Aging fish otoliths recovered from Pacific harbor seal (*Phoca vitulina*) fecal samples

Susan D. Riemer (contact author)
Oregon Department of Fish and Wildlife
1495 East Gregory Road
Central Point, Oregon 97502
Email address: Susan.D.Riemer@state.or.us

Robert Mikus
Oregon Department of Fish and Wildlife
4412 Silverton Road NE
Salem, Oregon 97305

Seals and sea lions are opportunistic predators that feed on a variety of fish and cephalopods, including some commercially and recreationally important species. Concerns over their interactions with commercial and sport fishing operations, and other human activities, has a long history in the Pacific Northwest (Everitt and Beach, 1982). The perceived increase in such interactions led, in part, to the U.S. Congress amending the Marine Mammal Protection Act (MMPA) in 1994. Chief among the amendments was a call for research to determine 1) whether California sea lions (*Zalophus californianus*) and Pacific harbor seals (*Phoca vitulina)* were affecting the recovery of listed or depleted salmonids, and 2) what broader impacts they may have on the coastal ecosystems of Oregon, Washington, and California (NMFS, 1997). In this note, we begin to address the latter question. Specifically, we describe a novel application of otolith aging techniques that can be used to increase the understanding of pinniped foraging ecology and, thus, their potential impact on the fishery resources of coastal ecosystems.

The Oregon Department of Fish and Wildlife's (ODFW) Marine Mammal Research Program has studied harbor seal foraging habits since the mid-1980s, primarily through the collection and analysis of scat (fecal) samples (Riemer and Brown, 1997; Riemer et al.[1]; Wright et al.[2]). Our results, as well as those from other pinniped food habit studies in Oregon (Graybill, 1981; Brown and Mate, 1983; Roffe and Mate, 1984; Orr et al., 2004), indicate that these animals consume a large number of diverse prey species. Concurrent research in Oregon indicates that Pacific harbor seals have increased significantly following protection under the MMPA; Brown et al. (2005) estimated that the 2002 statewide population total was 10,087 individuals. As noted above, these types of increases in pinniped abundance have led to more frequent interactions with coastal fish resources and hence an increased interest in the composition and abundance of prey in their diet.

Fortunately, new techniques have recently been developed to analyze pinniped diets. For example, rather than using traditional methods that rely strictly on otoliths (fish ear bones) for identifying prey, many researchers now try to identify all skeletal structures recovered from scats, which provide a more complete picture of pinniped diets (Olesiuk et al., 1990; Cottrell et al., 1996; Riemer and Brown, 1997; Browne et al., 2002). In addition, researchers are beginning to use molecular genetic methods to provide greater resolution in determining diet composition (Purcell et al., 2004; Deagle et al., 2005; Kvitrude et al., 2005). In this note, we add to this growing list of techniques by describing a novel use of fish otolith aging techniques to further our understanding of pinniped diets.

Fisheries scientists have aged fish otoliths to aid in the management of commercial and recreational fisheries (Love et al., 2002). Marine mammal scientists, on the other hand, have relied upon the identification of otoliths recovered from scats to identify the prey of pinnipeds (Brown and Mate, 1983; Beach et al.[3]; Harvey, 1989; Pierce and Boyle, 1991). However, the age of prey has rarely been considered when describing seal and sea lion diets. We believe that estimates

[1] Riemer, S. D., R. F. Brown, B. E. Wright, and M. Dhruv. 2001. Monitoring pinniped predation on salmonids at Alsea River and Rogue River, Oregon: 1997–1999. Unpubl. Contract Rep. to Pacific States Marine Fisheries Commission, NOAA Grant No. NA87FX0464, 38 p. [Available from OR Dept. Fish. and Wildl., 7118 NE Vandenberg Ave., Corvallis, OR 97330.]

[2] Wright, B. E., R. F. Brown, S. D. Riemer, and A. M. Ougzin. 2002. Pinniped predation on adult salmonids in the Alsea Estuary, Oregon. Unpubl.Contract Rep. to Pacific States Marine Fisheries Commission, NOAA Grant No. NA17FX1603, 35 p. [Available from OR Dept. Fish. and Wildl., 7118 NE Vandenberg Ave., Corvallis, OR 97330.]

[3] Beach, R. J., A. C. Geiger, S. J. Jeffries, S. D. Treacy, and B. L. Troutman. 1985. Marine mammals and their interactions with fisheries of the Columbia River and adjacent waters, 1980–1982. NWAFC (Northwest Alaska Fisheries Science Center) processed rep. 85-03, 316 p. NWAFC, National Marine Fisheries Service, Northwest Region, 7600 Sand Point Way N.E., Seattle, WA 98115-0070.

