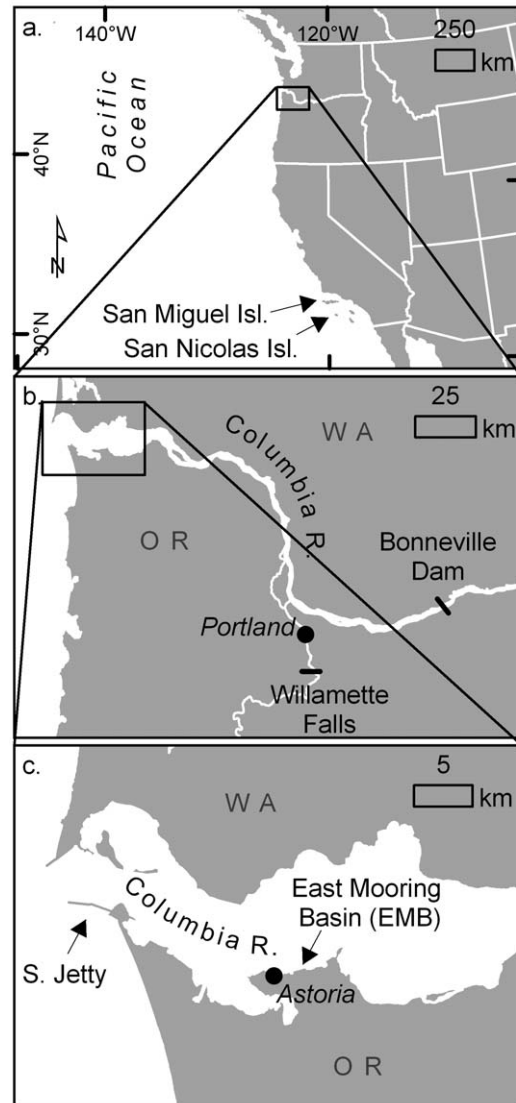


Figure 1. (a) California sea lion range map (U.S. Stock) showing the locations of the San Miguel and San Nicolas Island rookeries. Insets show (b) the locations of Bonneville Dam on the Columbia River and Willamette Falls on the Willamette River, and (c) the East Mooring Basin and south jetty haul-outs near the mouth of the Columbia River.

sea lions from August-June. The only other large haul-out near the mouth of the river is the south jetty (Figure 1c). A third location of interest, though not the site of trapping activity, is Willamette Falls on the Willamette River, a major tributary of the Columbia River (~205 km from Columbia River mouth; Figure 1b). Similar to the

situation at Bonneville Dam, California sea lions have regularly occurred at the fish ladders at the base of the falls each spring to feed on migrating adult salmonids (NMFS 1998).

Methods

Sea Lion Capture and Handling

California sea lions were captured using haul-out traps. Each trap consisted of a chain link cage (3.4 m² to 5.5 m²) attached to a wood platform (3.7 m² to 6.1 m²) atop an anchored buoy or dock float. Sea lions entered and exited traps via a vertically-sliding door kept open to allow the trap to be used as a haul-out. Sea lions were processed on a barge that was motored up to and attached to the trap. The barge was equipped with three adjoining cages. The first was a "holding" cage into which one to three sea lions were herded from the trap. From there sea lions entered a "weight" cage which rested upon a 2268 kg capacity platform scale. After weighing, sea lions were individually moved into a "squeeze" cage that restrained them for marking. The stainless steel squeeze cage measured 1 m × 1 m × 2.3 m and consisted of a solid deck, casters, and vertically-sliding doors at each end. The body of the cage consisted of adjustable, padded curvilinear bars for restraining animals and allowing access to the rump for marking and instrumentation. Each sea lion was permanently hot-branded with a "C" and a number on its rump (with the letter above the number). While in the squeeze cage, animals were also measured (length and girth) and tagged with plastic livestock ear-tags (Allflex USA, Inc., DFW Airport, TX) on each fore-flipper.

Satellite Telemetry

A sample of sea lions was instrumented with location-only Sirtrack (Havelock North, New Zealand) KiwiSat 101satellite-linked platform transmitter terminals (PTTs). The PTTs were placed on two types of sea lions: (1) those that had been caught or previously observed at Bonneville Dam on the Columbia River, or observed at Willamette Falls on the Willamette River; and (2) on sea lions captured at the EMB in Astoria with no known history at the dam or falls. We referred to these as "river" and "unknown" types, respectively. We attempted to match unknown-type animals to river animals based on size since river animals

tended to be of above average size. It is important to note that "unknown" does not necessarily imply "non-river," as unknown types may have occurred at Bonneville Dam or Willamette Falls prior to branding and were thus largely unidentifiable.

