Observations of Harbor Seal Predation on Hood Canal Salmonids from 1998 to 2000

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Introduction

Foraging ecology of pinnipeds has been the subject of scientific investigations for many years because pinnipeds are often perceived as being in competition with human fisheries. Examples of pinniped-fishery interactions during the last century exist in various locations throughout the world. Seal and sea lion populations in the northeast Pacific rely on groundfish, herring, salmon and squid as major components of their diet (Lowry & Frost 1985). These same stocks are also large components of commercial fishery operations. Grey seals in Britain have been implicated in a number of detrimental fishery interactions ranging from predation on free swimming and net-pen salmon to more indirect effects of driving fish away from nets and increasing the presence of codworm in the Atlantic cod (Harwood & Greenwood 1985). However, pinniped-fishery interactions must also be examined with some perspective. During the late nineteenth and early twentieth centuries, many pinniped stocks throughout the world were hunted to a small fraction of their former population levels (Beddington & Mare 1985) for both fur and to reduce fishery interactions. From early in the twentieth century until passage of the federal Marine Mammal Protection Act of 1972 (MMPA), Washington State had an active pinniped control unit and bounty program for the removal of pinniped species. Significant conservation efforts in the last century and passage of laws such as the MMPA have allowed many pinniped populations to rebound; however many remain critically low (VanBlaricom et al. 2001).

In recent years, the west coast of the United States has seen the emergence of a new category of pinniped-fishery interactions. Since the passage of the MMPA, populations of California sea lions (*Zalophus californianus*) and Pacific harbor seals (*Phoca vitulina richardsii*) have experienced dramatic increases throughout the West Coast, and may be at their highest levels in several centuries (NMFS SAR 2001). Increases in pinniped populations have coincided with dramatic decreases of many marine and anadromous fish populations (WDF et al. 1993). A number of these populations have declined to a point where they have been listed, or are under consideration for listing, as endangered or threatened under the federal Endangered Species Act (ESA) of 1973 as amended. There has been a growing concern throughout the West Coast that pinnipeds, while not likely the cause of any decline in salmonids, have the potential to affect the recovery of many threatened and endangered salmonid stocks (NMFS 1999).

Ballard Locks and Willamette Falls

The importance of understanding potential impacts pinnipeds could have on declining salmonid populations came to the forefront when California sea lions were consistently observed foraging on returning winter steelhead (*Oncorhyncus mykiss*) at the Ballard Locks in Seattle, Washington. The situation at Ballard was ongoing from the mid-1980s through 1995 and was well documented (NMFS 1995). At the peak of predation activity, close to sixty percent of the returning winter steelhead run was being consumed by sea lions. As the number of returning steelhead declined to critically low levels, various non-lethal mitigating actions were employed in an attempt to reduce the level of predation on steelhead. By 1995, non-lethal actions were determined to be ineffective and, after a number of hearings and detailed investigations, National Marine Fisheries Service (NMFS) issued a permit to the Washington Department of Fish and Wildlife (WDFW) for lethal removal of individual pinnipeds under Section 120 of the MMPA. Before lethal removal, however, arrangements were made to relocate predatory sea lions to a captive situation at Sea World in Orlando, Florida. Since the individual sea lions were removed from the area, little or no predation has been observed. However, while there was an initial increase in numbers of returning steelhead in the years directly following removal of predatory sea lions, the annual number of returning spawners has remained critically low.

The issue of California sea lion predation on Threatened or Endangered salmonids has not been limited to the Ballard Locks. Since 1992, the Oregon Department of Fish and Wildlife (ODFW) has reported observing California sea lions foraging on salmon and steelhead at the Willamette Falls fishway, 101 miles upstream from the mouth of the Columbia River (NMFS 1997a). Peak foraging activity coincides with the return of adult spring Chinook salmon (*O. tshawytscha*) and winter steelhead. Both salmonid populations have experienced declines in recent years. Conservation of these particular two salmonids is especially important because they are the only remaining native salmonid populations that exist above Willamette Falls. A cooperative effort between NMFS and ODFW was begun in 1997 to reduce sea lion predation on returning salmonids, in part because of similarities to the situation observed at the Ballard Locks (NMFS 1997a).

