Monitoring Pinniped Predation on Salmonids at the Alsea River, Oregon

Fall 2000 Contract Report

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REPORT SUMMARY

The co-occurrence of abundant pinnipeds (seals and sea lions) and depressed salmonid stocks has been identified as a potentially significant problem in the recovery of some salmon populations. At the Alsea River, Oregon, several hundred Pacific harbor seals (*Phoca vitulina richardsi*) co-occur during the fall and winter with a depressed run of wild coho salmon (*Oncorhynchus kisutch*), as well as with more robust runs of fall chinook (*O. tshawytscha*) and winter steelhead (*O. mykiss*). During September-November 2000, we attempted to assess whether pinnipeds might pose a threat to the recovery of coho in the Alsea basin using three approaches: (1) surface feeding observations to estimate total predation; (2) marking and resighting of seals to characterize movements, habitat use and foraging behavior; and (3) collection of seal fecal (scat) samples to describe diet.

We conducted 1,518 hours of surface feeding observations across 29 sites (31-90 hours per site) from 13 September – 29 November 2000. During this time we observed 55 predation events during surface feeding observations, of which 41 were identified as salmonids, 4 as non-salmonids, and 10 were unidentified fish; we observed an additional 5 salmonid predations while conducting other activities, resulting in a total of 60 events. Fifty-nine of the events were by seals and one was by a California sea lion (*Zalophus californianus*). Of the 46 salmonid predations, 11% were identified as coho, 24% as fall chinook, 2% as winter steelhead, and 63% could not be identified to the species level. We found no evidence to suggest that the occurrence of a salmonid predation event was dependent on tidal stage, time of day, or river discharge. On a more limited basis, we documented seals foraging in the river at night but did not observe any salmonid predation events during that time.

We marked 62 seals with uniquely identifiable head patches, of which 25 were fitted with radio transmitters. During surface feeding observations we resighted 23% of the marked seals at least once in the river; 40% were only observed in the bay and 37% were never resighted. Marked seals were involved in 23% (14 of 60) of all observed predation events. A single individual was responsible for at least 10% (6 of 60; 4 salmonid and 2 unidentified), and possibly as much as 16.6% (10 of 60; 7 salmonid and 3 unidentified), of all observed predation events. Post-study resightings of marked seals have occurred as far as southern Oregon (approximately 250 km) and northern California (approximately 700 km).

We collected 139 harbor seal scat samples from which 37 prey items were identified. Pleuronectids (English sole (*Parophrys vetula)* and rex sole (*Glyptocephalus zachirus*)) and Pacific sand lance (*Ammodytes hexapterus*) were among the most frequently occurring prey items found in scat. Salmonids were found in 8.9% of scat, which represented at least 13 individual fish (7 adults and 6 juveniles).

From our surface observations we estimate that, at a minimum, pinnipeds (primarily seals) consumed 120 adult coho (a 95% confidence interval (CI) for this total is 13 to 225 coho). This is a minimum estimate because our inference is limited to only those hours and sites that were actually available for sampling (which was approximately 22% of all possible daylight hours and sites within the estuary). If we inflate the minimum estimate to include all possible hours and sites (i.e., assume our sample was repre-

sentative), the estimated total is 539 coho (95% CI: 62-1,015). The estimated wild coho spawner abundance for the Alsea Basin in 2000 was 2,414 (95% CI: 221-4,607). Our minimum and inflated consumption estimates therefore represent 5% (95% CI: >0-10%) and 18% (95% CI: >0-39%) of the estimated run size, respectively.

Given the uncertainty surrounding the current predation and spawner abundance estimates, it is difficult to assess how much impact seals are having on the recovery of coho in the Alsea basin. Future research to better address this question will include: (1) implementing a sampling design that will allow for an unbiased estimate of salmonid consumption by pinnipeds for all possible daylight hours and sites within the estuary; (2) genetic analysis of salmonid bones found in scat to estimate the proportion of coho in the diet; and (3) continued refinement of the overall base of knowledge about pinnipeds and salmonids in the Alsea system.

INTRODUCTION

This report summarizes the fourth year of research on pinniped predation on salmonids at Alsea Bay, Oregon, conducted by the Oregon Department of Fish and Wildlife's Marine Mammal Program. Background and motivation for this research is described in Riemer et al. (2001). Our objective in 2000 was to continue our assessment of whether pinnipeds posed a threat to the recovery of coho salmon (*Oncorhynchus kisutch*) in the Alsea basin. We carried out this assessment using three approaches: (1) surface feeding observations to estimate total predation; (2) marking and resighting of Pacific harbor seals (*Phoca vitulina richardsi*) to characterize movements, habitat use and foraging behavior; and (3) collection of seal fecal (scat) samples to describe diet.

METHODS

Study Area

The Alsea River study area is located on the central Oregon coast approximately 210 km south of the Columbia River mouth (Figs. 1 and 2) and is described in Riemer et al. (2001).

Capture and tagging of harbor seals

Harbor seals hauled out in Alsea Bay (Fig.2: sites W and M) were captured, handled, and marked using procedures outlined in Jeffries et al. (1993). This technique consisted of rapidly deploying a large net in the water immediately in front of the haul-out area and pulling it to shore in the manner of a beach seine. Seals were extracted from this net at the waters edge and placed in individual hoop nets for holding and handling purposes on high ground. Seals were weighed, measured, sex was determined, and general age classes (adult, sub-adult, yearling, pup) were estimated. A 1.0-2.0 cc prophylactic IM injection of Valium (Diazepam) was administered to most of the larger, more aggressive seals to reduce stress during handling and tagging. Individually numbered plastic cattle ear tags were applied in the webbing of both hind flippers of each seal and a subset of those handled were fitted with individually color-coded neoprene patches. The patches (diameter = 9 cm; thickness = 6.5 mm) were cut from wet suit material of four different exterior-surface colors: black, red, light blue, and yellow. Each patch was also equipped with two sets of colored tassels (approx. 24 strands each) made of nylon craft lace in various combinations of dark blue, light blue, dark green, light green, yellow, blaze orange, and raspberry. These patches (termed "beanies") were secured to the pelage just behind the top of the head with cyano-acrylic superglue (Locktite 422) so that individual animals in the water might be identified when seen at the surface. A subset of those seals with beanies was also equipped with VHF radio transmitters on individual frequencies. The radio tags (Advanced Telemetry Systems, Inc.) were attached to the beanies between the two tassel sets allowing reception of the radio signal when the animal was at the waters surface, as well as when found on a haul-out area.

Surface feeding observations

Field protocols for conducting surface feeding observations are described in Riemer et al. (2001). Definitions of the target and sampled populations, and descriptions of the sampling design and estimation procedures used in 2000 are described below.

Target and sampled populations

Surface feeding observations are used to measure the number of free-swimming salmonids predated by pinnipeds over a specified area for a specified length of time. These measurements are then used to estimate the total number of salmonids predated by pinnipeds over some larger area and time frame. Estimation is carried out using finite population sampling formulas. In order to use such methods we must first define a target population and a sampled population. The former is the collection of all sampling units about which one would like to make an inference; the latter is the subset of the target population that is accessible for sampling (Morrison 2001).

The target population for this study consisted of all daylight hours from September 1-November 30, 2000 (time) in the Alsea River study area (space). Time and space, however, are both continuous dimensions that first must be made discrete before we can sample from them. We did this by defining our sampling units to be 150 m radius circles (or semi-circles) that were observed for 60 minutes in duration (termed "site-hours"). Sites were located along the river channel, or in the case of sites within the bay, along the main sub-tidal channels. Our working definition of the target population was the product between (1) the total number of non-overlapping 300 m long segments of sub-tidal or river channel, and (2) the total number of daylight hours from September 1 – November 30 2000 (Table 1).

The sampled population for this study consisted of the product between (1) 29 sites that were originally selected during 1997-1999 on the basis of convenience or judgment, and (2) the total number of daylight hours between September 13 – November 29, excluding September 16 and November 21-22, and excluding 15-45 minutes after sunrise and before sunset (time was used for traveling to and from sites) as well as 20 minutes periods between observations (time used for traveling between sites). The sampled population was approximately 22% of the target population; we sampled approximately 10% of the former (Table 1).

Sampling design

Site-hours used for surface feeding observations were selected in accordance with a stratified, two-stage unequal probability sampling design (Thompson 1992, Sarndal et al. 1997). The sampled population was stratified by dividing it into groups of 3 consecutive days. Next, we created 18 primary sampling units (PSUs) per stratum by first dividing the 29 sites into 6 zones (each with 4-7 contiguous sites per zone). The 6 zones were then multiplied by the 3 days in the stratum resulting in 18 “zone-days”. Thus each primary sampling unit (zone-day) consisted of 4-7 sites and 5-9 hours (depending on day length), or in other words 20-63 site-hours per zone-day. These site-hours served as the secondary sampling units (SSUs) for the second stage of sampling.

We selected our first-stage samples using a concept normally associated with experimental design rather than sampling, namely Latin squares. Specifically, we used a Latin rectangle design with rows (3 days) common to two squares, and columns (6 zones) unique to each square. Latin squares are derived from an arrangement of the Latin letters into a square array such that each letter appears once in each column and once in each row of the square (Keuhl 1994). We used this idea to ensure a certain amount of temporal and spatial balance in our first-stage samples.

