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Nocturnal activity by mammal-eating killer whales at a predation hot spot in the Bering Sea

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The importance of food availability (bottom-up control) *vs*. predation (top-down control) in affecting population dynamics of individual species and the structure of marine communities and ecosystems is in most cases poorly known, but vigorously debated. This debate has recently focused on the dramatic declines of populations of four species of marine mammals in Alaska (Estes *et al.* 1998, Springer *et al.* 2003, 2008; Williams *et al.* 2004, Fritz and Hinckley 2005, Trites *et al*. 2007, Wade *et al*. 2007). Between the early 1970s and late 1990s, the abundance of harbor seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), and sea otters (*Enhydra lutris*) collapsed sequentially by 80%–90% throughout southwest Alaska—the Aleutian Islands, Bering Sea, and western Gulf of Alaska. The major portion of each collapse occurred over short intervals of about 10 yr. Harbor seals have since begun a slow recovery in at least a part of this range (Small *et al*. 2003); sea lions have variously increased somewhat, remained stable, or continued to decline (NMFS 2007); and sea otters were still declining in most areas through the early 2000s (Doroff *et al*. 2003, Estes *et al*. 2005, J. Estes[1]). Across that entire span of years, a fourth species, the northern fur seal (*Callorhinus ursinus*) on the Pribilof Islands in the Bering Sea, has experienced a less precipitous, but continuing, and now concerning, decline—for example, pup production, the index of total abundance, has fallen by 26% since 2002 and their abundance is just 24% of the peak in 1955 (Trites and Larkin 1989, Towell and Fowler 2006).

Three principal hypotheses have been proposed to explain these collapses and the lack of significant recovery: direct mortality from human activities, nutritional limitation, and predation. Direct mortality of sea lions was caused primarily by commercial harvests, bycatch in commercial fisheries, and legal and illegal shooting (Atkinson *et al*. 2008): direct mortality has not been invoked as a cause of the declines of any of the other species in the region since the mid 1970s or earlier. The cause of purported nutritional limitation of pinnipeds is thought to be climate change or commercial fisheries, or both, which altered the availability of various species of

[1]Unpublished data from J. Estes, Department of Ecology and Evolutionary Biology, University of California, Santa Cruz, CA 95064.

forage fishes important to them and led to deleterious effects on populations (Trites and Donnelly 2003, Fritz and Hinckley 2005, Trites *et al.* 2007). The evidence of nutritional limitation as the cause of the pinniped declines is equivocal (Springer *et al.* 2008), and a long-term study of body condition and growth of Alaskan sea otters refutes the hypothesis for that species (Laidre *et al.* 2006). The predation hypothesis maintains that mammal-eating ("transient") killer whales (*Orcinus orca*) underwent a dietary shift in the 1970s, increasing their consumption of pinnipeds and sea otters as a result of the depletion of great whales, formerly important prey, by industrial whaling in the northern North Pacific Ocean beginning in the 1950s (Springer *et al.* 2003, 2008). The intensive hunting of whales removed huge quantities of biomass that undoubtedly altered the ecosystem in various significant ways (Springer *et al.* 2006).

Studying predation by highly mobile predators is challenging because, for example, transient killer whales in the North Pacific Ocean typically roam in small groups and use stealth to hunt, making it difficult and expensive to consistently observe them using traditional vessel-based surveys. Although visual descriptions of killer whale predation provide invaluable information, there are limitations on quantifying overall impacts on a large scale, and it is virtually impossible to detect all predation events from visual observations alone. Tagging killer whales helps identify distribution patterns and diving behavior, but the tags stay attached for comparatively short intervals and produce data from few individuals (Baird *et al.* 2005). Following individuals and groups from boats can provide detailed information on hunting behavior (Baird 1994, Deecke *et al.* 2005), but over short intervals that are constrained by daylight and sea state.

An approach that has become extremely useful for determining the presence or absence of marine mammals in general, and for clarifying ecological questions related to behavior and distribution on feeding grounds, is continuous passive acoustic recording (Swartz *et al.* 2003, Clark and Clapham 2004, Wade *et al.* 2006). To test the efficacy of this method for monitoring killer whale activity, we undertook an acoustic pilot study of killer whales at St. Paul Island (Pribilof Islands, Fig. 1). The world's largest concentration of northern fur seals breeds and rears pups on St. Paul Island (York *et al.* 2000), and transient killer whales frequent near-shore waters there in summer through fall and prey on fur seals (Hanna 1922, A. Springer[2]).