Transmitters were secured to light weight nylon mesh netting and then glued to the sea lion's pelage mid-dorsum using 5-min epoxy. A conductivity sensor on the instrument detected whether the animal was wet or dry. In the first season of the study (2003-2004) the conductivity sensor triggered a haul-out switch to suppress transmissions whenever an animal was out of water for six hours. Haul-out switches were subsequently deactivated due to the switch activating while the animal was upriver in fresh water. With the exception of one continuously operating PTT used in 2006-2007, all PTTs were duty-cycled to transmit 8 hr each day: 4 hours from between approximately 0300-0800 Pacific Standard Time and 4 hours between approximately 1500-2000 (actual transmission times varied by PTT). Duty-cycling was used to conserve battery power, maximize satellite reception, and limit operating cost. Because California sea lions undergo an annual molt each fall (approximately September-November), PTTs were only deployed from November (subsequent to molt) through May (prior to southward migration).

We determined animal locations using the Argos satellite telemetry system (Collecte Localisation Satellites (CLS) 2008), which calculates locations based on the Doppler shift in PTT radio signals (uplinks) received on polar-orbiting satellites. The accuracy of Argos location fixes is based on the number of uplinks received by a passing satellite. Each fix is assigned a location quality class (LC) which decreases in accuracy in the following order: 3, 2, 1, 0, A, B and Z. Standard deviations of the estimated location errors for location classes 3, 2, 1, and 0 are reported to be <250, 250 to <500, 500 to <1,500, and ≥1,500 m (CLS 2008). Location classes A and B are fixes with no reported accuracy; LC Z are instances in which no valid location was determined. Rather than simply discard low-accuracy fixes (i.e., LCs 0, A, B), which can comprise over 50% of marine mammal data (Freitas et al. 2008), most Argos users choose to retain all LCs that pass a filtering algorithm, typically based on an animal's swim speed (e.g., McConnell et al. 1992, Austin et al. 2003, Freitas et al. 2008). We filtered our location data using the algorithm of Freitas et al. (2008),

which is based on travel speed, distance between successive locations, and turning angle.

Data Analysis

Argos location data was received in diagnostic format via daily e-mails and converted to an analyzable format using a custom SAS (Version 9.1, SAS Institute Inc., Cary, NC, USA) program. Data were filtered using the Freitas et al. (2008) algorithm as implemented in the R (Version 2.6.1, R Foundation for Statistical Computing, Vienna, Austria) package “argosfilter.” We used the default filter settings including a travel speed of 2 ms^{-1} which approximates the published literature on otariid swim speeds (e.g., 2.5 ms^{-1} in Feldkamp et al. 1989 and 1.9 ms^{-1} in Ponganis et al. 1991). Filtered location data were mapped and geoprocesed using ArcGIS (Version 9.2, Environmental Systems Research Institute (ESRI), Inc., Redlands, CA) and Hawth's Tools (Beyer 2004).

Filtered location data were spatially joined with bathymetric (Amante 2008) and coastline (ESRI 2006) data layers to summarize the approximate water depth and distance to shore for each point. We classified locations as “at-sea” (as opposed to hauled-out or in a river) when the conductivity sensor indicated the PPT was wet and the spatially joined location data indicated negative elevation and positive distance from shore. Hauling behavior was inferred from obtaining >1 “dry” conductivity sensor reading from within 3 km of a known haul-out location (haul-out locations from Jeffries et al. 2000, Ban and Trites 2007, NMFS 2007, and Oregon Department of Fish and Wildlife [ODFW] 2008). Finally, we classified location data into four temporal seasons: “winter/nonbreeding,” “southbound migration,” “summer/breeding,” and “northbound migration.” The start and end dates of each period varied by individual and were defined by when an animal initiated directed travel to or from rookeries in the Channel Islands (i.e., San Miguel Island, San Nicolas Island) off southern California (Figure 1a).

Results

Sea Lion Captures

We deployed 29 PTTs on 26 male California sea lions over the course of three seasons (Table 1). One sea lion was instrumented over two seasons (C265 in 2003-2004 and 2006-2007) and two sea

lions were re-instrumented within the same season (C376 in 2004-2005 and C319 in 2006-2007). Fourteen of the 26 animals were river-type animals that had been previously documented foraging for salmonids at either Willamette Falls ($n = 1$) or Bonneville Dam ($n = 13$). Of the remaining 12 unknown-type animals, eight were unbranded at the time of capture; the remaining four were recaptures of previously branded animals. We found no significant difference in the mean weight between instrumented river-type and unknown-type animals (river: $n = 15$, mean = 299.7 kg, SD = 82.3 kg; unknown: $n = 13$, mean = 287.8 kg, SD = 52.6 kg; $t = 0.461$, $P = 0.649$; 95% confidence interval of difference: -41.3 to 65.1). Instrumented animals, however, were significantly heavier than non-instrumented animals caught during the same time period (instrumented: $n = 28$, mean = 294.2 kg, SD = 69.1 kg; non-instrumented: $n = 319$, mean = 247.1 kg, SD = 59.5 kg; $t = 3.49$, $P = 0.001$; 95% confidence interval of difference: 19.6 to 74.7 kg).