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of the age of prey will result in a more comprehensive picture of pinniped diets and help to augment stock assessments that use age-specific models. We report our application of these techniques to Dover sole (*Microstomus pacificus*) otoliths recovered from Pacific harbor seal scat samples collected in an Oregon estuary. Dover sole were selected as a case study because they are a common prey of harbor seals in Oregon (Riemer and Brown, 1997) and their otoliths have been aged successfully in previous studies (Hagerman, 1952; Brodziak and Mikus, 2000).

Materials and methods

We conducted our study during the spring and summer of 1996, and year-round from 1997 through 2002, in the Alsea Estuary located near Waldport, Oregon (44°26′N, 124°3′W). The local harbor seal population in this area consisted of approximately 600 animals throughout the study period. Scat samples from this population were obtained during low tides by approaching haul-out areas on foot or by boat, and slowly moving the animals into the water. Samples were placed in individually labeled plastic bags and frozen. The number of scat samples collected during each trip varied depending on the number and location of animals hauled out, and on weather and ocean conditions.

Scats were thawed and partially dissolved in water, then rinsed through a series of nested sieves (2 mm, 1 mm, 0.71 mm). All prey hard parts (e.g., otoliths, bones) recovered were dried and placed in individually labeled jars. Prey species were identified from all prey hard parts recovered from each sample. Dried hard parts were examined under a dissecting microscope and identified by using a comparative collection of fishes from the northeast Pacific Ocean and Oregon estuaries. Otoliths and diagnostic bones were identified, counted, and the side (left or right) was noted to estimate a minimum number of individuals (MNI) represented in each sample by following the procedures described by Lance et al.[4]

Otoliths selected for aging were given individual identification numbers and stored in gelatin capsules. One sample with 65 similarly size otoliths was subsampled by randomly selecting the first 18 otoliths recovered. Before aging, otoliths were measured to the nearest mm for total length, width, and length of sulcus by using an optical micrometer. Degree of erosion (level 1 having the least amount of erosion and level 3 having the greatest) was recorded by following techniques described in Tollit et al. (1997). Reference photographs were taken of each otolith with a dissecting microscope and digital camera before age estimates were determined.

Final otolith ages were determined by using one of two techniques. First, all fish otoliths were submerged in a dish of ethanol with a black background and annuli were counted under a dissecting microscope with reflected light (i.e., surface aged). Second, fish ≥ four years were re-aged according to the method described in Pikitch and Demory (1988) (i.e., break-and-burn method). The first annulus deposited was determined to be the completion of growth for the first year following the convention for aging adult Dover sole (Chilton and Beamish, 1982). In some cases, a mark within the otolith core was counted as the initial increment because it met the identification criteria for an annual increment.

Results

Dover sole remains (bones and otoliths) were recovered from 296 of the 3370 harbor seal scat samples collected during the study period (Table 1). Dover sole otoliths were recovered from 132 of these scat samples. Eighty-nine of these otoliths (21%) were excluded from our analyses because of poor condition (erosion or breakage), extremely small size, or because they had been randomly subsampled. The majority of otoliths were moderately eroded (level 1: 16%, level 2: 64% and level 3: 20%).

Of the 339 otoliths analyzed, 98.2% were assigned an age; 71.2% (237) by surface aging and 28.8% (96) by the break-and-burn method. Six otoliths were excluded from age estimates because of extreme edge wear and erosion. Forty-nine (92.5%) of the scats with more than one otolith analyzed resulted in fish of multiple ages.

The majority (70.6%) of otoliths analyzed were from one-, two-, and three-year-old fish; the rest were from four to six year-old (25.8%) and seven to 12 year-old (3.6%) (Table 1). Of the juvenile fish otoliths recovered, the presence of one- and two-year-old fish peaked in July, and three-year-old fish were found most frequently in August. Three of the four oldest fish otoliths were recovered during the summer months, and one 10-year-old fish was recovered in May. The scat samples collected during fall (September–November) primarily included two- and three-year-old fish (72.5%).

Aging otoliths of Dover sole increased MNI in harbor seal scats by 13% (269 versus 238). In most cases the number of Dover sole increased by one fish per scat when using both age and otolith side to enumerate MNI.

Discussion

We have shown in the present study that 1) Dover sole otoliths recovered from harbor seal scats can be successfully aged, and 2) seals in the Alsea River consumed Dover sole that ranged in age from one to 12 years. Interestingly, the highest frequency of occur-

[4] Lance, M. M., A. J. Orr, S. D. Riemer, M. J. Weise, and J. L. Laake. 2001. Pinniped food habits and prey identification techniques protocol. AFSC (Alaska Fisheries Science Center) Proc. Rep. 2001-04, 36 p. Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 1

Age distribution for Dover sole (*Microstomus pacificus*) consumed by harbor seals (*Phoca vitulina*), based on otoliths recovered from scats collected in the Alsea Estuary, Oregon. Total number of scats collected (*n*), scats with Dover sole bones and otoliths (*n*-Dover), and otoliths only (*n*-otoliths), and the number of Dover sole otoliths recovered (*n*) and successfully aged (*n*-aged) were pooled monthly over all years from 1996 through 2002.

