Pinniped Predation on Adult Salmonids in the Alsea Estuary, Oregon

2002 Progress Report

Bryan E. Wright, Robin F. Brown, Susan D. Riemer, and Aicha M. Ougzin

Oregon Department of Fish and Wildlife
Marine Mammal Program
7118 NE Vandenberg Avenue
Corvallis, OR 97330

In partial fulfillment of requirement for:
PSMFC/ODFW Subcontract No. 02-14
NOAA Grant No. NA17FX1603

June 2003

Executive 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 salmonid populations. One such problem may occur at the Alsea Estuary, Oregon, where a relatively large population of Pacific harbor seals (*Phoca vitulina richardsi*) co-occurs with a depressed run of threatened coho salmon (*Oncorhynchus kisutch*). We investigated this potential problem during fall 2002 using three approaches: (1) surface feeding observations to estimate total diurnal adult salmonid predation by seals; (2) marking and tracking of seals to characterize their movements, habitat use and foraging behavior; and (3) collection of seal fecal (scat) samples to describe their diet.

From 1 September – 23 November 2002 we conducted 759.5 hours of daytime surface feeding observations across 63 sites in the estuary. During this time we observed 17 instances of seals handling or consuming what were believed to be previously live, free-swimming adult salmonids. We also conducted 77.5 hours of nighttime surface feeding observations across two sites. During these nighttime observation periods we observed 3 instances of seals, and one instance of a California sea lion (*Zalophus californianus*), handling or consuming what were believed to be previously live, free-swimming salmonids.

We captured and marked 59 seals over four capture attempts on 21-23 August and 6 September 2002. Seals were outfitted with acoustic transmitters and tracked using an array of 15 automated data-logging hydrophones. We logged over 375,000 detections from 56 seals over the 12-week study period. Twenty-three seals were detected in the riverine portion of the study area at least once. Collectively, these 23 seals made 593 trips upriver totaling 5,067 hours; just 7 seals, however, accounted for 94% of the total hours. Seventy-three percent of the total hours spent upriver occurred at night.

We collected 117 harbor seal scat samples from which over 30 prey items were identified. Pacific herring (*Clupea pallasii*), and a variety of flatfish (English sole (*Parophrys vetula)*, rex sole (*Glyptocephalus zachirus*), and Dover sole (*Microstomus pacificus*)) were among the most frequently occurring prey items found in scat. Adult salmonid remains were recovered from 9.4% of the samples.

From our daytime surface observations we estimate that seals consumed 1,160 adult salmonids during daylight hours over the 84-day study period (a 95% confidence interval (CI) for this total was 500 to 1,820 salmonids; coefficient of variation (CV) = 29%). We currently have no unbiased way to estimate how much predation occurred at night. Circumstantial evidence, however, suggests that predation may have occurred more at night than day. If we assume that diurnal predation represented as little as 10%, and as much as 90%, of the total predation, then

point estimates for total predation (day plus night) varied by an order of magnitude from 11,600 to 1,290 fish, respectively (CV for each point estimate remained 29% since the diurnal proportion was treated as a constant).

We currently have no unbiased way to estimate what proportion of total predation was coho. Circumstantial evidence suggests that coho were neither exclusively preferred nor avoided by seals relative to other salmonids. If we assume that coho predation represented as little as 10%, and as much as 90%, of the total predation, then point estimates for coho predation varied by two orders of magnitude from 130 to 10,440 fish, respectively (CV for each point estimate remained 29% since diurnal and coho proportions were treated as constants). Putting this in context, the preliminary estimated coho escapement for the Alsea Basin was 5,767 fish (95% CI: 2,220 – 9,314; CV=28%). Translating the 10% and 90% figures from above into predation rates yielded point estimates ranging from 2% to 64% of potential escapement, respectively (CV=40% and 36%, respectively).

This work obviously resulted in a broad range of possible predation estimates. If actual predation levels fall anywhere other than the low end of our range, then coho predation could be at levels of concern for recovery. The broad range was due to the difficulty in accurately estimating nocturnal and coho-specific predation. We currently do not have a solution to this problem. We do know, however, that with increased effort (and hence cost) it would be possible to achieve more precision in our diurnal salmonid predation estimate. However, without a way to adequately address nocturnal and coho-specific predation the benefits of improving our diurnal estimate are questionable.

INTRODUCTION

This report summarizes the fifth year of research conducted by the Oregon Department of Fish and Wildlife's Marine Mammal Program on pinniped predation on salmonids at the Alsea Estuary. Background and motivation for this research is described in Riemer et al. (2001). Our objective in 2002 was to complete our assessment of whether pinnipeds posed a threat to the recovery of coho salmon (*Oncorhynchus kisutch*) in the basin. We carried out this assessment using three approaches: (1) predation observations to estimate total diurnal adult salmonid predation by Pacific harbor seals (*Phoca vitulina richardsi*); (2) marking and tracking of harbor seals to characterize their movements, habitat use and foraging behavior; and (3) collection of harbor seal fecal (scat) samples to describe their diet.

METHODS

Study area

The Alsea Estuary study area is located on the central Oregon coast (Fig. 1) and is described in Riemer et al. (2001).

Diurnal predation observations

Field protocols for conducting predation observations are described in Riemer et al. (2001). The sampling design and estimation procedures used in 2002 are described below.

Sampling design

Predation events exist in a spatio-temporal matrix (i.e., their occurrence can be defined by a point on a map and a moment in time). The first step, therefore, in trying to estimate the total number of such events is to define the spatio-temporal domain from which to sample. We defined the spatial component of this domain as the main sub-tidal channel from the mouth of the Alsea River to the approximate head-of-tide (Fig. 1: observation sites 1-63). We divided this channel into sixty-three non-overlapping segments, each 300 meter (m) long by ≤ 150 m wide (width varied according to the channel). The temporal component of the sampling domain consisted of all daylight hours from 9/1/02-11/23/02 (12 weeks), less the first and last ½ hour of each day to allow for boat travel to and from sites. We divided this daylight sampling period into half-hour time blocks, which resulted in a total of 1,669 such blocks (e.g., an 11 hour day would have 22 blocks).

The product of the spatial (63 sites) and temporal (1,669 blocks) components yielded a sampling frame consisting of 105,147 individual elements (i.e., “segment-blocks”).

A sample totaling 1,539 elements (1.5% of the frame) was selected with equal probability in accordance with a three-stage cluster sampling design, with multiple systematic samples at each stage (Cochran 1977, Thompson 1992). This design was developed to accommodate the challenges imposed by sampling rare events in space-time. The first-stage sampling units consisted of days of the week (i.e., Sunday, Monday, etc.). When a day was picked (e.g., Monday), every other day of the same type in the study period was automatically included in the systematic sample. The result was a “cluster” of 12 temporally dispersed days. A nonrandom sample of 5 days (Monday-Friday) was chosen from the 7 in the interval, resulting in five 12-day clusters, or primary sampling units (PSUs). The first-stage sampling fraction was 71.4% (5 out of 7). Monday-Friday was chosen for the obvious benefits associated with coinciding with the normal work week (safety, scheduling, etc.). We assumed that the response variable (predation event) was unrelated to day of the week. This assumption was supported by previous work which showed that seal movements and observed predation events did not appear to be associated with the day of the week.

The second-stage sampling units (SSUs) consisted of discrete units of space-time within each day type, namely a 300 m long channel segment and 90 minutes. For example, a channel segment running from river km 1.2 to 1.5 (segment number 5) during 0700 to 0830 on 10/10/2002 would represent one element of the second-stage sampling unit within the “Thursday” PSU. Within every available 90-min period, there were 63 segments available for sampling. Importantly, however, the sampling interval contained 65 SSUs: the 63 segments in the first 90-minute period, plus the first 2 segments in the second 90-minute period (hence segments 1 and 2 occurred twice but during different 90-minute periods). When a segment-period from the interval was randomly chosen, say number 4 of 65 in the first period, then every subsequent fourth segment-period was automatically included in the systematic sample. What this achieves, due to the extra two-segment periods in the interval, is a one-way movement upriver through time by the observer. Continuing with the example above, if segment 5 is selected from 0700-0830, then the next segment-period that is automatically selected is segment 7 from 0830-1000 (and then segment 9 from 1000-1130 and so on). At the end of the available daylight period, the next automatically included segment occurs on the following Thursday morning (since all the SSU’s are within one PSU). A random sample of 2 segment-periods was chosen from each PSU, resulting in a grand total of 10 SSUs (two for each of 5 PSUs), where each SSU itself was a cluster of approximately 77 secondary sampling elements. The second-stage sampling fraction was 3% (2 out of 65).

The third-stage or tertiary sampling unit (TSU) was simply a subdivision of the temporal component of the SSU into 3 consecutive time blocks, each 30 minutes long. Using segment 5 from 0700-0830 as an example, the 3 TSUs within this element of the SSU are 0700-0730, 0730-0800, and 0800-0830. A restricted random sample of 2 segment-blocks was chosen from each SSU, resulting in a grand total of 20 TSUs (two for each of the 10 SSUs). The third-stage sampling fraction was therefore 66% (2 out of 3). The restriction on random sampling was that, while any individual TSU was available for sampling, of the three possible combinations – 1 & 2, 2 & 3, and 1 & 3 – only the adjacent times were allowed (i.e., 1 & 2 and 2 & 3). This was necessary in order to allow for travel time to the next segment as well to provide breaks for observers.

Observers navigated to selected observation sites using a combination of visual landmarks, aerial photographs, GPS units (WAAS-capable, Garmin GPS 76), and laser rangefinders (Bushnell Yardage Pro 500).

Estimator for total diurnal salmonid consumption

Let y_{iju} be the observed number of adult salmonids consumed by pinnipeds in the u^{th} tertiary sampling unit, within the j^{th} secondary sampling unit, drawn from the i^{th} primary unit. Note that y_{iju} is the sum of observations over the approximately 77 tertiary sampling elements (30 minute segment-blocks) in the TSU. In other words, it is the sum of approximately 38.5 hours of observation spread over 12 weeks and across nearly all 63 channel segments. The total number of hours varies slightly between PSU's, but bias caused by this is likely negligible when the number of elements exceeds 50 (Cochran 1977 pg. 206). Sampling units at each stage of the design are heterogeneous with respect to time and space. This is in keeping with the systematic or cluster sampling principle (Thompson 1992, pg. 118), which states that in order to obtain estimators of low variance, the population should be partitioned such that within-cluster heterogeneity is high and between-cluster variance is low. Furthermore, since predation events are rare and unpredictable (previous research showed 1 event for every 30-40 hours of effort), the sampling units are large enough in space and time to likely capture at least one predation event.