Sampling of the Latin rectangle was carried out as follows. First, a “coin” was tossed twice (via computer), where the probability of heads was 0.65. If the outcome was two heads (with probability 0.4225), then a 3x3 Latin square containing the 3 zones with sites we wanted to sample with high probability was sampled. (These three zones had sites with the highest predation rates during 1997-1999 and we therefore chose to weight them most heavily in 2000.) Owing to the Latin rectangle design, each zone and day was sampled twice and only twice within the 3-day period. If the outcome was two tails (with probability 0.1225), then the 3x3 Latin square containing zones with sites having previously low predation rates were sampled, again where each zone and day was sampled twice and only twice within the 3-day period. Finally, if the outcome was one head and one tail (with probability 0.455), then the 3x6 Latin rectangle was sampled, where each of the six zones was sampled once and only once, and each day was sampled twice and only twice, within the 3-day period. This overall sampling scheme created a sample space containing 48 unique samples, wherein some zone-days had different inclusion probabilities than others. This situation required us to use estimators appropriate for unequal probability sampling (i.e., the Horvitz-Thompson estimator).

Once a zone-day had been selected for sampling, we next selected our second-stage sample of site-hours. We did this via a series of coin tosses and die rolls (via computer). The first toss determined whether the sampling would commence at sunrise or end at sunset. The second and third tosses determined whether each of two observers started or ended their day at sunrise or sunset, respectively. Finally, a die roll was used to select which site(s) would be sampled for a given hour selected. Inclusion probabilities were then calculated for each site-hour based on all possible outcomes of the coin tosses and die roll. Because day length was less than the sum of two 8-hour shifts, the probability of sampling the middle of the day was greater than the probability of sampling either the early morning of late afternoon hours. As in the first-stage sample, this situation required us to use estimators appropriate for unequal probability sampling (i.e., the Horvitz-Thompson estimator).

Estimator for total number of fish consumed by pinnipeds

An unbiased estimate of the total number of fish consumed C for stratum h was calculated using the following formula:

$$\hat{C}_h = \sum_{S_I} \frac{\hat{t}_{i\pi}}{\pi_{Ii}} \tag{1}$$

where

$$\hat{t}_{i\pi} = \sum_{S_i} \frac{y_{k|i}}{\pi_{k|i}} \tag{2}$$

is the Horvitz-Thompson estimate for the i^{th} PSU, π_{Ii} = i^{th} PSU inclusion probability, $y_{k|i}$ = the observed number of predations in the k^{th} SSU in the i^{th} PSU, and $\pi_{k|i}$ = the k^{th} SSU inclusion probability in the i^{th} PSU.

An unbiased estimate the of the variance of the total can be calculated using the following formula:

$$v(\hat{C}_h) = \sum\sum_{S_I}\left[\left(\frac{\pi_{Iij} - \pi_{Ii}\pi_{Ij}}{\pi_{Iij}}\right)\left(\frac{\hat{t}_{i\pi}}{\pi_{Ii}}\right)\left(\frac{\hat{t}_{j\pi}}{\pi_{Ij}}\right)\right] + \sum_{S_I}\left\{\sum\sum_{S_i}\left[\left(\frac{\pi_{kl|i} - \pi_{k|i}\pi_{l|i}}{\pi_{kl|i}}\right)\left(\frac{y_{k|i}}{\pi_{k|i}}\right)\left(\frac{y_{l|i}}{\pi_{l|i}}\right)\right]\right\} \tag{3}$$

where π_{Iij} = the joint inclusion probability of the i^{th} and j^{th} PSU, and $\pi_{kl|i}$ = the joint inclusion probability of the k^{th} and l^{th} SSU in the i^{th} PSU.

Upon analysis of our data we encountered several problems with this variance formula. First, if predations were observed in only one PSU per stratum then the first term in equation (3) would equal zero, implying there is no variability between PSUs when, in fact, there is. Second, if predations were observed in only one SSU per PSU then the second term in equation 3 would equal zero (again implying zero variance). Since we rarely observed more than one predation per PSU, and only one-third of all strata had more than one PSU with observed predations, using equation 3 resulted in many zero variance estimates. Lastly, it is not uncommon for some sampling designs to lead to negative variance estimates for some samples using unequal probability designs (Sarndal et al. 1997). This occurred in approximately one-half of our strata that had observed predations. For these two reasons (zero and negative variances), we instead used an alternative approximate variance estimator (Thompson 1992, pg. 50):

$$v(\hat{C}_h) \approx \left(\frac{N-n}{N}\right)\frac{s_t^2}{n} \tag{4}$$

where N = total number of PSUs in stratum h, n = number of PSUs sampled, and

$$s_t^2 = \frac{\sum_{\mathrm{i}=1}^{n} (t_\mathrm{i} - \hat{C}_h)^2}{n-1} \tag{5}$$

where

$$t_\mathrm{i} = n \frac{\hat{t}_{i\pi}}{\pi_{Ii}} \tag{6}$$

We applied this estimator to the first-stage estimates (PSUs) only, so it underestimates total variance because it does not include variation from the second-stage (SSUs). However, this underestimation is mitigated by the fact that the approximate variance estimator is considered conservative (tending to be larger than the actual variance). Estimated totals and variances for each stratum were summed to produce the overall estimate of the total number of fish consumed $\hat{C}_f$ and its associated variance.

Estimators for total number of salmonids and coho consumed by pinnipeds

Since some observed predation events are not identified as either salmonids or non-salmonids, the first step in estimating the total number of coho consumed was to apportion the total number of fish consumed (which includes the "unknowns") to salmonids. We did this by multiplying $\hat{C}_f$ by the estimated proportion of kills that were salmonids $P_{s.}$

P_s was estimated as the ratio of observed predations that were salmonids to the observed predations that were identified (i.e., salmonids plus non-salmonids). We computed a bootstrap estimate of the variance of $\hat{P}_s$ by resampling with replacement from the list of all observed predation events 10,000 times, each time computing $\hat{P}_s$. The variance of $\hat{P}_s$ was then calculated from the 10,000 resampled estimates. Thus, the total number of salmonids consumed by pinnipeds C_s was estimated as:

$$\hat{C}_s = \hat{C}_f * \hat{P}_s \tag{7}$$

The variance of $\hat{C}_s$ was estimated assuming independence (Goodman 1960):

$$v(\hat{C}_s) = (\hat{C}_f)^2 * v(\hat{P}_s) + (\hat{P}_s)^2 * v(\hat{C}_f) - v(\hat{C}_f)v(\hat{P}_s) \tag{8}$$

We repeated this process to estimate the total number of coho consumed C_c. That is, we apportioned $\hat{C}_s$ by multiplying it by $\hat{P}_c$ (the observed ratio of coho to identified salmonids):

$$\hat{C}_c = \hat{C}_s * \hat{P}_c \tag{9}$$

Again, the variance of $\hat{C}_c$ was estimated assuming independence (Goodman 1960):

$$v(\hat{C}_c) = (\hat{C}_s)^2 * v(\hat{P}_c) + (\hat{P}_c)^2 * v(\hat{C}_s) - v(\hat{C}_s)v(\hat{P}_c) \tag{10}$$

where the variance of $\hat{P}_c$ was estimated by bootstrapping the list of all observed salmonid predation events as described for $\hat{P}_s$.

Estimator for proportion of coho run consumed by pinnipeds

We obtained an estimate of the total coho spawner escapement E_c in the Alsea basin for the 2000 spawner year from Oregon Department of Fish and Wildlife (ODFW) (2001). We combined this estimate with our estimate of the total number of coho consumed to estimate the total coho run size R_c. The estimated variance of $\hat{R}_c$ is simply the sum of the variances of $\hat{E}_c$ and $\hat{C}_c$.

Finally, we estimated the proportion of the estimated run size taken by pinnipeds T_c as:

$$\hat{T}_c = \frac{\hat{C}_c}{\hat{R}_c} \tag{11}$$

The variance of this ratio was estimated using a Taylor series approximation (Casella and Berger, pg. 330):

$$v(\hat{T}_c) \approx \left(\frac{\hat{C}_c}{\hat{R}_c}\right)^2 \left[\left(\frac{v(\hat{C}_c)}{\hat{C}_c^{\,2}}\right) + \left(\frac{v(\hat{R}_c)}{\hat{R}_c^{\,2}}\right)\right] \tag{12}$$

This variance approximation assumes that $\hat{C}_c$ and R_c are independent. It seems likely, however, that the number of coho taken by pinnipeds might increase with increasing run size. If this is the case than the variance estimate is too large (i.e., conservative).

Confidence intervals for $\hat{C}_f$, $\hat{C}_s$, $\hat{C}_c$, $\hat{R}_c$, and $\hat{T}_c$, were constructed using a normal approximation:

$$estimate \pm 1.96\sqrt{\tilde{\text{v}}(\text{estimate})} \tag{13}$$

Confidence intervals for $\hat{P}_s$ and $\hat{P}_s$ were constructed using percentile confidence limits (Manly 1997). The confidence interval for $\hat{E}_c$ was taken from ODFW (2001).