Argos Data

We received a total of 14,539 location fixes (54% $\text{LC} \geq 1$) from the Argos satellite system. Filtering based on the Freitas et al. (2008) algorithm eliminated 2947 locations (20.2%) resulting in a working dataset of 11,596 locations (64% $\text{LC} \geq 1$). Sea lions were tracked from as early as 14 November to as late as 30 August, a period spanning over 9 months. Transmitters operated for an average of 87.9 d (range 23-200 d) although valid locations were only received on an average of 85% of operational days (range 52.4-100%). Mean number of location fixes per day (conditional on receiving at least one fix) ranged from 2.5 to 8.3 for duty-cycled PTTs ($n = 28$), and 12.4 fixes per day for the single PTT that was not duty-cycled.

“River”-Type Sea Lion Movements

We tracked the movements of 14 river-type sea lions from as early as 14 November to as late as 9 August (Figure 2a). Animals tracked during the “winter” season traveled as far south as Cape Arago, Oregon, to as far north as the Strait of Juan de Fuca (Figure 3a, Table 2). While at-sea, wintering river-type sea lions generally remained over the continental shelf (i.e., within the 200 m depth contour) traveling no further than 70 km from shore. All 14 river-type sea lions were tracked

TABLE 1. Summary of trapping and tracking information for 26 male California sea lions (29 PTT deployments) captured in the Columbia River during the 2003-2004, 2004-2005, and 2006-2007 field seasons; individuals captured and tracked more than once are indicated by an asterisk (*). Missing data denoted by NA (not available).

ID (brand_PTT)	Type ¹	Trap site ²	Deployment Date	Transmission duration (d)	Mass (kg)	Length (cm)	Girth (cm)
C265_45850*	R	EMB	1/14/2004	55	167	225	194
C327_45851	R	EMB	2/9/2004	71	NA	NA	NA
C376_45852*	U	EMB	12/23/2004	66	380	254	202
C474_45853	U	EMB	2/2/2005	113	315	232	204
C376_45851*	U	EMB	3/10/2005	174	302	NA	NA
C526_45850	U	EMB	3/10/2005	80	315	247	194
C332_55576	U	EMB	5/7/2005	84	285	219	180
C529_55577	U	EMB	5/7/2005	24	342	240	210
C257_62173	R	EMB	11/14/2006	39	240	225	175
C319_45852*	R	EMB	11/14/2006	50	369	255	210
C344_62175	U	EMB	11/20/2006	23	339	242	204
C390_62174	R	EMB	11/20/2006	111	326	265	196
C630_62176	U	EMB	12/2/2006	133	208	220	164
C313_62178	R-W	EMB	1/26/2007	60	276	245	170
C631_62177	U	EMB	1/26/2007	200	230	224	180
C265_62179*	R	EMB	1/31/2007	115	294	230	180
C632_62181	U	EMB	2/1/2007	175	243	250	188
C309_62182	R	EMB	2/5/2007	62	243	235	170
C633_62180	U	EMB	2/22/2007	92	309	232	170
C634_62183	U	EMB	2/22/2007	122	247	228	162
C507_62185	R	EMB	3/5/2007	58	244	228	166
C642_62186	U	EMB	3/16/2007	83	227	247	174
C443_62187	R	BD	4/4/2007	73	323	NA	NA
C643_62188	R	BD	4/4/2007	89	334	235	192
C644_62189	R	BD	4/4/2007	110	225	226	152
C645_62190	R	BD	4/4/2007	128	262	235	178
C653_62184	R	BD	4/18/2007	55	325	235	190
C319_62191*	R	BD	4/19/2007	32	523	NA	NA
C669_62176	R	BD	4/25/2007	71	345	NA	NA

¹R = "river"-type previously detected at Bonneville Dam; R-W = "river"-type previously detected at Willamette Falls;

U = "unknown"-type not previously detected at either Bonneville Dam or Willamette Falls.

²EMB=East Mooring Basin trap site, BD=Bonneville Dam trap site.

or observed upriver at either Willamette Falls (n = 1 sea lion; C313) or Bonneville Dam (n = 13 sea lions; 11 tracked via satellite and 2 visually observed subsequent to PTT failure). Minimum upstream and downstream transit times between the EMB haul-out and Bonneville Dam (river distance = ~210 km) were 1.9 d and 1 d (based on 14 trips by 11 sea lions), which equate to travel speeds of approximately 4.6 km h⁻¹ and 8.8 km h⁻¹. Duration at the dam ranged from 2 d to 43 d. For the individual that traveled to Willamette Falls (river distance = ~180 km), the minimum upstream and downstream transit times were 3.5

d and 2 d, which equate to travel speeds of approximately 2.1 km h⁻¹ and 3.7 km h⁻¹.