An unbiased estimator (Cochran 1977, pg. 286) for the total number of adult salmonid predation events, S, is:

$$\hat{S} = NMK\bar{\bar{\bar{y}}} = NMK\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{u=1}^{k} y_{iju}}{nmk} \quad (1)$$

where

N = number of first-stage sampling units (days of week) in the population (N = 7)

M = number of second-stage units (segment-periods) in each first-stage unit (M = 65)

K = number of third-stage units (segment-blocks) in each second-stage unit (K = 3)

n = number of first-stage units sampled (n = 5)

m = number of second-stage units sampled from the i^{th} first-stage unit (m = 2)

k = number of third-stage units sampled from the j^{th} second-stage unit (k = 2)

y_{iju} = sum of the observed adult salmonid predations from the u^{th} third-stage unit

Since the sampling fractions are constant across each stage, equation (1) can be rewritten as:

$$\hat{S} = 68.25 \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{u=1}^{k} y_{iju} \qquad (2)$$

In other words, each observed adult salmonid predation (y-value) represented itself and an additional 67.25 predations that were not observed.

An unbiased estimator for the variance of the total, $v\hat{a}r(\hat{S})$, is:

$$(NMK)^2 \left[\frac{\left(\frac{N-n}{N}\right)}{n} \frac{\sum_{i=1}^{n} (\bar{\bar{y}}_i - \bar{\bar{\bar{y}}})^2}{n-1} + \frac{\frac{n}{N}\left(\frac{M-m}{M}\right)}{nm} \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} (\bar{y}_{ij} - \bar{\bar{y}}_i)^2}{n(m-1)} + \frac{\frac{n}{N}\frac{m}{M}\left(\frac{K-k}{K}\right)}{nmk} \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{u=1}^{k} (y_{iju} - \bar{y}_{ij})^2}{nm(k-1)} \right] \qquad (3)$$

where

$\bar{y}_{ij}$ = mean number of predation events observed over the k TSUs in the j^{th} and i^{th} SSU and PSU, respectively

$\bar{\bar{y}}_i$ = mean number of predation events observed over the m SSUs in the i^{th} PSU

$\bar{\bar{\bar{y}}}$ = mean number of predation events observed over the n PSUs

Nocturnal predation observations

We conducted limited nighttime surface feeding observations from diurnal observation sites 25 and 43 (Fig. 1). We chose these locations because they were sites where we had observed diurnal predation events in the past and we had access to private docks from which to safely make observations. All observations occurred within 3 hours of sunrise and sunset.

Observations were conducted 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. Observations were not made according to a probability sampling design and were therefore not used to estimate total nocturnal predation. Our objectives for the nocturnal observations were simply to document if seals were successfully foraging for salmonids at night.

Harbor seal movements

Harbor seals hauled out in Alsea Bay (Fig. 1: haul-out sites 1-2) 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. Each seal was outfitted with an ultrasonic transmitter (V16-1H-R256 coded pinger manufactured by VEMCO Limited). Transmitters were secured to the pelage dorsally between the shoulder blades with cyano-acrylic superglue (Locktite 422).

Seals were passively tracked using an array of 15 acoustic receivers (Fig. 1: acoustic receiver sites A-O). Each receiver (VR2 Version 1.08 manufactured by Vemco Limited) was moored to an 18 kilogram kedge anchor with a 1.25 cm line and two Styrofoam floats. Water depth across sites ranged from 1 – 20 m at low tide. We tested transmitter range throughout the study by towing 1-2 test transmitters behind a boat traveling at < 8 kph towards and away from each receiver. The average transmitter range was approximately 300 m for most receivers but varied according to environmental conditions such as ambient noise, salinity, turbidity, and local topography. For example, the 3 offshore receivers (A-C in Fig. 1), which were in deeper water (20 m) and higher salinity than estuarine receivers, had an average range greater than 300 m while the receiver located at the mouth (D in Fig. 1), which was in a deep (20 m) narrow slot and subject to extreme turbulence during flood and ebb tides, had an average range of less than 300 m.

Receivers were deployed for varying lengths of time during the study due to vandalism, weather, and unforeseen problems. Receivers deployed less than the full length of the study periods were as follows: receivers B and C were recovered 4 November; receiver A was deployed from 2 October – 4 November; receiver E was deployed 16 September; receivers H and I were deployed 20 September; and receiver M was out of service from 4 October to 10 October. Receiver J was moved 300 m downriver on 27 September in response to complaints by local anglers.

Scat collection, processing and identification

We attempted to collect scat at low-tide haul-out sites within Alsea Bay (Fig. 1: haul-out sites 1-2) every 1-2 weeks. 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).

Haul-out counts

We attempted to count seals at low-tide haul-out sites within Alsea Bay (Fig. 1: haul-out sites 1-2) every 1-2 weeks. Haul-out counts were also conducted prior to scat collection activities.

RESULTS

Salmonid predation observations

From 1 September – 23 November 2002 we conducted 759.5 hours of daytime surface feeding observations across 63 sites in the estuary (10-14 hours per site) (Figs. 2 & 3). During this period we observed 17 instances of seals handling and/or consuming what were believed to be previously live, free-swimming adult salmonids (Table 1). (It's necessary to qualify these events as "live, free-swimming adult salmonids" because we also observed seals consuming salmonid remains scavenged from fish-cleaning stations and crab pots.) Events were observed nearly every week of the study and across the entire length of the study area (Figs. 2 & 3). Despite observing fewer seals in the river than the bay, observations of predation events were the opposite with 76% of them occurring in the river (observation sites 20 and above, Fig. 3). Prey-sharing occurred in 47% of the events. Timing of predation events appeared unrelated to river discharge (Fig. 4).

We conducted 77.5 hours of nighttime surface feeding observations across two sites. During this time we observed 3 instances of seals, and 1 instance of a California sea lion (*Zalophus californianus*), handling and/or consuming what were believed to be previously live, free-swimming salmonids (Table 1). All four events occurred at observation site 45; events occurred on 11 September (1 event), 13 September (1 event), and 10 October (2 events).

Movements

We captured and marked 59 seals over 4 days on 21-23 August and 6 September 2002 (Table 2). Three transmitters were lost at the outset of the study when tagged seals were recaptured. From the remaining 56 tags we logged over 375,000 detections across 15 receivers during the 84-day study period.

The majority of tagged seals remained within the study area for the duration of the study; the median number of days seals were detected was 74.5. A variety of patterns emerged from the detection data, examples of which are depicted in Figure 5. These included apparent preferences for the ocean (Fig. 5A), bay (Fig. 5B), and river (Fig. 5C), as well as no apparent preference (Fig. 5D). Nearly all seals were detected in the lower bay and ocean, while detections declined with increasing distances upriver (Fig. 6). In general, seals captured at the mouth haul-out were detected primarily in the ocean and bay, while seals captured at the bay haul-out were detected primarily in the bay and lower river (Fig. 7). Although 23 seals were detected in the river portion of the study area at least once, just 7 seals accounted for 94% of the 5,067 total hours spent there (Fig. 8). Seventy-three percent of the total hours spent upriver occurred at night; this was approximately 20 percentage points more than expected based on the availability of nighttime hours.

Scat analysis

We collected 117 harbor seal scat samples over 8 occasions from 6 September – 15 November 2002 (Table 3). Over 30 prey items were identified (Table 4); Pacific herring (*Clupea pallasii*), and a variety of flatfish (English sole (*Parophrys vetula)*, rex sole (*Glyptocephalus zachirus*), and Dover sole (*Microstomus pacificus*)) were among the most frequently occurring prey items found in scat. Adult salmonid remains were recovered from 9.4% of the samples.

The majority of the samples (95%) were collected at the mouth haul-out site. Three of the six scat (50%) collected from the bay haul-out contained adult salmonid remains; this is in contrast to the mouth, where only 8 of 111 (7.2%) contained adult salmonid prey remains.

Haul-out counts

Harbor seals hauled out primarily at two locations in 2002: the mouth and bay sites (Fig. 1: haul-out sites 1 and 2, respectively). Maximum counts for the mouth and bay sites were 350 and 260 animals, respectively; the maximum estuary-wide count for the season of 540 animals occurred on 21 October (Table 5).

Salmonid predation estimates

Expanding the 17 diurnal salmonid predation events that we observed, we estimate that seals consumed 1,160 adult salmonids during daylight hours over the 84-day study period (a 95% confidence interval (CI) for this total was 500 to 1,820 salmonids; percent coefficient of variation (CV) = 29%). Though circumstantial evidence (observations and movements) suggests that there may be more predation at night than day, we currently have no unbiased way to estimate how much nocturnal predation occurred. We therefore present a range of possible results (Fig. 9). For example, if we assume that diurnal predation represented as little as 10%, and as much as 90%, of total predation, then point estimates for total predation vary by an order of magnitude from 11,603 to 1,289 fish, respectively (CV for each point estimate remained 29% since the diurnal proportion was treated as a constant).

Coho predation rate

As with nocturnal predation, we currently have no unbiased way to estimate what proportion of the total estimated predation were coho. Circumstantial evidence (scat analyses and observations) suggests that coho were neither exclusively preferred nor avoided by seals relative to other salmonids. Again, we present a range of possible results (Fig. 10). For example, if we assume that coho predation represented as little as 10%, and as much as 90%, of the total predation, then point estimates for coho predation varied by two orders of magnitude from 128 to 10,440 fish, respectively (CV for each point estimate remained 29% since diurnal and coho proportions were treated as constants). Putting this in context, the preliminary estimated coho escapement for the Alsea Basin of 5,767 fish (95% CI: 2,220 – 9,314; CV=28%). Translating the 10% and 90% figures above into predation rates (Fig. 11) yielded point estimates ranging from 2% to 64% of potential escapement, respectively (CV=40% and 36%, respectively; CV's increased since they include uncertainty of escapement estimate).