Of the numerous lessons and knowledge gained from the situations at Ballard and Willamette Falls, three stand out. First, resource managers and researchers need to take a proactive approach by initiating studies to understand the impact of pinnipeds on a declining population before actually reaching threatened or endangered levels. Section 120 of the MMPA requires that a “significant negative impact” to the threatened or endangered fish population be demonstrated in a quantitative manner. This requires several years of research and if not done prior to a population reaching critically low levels, valuable time may be spent investigating impacts instead of implementing management action that could lead to recovery (NMFS 1997b).

The second lesson is, while there are certainly unique aspects to Ballard and the Lake Washington Ship Canal, and to some extent the Willamette Falls fishway, that allowed unprecedented levels of pinniped predation on returning salmonids, it is reasonable to expect analogous situations to exist in a more natural environment. Pinniped haul-outs throughout the west coast often occur at or near mouths of rivers that support a number of declining salmonid populations. At any such estuarine or nearshore area where fish passage is constrained by natural or artificial barriers, there are possibilities for predation to occur (NMFS 1999). The key question, however, is not whether predation is occurring, but rather if predation is negatively affecting the ability of a particular salmonid population to recover from low numbers. Additionally, any negative affect pinniped predation may be having on the recovery of a particular salmonid stock should be considered within the context of a myriad of other factors such as habitat degradation, harvest, climate change, and pollution.

The predator prey relationship between salmon and pinnipeds, such as harbor seals and California sea lions, has been evolving for hundreds of years and the complexity of that relationship must be considered when looking to Ballard and Willamette as examples. California sea lions, salmonid populations, and any artificial barriers and human modifications there now did not exist one hundred years ago and most of the intricate predator-prey relationships that would exist after centuries of evolution are not present. So, while analogous situations to those observed at these two locations may exist, any assumption that analogous solutions exist, with regard to predation and potential for impact on recovery, is likely incorrect.

The final theme that emerged was that methods used to evaluate food habits of pinnipeds were inadequate to effectively estimate and predict the impact such predation may or may not have on a particular salmonid population (NMFS 1997b). Scat collection and analysis would have to be combined with other techniques and technologies such as direct surface observation for predation events, genetic analysis, and comprehensive population modeling approaches.

Pinniped Food Habits

Research on the food habits of California sea lions and Pacific harbor seals in the past has shown that they are opportunistic consumers, with the majority of their diets consisting of seasonally and locally abundant prey. For sea lions and harbor seals in greater Puget Sound and Strait of Georgia, this translates into a diet, while diverse, made up mostly of Pacific hake and Pacific herring (Calambokidis et al. 1978; Calambokidis et al. 1989; Olesiuk et al. 1990). In some locations, significant pinniped predation has been reported on returning adult salmonids (Roffe and Mate 1984; Bigg et al. 1990; Jeffries and Scordino 1997) or out-migrating smolts and fry (Bigg et al. 1990; pers. comm., P. Olesiuk, DFO, Nanaimo, BC). While salmonids have been found in the diet of local pinnipeds, the vast majority of studies were not designed to address impacts of pinniped predation on specific salmonid populations.

Previous studies were mostly conducted on an opportunistic basis, not necessarily within a period of high salmonid abundance, and focused on collection of scat and analysis of prey remains. Understanding the role of salmonids in the diet of seals and sea lions is especially problematic because, until recently, only otoliths (ear bones) were used to identify prey items and smaller pinnipeds, such as harbor seals, often do not consume the head (which contains otoliths) of larger prey. In fact, recent analysis of the frequency of occurrence of salmonids in the diet of harbor seals in Hood Canal has shown an approximate five-fold increase in the percentage of scats containing salmonids when all structures are used (M. Lance unpublished). Other factors, involving gut retention and potential that scats collected are not a representative sample of the population, may further limit the ability to interpret the role of salmonids in the diet of pinnipeds with scat analysis alone.

Hood Canal - Harbor Seals and Summer Chum

Hood Canal is a fjord-like body of water that lies just east of the Olympic Peninsula and makes up the western most portion of Puget Sound in Washington State. Five major rivers (Quilcene, Dosewallips, Duckabush, Hamma Hamma and Skokomish) originate from headwaters in the Olympic Mountains and flow into Hood Canal (Figure 1). Each river supports runs of various salmonid species including chinook, coho (*O. kisutch*), chum and pink (*O. gorbuscha*). Steelhead and sea run cutthroat (*O. clarkii*) are present as well. In recent years, many salmonid runs have declined sharply, with several (chinook, summer chum and Dosewallips pinks) listed in the 1992 Salmon and Steelhead Stock Inventory (WDF et al. 1992) as critical or depressed. Hood Canal summer