The median start date of the southbound migration from the Columbia River to the breeding grounds was 20 May (range: 7 May to 27 May; n = 8 sea lions) (Figures 2a, 3b). Individuals traveled either to San Miguel Island (approximately 1460 km) or San Nicolas Island (approximately 1580 km). Travel times to the former ranged from 11-20 d (n = 5 sea lions) and to the latter from 12-21 d (n = 2 sea lions). The maximum travel speed was approximately 130 km d⁻¹ or 5.4 km h⁻¹. Individuals generally traveled along the contour of

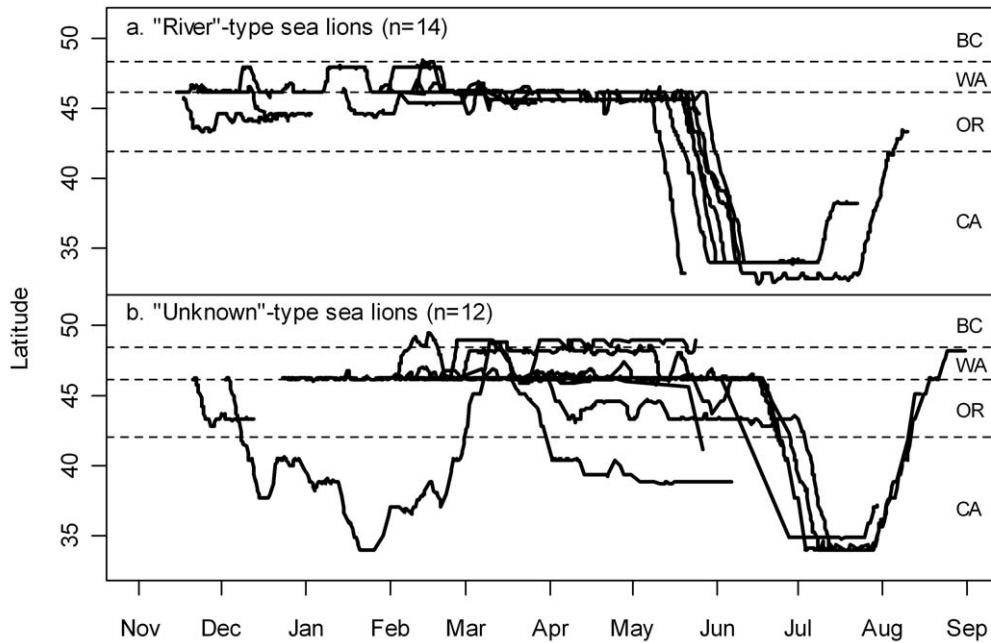


Figure 2. Latitude by date movement profiles for (a) 14 "river"-type and (b) 12 "unknown"-type male California sea lions based on satellite telemetry during 2003-2004, 2004-2005, and 2006-2007. Dashed lines represent coastal latitudinal boundaries between California, Oregon, Washington, and British Columbia.

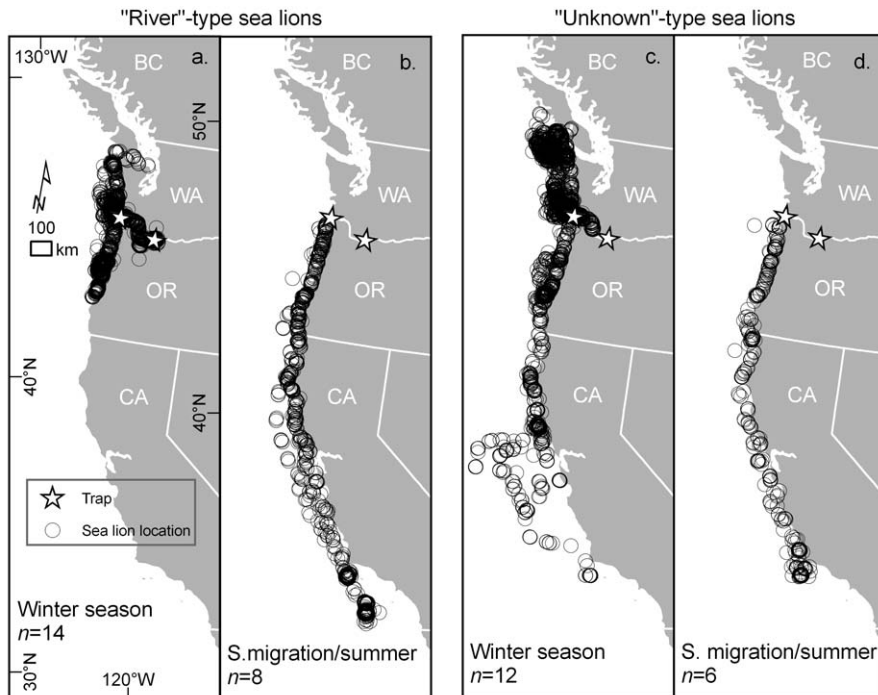


Figure 3. Locations of California sea lions by type and season based on satellite telemetry during 2003-2004, 2004-2005, and 2006-2007. Approximate winter and south migration-summer seasons for "river"-type sea lions were (a) November-May and (b) June-July; dates for "unknown"-type sea lions were (c) November-mid June and (d) mid June-July.