DISCUSSION

In order to evaluate the potential impact seals or sea lions might have on a specific salmonid run, accurate estimates (i.e., unbiased and precise) are needed of (1) the escapement or spawner abundance of that run, and (2) the number of potential spawners in that run consumed by pinnipeds. Our objective in the Alsea Estuary has been to provide the latter, namely the number of adult coho consumed by harbor seals. Our primary method for doing this was through direct observation of seals bringing these large prey to the surface for manipulation and consumption. We were limited in our attempts to do this by (1) being restricted primarily to daylight hours and (2) not being able to consistently and reliably identify salmonid prey to species. As a result, we were only able to estimate total diurnal salmonid predation with any confidence; the extent of nocturnal predation and coho predation remains speculative.

Diurnal predation

Our estimate of total diurnal salmonid predation, while being the most accurate estimate we have been able to generate to date, is nevertheless likely an underestimate. This is due in part to the large size of the estuary which made it difficult to devise a logistically efficient sampling design that covered all areas where seals and salmonids might interact. In fact, the Alsea Estuary is one of the largest areas where surface feeding observations have been attempted and probably represents the limit at which such a method is feasible. Most other studies have occurred at locations with only a one or two observation sites (NMFS 1999; London et al. 2002). The only known larger site that was ever attempted was the lower Columbia River which quickly proved infeasible (Laake et al., 2002). Areas that may represent undercoverage in our spatial sampling frame included: (1) tidal mudflats in the bay that were only available to seals and salmonids at high tide; (2) Drift Creek, which is a large spawning tributary located at observation site 25; and (3) the Alsea River above observation site 63. If predation occurred in these unsampled areas then our diurnal estimate would be biased low.

Nocturnal predation

It is not feasible to replicate our diurnal sampling design at night in order to estimate the amount of predation that occurs during that time. We do know, however, that seals successfully forage for salmonids at night; it has been documented in this study (Table 1) as well as others (London et al. 2002). Results from our movement study have provided intriguing insight into this question. From our diurnal observations (Fig. 2 & 3), as well as our previous research (Riemer 2001, Wright 2002), we know that the majority of observed salmonid predation occurred in the river. This is likely due to an increase in foraging opportunities and success conferred by the narrowing of the river channel and perhaps the behavior of the fish themselves as they proceed upriver. For example, fish may bunch up and “hold” while they adapt to freshwater and wait for river levels to increase with fall rains, which in turn may make them easier to find and capture. If seals are only going upriver to feed on salmonids (which we believe to be the case), then, as Figure 8 shows, they are in fact doing so more at night then during the day. If their nocturnal foraging success is greater than or equal to their diurnal success, then total predation is likely somewhere on the left-hand side of Figure 9.

Coho predation

From surface observations, it is not possible to consistently and accurately identify what type of salmonid a seal may have predated. This leaves species-specific predation estimation to an indirect method such as scat analysis. That is, we estimate the proportion of coho consumed based on the proportion found in scat. This assumes that the scat sample is representative of the seal population over the study period (see below), and that passage rates through the seal gastrointestinal tract are the same between salmonid species.

Since salmonid remains (with the exception of otoliths) cannot be identified to species based on morphological characteristics, genetic analysis of remains is required in order to use this approach. We have not yet conducted such an analysis on scat collected in 2002 but we have done so for scat collected during equivalent periods from 1997-2001 (Table 6). This work showed a variety of things: (1) it documents for the first time that seals in Alsea Bay do in fact eat coho (this was assumed and expected but difficult to prove from direct observation); (2) the range of collection dates with coho remains suggests our 3-month fall study period coincides well with run timing; (3) seals don't appear to exclusively prefer or avoid coho relative to chinook; and (4) the presence of scat containing both coho and chinook salmon suggests that some of the scat containing single species likely contain remains from more than one individual of the same species. The last finding suggests that it will be necessary to take the genetic work one step beyond species identification to the identification of individual fish. This will allow us to make an estimate of the frequency of coho in the diet based on individual bones rather than on individual scat.

Even assuming equal passage rates between salmonid species, the above method will not provide an unbiased estimate of the proportion of coho in the diet unless the scat sample is representative of the population of seals under study. Results from 2002 suggest our sample may not be representative. In the Alsea estuary in 2002 there were two haul-outs used by seals and upon which we attempted to collect scat. Even though we attempted to collect scat from both sites, the majority of our samples came from the mouth (Table 3). It is clear from the movement data that seals captured at the mouth haul-out tend to spend most of their time in the ocean and bay, and seals captured at the bay haul-out tend to spend most of their time in the bay and river (Fig. 7). Therefore, if most of our sample comes from the mouth, then we are likely not obtaining a representative sample of the overall diet of the population. This is dramatically illustrated by the movements of seal #25M2 in Figure 5C. This seal, which we suspect specializes on adult salmonids during the fall, did not appear to use the mouth haul-out. This means that its scat was largely unavailable for sampling, and as a result, we may have missed the scat from the very animals we are most interested in. In scat collections from previous years, we have also found that the percent frequency of occurrence of salmonid remains was higher at the bay haul-out site, even though the number of samples collected at the site was relatively low.

Predation impact

Even without the limitations noted above, assessing the role of pinniped 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 that "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 due to low marine survival, 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 might provide the information necessary to make such an assessment. However, without a way to adequately address nocturnal and coho-specific predation the benefits of continued diurnal monitoring are questionable.

ACKNOWLEDGEMENTS

Many people contributed in numerous ways to make this project possible. Funds were provided by NOAA Fisheries (Northwest Regional Office) and by the Oregon Department of Fish and Wildlife (Wildlife Diversity Program). The Pacific States Marine Fisheries Commission secured and administered the federal funds for this project. Joe Scordino (NOAA Fisheries) was instrumental in developing pinniped predation studies in Oregon. Our field project staff, whose hard work and dedication made this work possible, were Jennifer Duncan, Jean Higgins, and Lisa Sztukowski. The following people assisted with our seal capture efforts: Rick Boatner, Peg Boulay, Jesse Brown, Patty Burke, Chris Carey, Kevin Goodson, Troy Guy, Justin Jenniges, Dylan Kesler, Jennifer Lloyd, Tracy MacAuley, Bill Miller, Jack Mortenson, Jeanne Ross, Jon Scordino, John Seabourne, Matt Tennis, John Toman, Judy Tuttle, and Tami Wagner. Carl Shreck, Shaun Clements, and Mark Karnowski of the Oregon Cooperative Fish and Wildlife Research Unit loaned us their acoustic receivers and their expertise on how to use them. Michael Banks and Mary Kvitrud of Hatfield Marine Science Center's Marine Fisheries Genetics Lab analyzed salmonid remains from our scat samples. Finally, we'd like to acknowledge our colleagues in the West Coast Cooperative Pinniped Program for their ongoing support and advice.

LITERATURE CITED

Cochran, W. G. 1977. Sampling Techniques, 3rd Ed. John Wiley and Sons, NY

Jeffries, S. J., R. F. Brown, and J. T. Harvey. 1993. Techniques for capturing, handling and marking harbour seals. Aquatic Mammals. 19.1: 21-25.

Laake, J. L., P. Browne, R. L. DeLong, and H. R. Huber. 2002. Pinniped diet composition: a comparison of estimation models. Fishery Bulletin 100(3): 434-447.

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. Alaska Fisheries Science Center Processed Report 2001-04.

Lawson, P. 1999. Appendix B.13. Assessing the impact of pinniped predation on coho salmon populations: a life-history modeling approach. Draft workshop summary: Review of field and analytical methodologies for assessing pinniped predation on salmonids, April 20-22, 1999, Newport, OR. National Marine Fisheries Service.

London, J. M., M. M. Lance, S. J. Jeffries. 2002. Observations of Harbor Seal Predation on Hood Canal Salmonids from 1998 to 2000. Unpublished contract report to National Marine Fisheries Service, NOAA Grant No. NA17FX1603.

National Marine Fisheries Service (NMFS). 1999. Pinniped predation on salmonids: preliminary reports on field investigations in Washington, Oregon, and California. NMFS Northwest Region Compiled Report.

Nickelson, T.E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Oregon Department of Fish and Wildlife, Fish Information Report 98-4. Portland.

Nickelson, T.E. 2001. Population assessment: Oregon coast coho salmon ESU. Oregon Department of Fish and Wildlife, Fish Information Report 2001-2. Portland.

Nickelson, T.E. and P. Lawson. 1998. Population viability of coho salmon *Ocorhynchus kisutc*h, in Oregon coastal basins: Application of a habitat-based life-cycle model. Canadian Journal of Fisheries and Aquatic Sciences 55: 2383-2392.

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. Unpublished contract report to National Marine Fisheries Service, NOAA Grant No. NA87FX0464.

Thompson, S. K. 1992. Sampling, John Wiley & Sons, NY.

Wright, B. E., S. D. Riemer, and R. F. Brown. 2002. Monitoring pinniped predation on salmonids at the Alsea River, Oregon. Unpublished contract report to National Marine Fisheries Service, NOAA Grant No. NA87FX0464.