All of the above estimates are valid only for the sampled population. We felt, however, that we would be remiss if we did not compute an additional set of estimates for the larger target population. By definition, they are not unbiased. If, however, we assume that the sampled population is representative of the target population, then they are probably reasonable.

The sampled population was approximately 22.1% of the target population (Table 1). We therefore applied a correction factor of 4.52 (1/0.221) to the estimate of total fish consumption $\hat{C}_f$ to obtain $\hat{C}'_f$, the estimated total number of fish consumed for the target population. The variance of the inflated estimate is:

$$v(4.52 * \hat{C}'_f) = 4.52^2 \, v(\hat{C}'_f) \tag{14}$$

All other subsequent calculations proceeded as outlined above.

Nighttime observations

We conducted limited nighttime surface feeding observations from a dock at site 15 (Fig. 2). We chose this location because it was a site where we had observed frequent daytime salmonid predation events and we had access to a dock from which to safely make observations. We followed the same protocol as that used for daytime observations with the exception of using night-vision equipment instead of binoculars. This equipment consisted of Generation 3 head-mountable ITT Night Vision Goggles (ITTC-F5001P), a 3X military-spec slip-on f1.2 magnifier lens, and a NiCad powered Maxa Beam infra-red illuminator with 4-6 million candle power.

Influence of tide, time and river discharge on salmonid predation

We tested the null hypothesis that the occurrence of one or more predation events per site-hour was independent of tide, time of day, and river discharge, respectively, using a chi-square test of independence. Tidal stage was determined for the middle of each observation period using the following formula (modified from Williamson and Hillemeier, 2000):

$$\text{Tidal stage} = -(\text{A} - \text{D}) / (\text{B} - \text{C}) \tag{15}$$

where A = middle of the observation period, B = time of last tide (high or low), C = time of next tide (high or low), D = time of nearest low tide (equals B or C). Values of one and negative one represent high tides; zero represents a low tide. The distance of a value from zero represents its relative distance from low tide. Negative and positive numbers represent ebbing and flooding tides, respectively. Tidal stage was converted to a categorical variable using the following cutoff values: ebbing high = -1 - (-0.5), ebbing low = <-0.5 - 0, flooding low = >0 - 0.5, and flooding high = >0.5 - 1.

Time of day was also determined from the middle of each observation period and was standardized on a scale of 0 to 1:

$$\text{Time} = (\text{middle of observation period} - \text{sunrise}) / (\text{sunset} - \text{sunrise}) \tag{16}$$

Values of 0 and 1 represent sunrise and sunset, respectively; 0.5 equals halfway between sunrise and sunset. Time of day was converted to a categorical variable using the following cutoff values: Morning = 0 – 1/3, Midday = >1/3 – 2/3, and Afternoon = >2/3 – 1.

We obtained mean daily river discharge data for the Alsea River from a United States Geological Survey gauge station (no. 14306500). Discharge was categorized as either "rising" or "falling" depending on whether mean daily river flow on day i was greater than or less than mean daily river flow on day i-1. If there was no change in river flow, we assigned a category based on a fair coin toss (this only occurred on one of 75 days).

Haul-out counts and radio-telemetry

We conducted counts of harbor seals at low-tide haul-out sites within Alsea Bay (Fig. 2) every 1-2 weeks. We recorded the number of seals, the presence and identification of marked seals (flipper tags and/or beanies), and we listened for radio-tagged animals. Beginning in October, we expanded our search for marked seals to known haul-out locations at Cape Foulweather, Yaquina Head, Yaquina Bay, Seal Rock, Cape Perpetua and Strawberry Hill (Fig. 1). We continued this effort after the study ended through the summer of 2001.

Scat Collection, Processing and Identification

We used protocols for collecting and processing scat (fecal) samples, identifying prey hard parts, and summarizing data as described in Riemer et al. (2001) and Lance et al. (2001).

RESULTS

Surface feeding observations

We conducted 1,518 hours of surface feeding observations across 29 sites (31-90 hours per site) from 13 September – 29 November 2000 (we did not conduct observations on September 16 or November 21-22). We observed solitary California sea lions (*Zalophus californianus*) within the Alsea River study area on only three occasions: September 27 (site 16), October 14 (sites 12 and 13), and November 7 (sites 22-24);

all remaining observations of pinnipeds were harbor seals. Although observations of seals generally declined the further upriver we sampled, the majority of observed salmonid predations occurred above site 14 (Figs. 3 and 4).

We observed 55 predation events during surface feeding observations, of which 41 were identified as salmonids, 4 as non-salmonids, and 10 were unidentified; we also observed an additional 5 salmonid predations while conducting other activities, resulting in a total of 60 observed events (Table 2). Of the 46 salmonid predations, 11% were identified as coho, 24% as fall chinook, 2% as winter steelhead, and 63% could not be identified to the species level. All but two of the salmonid predations occurred in the river (above site 13) and all but one were by harbor seals (the remainder by a California sea lion). Multiple individuals (2-4) participated in 15% of the 45 salmonid events attributable to seals. We found no evidence to suggest that the occurrence of a predation event was dependent on tidal stage, time of day, or river discharge (Table 3; Fig. 5).

We conducted 17 hours of nighttime surface feeding observations from a marina dock at site 15 (Fig. 2). Observations occurred during 5 shifts over the course of 4 days (October 24-26 and November 2); 3 shifts began at sunset and lasted 3-4 hours, and 2 shifts ended at sunrise, having started 3-4 hours earlier. We observed seals during 4 of the 5 shifts. Two of these 4 shifts had at least one seal actively foraging near or under the docks. We did not observe any salmonid predation events during these observations.

Capture, marking, and resighting of harbor seals

We captured 137 individual seals (excluding 2 recaptures) over 3 trapping periods: July 18-20, August 29-31, and September 12, 2000. We did not attach beanies to seals in July because animals were still molting. The overall sex and age ratios for captured animals were 1.7:1 females-to-males, and 2.7:1 adults-to-sub-adults, respectively. We affixed beanies to 63 individuals (8 adult males, 9 sub-adult males, 38 adult females, and 7 sub-adult females). Tassel colors were not recorded for one sub-adult male and he was therefore excluded from resighting summaries (i.e., resightable total = 62 seals); in addition, sex was not recorded for one adult. We attached radio transmitters to 25 beanies (7 adult males, 4 sub-adult males, 9 adult females, and 5 sub-adult females). One animal (a sub-adult male) captured and tagged on August 30 lost his transmitter (but not his beanie) when he was recaptured on September 12.

We resighted beanied seals 347 times during surface feeding observations (Figs. 6A and 6B). However, only 48% (167 of 347) of these observations were complete and correct. That is, we were only able to both see and correctly identify the base and both tassels 48% of the time. Incomplete identifications were largely due to difficulty in seeing the base color though it was not uncommon for at least one tassel to remain unidentified. We resighted 23% of the marked seals at least once in the river (above site 13); 40% were only observed in the bay and 37% were never resighted (Fig. 7). Post-study resightings of marked seals have occurred at nearly every known haul-out in the vicinity of Alsea Bay (within 40 km), and as far south as Gold Beach, Oregon (250 km) and The Sea Ranch, California (700 km).

Marked seals were involved with 23% (14 of 60) of all observed predation events. Remarkably, at least 10% (6 of 60; 4 salmonid and 2 unidentified), and possibly as much as 16.6% (10 of 60; 7 salmonid and 3 unidentified), of observed predations were by a single individual at a single site over a two-week period (Table 4).

Haul-out counts

The average count of seals hauled-out at low tide in Alsea Bay over the course of the study was approximately 400 (maximum count was 459). Seals hauled out primarily at the West Bridge, East Bridge, and Mac Marina sites; they were rarely observed at the Mouth or North Channel haul-outs (Figure 2). These counts and locations are comparable to previous years studies.

Scat collections

A total of 139 harbor seal scat samples were collected from four haul-outs in the lower river and estuary (Mac Marina, East and West bridge and the mouth); all samples were combined for presentation in this report. Of the total number of samples collected, 124 contained prey remains (89.2%). Twenty-one samples contained only unidentified fish remains. Twenty species of fish and cephalopods were identified, with an additional 17 prey items identified to the genus, family or order level (Tables 5 and 6). A minimum number of 1,440 individual prey items (MNI) were enumerated from the scat samples collected.

The most frequently occurring prey items were fish from the families Pleuronectidae (38.7%) and Ammodytidae (36.3%). English sole (*Parophrys vetula* 17.7%), rex sole (*Glyptocephalus zachirus*, 11.3%), and five other species represented the family Pleuronectidae. The family Ammodytidae was represented by a single species, Pacific sand lance (*Ammodytes hexapterus*). The most commonly occurring prey species did not vary appreciably between months of the study. However the high frequency of occurrence of Pacific sand lance identified in the 2000 collection was different from the previous 3 years when this species occurred infrequently (1997: 1.6%; 1998: 4.5%; 1999: 6.5%). Other prey species identified in these samples were similar in frequency to previous year's collections at these sites.