TABLE 2. Number of instrumented male California sea lions detected at haul-out sites and rookeries by type and season. Use of sites were inferred from transmitter conductivity sensor and proximity to site.

Region	Haul-out site	Lat	Lon	“River”-type		“Unknown”-type	
				Winter	S. migration/summer	Winter	S. migration/summer
BC	Estevan Pt.	49.404	-126.589			1	
	Ucluelet Harbor	48.940	-125.535			1	
	George Fraser Isl.	48.913	-125.513			1	
	Folger Isl.	48.829	-125.245			3	
WA	Bodelteh Isl.	48.175	-124.758			2	
	Carroll Isl.	48.005	-124.724	1		1	
Columbia R.	S. Jetty	46.234	-124.070	3		6	
	Warrenton	46.170	-123.913	2		2	
	East Mooring Basin	46.196	-123.801	14		12	
	Willamette Falls	45.365	-122.604	1			
	Bonneville Dam	45.647	-121.948	11*			
OR	Cape Falcon	45.768	-123.984			1	
	Cascade Head	45.075	-124.007	2	3	4	1
	Yaquina Bay	44.630	-124.052	3	1	2	
	Sea Lion Caves	44.121	-124.128	1			
	Cape Arago	43.309	-124.400	1	2	3	3
	Blacklock Pt.	42.876	-124.536		1		
	Orford Reef	42.787	-124.598			2	
	Rogue Reef	42.444	-124.475		1		1
	Rogue River	42.421	-124.429		1		
CA	Crook Pt.	42.242	-124.412		1		
	Castle Rock	41.762	-124.249		2		1
	Scotty Pt.	41.102	-124.163				1
	Cape Mendocino	40.447	-124.406		6	2	2
	Soldier Frank Pt.	39.757	-123.837			1	
	Pt Cabrillo	39.361	-123.826		1	1	
	Cuffys Pt.	39.144	-123.735		1		
	Fish Rock	38.800	-123.592		2	2	1
	Bodega Rock	38.296	-123.048		1		1
	Pt. Reyes	37.997	-122.999		1		
	Farallon Isls	37.699	-123.010			1	1
	Año Nuevo	37.109	-122.335		1	1	1
	Cape San Martin	35.886	-121.460				1
	Lion Rock	35.222	-120.873				1
	Pt. Sal	34.897	-120.673				1
Rookery	San Miguel Isl.	34.037	-120.427		6	1	3
	San Nicolas Isl.	33.237	-119.546		2		
n				14	8	12	6

*Two additional “river”-type individuals were visually observed subsequent to premature failure of their PTT packages.