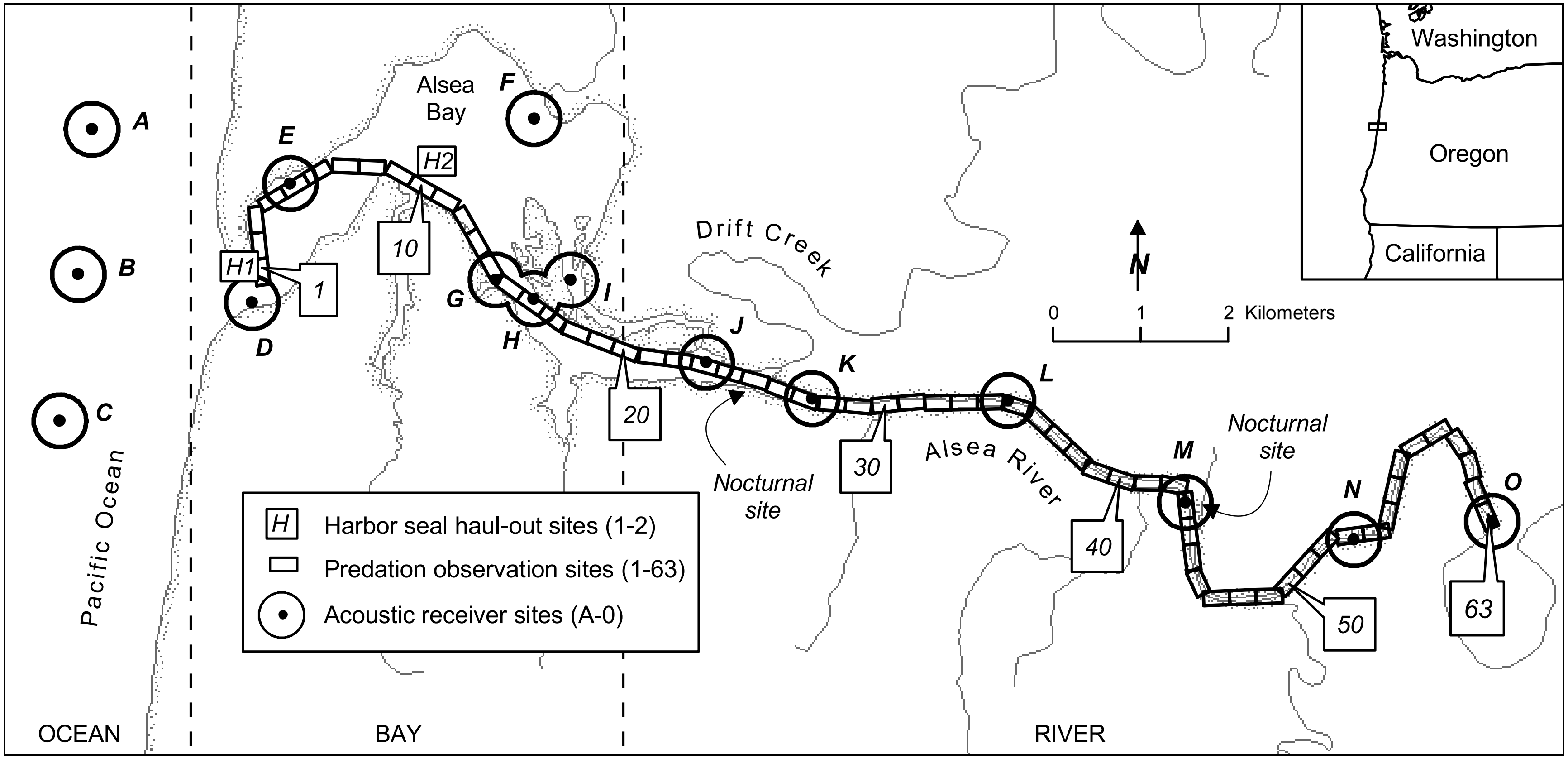

Figure 1. Map of the Alsea Estuary, Oregon showing locations of harbor seal haul-out sites, diurnal predation observation sites, and acoustic receiver sites. Circles around acoustic receiver sites depict the average transmitter detection distance of 300 m. Nocturnal predation observation sties were at diurnal observation sites 25 and 43. Vertical dashed lines indicate approximate boundaries between the ocean, bay, and river portions of the study area. All tributaries depicted on the map (including the mainstem) contain coho salmon spawning habitat.

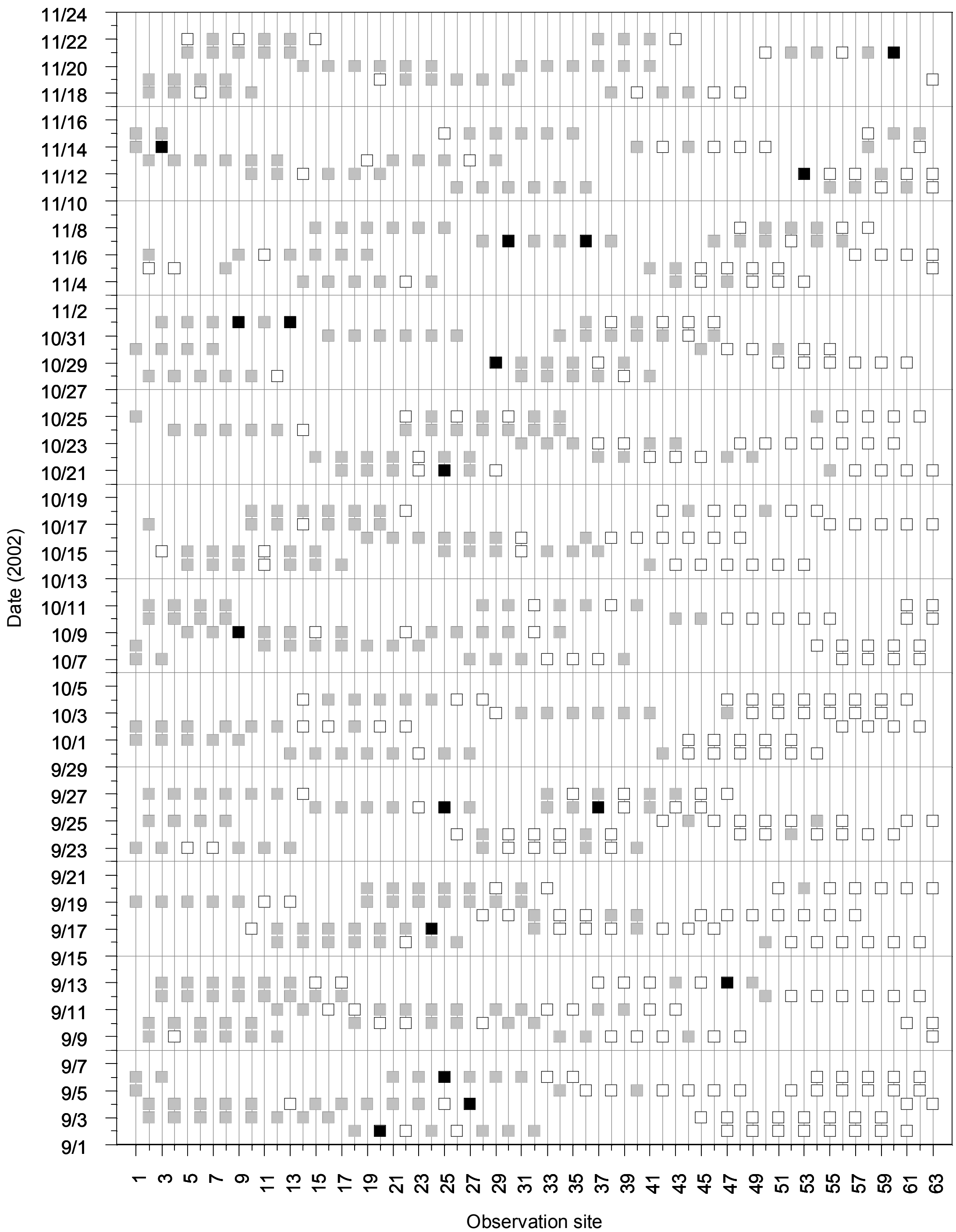

Figure 2. Diurnal predation observation results from the Alsea Estuary, Oregon, 1 September - 23 November, 2002. Each square represents either 30 or 60 minutes of observation and depicts one of three possible outcomes: a white square indicates no seals were observed; a gray square indicates at least one seal was observed; and a black square indicates a salmonid predation event was observed.

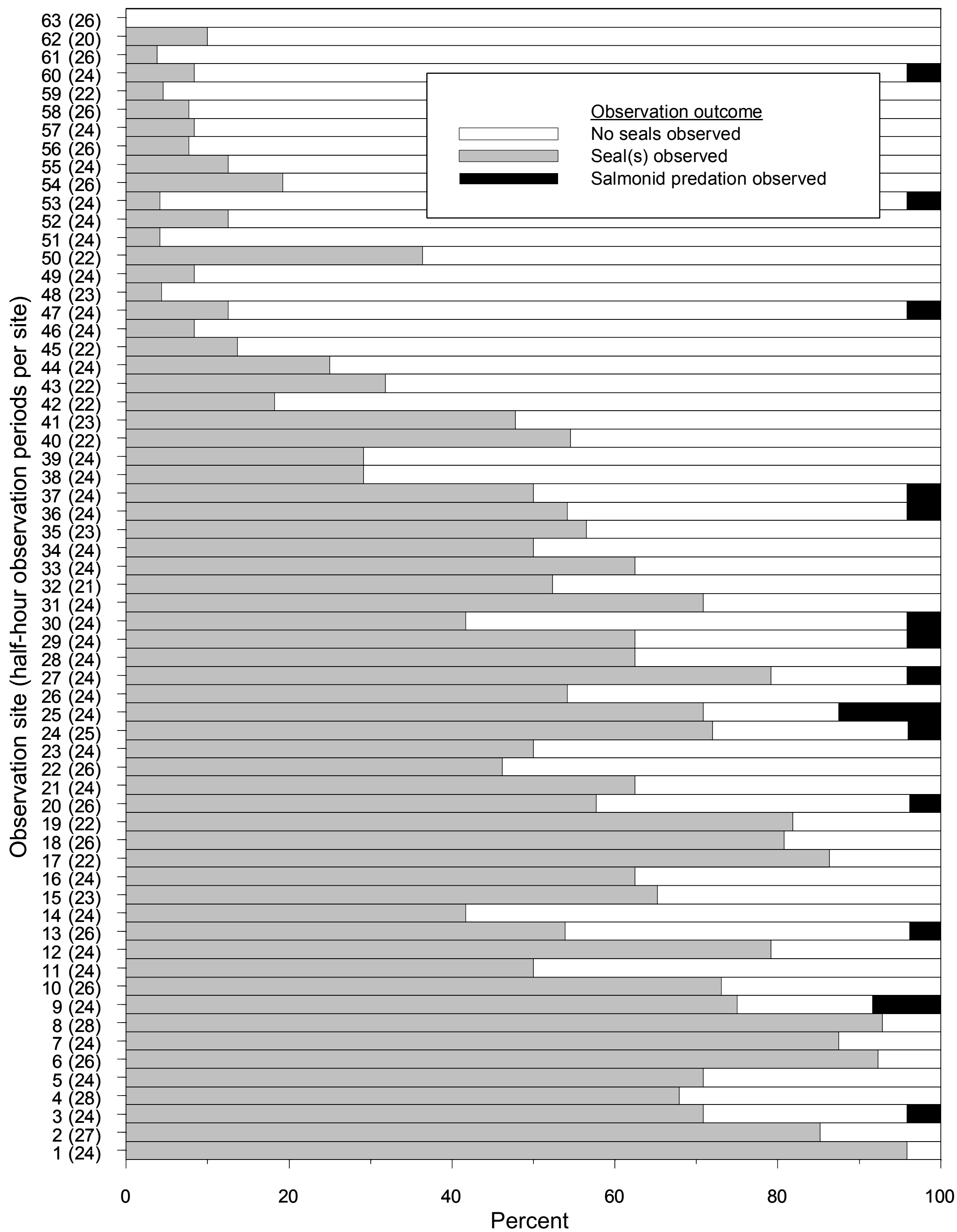

Figure 3. Diurnal predation observation results from the Alsea Estuary, Oregon, 1 September - 23 November, 2002. Results are expressed as the percent of observation periods resulting in one of three possible outcomes (see legend above).