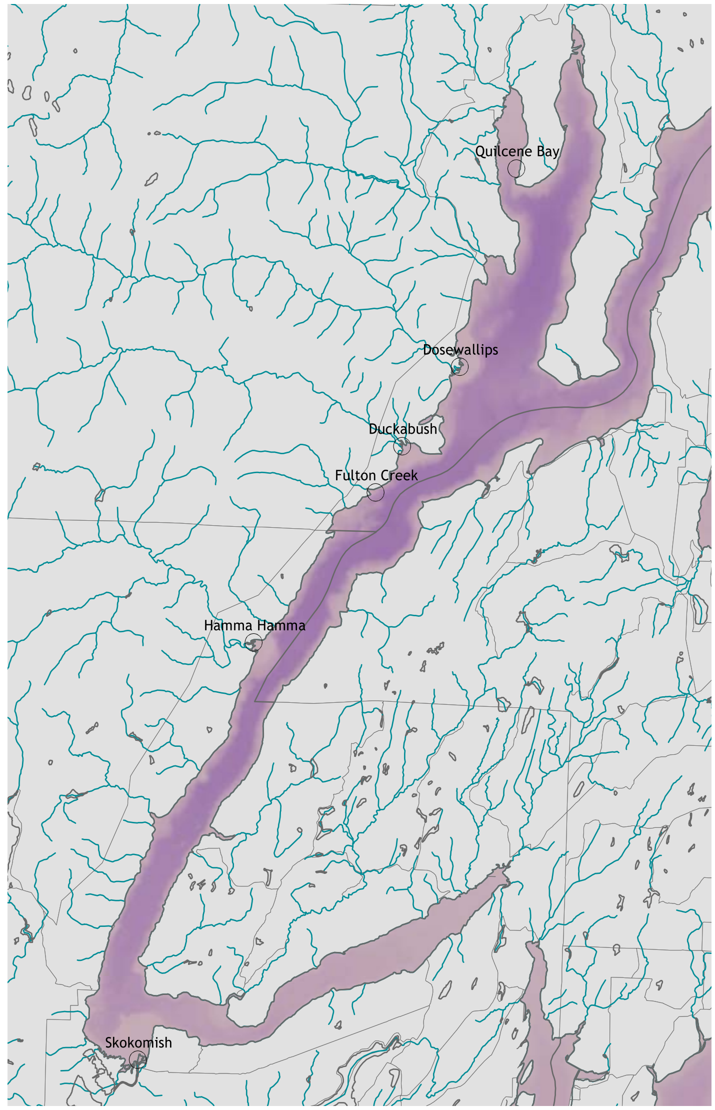

Figure 1. Map showing location of surface observation sites and scat collection sites in Hood Canal, Washington.

chum and Puget Sound chinook (including some runs in Hood Canal) were recently listed as "Threatened" under the ESA.

Harbor seal populations in Hood Canal are considered abundant and healthy (+1200 animals) (Forney et al. 2000; Jeffries et al. 2000), with haulout sites in close proximity to each of Hood Canal's major river systems. Aerial survey counts from 1998 are shown in Table 1. Previous studies in Hood Canal have examined harbor seal diet by identification of otoliths found in scat (Calambokidis et al. 1978; Calambokidis et al. 1989). Pacific hake (*Merluccius productus*) composed more than eighty percent of

Table 1. Aerial survey counts of Pacific Harbor seals in Hood Canal, Washington, overall and by haulout site during fall (Sept-Nov) 1998

Survey Date	Quilcene Bay	Dosewallips	Duckabush	Hamma Hamma	Skokomish
09/13	25	49	0	85	168
09/20	96	119	58	109	154
09/21	107	141	36	119	133
09/28	52	185	28	79	138
10/01	130	276	27	104	168
10/06	16	302	0	82	93
10/15	83	277	0	27	154
11/01	114	480	0	0	209

the diet based on scat collected at the Skokomish, Duckabush, and Dosewallips rivers as well as in Quilcene Bay.

NMFS Investigation and the West Coast Pinniped Study

In February of 1997, NMFS completed a review of scientific information on impacts of California sea lions and Pacific harbor seals on West Coast salmonids for Congress. The report discussed themes previously mentioned as a result of the Ballard situation and identified a number of locations where there was a potential for pinnipeds to impact recovery of declining salmonids. This led to the initial allocation of resources to Oregon Department of Fish and Wildlife (ODFW) to begin evaluating the use of direct surface observations as a way of estimating the predation rates of pinnipeds on salmonids. The study was expanded to include WDFW and California Fish and Game (CFG) in 1998. All three states have coordinated their research efforts through the Pacific States Marine Fishery Commission and have adapted a similar approach and objective to each specific study site.