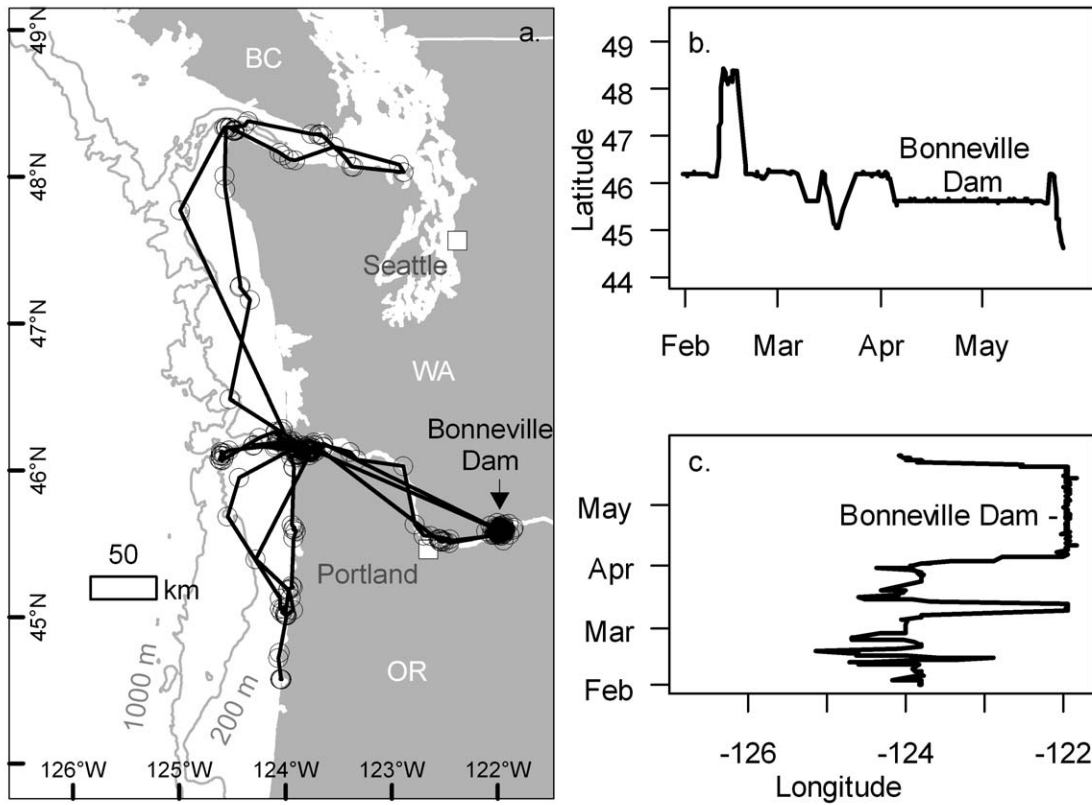


Figure 4. (a) Movement path, and (b) latitudinal and (c) longitudinal movement profiles for C265, a “river”-type California sea lion tracked from 1 February 2007 to 25 May 2007.

the coastline over the continental shelf. A notable exception was C653, which, after hauling out at Cape Mendocino on the afternoon of 22 May 2007, moved offshore beyond the continental slope (up to 74 km from shore and in water over 3,600 m deep) until returning to shore near Big Sur on the afternoon of 26 May. The most frequently used haul-outs during southbound migration were Cascade Head and Cape Arago in Oregon, and Castle Rock, Cape Mendocino, and Fish Rock in California (Table 2). Only two animals had PTTs that functioned long enough to document breeding season duration and northbound migration start dates: C644 left San Miguel Island on 7 July 2007 after a 28 d stay; C645 departed San Nicolas Island on 22 July 2007 after a 42 d stay.

In order to better illustrate the movements of a river-type sea lion we plotted the track of C265 as a function of latitude, longitude, and time (Figure 4). This animal appeared to display a moderate level of fidelity to the EMB haul-out,

using it in-between four separate extended “trips” during February to May 2007. In sequential order these trips were to: (1) the Strait of Juan de Fuca; (2) Bonneville Dam; (3) Cascade Head; and (4) back to Bonneville Dam, where it stayed for over a month before beginning its southward breeding migration. Fortunately, we recaptured and weighed C265 three times during this period. It weighed 294 kg on 31 January, 254 kg on 6 March, and 473 kg on 21 May, indicating that it lost 1.2 kg d⁻¹ during its trip to the Strait of Juan de Fuca, whereas by the end of its second stay at Bonneville Dam it had gained 2.9 kg d⁻¹.

“Unknown”-Type Sea Lion Movements

We tracked the movements of 12 unknown-type sea lions from as early as 20 November to as late as 30 August (Figures 2b). Animals tracked during the “winter” season traveled as far south as San Miguel Island in southern California, to as far north as Vancouver Island, British Columbia (Figure 3c,