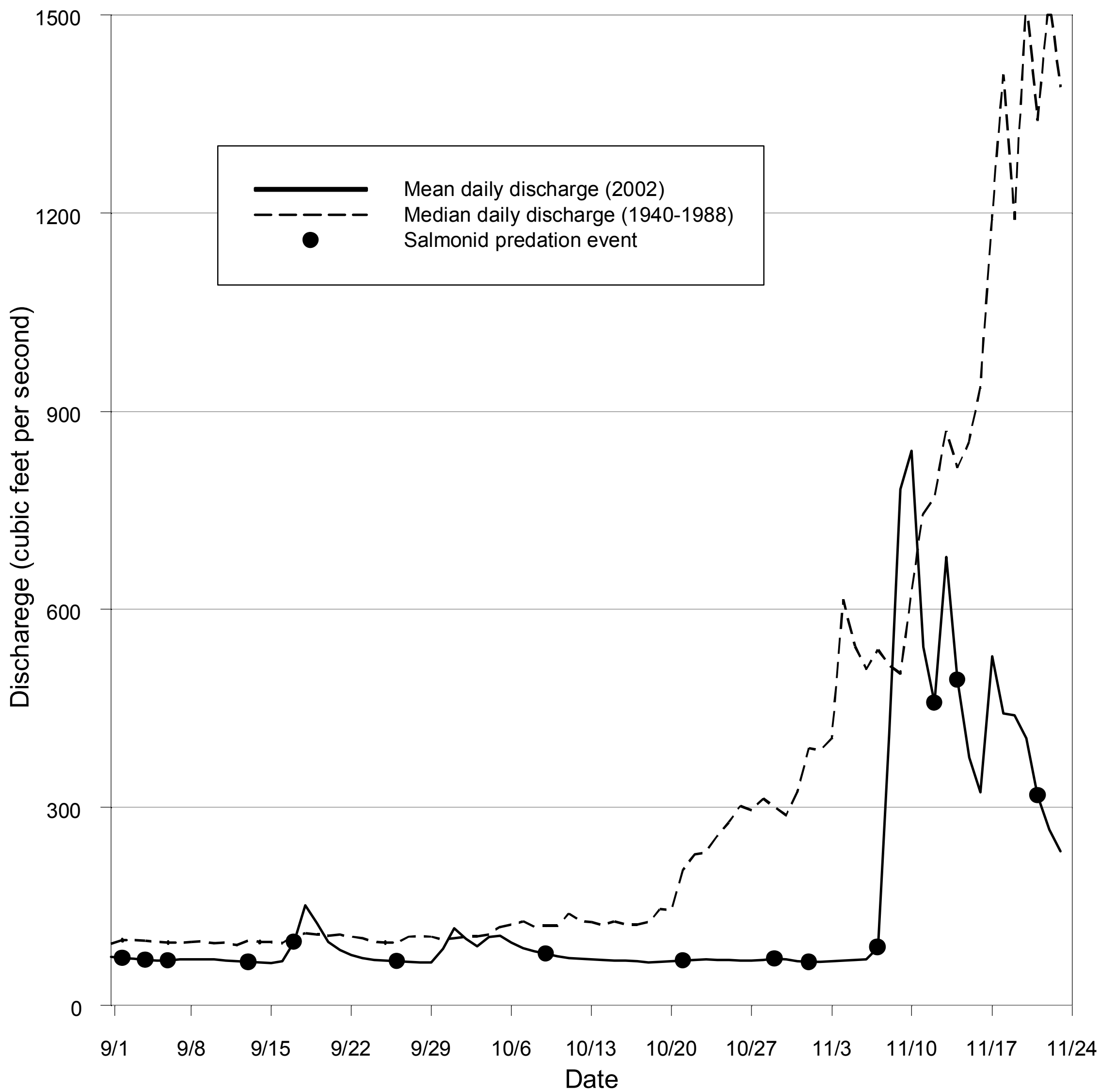

Figure 4. Relationship between diurnal predation events and mean daily river discharge at the Alsea Estuary, Oregon, from 1 September - 23 November, 2002.

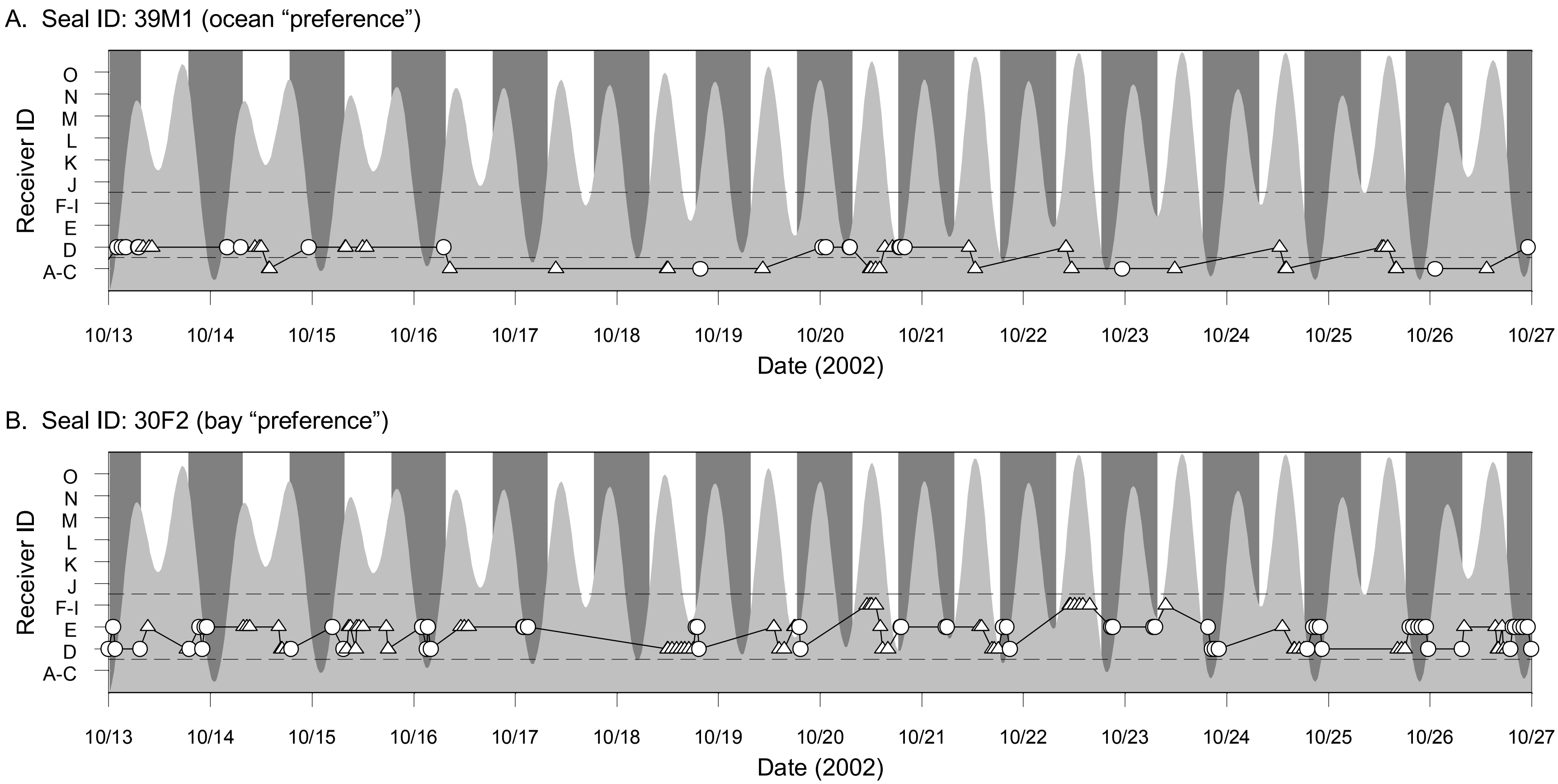

Figure 5. Movement profiles for four harbor seals (A-D) in the Alsea Estuary, Oregon, 13 October - 27 October 2002. Dark and light vertical bars represent night and day, respectively. Light gray foreground represents tide cycle (tidal range is approximately 8 feet). Horizontal dashed lines demarcate the ocean, bay, and river portions of the study area. Seal detections are represented by circles (night) and triangles (day). Ocean receivers (A-C), and upper bay receivers (F-I) were grouped for this presentation (see Fig. 1).