Salmonid remains were found in 8.9% (adults: 5.6%; juveniles: 3.2%) of the 124 scat samples with prey remains (Tables 5). The presence of salmonids in the samples varied little between months (Table 7). A minimum number of 7 adult salmonid individuals were identified in all scat samples (5.6% FO). No salmonid otoliths were recovered in these samples.

Coho spawner abundance

The estimated wild coho spawner abundance for the Alsea Basin in 2000 was 2,414; a 95% confidence interval (CI) was 221 to 4,607 coho (ODFW 2001). Estimates of spawner abundance during fall and winter

2000-2001 were influenced by extremely dry conditions and low stream flows; spawning after the termination of spawner surveys may have contributed to an underestimation of coho in the Alsea basin (Nickelson 2001).

Predation estimates

Our inferences from surface observations regarding pinniped predation on salmonids are valid only for the sampled population (Table 1). However, we feel we would be remiss if we did not attempt to provide an estimate for the target population as well. We therefore present results for both the sampled and target populations, keeping in mind that only the former is defensible on statistical grounds. The extrapolation to the target population is reasonable insofar as the sampled population is representative of it. Neither set of estimates, however, includes nighttime predation; they are therefore likely to be conservative.

For the sampled population we estimate that pinnipeds (primarily seals) consumed 418 adult salmonids (95% CI: 291-543) (Table 8). Of these, we estimate that 120 were coho (95% CI: 13-225); this represents an estimated 5% (95% CI: >0-10%) of the entire coho run for 2000. For the target population we estimate that pinnipeds consumed 1,887 adult salmonids (95% CI: 1,318-2,455) (Table 8). Of these, we estimate that 539 were coho (95% CI: 62-1,015); this represents an estimated 18% (95% CI: >0-39%) of the entire coho run for 2000.

DISCUSSION

Harbor seal scat collection and identification

The limitations for using scat for pinniped diet analysis and difficulties in scat collection techniques at the Alsea River are discussed in Riemer et al. (2001) and Lance et al. (2001). The harbor seal scat samples collected at the Alsea in 2000 indicated a diet similar in prey composition to previously reported seal food habits studies in Oregon. Flatfish, rockfish (Scorpaneanidae), smelt (Osmeridae), sculpin (Cottidae), Pacific tomcod (*Microgadus proximus*), herring (Clupeidae), anchovy (Engraulidae), Pacific sand lance and cephalopods (Loliginidae and Octopodidae) were often reported as the most common prey items for harbor seals (Graybill 1981, Brown and Mate 1983, Beach et al 1985, Riemer and Brown 1997). The presence and frequency of many harbor seal prey species identified in the scat samples tended to be similar during all weeks during September and October. A small sample collection for November (n = 3) does not allow for a fair comparison with other months and years. Although California sea lions are infrequent visitors to the Alsea River, a single California sea lion was observed predating a salmonid in the upper river during the study period. No California sea lion scat samples were collected during this study. Cascade Head on the north coast is the only location where California sea lion scat samples have been examined in Oregon. The most common prey items by frequency of occurrence in 120 samples collected in February and October of 1994 were Pacific mackerel (*Scomber japonicus*, 56.7%), Pacific whiting (*Merluccius productus*, 33.3%), Pacific herring (*Clupea pallasii*, 26.7%), cephalopods (21.7%), Pacific sardine (*Sardinops sagax caeruleus*) (20.0%), and salmonids (20.0%) (Riemer and Brown 1997).

Predation estimates

Our assessment of the potential impact of pinniped predation on coho salmon populations in the Alsea basin remains equivocal. Our best estimate of the likely level of predation on returning adult coho (18%) is imprecise (CV = 57.5%) and suffers from at least two limitations (both of which we hope to rectify in 2002). The first is the discrepancy between the sampled and target population. As we have progressed in our understanding of pinniped-salmonid interactions in the Alsea estuary, our observation methods have changed from being all land-based to nearly all boat-based. This has freed us from being restricted to a limited number of accessible shore-side vantage points from which to conduct observations. In 2002 we plan to implement a new sampling design that is entirely boat-based and will thus result in a dramatic decrease in the discrepancy between the sampled and target population. (Sampling during nighttime hours, however, will remain a largely insurmountable challenge.)

The second limitation in our current assessment stems from the difficulty in identifying predated salmonids to species. Most observed predations occur at a distance and are of short duration. Identification to salmonid or non-salmonid is often the best an observer can do. When we do identify a prey to species, we are assuming that identification is independent of species (e.g., a coho was as likely to be identified as a chinook). If identification is dependent on species, then apportioning kills by observed ratios of identified prey items will result in biased estimates. We plan to address this (at least partially) by genetically identifying all salmonid remains found in scat and by attempting to collect scale samples from observed predation events.

Even without such limitations, assessing the role of predation on salmonid populations remains a difficult task. Results from recent work on Oregon's coastal coho salmon populations have highlighted the overriding importance of marine survival and quality of spawning habitat on coho population dynamics (Lawson 1999; Nickelson and Lawson 1998; Nickelson 1998; Nickelson 2001). For example, Lawson (1999) states "identifying risk to salmon runs from pinniped predation has proven to be difficult given the sensitivity of such analyses to marine survival rates." He goes on to say, "At low marine survival rates any additional mortality, from mammals, birds, fish, or humans, increases risk to populations. At higher levels of marine survival the salmon population size may be affected by predation, but extinction risk is likely to be low". Highlighting the importance of habitat, Nickelson (2001), in his assessment of the relative health of Oregon's coastal coho populations, found that the Alsea population complex (of which the Alsea River population is but one, albeit the largest, component) was both viable and at a low risk of extinction, owing in part to the large amount of high quality spawning habitat in this complex.

As coho populations progress over time, and are subject to cycles of high and low marine survival, their population size and distribution within a basin will expand and contract (Nickelson 1998). It is presumably during periods of population contraction, coupled with low or declining habitat quality, that pinnipeds could have their greatest impact. If, as it appears, we are entering a period of high marine survival, and habitat quality remains high in the Alsea complex, then the coho population should show signs of improvement. If it does not, then it may be reasonable to suspect that pinnipeds may be having a negative impact on the recovery of the population. Continued monitoring of coho, pinnipeds, and their interactions in the Alsea basin will provide the information necessary to make such an assessment.

ACKNOWLEDGEMENTS

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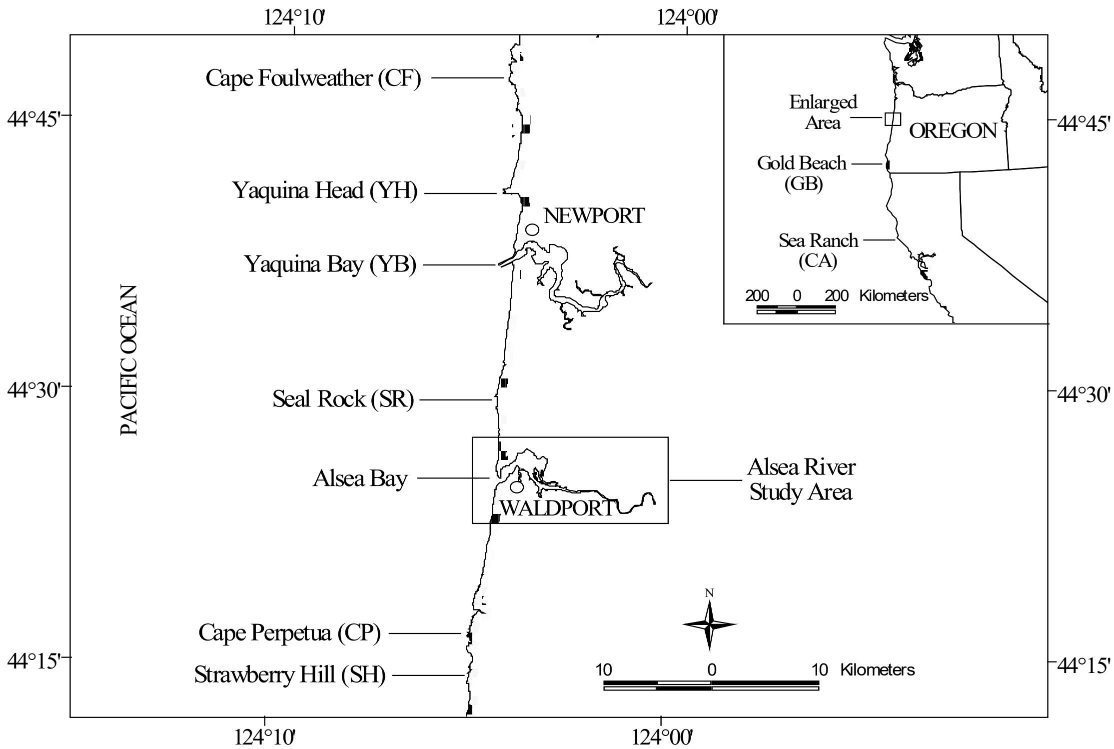

Figure 1. Study area location on the central Oregon coast. Place names with initials on large map identify harbor seal haul-out sites near Alsea River study area (Fig. 2); place names with initials on inset identify sites outside of general study area where seals marked in Alsea Bay were resighted after the study was completed.