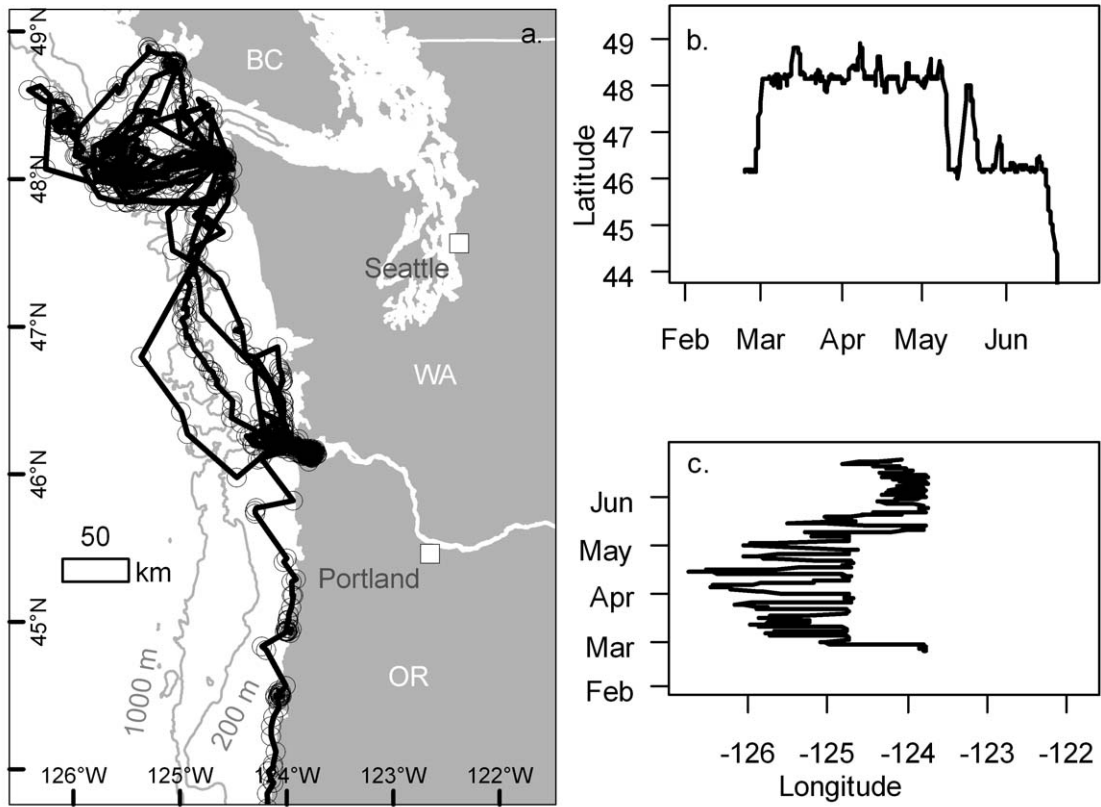


Figure 5. (a) Movement path, and (b) latitudinal and (c) longitudinal movement profiles for C634, an “unknown”-type California sea lion tracked 22 February 2007 to 20 June 2007.

Table 2). While at-sea, unknown-type sea lions generally occurred over the continental shelf and slope, but a single individual (C630) traveled as far as 280 km off central California over water 4500 m deep during January and February 2007. None of the 12 unknown-type sea lions were ever tracked or observed at Willamette Falls or Bonneville Dam. However, one individual (C376) went up the Columbia River as far as the Kalama River mouth (~rkm 116) for two days in January, and another (C474) went further upstream to the mouth of the Lewis River (~rkm 138) during several trips in March and April.

The median start date of the southbound migration from the Columbia River to the breeding grounds was 15 June (range: 21 May to 17 June; $n = 5$ sea lions) (Figure 2b, 3d). Of the four animals tracked to southern California, three went to the San Miguel Island rookery, and one remained on the mainland at Point Sal. Travel times from the Columbia River to San Miguel ranged from

16–21 d ($n = 2$ sea lions). The maximum travel speed was approximately 99 km d^{-1} or 4.1 km h^{-1} . Individuals generally traveled along the contour of the coastline over the continental shelf. The most frequently used haul-outs during southbound migration were Cape Arago in Oregon, and Cape Mendocino in California (Table 2). Only two animals had PTTs that functioned long enough to document breeding season duration and northbound migration start dates: C376 left San Miguel Island on 28 July 2005 after a 20 d stay, and C631 departed San Miguel Island on 27 July 2007 after a 24 d stay. C376’s PTT continued to function all the way back to the Columbia River (21 d) where it hauled out briefly at the EMB before continuing north to Bodelteh Island, Washington.

In order to better illustrate the movements of an unknown-type sea lion we plotted the track of C634 as a function of latitude, longitude, and time (Figure 5). This animal was tracked from 22 February to 24 June, 2007. It spent the majority

of the winter season on multi-day trips (mean = 4.5 days per trip, $n = 8$ trips) over the continental slope (over water up to ~2400 m deep), approximately 80 km west of the Bodelteh Island haul-out (off northwest Washington) and 80 km southwest of the Folger Island haul-out (Barkley Sound, Vancouver Island, BC). This animal didn't return to the EMB until over two months later in May. It then staged several shorter foraging trips northwest of the Columbia River mouth before migrating south on 15 June.

Discussion

While there has been much research on pinniped movements and foraging behavior in general (e.g., see reviews in Bowen and Siniff [1999] and Wells et al. [1999]), our study helps fill a gap in the literature on male California sea lion movements. Our results showed that animals captured in the Columbia River exhibited considerable within and between animal variation in movements, and thus, presumably, foraging behavior. This is in contrast to Mate (1975) who speculated that males dropped out of their northward migration in an orderly fashion to over-winter at a given haul-out. Yet, in fairness, Mate (1975) noted the obvious need for telemetry in testing his hypothesis. River-type animals generally ranged less widely during the "winter" season and migrated earlier to the breeding grounds than their unknown-type counterparts. Interestingly, none of the animals from either group ventured into Puget Sound, Washington, where up to 1000 California sea lions can regularly occur during the nonbreeding season (Jeffries et al. 2000). Perhaps of greatest interest though was that all river-type sea lions again traveled to upriver foraging sites in the Columbia River basin (i.e., Willamette Falls, Bonneville Dam), whereas unknown-types did not exhibit this behavior.