We deployed a Marine Autonomous Recording Unit (MARU: developed by Cornell Bioacoustics Research Program) approximately 6 km offshore of St. Paul Island near several large fur seal rookeries and within a movement corridor of animals traveling to and from foraging areas west of the island (Robson *et al.* 2004). The unit was moored approximately 1 m off a flat, sandy bottom at a depth of 53 m and recorded continuously from 22 June to 12 July 2006. The acoustic detection range was approximately 4.5 km, based on the manufacturer's estimate, but varied in response to oceanographic conditions and background noise. The sampling rate was 10–16,000 Hz, which was sufficient to record killer whale calls, whistles, and

[2]Unpublished observations by A. Springer, Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775.

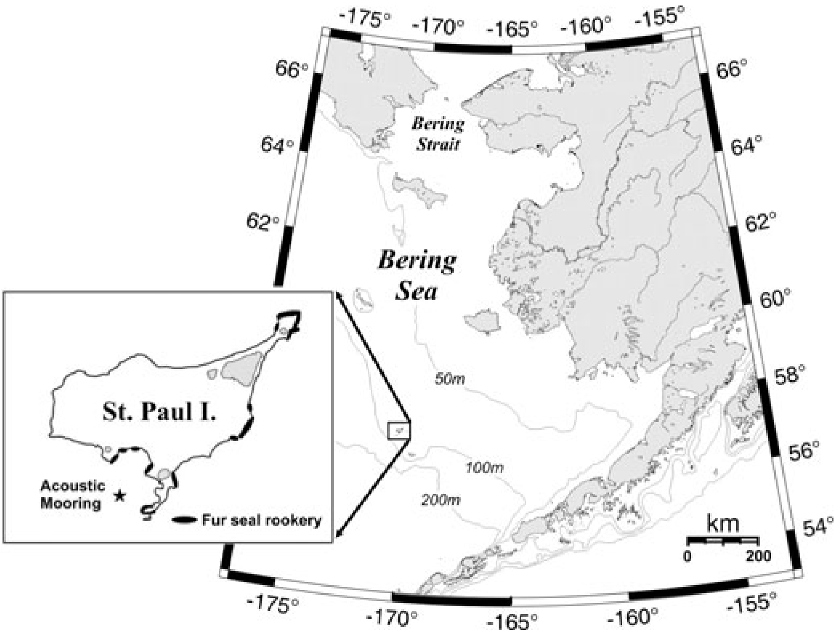

Figure 1. Locations of northern fur seal rookeries on St. Paul Island, Alaska and the approximate location of the acoustic mooring.

low-frequency components of echolocation. The recording system had a flat frequency response from 10 to 8,000 kHz. Analog recordings were continuously digitized into 15-min files and stored on a hard drive in the MARU, for a total of 480 recording hours. Sound files were analyzed with Raven Pro Beta (version 3.1) sound analysis software using a Fast Fourier Transformation size of 512 points, a 3-dB filter bandwidth of 46.8 ms, and an overlap of 88.9%. This resulted in a time resolution of 3.4 ms and a frequency resolution of 32.6 Hz. Each file was visually and aurally inspected for killer whale vocalizations. A vocal "detection" was defined as the presence of at least one killer whale call in a 15-min recording block. Only calls and whistles were used as detections because click-like sounds are not a reliable determinant of killer whale presence or absence, as transients appear to click less than fish-eating ("resident") killer whales (Barrett-Lennard *et al.* 1996), and the MARU recording system likely missed echolocation clicks with higher spectral energy (Au *et al.* 2004). Ambient noise from boats, water, and baleen whales were noted. When a file with background noise was encountered, it was temporally expanded and parsed into smaller segments to search for killer whale calls that were potentially masked.

Killer whale vocalizations were detected on 19 of 22 d of recording. Their presence within the detection range of the MARU on nearly all days was not expected, despite occasional visual sightings of animals in the vicinity of the island. Calls were detected in 166 of 1,920 recording segments (8.6%) during 20 full recording days. Vocalizations were much more frequent between midnight and noon than between