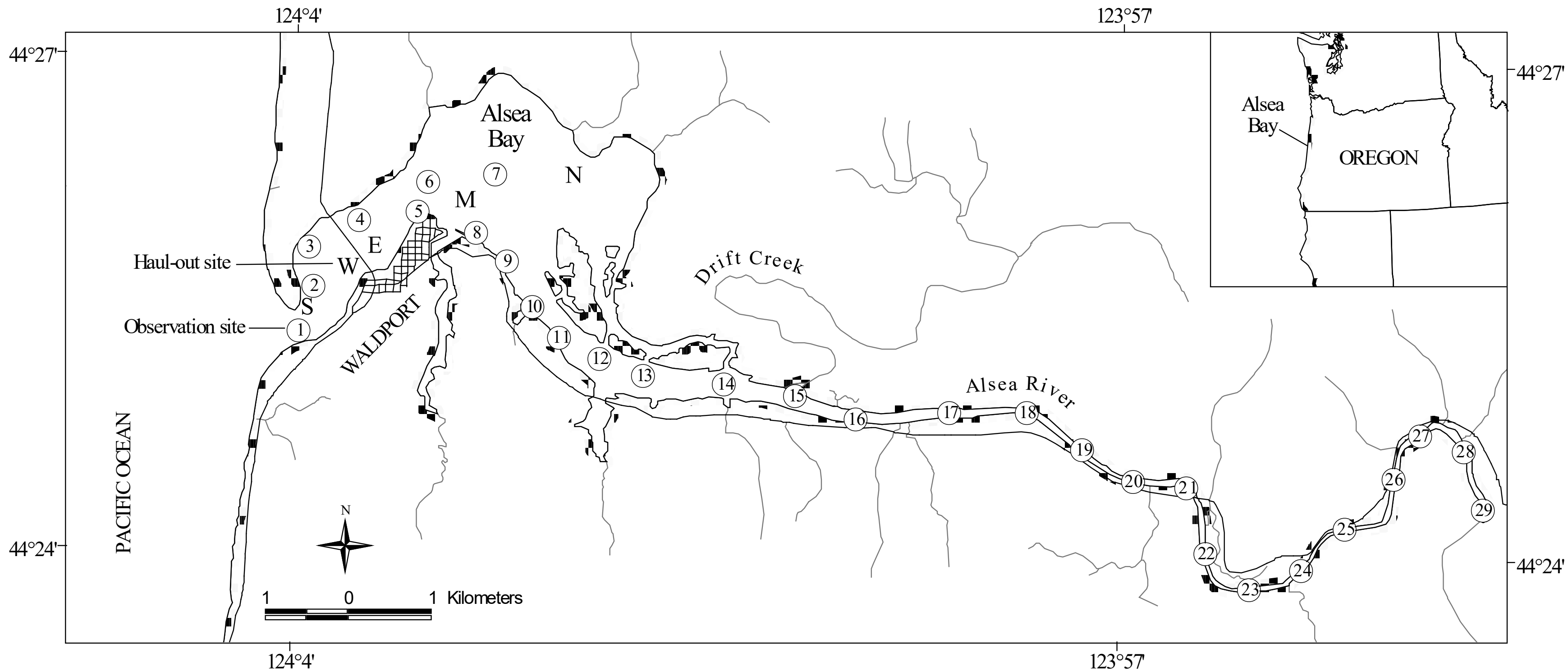

Figure 2. Alsea River study area. Circled numbers identify observation sites used for surface feeding observations. Letters identify low-tide haul-out sites used by harbor seals (S = Mouth, W = West Bridge, E = East Bridge, M = Mac Marina, and N = North Channel).

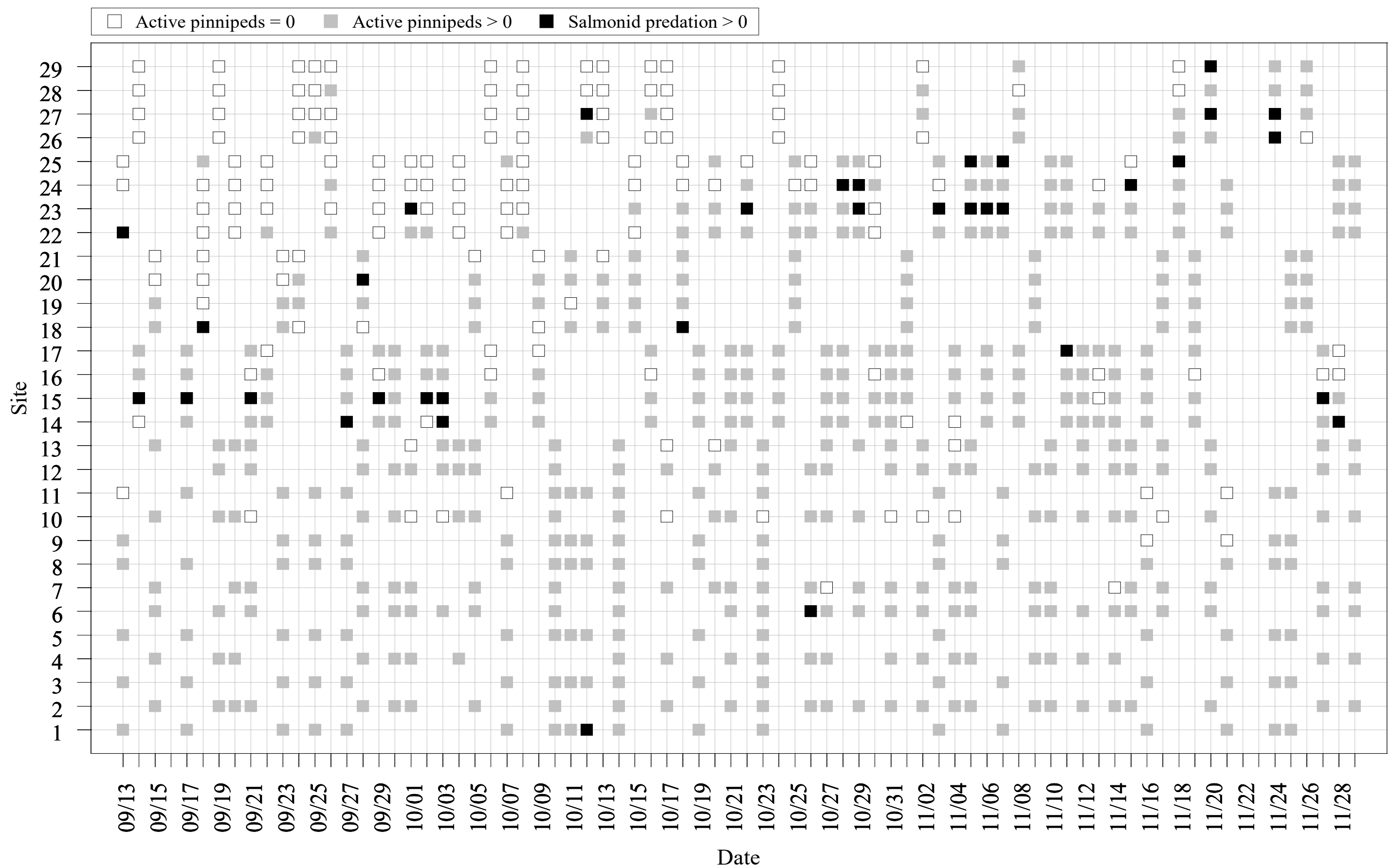

Figure 3. Summary of outcomes for 1,518 hours of surface observations by site and date. Each square represents from 1-5 hours of observation and depicts three possible outcomes: white indicates that no active pinnipeds were observed; gray, that at least one active pinniped was observed; and black, that at least one salmonid was observed predated by one or more pinnipeds. Active pinnipeds are defined as those that were in the water and not sleeping.