C. Seal ID: 25M2 (river "preference")

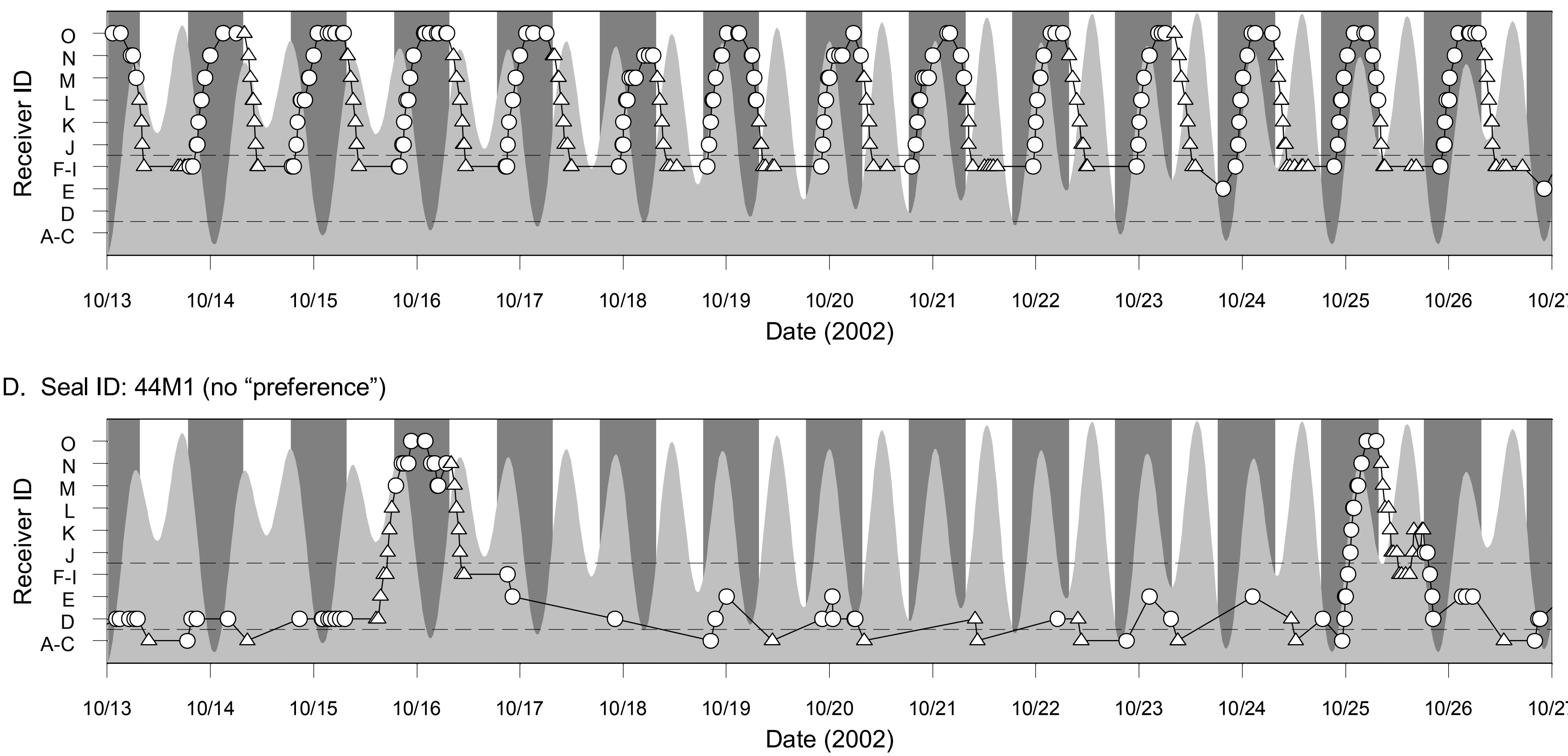

Figure 5 (continued).

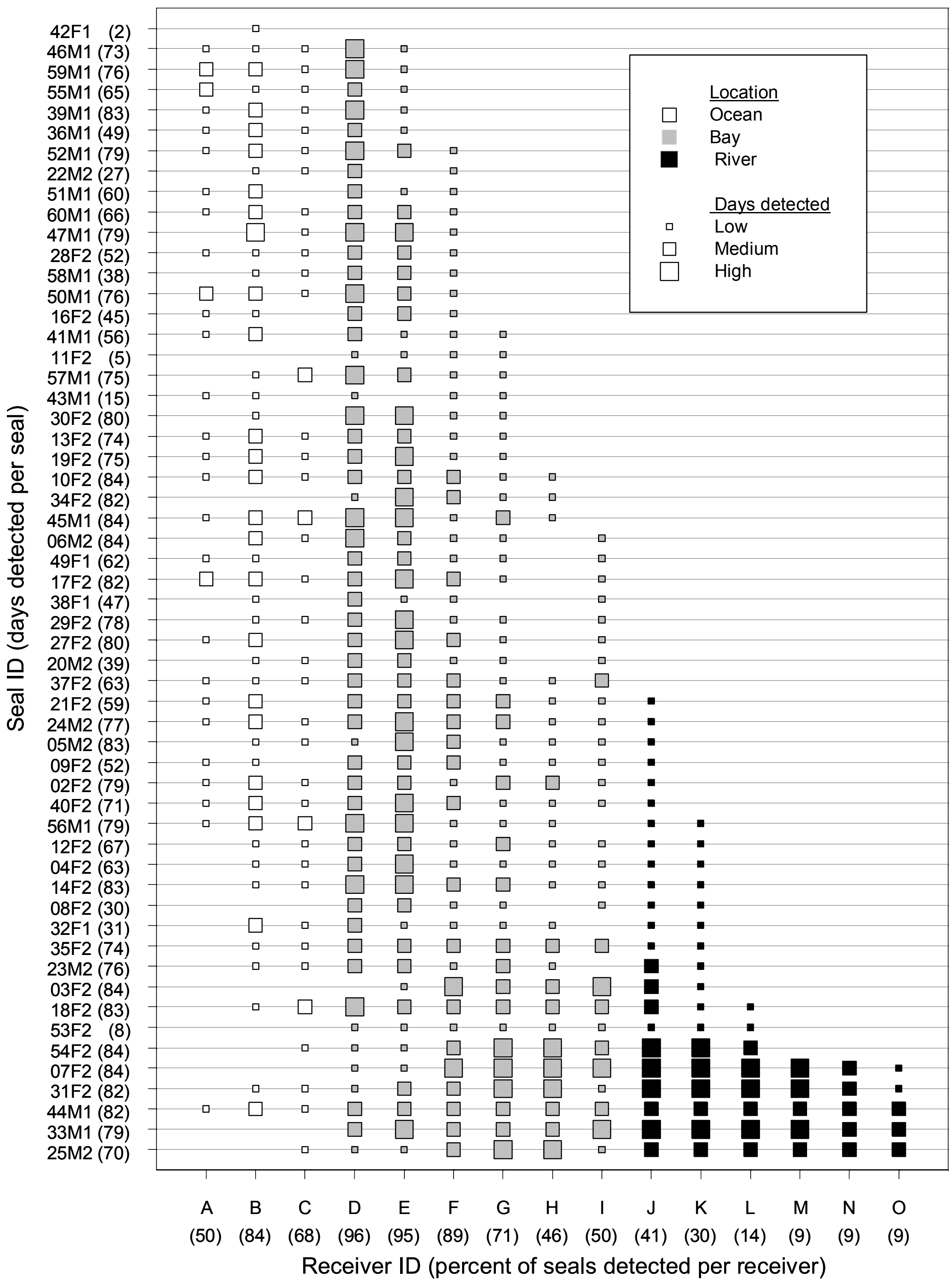

Figure 6. Detection summaries for harbor seals in the Alsea Estuary, Oregon, from 1 September - 23 November, 2002. Seal ID consists of transmitter number, sex, and haul-out at which it was captured. Relative square size indicates the percentage of days the seal was detected at a receiver (low = <25%, medium = 25-75%, high = >75%).

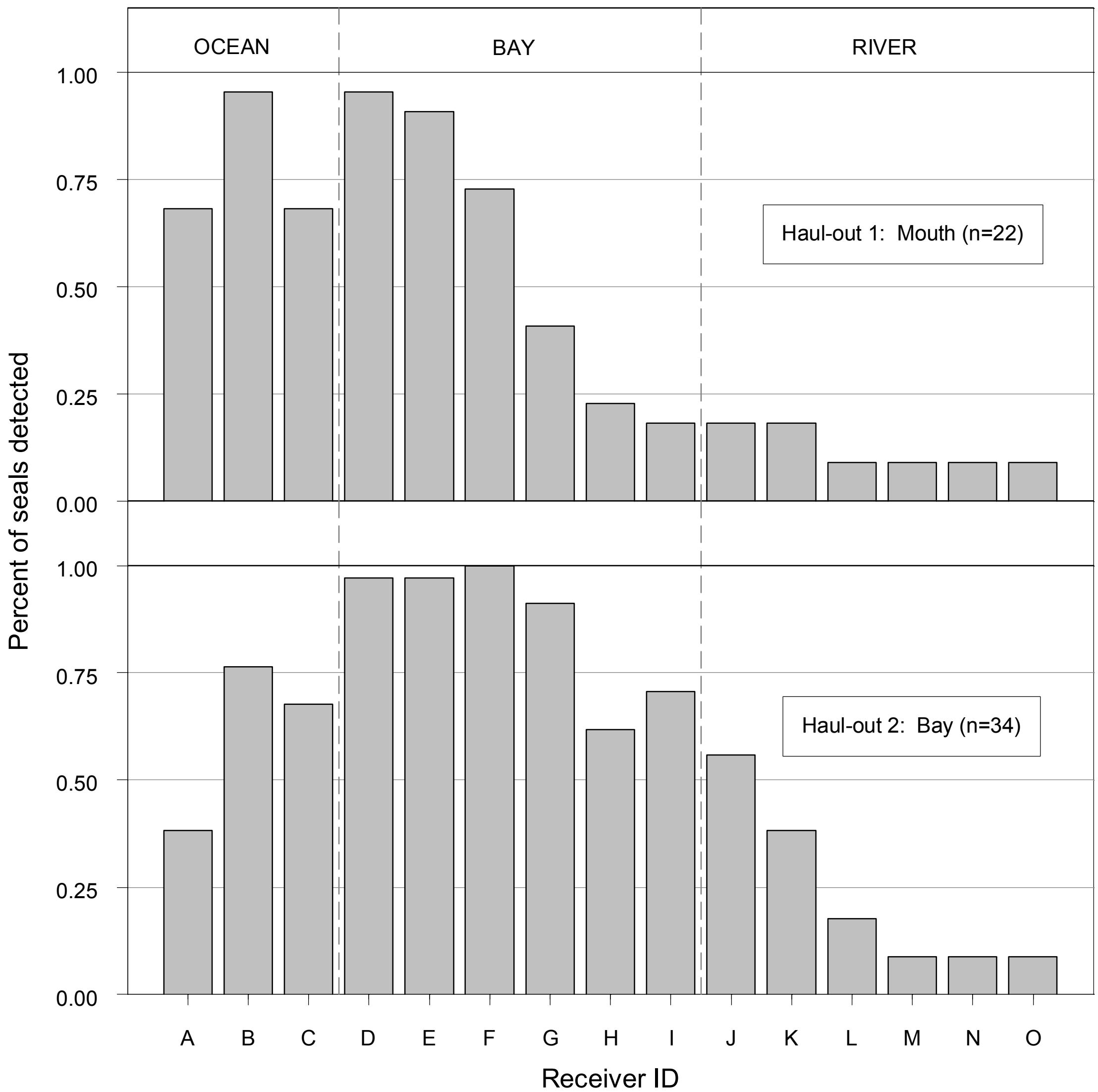

Figure 7. Comparison of acoustic receiver detections based on the haul-out at which harbor seals were captured, Alsea Estuary, Oregon, 1 September - 23 November, 2002.