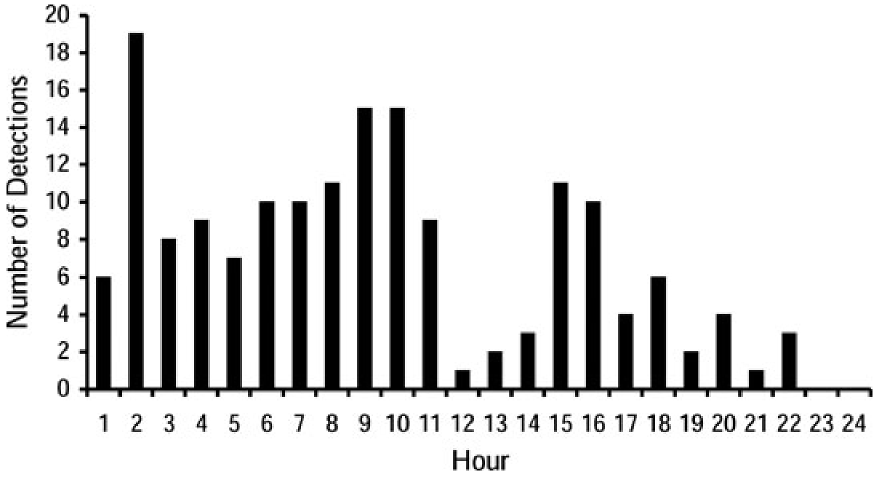

Figure 2. Killer whale vocal detections by hour from 22 June through 11 July 2006. Civil times (Alaska Daylight Savings Time) averaged across the recording period were sunset—2300, twilight (dusk)—2400, twilight (dawn)—0400, and sunrise—0500.

noon and midnight (Fig. 2). Most detections occurred 1 h after civil sunset, from 0100 to 0200.

It is not surprising that killer whales were so active at night, because many marine mammals are adapted for low light conditions (Piechl *et al.* 2001) and use acoustic senses to their maximum advantage (Norris 1966). Marine mammal species on which killer whales are known to prey in Alaska—sea otters, Steller sea lions, harbor seals, and northern fur seals—also are active at night (Gentry 1998, Frost *et al.* 2001, Thomas and Thorne 2001, Gelatt *et al.* 2002, Krafft *et al.* 2002, Wilken 2003, Rehberg 2005). Although darkness is of short duration during a portion of summer in Alaskan, there was civil twilight, sunset, dusk, dawn, and sunrise at St Paul Island (57.18°N) at the time our recordings were made.

We presume that all of the killer whales we recorded were transients. Resident killer whales are present in the southeastern Bering Sea and depredate longline fisheries along the edge of the continental shelf south of the Pribilof Islands, but such interactions have not been reported in the immediate vicinity of the islands (Yano and Dalheim 1995, Malavansky *et al.* 2007, Robson *et al.* 2007). Shipboard surveys for killer whales near St. Paul Island in summers of 2005 and 2006 identified transients only—no residents were seen (J. Durban[3]). Although characterizing transient call structure has more uncertainty associated with it than for residents (Yurk 2005), and separate Alaskan transient populations have different call repertoires (Ford and Ellis 1999, Saulitis *et al.* 2005), the calls we recorded resembled those of other transients in their tonal quality and contained fewer clicks and syllables than calls typical of residents. They also generally exhibited an undiversified call pattern (Fig. 3; Ford

[3]Unpublished data from J. Durban, Center for Whale Research, 255 Smugglers Cove Road, Friday Harbor, WA 98250.

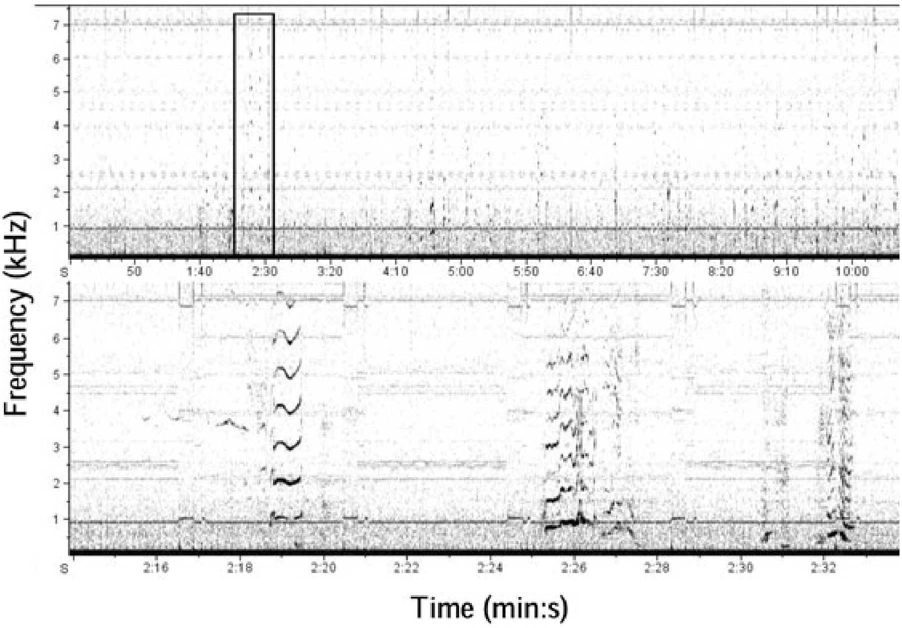

Figure 3. Upper panel: Example of a 15-min sonogram with killer whale vocalizations after a predation event on 8 July 2006. Lower panel: the enclosed segment in upper panel expanded to show individual vocalizations.