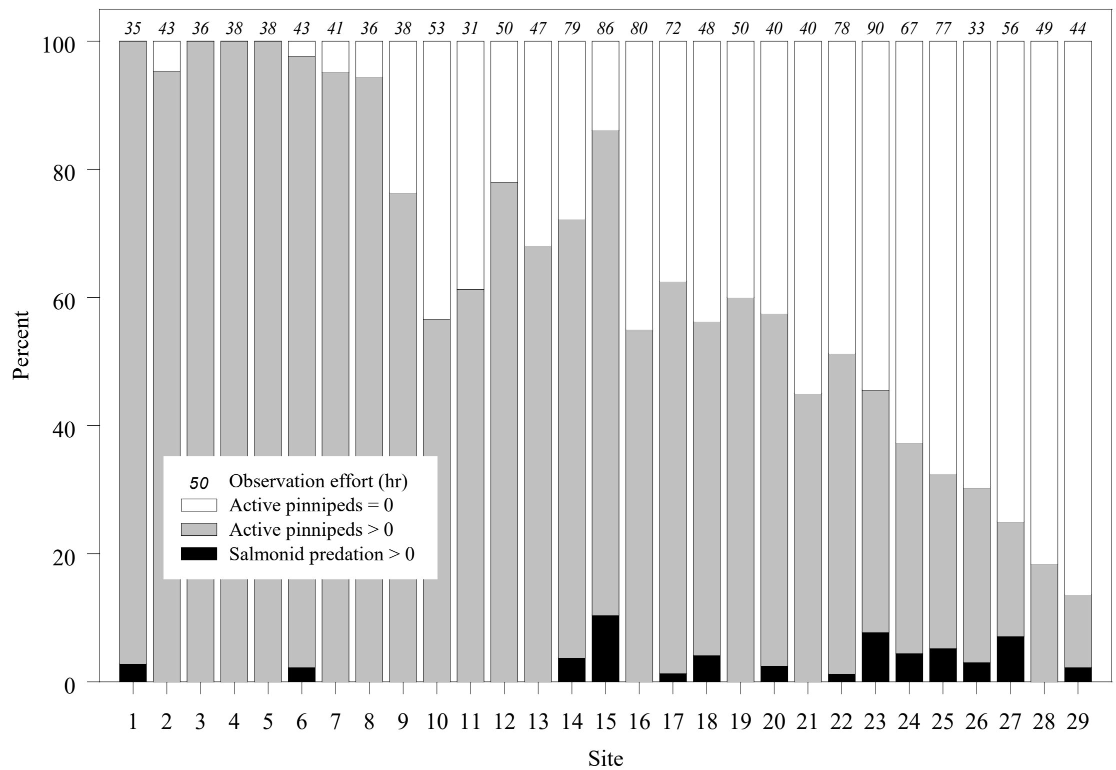

Figure 4. Outcome of surface feeding observations by site expressed as percent of total hours of observation (total hours per site are noted at top of each bar; grand total equals 1,518 site-hours). White bars denote hours in which no active pinnipeds were observed; gray, when at least one active pinniped was observed; and black, when at least one salmonid was observed predated by one or more pinnipeds. Active pinnipeds are defined as those that were in the water and not sleeping.

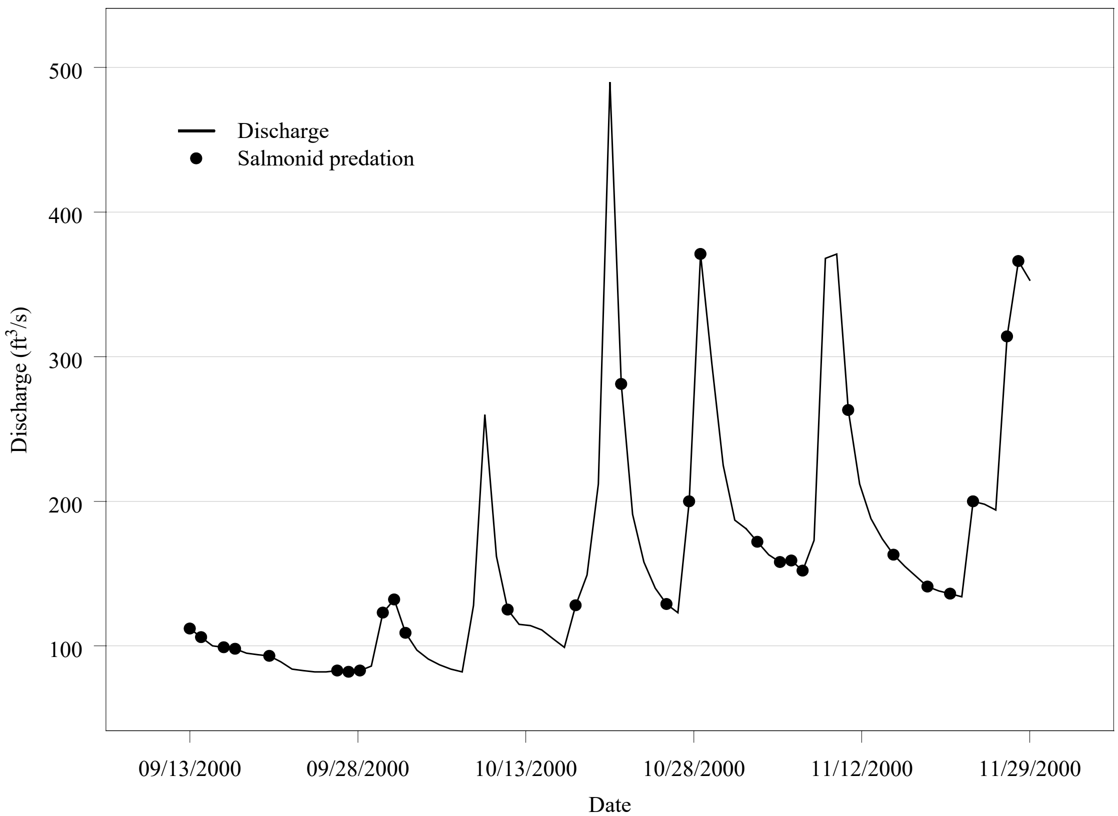

Figure 5. Relationship between on-effort salmonid predations by pinnipeds and mean daily discharge for the Alsea River (USGS gauge no. 14306500).

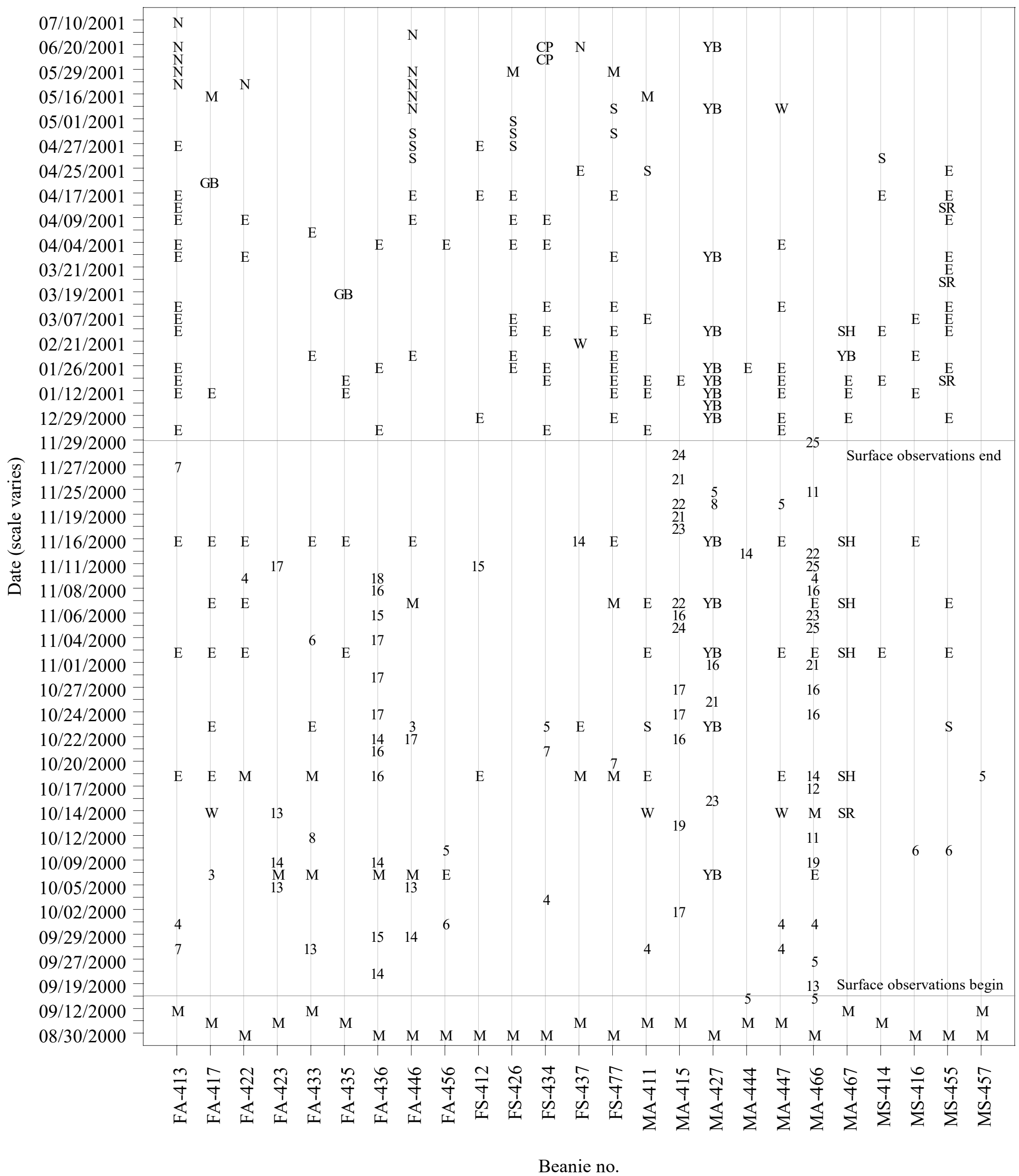

Figure 6A. Locations of visual and radio resightings of 25 harbor seals captured, tagged (beanie and radio-transmitter) and released in Alsea Bay, Oregon. Beanie number identifies sex (F = female, M= male), age (A = adult, S = sub-adult), and animal identification number. Location codes are as follows: numbers 1-29 = surface observation sites (Fig. 2); single letters = low-tide haul-out sites within Alsea Bay (Fig. 2); and two-letter combinations = sites outside of Alsea Bay (Fig. 1). Locations noted prior to beginning of study denote capture date and location (note: transmitter on MS-457 was lost during recapture on 9/12/00). If a seal was observed more than once per day, we plotted the location code representing the furthest distance from where it was originally captured.