	Scat			Otolith		Age (yr)												
Month	*n*	*n*-Dover	*n*-otoliths	*n*	*n*-aged	1	2	3	4	5	6	7	8	9	10	11	12	%[1]
Jan	33	0																0%
Feb	24	1	1	3	3		1	2										0.9%
Mar	103	2																0%
Apr	212	12	1	0	0													0%
May	230	22	11	12	11		6	2		2					1			3.3%
Jun	423	26	16	38	35	4	9	9	4	5	1	2		1				10.5%
Jul	347	91	40	174	118	26	32	23	18	11	6		1		1			35.4%
Aug	330	65	32	102	97	11	23	35	15	7	2		3				1	29.1%
Sep	806	54	21	65	55	1	23	17	7	4	2		1					16.5%
Oct	387	21	8	13	10	1	5	3				1						3.0%
Nov	173	2	2	20	4			2	1	1								1.2%
Dec	0																	0%
Total	3370	296	132	428	333	43	99	93	45	30	11	3	5	1	2	0	1	333

[1] Percentage of otoliths aged by month.

rence for Dover sole in our collections (ODFW[5]), and the greatest range in their age (Table 1), occurred during summer—a period when Dover sole move into shallow nearshore waters (Hagerman, 1952; Markle et al., 1992). This migration into nearshore waters brings fish into contact with an increasing population of pinniped predators.

The majority of Dover sole otoliths recovered from scats were those of fish younger than four years. In contrast, Dover sole landed in Oregon's commercial fishery between 1984 and 2004 were aged to be between three and 60 years old and the average age was 13 years (ODFW[5]). Of the 45,026 fish aged from the commercial fishery, over 50% were ages similar to those recovered from seal scat samples (four to 12 years) and had an average length of 33.4 cm. Of the fish checked, 79% were identified as mature. However, the majority (70.5%) of otoliths analyzed in our study were from one, two-, and three-year-old fish, whereas only one of the commercially caught fish was in this age range. Four- to six-year-old fish made up 0.3% of the commercially sampled fish and seven- to 12-year-olds made up the largest portion at 53.5%. This lack of younger age fish in the commercial fishery is partly due to the discarding of smaller unmarketable fish at sea. Sampson and Wood (2001) reported that from 1956 through 2000, between 5% and 14.6% of the commercial Dover sole catch at sea was discarded because of the small unmarketable size of the catch. What effect a consistent removal of older age fish and the discarding of younger fish by the commercial fishery, coupled with the take of younger age fish by an increasing number of predators could have on the population as a whole, is unknown.

Many species of marine fishes other than Dover sole contribute to important commercial fisheries in Oregon (ODFW[6]). Estimating prey age from fish otoliths recovered from seal and sea lion scats will be useful for researchers when describing impacts on long-lived marine species such as rockfish, which may be at greater risk to this long-term and increasing predation by coastal pinnipeds. Love et al. (2002) reported that rougheye rockfish (*Sebastes aleutianus*) live to at least 205 years and yelloweye rockfish (*S. ruberrimus*) to 118 years, whereas other species such as calico (*S. dalli*) and squarespot (*S. hopkinsi*) may only live for a decade or two. These older fish in some cases also have a late maturity; for example, only half of all yelloweye rockfish are mature at an age of 22 years.

As the sustainability of these species and the fisheries that target them become difficult to manage, there will be more interest in the impact of predators on these fish populations. Determining fish age has enabled biologists

[5] ODFW (Oregon Department of Fish and Wildlife). 1984–2004. Unpubl. data. [Data are on file at Oregon Department of Fish and Wildlife Newport-Marine Program office, 2040 S.E. Marine Science Drive, Newport, Oregon 97365.]

[6] ODFW (Oregon Department of Fish and Wildlife). 2000. Oregon Marine Fisheries 2000 status report, 109 p. [Available from Oregon Department of Fish and Wildlife Newport-Marine Program office, 2040 S.E. Marine Science Drive, Newport, Oregon 97365.]

to more accurately estimate appropriate fishing levels, particularly for rockfish species (Love et al., 2002). This information can also contribute to assessing the impact of pinnipeds on these species and can improve stock assessment models. Otolith age can provide information on the size of fish consumed when the age-length composition in the population or subgroup is available (Salthaug, 2003). In addition, age estimates provide information on the reproductive maturity of the prey consumed. Aging will also provide a more accurate estimate of the MNI of a particular prey species consumed than an estimate based on the maximum number of left or right otoliths of a similar size, particularly because different age fish can have otoliths of approximately the same size.

Researchers should note that the digestive process does cause erosion of otoliths and can result in underestimation of fish ages. We did not attempt to determine how otolith-based age estimates were affected by erosion, but a carefully designed captive feeding study would be able to address this issue in the future. However, because there are few other methods to determine the age distribution of fish taken by pinnipeds, this technique is useful when describing the diet of seals and sea lions.

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