1991, Deecke 2003, Matkin *et al.* 2007), and were structurally similar to calls of known transients recorded near the Pribilof Islands (J. Durban[3]). Preliminary analysis indicates that the calls we recorded do not match killer whale calls in southeast Alaska or Prince William Sound (Deecke 2003, Saulitis *et al*. 2005, V. Deecke[4] , H. Yurk[5]), which suggests that they are a separate group.

Transient killer whales in British Columbia and Southeast Alaska are typically silent when hunting, using stealth when stalking aurally sensitive prey: however, once an attack is launched or a kill is made they become highly vocal (Morton 1990, Guinet 1992, Barrett-Lennard *et al.* 1996, Deecke 2003, Deecke *et al*. 2005). Following this paradigm, and because our instrument was located near fur seal rookeries and within a major movement corridor, we further presume that the vocalizations we recorded were associated with predation events. As noted above, fur seals are known to be common prey of killer whales at St. Paul Island, and on one occasion we recorded vocalizations at the same time (0015 on 8 July 2006) that predation of a fur seal was visually documented within the reception range of our MARU (C. Matkin[6]). This event was followed by vocalizations for at least 2.5 h.

[4]Personal communication from V. Deecke, Sea Mammal Research Unit, University of St. Andrews, St. Andrews, Scotland KY16 8LB, 2007.

[5]Personal communication from H. Yurk, Department of Biology, University of British Columbia, Vancouver, BC V6 T 1Z1, 2007.

[6]Personal communication from C. Matkin, North Gulf Oceanic Society, Homer, AK 99603, 2006.

It must be noted, however, that although transient killer whales are usually silent while hunting, they do make some sounds for contact and when active at the surface (Saulitis *et al.* 2005, Deecke *et al.* 2005, V. Deecke[4]). Also, the acoustic repertoires of separate transient populations in Alaska do not necessarily adhere to predictable patterns (Saulitis *et al.* 2005). As these are the first extensive recordings of killer whales in the region of the Pribilof Islands, we cannot be certain of the vocal and behavioral repertories of these animals, and it is possible that some of the vocalizations we recorded and attributed to predation were other types of communication among them. For example, it is conceivable that the animals were not hunting and therefore able to "indulge" in contact calling (V. Deecke[4]). However, one thing is certain—they were calling at times of night when behavior could not be observed visually.

Researchers rely heavily on visual techniques to initially determine predation activity (Baird and Dill 1996, London 2006). The acoustic approach we used in this study expanded our observational window for killer whales to the 24-h cycle, as darkness and time constraints became irrelevant. Furthermore, it provided a continuous record for multiple weeks that would have been impossible to achieve using a traditional shipboard approach. The daily presence of killer whales near St. Paul Island and the amount of nocturnal vocal activity we recorded yielded important new insights into their behavior, their possible effect on the abundance of fur seals, and their potential ecological role as predators. These insights came from but one MARU at one end of St. Paul Island—there are other major rookeries of fur seals elsewhere (Fig. 1), well beyond the reception range of our instrument, where killer whales are commonly seen and occasionally seen preying on seals. This study further demonstrated that previous attempts to quantify the localized impact of killer whale predation using visual monitoring (*e.g.*, London 2006, Maniscalso *et al.* 2007) have limited interpretative value, and a broader scope of continuous observations is essential to adequately describe foraging budgets. Expanded recordings with acoustic arrays, in combination with visual observations, could verify if calls were produced by transient killer whales and if they were related to predation events. In addition, combined observations would provide an improved assessment of the number of killer whales in the area and patterns of presence, absence, and predation.

Observations of predation tend to be of dramatic and obvious attacks during daylight hours, with other behavioral states being undersampled. The results of this preliminary study suggest several things. The constant presence of killer whales indicates that this area is indeed a predation hot spot, as reported by residents of St. Paul I. and as indicated by our observations and those of other killer whale biologists (J. Durban and C. Matkin[7]). Also, the frequency of nighttime calling raises the possibility that there is considerable feeding then. Although some evidence indicates that killer whales may be less active at night (R. Baird[8]), that suggestion is based primarily on diving behavior in a different geographic region. Because fur seals at the Pribilof Islands typically depart at night from their rookeries on foraging trips

[7]Unpublished data from J. Durban, Center for Whale Research, 255 Smugglers Cove Road, Friday Harbor, WA 98250 and C. Matkin, North Gulf Oceanic Society, Homer, AK 99603.

[8]Personal communication from R. Baird, Cascadia Research, 218½ West 4th Avenue, Olympia, WA 98501, 2007.

(Gentry and Kooyman 1986, Gentry 1998), it appears that transient killer whales there, by hunting at night in a zone replete with prey, have adapted their diurnal activity cycle to maximize opportunities for successful hunting.

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