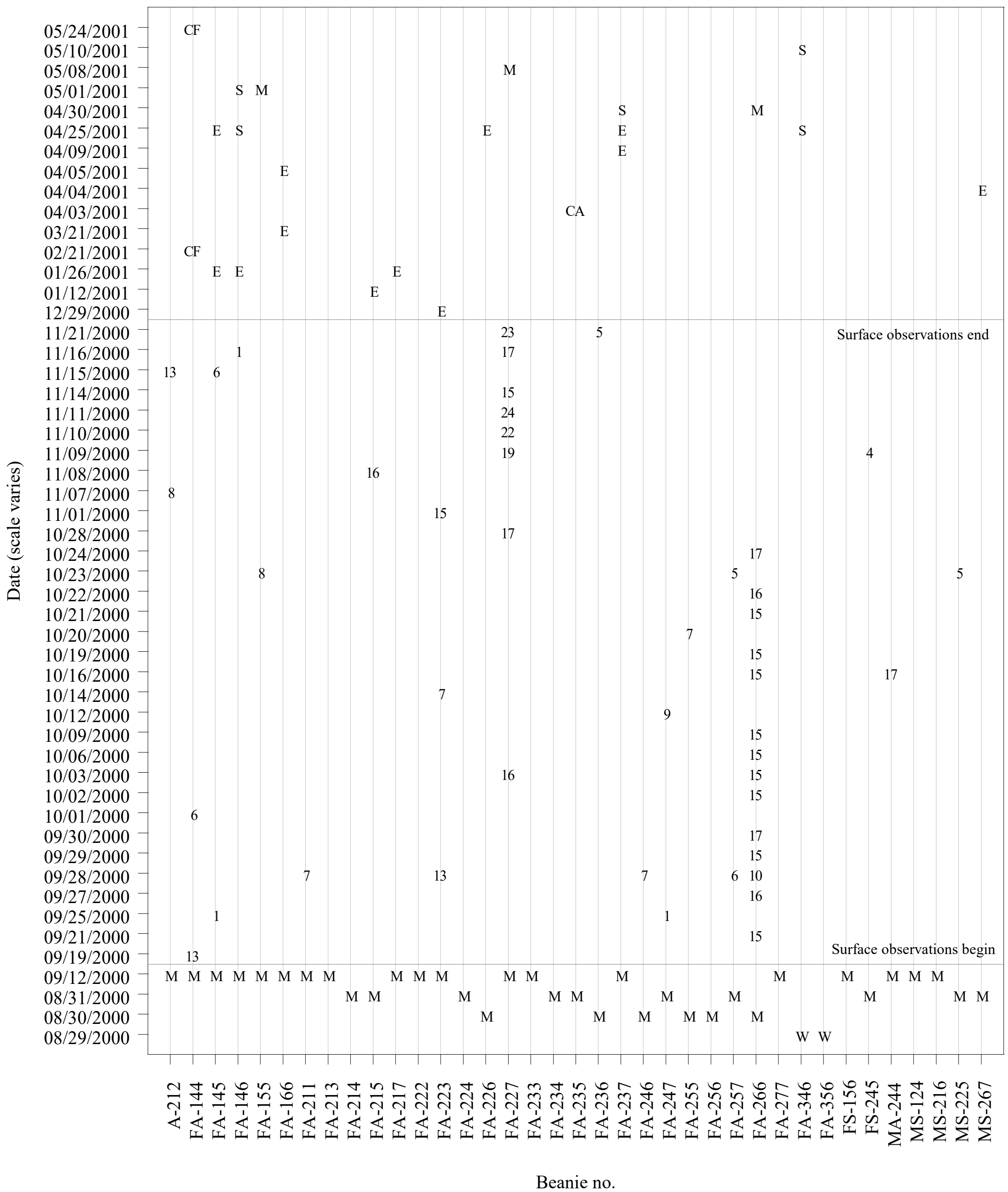

Figure 6B. Locations of visual resightings of 37 harbor seals captured, tagged (beanie only) and released in Alsea Bay, Oregon. Beanie number identifies sex (F = female, M= male), age (A = adult, S = sub-adult), and animal identification number. Location codes are as follows: numbers 1-29 = surface observation sites (Fig. 2); single letters = low-tide haul-out sites within Alsea Bay (Fig. 2); and two-letter combinations = sites outside of Alsea Bay (Fig. 1). Locations noted prior to beginning of study denote capture date and location. If a seal was observed more than once per day, we plotted the location code representing the furthest distance from where it was originally captured.

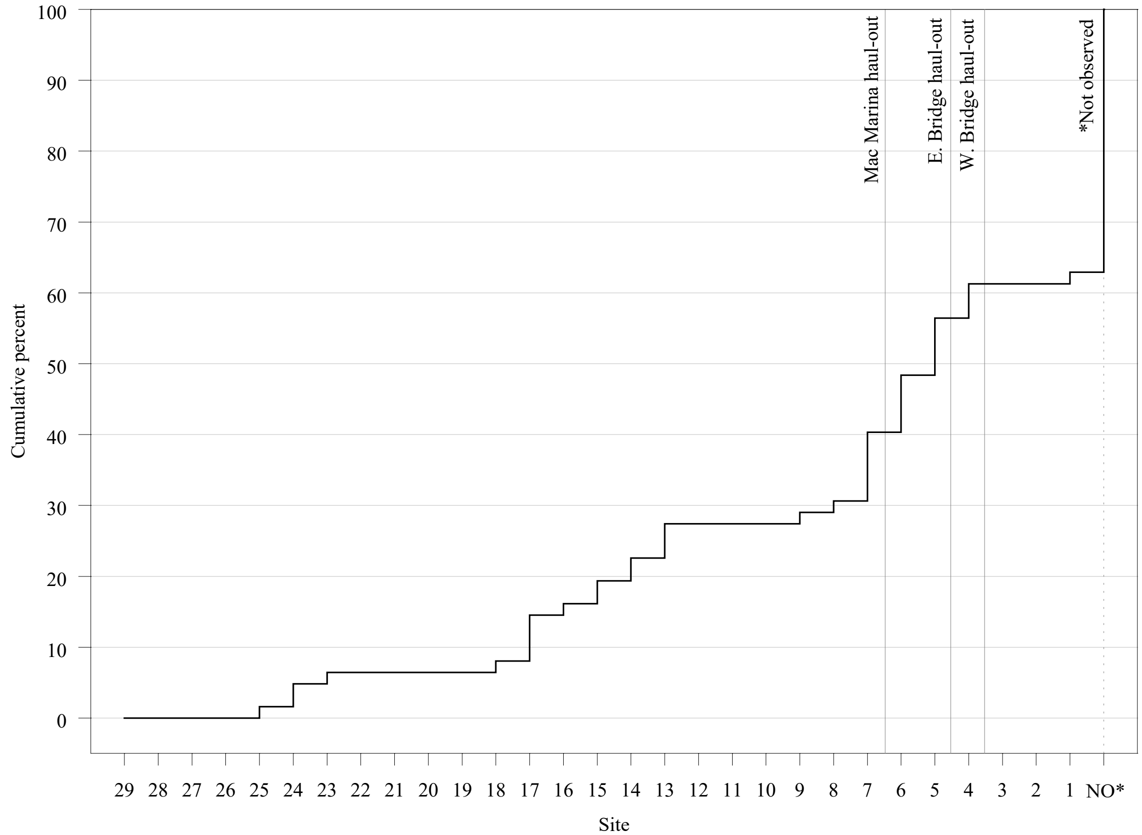

Figure 7. Percent of marked seals (n = 62) that were observed at or above sites 1-29 during on-effort surface observations. Seals that were not observed during on-effort observations are included under site 'NO' ('Not Observed'). Vertical lines denote locations of low-tide harbor seal haul-out sites used from September-November 2000.

Table 1. Summary of target population, sampled population, and sample, for the fall 2000 Alsea River pinniped-salmonid predation study.

Population	Sites	Hours (daylight)	Site-hours
Target	70[1]	1,001[2]	70,070
Sampled (% of target population)	29[3] (41)	535[4] (53.4)	15,515 (22.1)
Sample (% of sampled population)			1,518 (9.7)

[1]Length of main sub-tidal channel in the bay plus river (Fig. 2: site 1-29 plus site 5-7) divided by 300 m.

[2]Sum of daylight hours (sunrise-sunset) at Waldport, Oregon from 9/1/00-11/30/00.

[3]Non-probability sample of sites selected during 1997-1999 studies.

[4]Sum of daylight hours from 9/13-11/29 (less 9/16, 11/21-22), minus travel times to, from and between observation sites.

Table 2. Summary of observed predation events for fall 2000 Alsea River pinniped-salmonid predation study.