Direct Observation of Predation Events

In most cases, the use of direct observation of harbor seal foraging behavior is limited by the reality that the vast majority of foraging events take place several meters underwater. However, in those situations where seals are taking advantage of high prey concentrations in a limited area, direct observation, while not perfect, can provide significant insight into consumption rates and foraging behavior. Harbor seal predation on smolt and adult salmonids is one such scenario and observation of surface predation events is the basis for estimates of adult salmonid consumption at four river systems in Hood Canal, Washington.

Harbor seal surface predation events are defined as those times when a seal brings a captured salmonid to the surface for consumption. This is due in large part to the physical size of a prey. Many returning adult salmonids are greater than one-third the body length of an average harbor seal and significantly larger than other prey items found in the diet of Hood Canal seals. It should also be pointed out that, while captured salmonids are often brought to the surface for consumption, consumption underwater is possible and likely more common for smaller sized salmonids (e.g. Pink salmon) that require less handling time.

Each of the four major river systems on the west side of Hood Canal offers unique access to the mouth and estuarine areas where salmonid surface predation events can be observed. These areas are all less than one square kilometer and, for the most part, can be effectively covered visually by one or two observers. Additionally, the low flow levels and relatively shallow water that exist during the observation season provides observers with the ability to track seals underwater from their characteristic surface wake. Lastly, major harbor seal haul-outs are located at the mouth or within estuarine areas of each river. This, combined with the concentration of returning adult salmon in the estuary, has resulted in a significant proportion of salmonid predations occurring within an observable area.

Methods

Surface Observations to Determine Predation Rate

Field observations were conducted to record surface predation events on returning adult salmon from vantage points off the mouths of the Quilcene (Big and Little), Dosewallips, Duckabush, Hamma Hamma, and Skokomish rivers. The duration of field observation activity has varied from year to year. In 1998, observations were conducted from the first week of September through the second week in November. 1999 observations started the third week in August and concluded after the first week of November. 2000 observations started the same week as in 1999, but were finished the last week of October. Differences in observation schedules were due in large part to an increased understanding of salmonid abundance and timing, flood conditions at observation sites, and a desire to increase the efficient use of research time and money.

In 1998 and 1999 a non-stratified random sampling regime was employed, consisting of 3 six-hour periods randomly sampled across 3 days each week (Sunday-Saturday). Approximately 300 hours of observation were conducted at each of the river mouths in 1998 and 1999. Additionally, a second observation site was added to the Duckabush in 1999 to address predation events occurring upstream from the Highway 101 Bridge that were not viewable from the lower site. For each sampling week, the selection of specific sites for making surface predation observations was made randomly and scheduled in advance. Each daily observation period was scheduled to begin either 15 minutes after sunrise or end 45 minutes before sunset to allow adequate ambient light for observations. Observations were made from either a 16 ft tower blind (Dosewallips, Duckabush, Hamma Hamma, and Skokomish), or ground vantage point which allowed viewing of predation events within and around the lower main channel and tidal areas of each river.

In 1998 and 1999, the daily observation period lasted a total of 6 hours from arrival. Binoculars and spotting scopes were used to scan the area for pinniped presence and detection of predation events. Locations of predation events were identified and recorded based on a gridded location map of each observation site. The first 20 minutes following arrival were spent organizing equipment, data forms and setting up for making observations. This was followed by three 100-minute observation periods with a 20 minute break between each. Weather, overall visibility conditions, maximum number of seals foraging in the river, and total number of salmonid predations was recorded for each 100-minute observation.