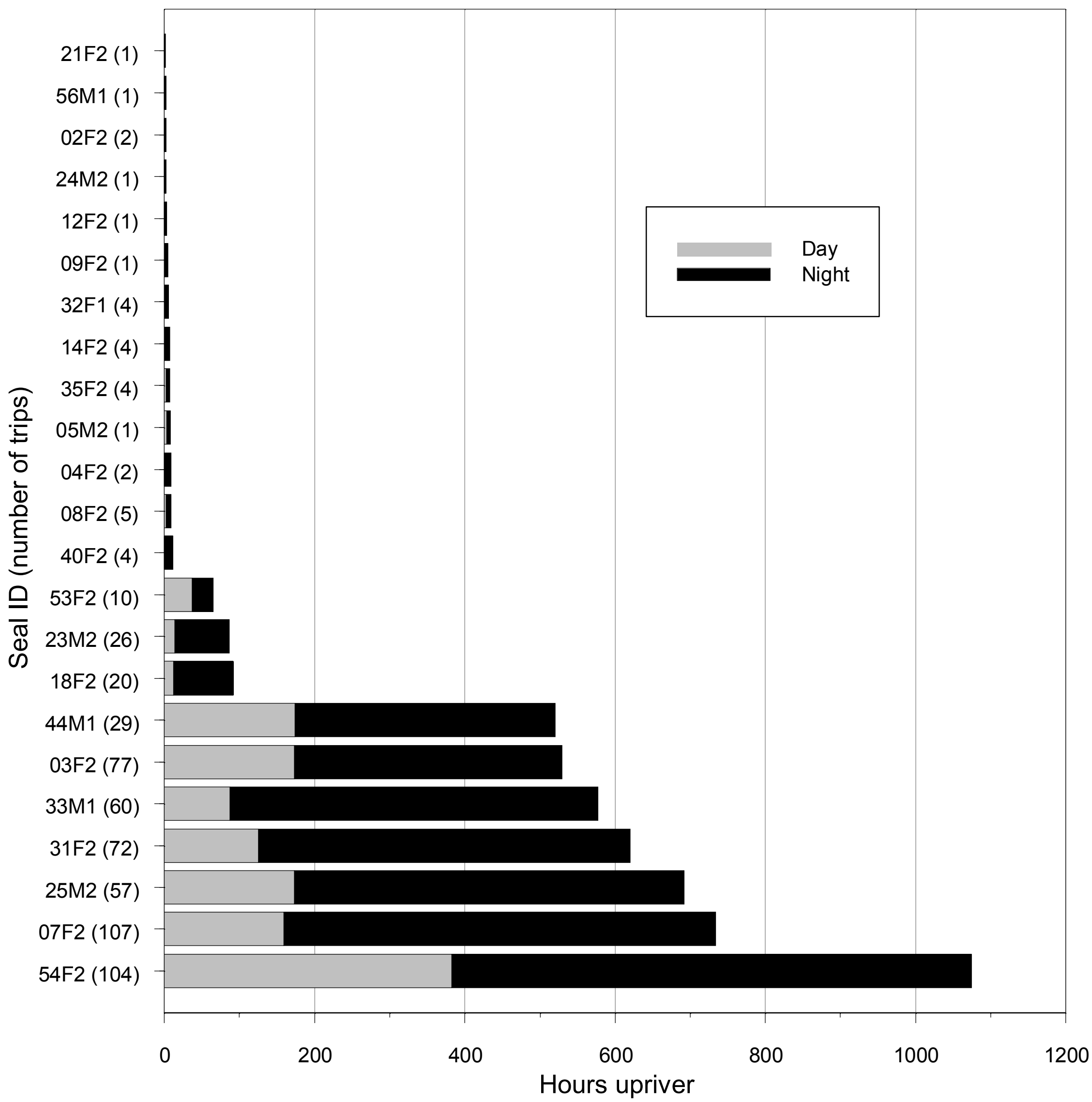

Figure 8. Total number of hours spent upriver by harbor seals in the Alsea Estuary, Oregon, 1 September - 23 November, 2002. Seal ID consists of transmitter number, sex, and haul-out at which it was captured; number of trips per seal in parentheses. The start and end of an upriver trip is defined by the time of first detection at receiver site J and either F, G, H, or I, respectively (Fig. 1).

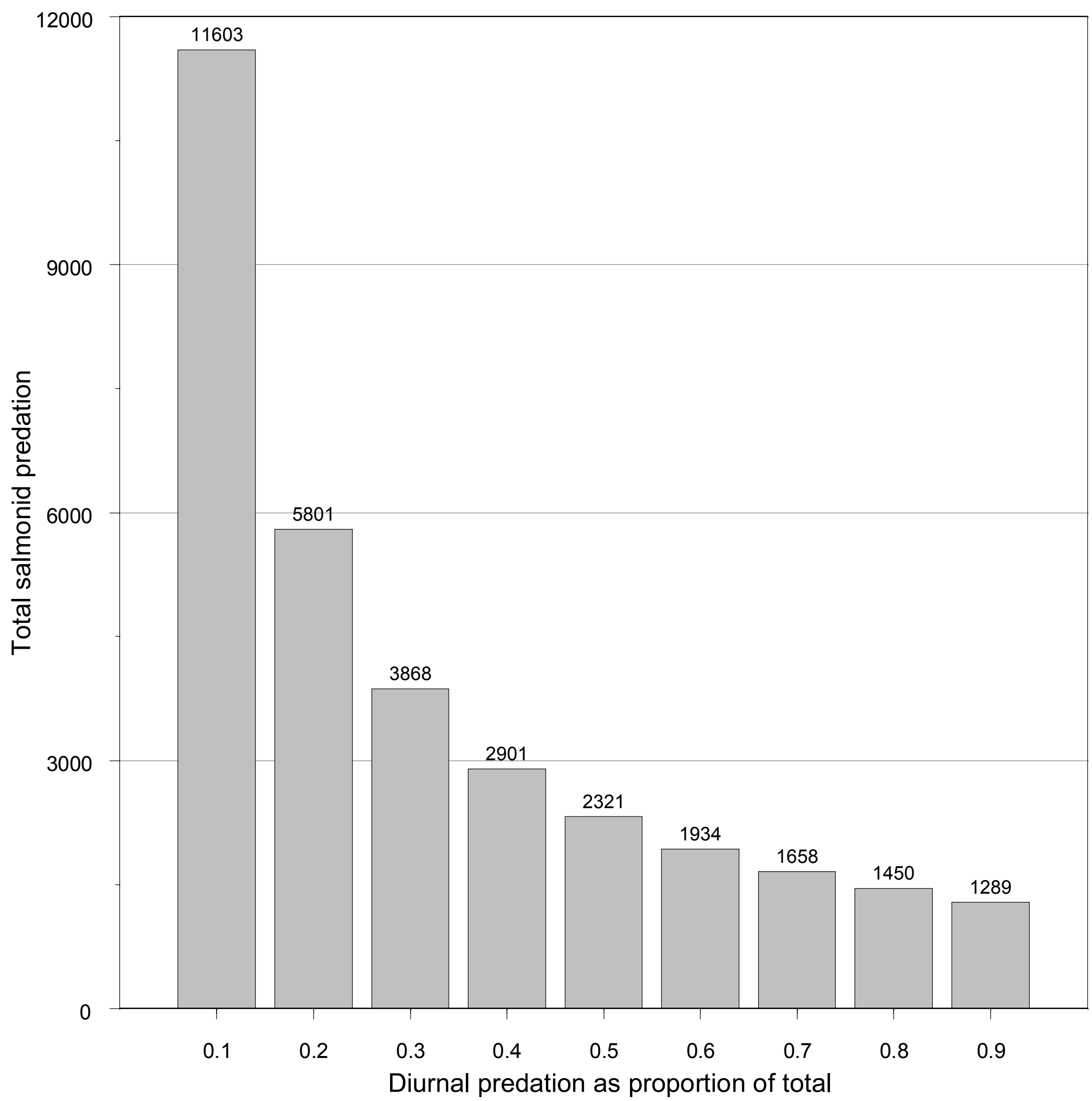

Figure 9. Estimated total adult salmonid predation as a function of the proportion of diurnal predation in the Alsea Estuary, Oregon, 1 September - 23 November, 2002. For example, if diurnal predation represents one-half of all predation that occurred (0.5), then the total loss of adult salmonids is estimated to be 2,321 fish. The coefficient of variation for each estimate is 29%.

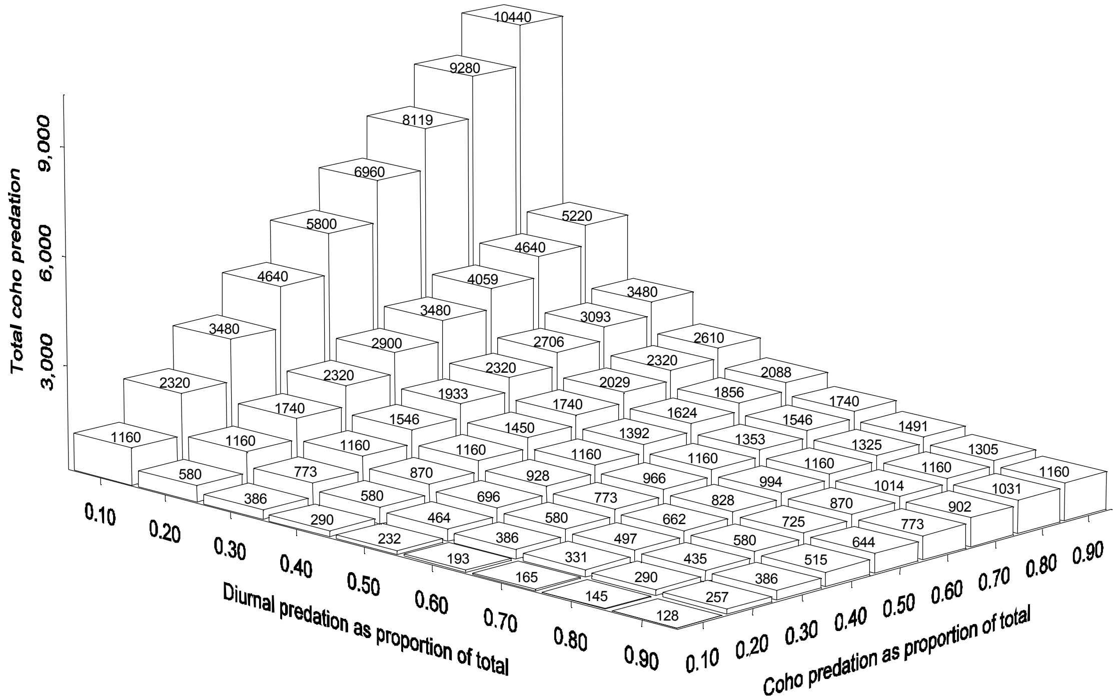

Figure 10. Estimated total adult coho predation as a function of the proportions of diurnal predation and coho predation in the Alsea Estuary, Oregon, 1 September - 23 November, 2002. For example, if diurnal predation represents one-half of all predation that occurred (0.5), and if coho represents one-half of all salmonid taken (0.5), then the total loss of adult coho is estimated to be 1,160 fish. The coefficient of variation for each estimate is 29%.