	Salmonids							
Effort*	Chinook	Coho	Steelhead	Unidentified	Total	Non-salmonids	Unidentified	Total
On	9	4	1	27	41	4	10	55
Off	2	1	0	2	5	0	0	5
Total	11	5	1	29	46	4	10	60

*On-effort refers to the 1,518 scheduled site-hours of surface feeding observations that were selected according to a probability based sampling design; off-effort refers observations made during the course of other activities (e.g., traveling between sites, rest breaks).

Table 3. Relationship between salmonid predation and physical and environmental factors. Chi-square test of independence tests the null hypothesis that the occurrence of salmonid predations is independent of tidal stage, time of day, and river discharge.

	Observed (expected) number of 1,518 site-hours with salmonid predation:		Chi-square test of independence		
Factor / levels*	≥ 1	= 0	χ^2	df	*P*-value
Tidal stage					
Ebb high	17 (12)	432 (437)	4.12	3	0.249
Ebb low	7 (7)	274 (274)			
Flood low	7 (9)	333 (331)			
Flood high	8 (11)	440 (437)			
Time of day					
Morning	8 (9)	344 (343)	0.28	2	0.869
Midday	20 (20)	765 (765)			
Afternoon	11 (10)	370 (371)			
Discharge					
Falling	26 (28)	1069 (1067)	0.595	1	0.440
Rising	13 (11)	410 (412)			

*See Methods section for definition of factor levels.

Table 4. Summary of predation events by marked seals for fall 2000 Alsea River pinniped-salmonid predation study.

Beanie ID	Beanie no.	Prey type	Effort	Date	Site
Complete	FA-266	Salmonid	On	9/21/00	15
	FA-266	Unidentified	On	9/27/00	15
	FA-266	Salmonid	On	10/2/00	15
	FA-266	Unidentified	On	10/3/00	15
	FA-266	Salmonid	On	10/3/00	15
	FA-266	Salmonid	On	10/3/00	15
	FA-423	Salmonid	On	11/11/00	17
	FA-436	Non-salmonid	On	10/31/00	15
	MA-466	Salmonid	Off	11/5/00	22
	MA-466	Salmonid	On	11/5/00	25
Partial*	x66	Unidentified	On	9/17/00	15
	xx6	Salmonid	On	9/17/00	15
	xx6	Salmonid	On	9/17/00	15
	xx3, xx6, x66	Salmonid	Off	9/22/00	15

*'Partial' beanie ID means that only one or both tassel colors were observed; the base color is unidentified (x) in all of these cases.

Table 5. Percent frequency of occurrence (FO) and minimum number of individual fish (MNI) for Pacific harbor seal prey species identified from 124 scat (fecal) samples collected at Alsea Bay, September-November, 2000. Prey species are listed by the lowest taxonomic level at which they were identified sorted in descending order by FO.

Common Name	Scientific Name	Family*	FO (%)	MNI
Pacific sand lance	*Ammodytes hexapterus*	Ammodytidae	36.3	877
Unidentified fishes		Unidentified fishes*	28.2	35
Pacific tomcod	*Microgadus proximus*	Gadidae	17.7	65
English sole	*Parophrys vetula*	Pleuronectidae	17.7	40
Unidentified righteye flounders		Pleuronectidae	16.9	38
Pacific herring	*Clupea pallasii*	Clupeidae	14.5	78
Sanddab species	*Citharichthys* spp.	Paralichthyidae	12.9	78
Unidentified flatfishes		Pleuronectiformes*	11.3	22
Rex sole	*Glyptocephalus zachirus*	Pleuronectidae	11.3	21
Salmonids	*Oncorhynchus* spp.	Salmonidae	8.9	13
Adult			5.6	7
Juvenile			3.2	6
Pacific whiting	*Merluccius productus*	Merluccidae	9.7	13
Pacific staghorn sculpin	*Leptocottus armatus*	Cottidae	8.1	15
Dover sole	*Microstomus pacificus*	Pleuronectidae	8.1	14
Sand sole	*Psettichthys melanostictus*	Pleuronectidae	8.1	10
Lingcod	*Ophiodon elongatus*	Hexagrammidae	7.3	10
Unidentified skates		Rajidae	7.3	9
Butter sole	*Isopsetta isolepis*	Pleuronectidae	6.5	27
Unidentified smelts		Osmeridae	5.6	15
Unidentified herring/shad		Clupeidae	4.8	6
Wolf-eel	*Anarrhichthys ocellatus*	Anarhichadidae	4.8	6
Unidentified rockfishes	Sebastes spp./Sebastolobus spp.	Sebastidae	4.0	12
Unidentified sculpins		Cottidae	4.0	5
Octopus species		Octopodidae	2.4	3
Slender sole	*Lyopsetta exilis*	Pleuronectidae	1.6	2
American shad	*Alosa sapidissima*	Clupeidae	1.6	2
Unidentified cephlapods		Cephlapoda*	1.6	2
Minnows		Cyprinidae	1.6	2
Northern anchovy	*Engraulis mordax*	Engraulidae	1.6	2
Surf smelt	*Hypomesus pretiosus*	Osmeridae	0.8	5

Buffalo sculpin	*Enophrys bison*	Cottidae	0.8	4
Unidentified gadids		Gadiformes	0.8	2
Starry flounder	*Platichthys stellatus*	Pleuronectidae	0.8	1
Unidentified hexagrammids.		Hexagrammidae	0.8	1
Squid species		Loliginidae	0.8	1
Shiner surfperch	*Cymatogaster aggregata*	Embiotocidae	0.8	1
Pacific lamprey	*Lampetra tridentata*	Petromyzontidae	0.8	1
Gunnels		Pholididae	0.8	1
Eelpouts		Zoarcidae	0.8	1

*'Family' also includes one order (Pleuronectiformes), one class (Cephlapoda), and 'Unidentified fishes'.

Table 6. Percent frequency of occurrence (FO) and minimum number of individual fish (MNI) for Pacific harbor seal prey species identified from 124 scat (fecal) samples collected at Alsea Bay, September-November, 2000. Prey species are listed by their family and sorted in descending order by FO.

Family*	Common Name	FO (%)	MNI
Pleuronectidae	Righteye flounders	38.7	153
Ammodytidae	Pacific sand lance	36.3	877
Unidentified fishes*	Unidentified fishes	28.2	35
Clupeidae	Herrings and shad	21.0	86
Gadidae	Cods	18.5	67
Paralichthyidae	Sanddab spp.	12.9	78
Cottidae	Sculpins	12.9	24
Pleuronectiformes*	Unidentified flatfishes	11.3	22
Merluccidae	Pacific whiting	9.7	13
Salmonidae	Salmonids	8.9	13
Hexagrammidae	Greenlings	8.1	11
Rajidae	Skates	7.3	9
Osmeridae	Smelts	6.5	20
Anarhichadidae	Wolf-eel	4.8	6
Scorpaneanidae	Rockfishes	4.0	12
Octopodidae	Octopus spp.	2.4	3
Engraulidae	Northern anchovy	1.6	2
Cyprinidae	Minnows	1.6	2
Cephlapoda*	Unidentified squids & octopuses	1.6	2
Zoarcidae	Eelpouts	0.8	1
Pholididae	Gunnels	0.8	1
Petromyzontidae	Pacific lamprey	0.8	1
Loliginidae	Squid spp.	0.8	1
Embiotocidae	Shiner surfperch	0.8	1

*'Family' also includes one order (Pleuronectiformes), one class (Cephlapoda), and 'Unidentified fishes'.

Table 7. Monthly totals for percent frequency of occurrence (FO) and minimum number of individuals (MNI) of adult salmonids recovered from scat samples collected at Alsea Bay, September-November, 2000.

Month	n	FO (%)	MNI
September	69	5.8	4
October	52	3.8	2
November	3	33.3	1
Total	124	5.6	7

Table 8. Summary of parameter estimates for the fall 2000 Alsea River pinniped-salmonid predation study.

		Sampled population			Target population		
Variable description	Notation	Estimate	CV (%)	95% CI	Estimate	CV (%)	95% CI
Estimated total number of fish consumed	$\hat{C}_f$	459	14.6	326-590	2,071	14.6	1,476-2,665
Estimated percent of fish that were salmon	$\hat{P}_s$	91	4.7	82-98	91	4.7	82-98
Estimated percent of salmon that were coho	$\hat{P}_c$	29	42.9	7-55	29	42.9	7-55
Estimated total coho spawner abundance	$\hat{E}_c$	2,414	45.5	221-4,607	2,414	45.5	221-4,607
Estimated total number of salmon consumed	$\hat{C}_s = \hat{C}_f * \hat{P}_s$	418	15.4	291-543	1,887	15.3	1,318-2,455
Estimated total number of coho consumed	$\hat{C}_c = \hat{C}_s * \hat{P}_c$	120	45.1	13-225	539	45.1	62-1,015
Estimated total coho run size	$\hat{R}_c = \hat{E}_c + \hat{C}_c$	2,534	40.0	526-4,540	2,953	35.5	893-5,012
Estimated percent of coho run consumed	$\hat{T}_c = \hat{C}_c / \hat{R}_c$	5	61.0	>0*-10	18	57.5	>0*-40

*Lower limit was less than 0 due to inadequacy of normal approximation (logic dictates that it must be greater than zero).