Foraging in rivers by pinnipeds is not new (e.g., Roffe and Mate 1984, Stanley and Shaffer 1995, Wright et al. 2007), and even at Bonneville Dam there are decades-old accounts of the occasional "seal" or "sea lion" (Tackley et al. 2008). Lyman et al. (2002) reviewed the historical and prehistoric evidence for pinnipeds in the lower Columbia River. While they noted historical accounts of Steller sea lions (*Eumetopias jubatus* [Schreber 1776]) up to 150 km from the mouth of the river, and harbor seals (*Phoca vitulina* [Linnaeus 1758])

up to rkm 324 (Celilo Falls), there was no mention of similar sightings of California sea lions. Furthermore, they found no archaeological evidence of California sea lions in the lower Columbia River, whereas evidence for harbor seals up to rkm 324 dated back 10,000 years. Their findings suggest to us that the recent (post 2000) occurrence of numerous California sea lions (10s-100s) so far up the Columbia River (246 km) is a new and recent phenomenon. Exactly what triggered this change in behavior is unknown. Possible causes include an expansion in foraging range by a sea lion stock at or near carrying capacity (Carretta et al. 2007), the decline of traditional prey in the lower river such as Pacific eulachon (*Thaleichthys pacificus* [Richardson, 1836]) (NMFS 2009), and being drawn upriver by record large spring Chinook runs in 2001 and 2002 (Fish Passage Center 2009).

Where an animal chooses to forage is governed by myriad factors and several researchers (e.g., Lowry and Forney 2005, Weise et al. 2006, Melin 2008) have shown that oceanographic conditions affect California sea lion distribution, abundance, and movements. Weise et al. (2006), for example, compared male California sea lion movements during a period of anomalously warm (positive) sea surface temperatures (SST) in winter 2004-2005 ($n = 3$ animals), versus a period of relatively "normal" oceanographic conditions in winter 2003-2004 ($n = 22$ animals). They found that male California sea lions traveled further offshore (up to 450 km) and for longer periods during the anomalous period. They interpreted this as a response to decreased prey abundance and disruption in the trophic structure caused by the positive SST anomaly. A visual comparison (not shown) of our data from these same two periods ($n = 2$ animals in 2003-2004, and $n = 5$ animals in 2004-2005) did not suggest a similar dichotomy in movement patterns. However, one animal we tracked during 2007 (C630) did exhibit a track similar to those noted by Weise et al. (2006) during the anomalously warm 2005 conditions. As noted earlier, this animal traveled as far as 280 km off central California during January and February 2007 (Figures 2b and 3c). Unlike early 2005, however, early 2007 was a period of relatively cold (negative) SST (NOAA 2007). This suggests to us a more equivocal relationship between SST and male California sea lion movements than that inferred by Weise et

al. (2006). Lack of a clear relationship between SST and offshore male sea lion movements is further supported by Lowry and Forney (2005), who flew aerial surveys up to 120 km off central and northern California during warm water El Niño conditions in 1998 and cold water La Niña conditions in 1999. In both years nearly all California sea lion sightings were within 40 km of shore, and none beyond 70 km.

It should be noted that our data, like most telemetry data, is subject to potential biases and limitations. One is whether instrumented animals are representative of the population from which they were drawn. While mean weight did not vary between river and unknown type animals, instrumented animals as a group were heavier than captured but non-instrumented animals from the same period. Whether they differed in other attributes (e.g., age-class), or whether captured and non-captured animals differed, is unknown. Staggered entry of animals into the study population (Table 1) can also present interpretation challenges. For example, a comparison of movements between behavioral types could be confounded by time if animals were tracked in different months. Similarly, estimating the mean number of trips to Bonneville Dam in a given season is problematic given that many animals were tagged after they may have already made one or more such trips. Lastly, bias may arise when inferring the true path of an animal based on an irregular time series of locations fixes of varying quality. This is of especial concern if the probability or quality of a location fix is associated with an animal's behavior (e.g., location fixes of hauled-out animals are probably more frequent and of higher quality than animals foraging at-sea).

Even given the potential biases inherent in telemetry data, it is clear from our data that not all California sea lions in the Columbia River specialize on salmonids at Bonneville Dam or Willamette Falls. This indicates that the problem of pinniped predation on threatened and endangered Columbia River salmonid stocks should

be addressed primarily at upriver sites such as Bonneville Dam rather than near the mouth of the river where several behavioral types may co-occur. More work is needed, however, to better understand the foraging ecology of California sea lions in this region, especially on the rates and causal factors of recruitment into the upriver subpopulation. Such work might include the use of time-depth-recorders to examine dive profiles (e.g., Melin et al. 2008), stomach temperature telemetry to estimate feeding rates (e.g., Austin et al. 2006), GPS tags to achieve greater spatial-temporal resolution of movements (e.g., Schofield et al. 2007), and development of new analytical approaches to model movement data (e.g., Johnson et al. 2008). Such work is urgently needed given the acute management concerns regarding California sea lions in the Columbia River and throughout their range.

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