The observation sampling-scheme was significantly altered in 2000. Data analysis from 1998 and 1999 indicated that predation rates were not constant across the entire tidal cycle with a majority occurring on the incoming tide. Stratified random sampling (Figure

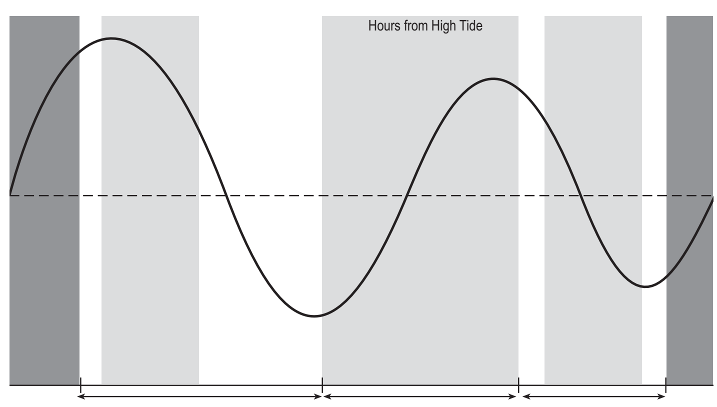

Figure 2. Schematic demonstrating the stratified sampling designed employed for surface observation schedules in 2000.

2) allowed concentration of observation effort on those times during which predations were more likely. The 2.5-month observation season was divided into five two-week periods. The two-week periods were divided into two strata. The first stratum consisted of four-hour periods during which the maximum percentage of predations had been observed at a particular site during the previous two field seasons. The second stratum consisted of the remaining time and was divided into 2-hour blocks. For instance, 1998 and 1999 observation data from Dosewallips indicated that 70% of the observed predations occurred between 4.5 hours before high tide and 0.5 hours before high tide. The first stratum consisted of those periods occurring during observable daylight hours. As in 1998 and 1999, observable daylight hours were defined as 30 minutes after sunrise to 45 minutes before sunset.

Once the two strata were determined, four maximum predation periods were chosen at random for each two-week period. Each of these periods was observed in its entirety. For the second stratum, two days were chosen at random and two two-hour periods were randomly chosen for each day. These two-hour periods did not overlap and occurred outside the maximum predation stratum. This schedule provided approximately 120 hours of observations at each Hood Canal river mouth in 2000 (except the Skokomish River).

The focus of the observer, during all years, was to cover the area encompassing each site where predation by seals was possible. The observer documented any predation or foraging event on the data form. Observers noted time, location, number of seals involved, species of salmon (if possible), a confidence factor of 1-5 for prey identification, and a variety of possible behaviors.

Calculation of Predation Estimates

Estimates of salmonid predation in 1998 and 1999 were determined through use of a two-stage sampling estimator (Cochran 1977). Each week served as an individual stratum with the primary units being the random sample of three of seven days per week and the sub-units the three 100-minute observation periods on those days. Where y_{ijh} equals the count in the hth 100-minute sample (h=1…K) within the jth day (j=1…7) in the ith week/stratum (i=1…L), then the estimates and variance of weekly predation and total predation are shown below:

$$\hat{Y}_i = \frac{7}{3}\sum_{j=1}^{3}\left(\frac{K}{3}\sum_{h=1}^{3} y_{ijh}\right) \qquad \hat{Y} = \sum_{i=1}^{L}\hat{Y}_i$$

$$V\hat{a}r(\hat{Y}) = \sum_{i=1}^{L}\left\{\left[\left(\frac{7-3}{7}\right)\frac{s_a^2}{3} + \left(\frac{3}{7}\right)\left(\frac{K-3}{K}\right)\frac{s_b^2}{3\times 3}\right](7K)^2\right\}$$

where $s_{a_i}^2 = \frac{\sum_{j=1}^{3}(\bar{y}_j - \bar{y})^2}{(3-1)}$ and $s_{b_{ij}}^2 = \frac{\sum_{j=1}^{3}\sum_{i=1}^{3}(y_{ij} - \bar{y}_j)^2}{3(3-1)}$

The additional up river site at the Duckabush River in 1999 was treated as independent during calculation of predation estimates. After estimates were finalized, they were combined with the original site (mouth) for comparison and analysis with fish numbers. Data collected in 2000 relied on a stratified random sampling estimator to calculate the number of predations for each biweek period.

Observation of potentially significant predation of summer chum by harbor seals has raised the importance of two key questions: allocation of salmonid predations to individual salmonid species and how to account for nighttime predation. Allocation of salmonid predations is especially problematic in Hood Canal because those species with reduced populations (summer chum, chinook) overlap in timing with often more abundant species (coho, pink, fall chum). The extent to which seals are selective towards one species over another is not known and likely not something that will be determined without additional effort. Given these constraints, we have settled on two scenarios with two different analysis assumptions. Each of these analysis scenarios is focused on determining the impact on summer chum and is thus reflective of only the time during which summer chum were present in each system.