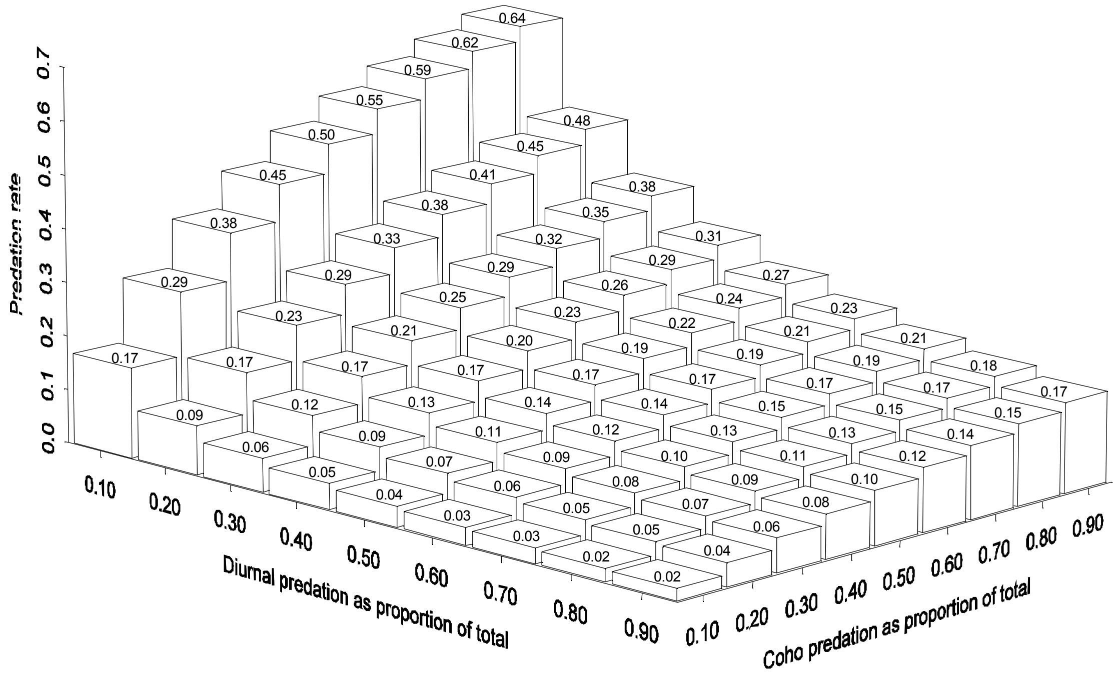

Figure 11. Estimated percent of adult coho escapement taken by harbor seals as a function of the proportions of diurnal predation and coho predation in the Alsea Estuary, Oregon, 1 September - 23 November, 2002. For example, if diurnal predation represents one-half of all predation that occurred (0.5), and if coho represents one-half of all salmonid taken (0.5), then the percentage of the total estimated run size consumed by seals is estimated to be 17%. The coefficient of variation for estimates range from 36% to 40%.

Table 1. Predation observations in the Alsea Estuary, Oregon, 1 September - 23 November, 2002.

	Prey type			
Observation type	Salmonid	Non-salmonid	Undetermined	Total
Diurnal - sample[1]	17	1	2	20
Diurnal - anecdotal[2]	6	0	2	8
Nocturnal – anecdotal[3]	4	0	2	6
Total	27	1	6	34

[1] These events occurred at predetermined sites during prescheduled times according to the probability sampling design. Only these salmonid predations were used to estimate total diurnal salmonid predation.

[2] These events were observed outside of the spatio-temporal bounds of the diurnal probability sample (e.g., while traveling between sites, during breaks, etc.).

[3] These events, while occurring at predetermined sites during scheduled times, were not made according to a probability sampling design and were therefore not used to estimate nocturnal salmonid predation.

Table 2. Harbor seal capture data for the Alsea Estuary, Oregon, 2002.

		Number of harbor seals tagged (number of tags lost during subsequent recaptures)		
Date	Haul-out site	Males	Females	Total
21 AUG 2002	2 - Bay	5	11(2)	16 (2)
22 AUG 2002	2 - Bay	2	18	20
23 AUG 2002	1 - Mouth	5	5 (1)	10 (1)
06 SEP 2002	1 - Mouth	13	0	13
Total		25	34 (3)	59 (3)

Table 3. Harbor seal scat collection data for the Alsea Estuary, Oregon, 2002.

	Number of scat collected (number without remains)		
Date	Haul-out 1 - Mouth	Haul-out 2 - Bay	Total
06 SEP 2002	26	-	26
17 SEP 2002	9 (1)	-	9 (1)
19 SEP 2002	20	-	20
07 OCT 2002	39 (3)	8 (4)	47 (7)
08 OCT 2002	0	-	0
09 OCT 2002	0	-	0
14 OCT 2002	2	-	2
21 OCT 2002	3 (1)	2	5 (1)
23 OCT 2002	1	-	1
06 NOV 2002	15 (2)	-	15 (2)
15 NOV 2002	6 (3)	-	6 (3)
Total collected	121(10)	10 (4)	131 (14)

Table 4. Percent frequency of occurrence (FO) of harbor seal prey identified collected the Alsea Estuary, Oregon, 2002.

	Percent frequency of occurrence by date and haul-out										
	06 SEP	17 SEP	19 SEP	07 OCT		14 OCT	21 OCT		23 OCT	06 NOV	15 NOV	
Prey category	1 - Mouth	1 - Mouth	1 - Mouth	1 - Mouth	2 - Bay	1 - Mouth	1 - Mouth	2 - Bay	1 - Mouth	1 - Mouth	1 - Mouth	Total
Pacific herring	42.3	50.0	90.0	38.9					100.0	7.7		41.9
English sole	80.8	12.5	5.0	38.9			50.0			38.5		36.8
Flatfish/not Dab	34.6		10.0	36.1	25.0					23.1		23.9
Rex sole	38.5	37.5	10.0	13.9			50.0			15.4		19.7
Dover sole	26.9	37.5	5.0	16.7	25.0							15.4
Pacific sand lance	11.5	12.5	5.0	11.1	25.0	100.0		50.0		23.1		13.7
Pacific tomcod	11.5		10.0	22.2						15.4	33.3	13.7
Smelt	11.5			19.4		50.0				7.7	33.3	11.1
Butter sole	19.2			16.7						7.7		10.3
Flatfish order	7.7	37.5		11.1	25.0		50.0			7.7		10.3
Sanddab	19.2	25.0		8.3			50.0			7.7		10.3
Sculpin	7.7		5.0	13.9					100.0	23.1		10.3
Salmon adult	7.7			5.6	50.0			50.0		7.7	100.0	9.4
Pacific hake	3.8	25.0	20.0	5.6	25.0							8.5
Northern anchovy					25.0	100.0		100.0		23.1		6.8
Unidentified fish	3.8		15.0	2.8			50.0	50.0		7.7		6.8
Herring/Shad	3.8			8.3			50.0			7.7	33.3	6.0
Shiner perch	3.8			2.8				50.0		15.4		4.3

Table 4 (cont.).

	Percent frequency of occurrence by date and haul-out											
	06 SEP	17 SEP	19 SEP	07 OCT		14 OCT	21 OCT		23 OCT	06 NOV	15 NOV	
Prey category	1 - Mouth	1 - Mouth	1 - Mouth	1 - Mouth	2 - Bay	1 - Mouth	1 - Mouth	2 - Bay	1 - Mouth	1 - Mouth	1 - Mouth	Total
Octopus	3.8			2.8			50.0			7.7		3.4
Pacific staghorn sculpin	7.7			2.8				50.0				3.4
Perch	3.8					100.0				7.7		3.4
Rockfish			5.0	5.6			50.0					3.4
Slender sole	3.8			2.8	25.0							2.6
Lamprey				2.8						7.7		1.7
Sand sole	7.7											1.7
Cephalopod			5.0									0.9
Eelpout								50.0				0.9
Gadidae						50.0						0.9
Gunnel				2.8								0.9
Irish lord				2.8								0.9
Lingcod									100.0			0.9
Pacific sandfish	3.8											0.9
Poacher		12.5										0.9
Salmon juvenile				2.8								0.9
Skates	3.8											0.9
Cartilaginous fish					25.0							0.9
n scat with remains	26	8	20	36	4	2	2	2	1	13	3	117

Table 5. Harbor seal haul-out data for the Alsea Estuary, Oregon, 2002.

Date	Harbor seal count		
	Haul-out 1 - Mouth	Haul-out 2 - Bay	Total
06 SEP 2002	350	105	455
18 SEP 2002	0	-*	-
20 SEP 2002	79	260	339
14 OCT 2002	150	-	-
18 OCT 2002	288	104	392
21 OCT 2002	350	190	540
01 NOV 2002	0	0	0
06 NOV 2002	300	-	-
Maximum count	350	260	540

* Haul-out count was not conducted.

Table 6. Results from the genetic analysis of salmonid remains in harbor seal scat samples collected in the Alsea Estuary, Oregon, during the fall (September – November), 1997-2001. Genetic analysis was based on all salmonid bones recovered scat samples.

	Scat sample		Genetic identification			Coho collection date	
Year	Total	With salmonid DNA	Coho only	Chinook only	Mixed spp.*	First	Last
1997	506	17	4	11	2	09 SEP	18 SEP
1998	392	24	15	4	5	19 SEP	19 OCT
1999	244	14	3	11	0	11 OCT	20 NOV
2000	140	6	3	1	2	13 SEP	28 SEP
2001	125	6	1	4	1	14 SEP	29 SEP

*Scat contained both coho and chinook with the exception of one scat in 2000 that contained chinook and either steelhead or cutthroat trout.