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At-sea and on-shore cycles of juvenile Steller sea lions (*Eumetopias jubatus*) derived from satellite dive recorders: A comparison between declining and increasing populations

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Abstract

We calculated the durations of time on-shore and at-sea for juvenile Steller sea lions (*Eumetopias jubatus)* using satellite dive recorders deployed between 2000 and 2002, and compared two genetically distinct populations; one increasing (eastern stock; $n = 42$) and one that experienced an 80% decline in population since the mid-1970s (western stock; $n = 89$). Data represented 24-h periods divided into 72 20-min increments indicating whether an animal was on-shore (dry) or at-sea (wet). Time apportioned between land and sea was described on a per-trip basis (rather than a 24-h cycle) and durations ranged from 20 min to several days. We tested differences in the durations of on-shore and at-sea events among sex, geographic region, year, and age at capture using mixed-effects models. Animal identifier was included as a random effect to account for repeated measures on the same individual. Sea lions from the eastern Aleutian Islands, central Aleutian Islands, and central Gulf of Alaska hauled out just after sunrise, and departure times coincided with dusk. For Prince William Sound and Southeast Alaska animals, arrivals and departures occurred throughout the day and were not related to crepuscular period. Mean duration on-shore did not differ among sex, region, year or age, and was unrelated to previous trip duration. This may suggest a minimum rest period for juvenile Steller sea lions or that dependant animals are maximizing their time on-shore suckling. Time spent at-sea varied among individuals from both populations and development of maternal independence, inferred from significant increases in time spent at sea, occurred approximately 10 months later in individuals from Prince William Sound and Southeast Alaska than in the other regions, suggesting environmental and developmental differences among regions.

Keywords: Satellite telemetry; Pinniped; Biological development; Repeated measures; North Pacific; Gulf of Alaska

1. Introduction

Steller sea lions (*Eumetopias jubatus*) range from Russia and Japan along the Aleutian Islands, into the Gulf of Alaska, and south to California. As a

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result of an 80% decline in the Steller sea lion population between the late 1970s and 1990s (Loughlin et al., 1992; Loughlin, 1997), the western stock of the population (Bickham et al., 1996; Loughlin, 1997) was listed as endangered under the US Endangered Species Act (ESA). The cause of the decline has not been determined but is attributed to a number of factors both environmental and anthropogenic (Trites and Larkin, 1992; Loughlin and York, 2000). Commercial fishing activity and changes in the oceanic environment have been implicated as ultimate causes of the decline by potentially precipitating changes in prey abundance or composition (Alverson, 1992; Loughlin and York, 2000). A critical time for Steller sea lions is the first year following birth (York, 1994; Merrick and Loughlin, 1997); models developed by Holmes and York (2003) indicated severely low survival rates of juvenile Steller sea lions and low fecundity were associated with declines in the 1980s and 1990s. In contrast to the declining western stock, the numbers of Steller sea lions in Southeastern Alaska (eastern stock) have increased substantially (Calkins et al., 1999), and animals in this stock are currently listed as threatened under the ESA.

Pups are born between late May and early July with the median peak of pupping occurring mid-June (Pitcher and Calkins, 1981; Pitcher et al., 2001). Throughout the lactation period, otariid pups are dependant on their mothers for nutrition (Bonner, 1984); however, prior to weaning some neonates may supplement milk with solid food (Trillmich, 1996; Raum-Suryan et al., 2004). Unlike other pinniped species, time of weaning for Steller sea lions is not well defined. Weaning likely occurs gradually from 4 months to 1 year of age; however, some individuals may suckle for up to 3 years (Pitcher and Calkins, 1981). Prior to weaning, pinniped pups must develop swimming and diving abilities and adult pelage while increasing energy stores (Bowen, 1991) to maximize their chance of survival once independent. Diving ability for Steller sea lions develops throughout their first year (Richmond, 2004) and is reflected in increased duration, distance travelled, and maximum depth of foraging bouts (Merrick and Loughlin, 1997; Loughlin et al., 2003; Raum-Suryan et al., 2004; Fadely et al., 2005; Pitcher et al., 2005).

Attendance patterns for adult female Steller sea lions are well documented (Higgins et al., 1988; Hood and Ono, 1997; Merrick and Loughlin, 1997; Trites and Porter, 2002; Milette and Trites, 2003), but little is known about patterns of time spent on shore or at sea for juveniles. Due to their remote location and ease of disturbance, few studies have been conducted on the haul-out patterns of juvenile sea lions. The primary focus of juvenile sea lion research has been development of diving, animal movements, and distribution at sea (Merrick and Loughlin, 1997; Loughlin et al., 2003; Raum-Suryan et al., 2004; Fadely et al., 2005; Pitcher et al., 2005). However, changes in patterns of haul-out behaviour as young sea lions develop provide important information regarding their success as they move toward independence.

Using telemetry, Loughlin et al. (2003) found that for 10 juvenile sea lions in the Gulf of Alaska and the Aleutian Islands, time at-sea varied by age and ranged from about 6 to 24 h, however, they did not report time on shore. Dependant pups in the winter spend little time at sea, usually less than 1 d (Fadely et al., 2005), and changes in dive behaviour include increased depth and duration of dives and increased time at sea at 9 months of age (Loughlin et al., 2003; Fadely et al., 2005; Pitcher et al., 2005). Raum-Suryan et al. (2004) reported that increases in trip distance and duration occur from April to June for young-of-the-year and juvenile sea lions, indicating that annual timing for weaning may be less variable then animal age.

The main objective of this study was to describe the on-shore and at-sea behaviour of juvenile ($\leqslant 3$ years old) Steller sea lions from both population stocks using data derived from satellite dive recorders (SDRs). SDRs are widely used to track movements and describe dive behaviour of pinnipeds (Merrick and Loughlin, 1997; Arnould and Hindell, 2001; Loughlin et al., 2003), and also provide a higher resolution (20 min) measure of attendance behaviour, using continuous "time-lines", than are obtained from methods such as direct observation. Since data from SDRs are collected continuously over a 24-h period, no assumptions are required regarding animal behaviour during times when visual assessment is not possible or if an individual changes location.

We describe patterns of haul-out usage for juvenile Steller sea lions and analyse onshore and at-sea patterns with respect to sex, geographic region, year, and estimated age. Describing haul-out cycles for young sea lions is important for understanding the relationships of physiological and environmental changes during the transition