Scenario 1 assumes that there is no selection by harbor seals for or against summer chum in relation to other salmonids, and the percentage of predations with respect to total salmonid abundance is used to determine the impact on summer chum. This scenario is the most objective, however, the role other more numerous species play as a buffer to summer chum may be artificially elevated.

Scenario 2 assumes the small number of predations identified by observers to species is reflective of all salmonid predations and this percentage is used to estimate the impact of predations on summer chum. This scenario relies heavily on the ability of observers to identify predations to salmonid species and that each species is equally identifiable. Most predations occur at a fair distance from the observer, last only a few seconds, are mostly underwater and often provide little information that would allow an observer to determine species. Additionally, the differences in size, color and life history of each salmonid species (e.g. chum vs coho) is variable and an assumption that each species is equally identifiable is likely not accurate.

Nighttime predation was explicitly addressed during the 2000 field season. Night observation periods were selected to occur during four-hour high predation strata that existed between sunset and sunrise, and within 24 hours of a similar daytime observation. This allowed a paired analysis for comparison of mean number of predations and number of foragers. Observers were positioned at the Mouth Site and at the Highway 101 bridge on the Duckabush River and observations were made using an ITT 5001P head-mounted night vision goggle with a slip-on 3X magnifier lens. All attempts were made to identify and record predation activity following the same protocols used during daylight hours.

Scat Collection and Food Habits Analysis

Information on the diet of harbor seals in Hood Canal was obtained by collecting fecal samples (scats) for examination and identification of prey hard parts (i.e. otoliths, bones, cephalopod beaks, etc). Scat collections were attempted at roughly 10-14 day intervals at harbor seal haulout areas near Quilcene Bay, Dosewallips River, Duckabush River, and Hamma Hamma River in 1998, 1999, and 2000 and the Skokomish River in 1998 and 1999. Fall collections were made from mid July to early December in 1998, 1999, and 2000 (Table 2). All scats found on haul out sites were collected in their entirety. In an effort to minimize contamination of genetic material between scats, gloves were worn and each scat was collected with a unique tongue depressor. Each scat was placed in an individual plastic bag and labeled with location and date. All scat were frozen for processing at a later time.

Prior to scat processing for food habits, genetic material was removed. This was done by dissolving the entire scat in a buffer solution and removing four, one-milliliter aliquots. Individual identification numbers were assigned at this time. Scat processing followed standard protocols used to identify pinniped prey and diet (Lance et al. 2001). The sample was rinsed by running water through three interlocking sieves (2.0 mm, 1.0 mm, 0.71 mm). All prey hard parts were removed from the sieves using forceps and placed in 20 ml glass scintillation vials with a 50 percent alcohol solution. After approximately one week, the alcohol was poured off samples and they were dried before being closed and stored for subsequent identification. Invertebrates, cartilaginous fish remains, eggs, and cephalopod beaks were placed in separate vials and stored in alcohol.

Table 2. Number of Pacific harbor seal scat samples collected at each study haulout site in Hood Canal, Washington during fall of 1998, 1999, and 2000.

Location	1998	1999	2000
Quilcene Bay	156	115	245
Dosewallips River	243	202	156
Duckabush River	7	10	127
Hamma Hamma River	68	41	80
Skokomish River	127	48	`
All Sites	**601**	**416**	**608**

Prey species were determined by using all identifiable prey hard parts recovered from each sample (Lance et al. 2001). Hard parts include otoliths, skeletal bones, cartilaginous parts, eye lenses, and cephalopod beaks and statoliths. Samples were examined under a dissecting microscope and diagnostic prey parts were separated for identification. Hard parts were identified and enumerated by WDFW staff (ML) using a comparative reference collection of fishes from Puget Sound and the outer coast of Washington, and published bone and otolith identification keys (Cannon 1987; Morrow 1979). Diagnostic bones were identified, enumerated, and sided to give a minimum number of individuals (MNI) for each species and followed standard prey identification protocols (Lance et al. 2001). Diagnostic bones used to determine MNI typically varied by species. If two distinct sizes of bones were identified for a given species in a sample, two individuals were recorded for that species. For comparative purposes, data were collected as MNI based on otoliths only and MNI based on all other bones. Recently, there has been a great deal of discussion about the accuracy of using MNI in consumption models due to biases associated with using data based on scat analysis. Some of these biases include effects of "meal" size, prey composition of a "meal", passage rates, rates of digestion, and use of different structures to calculate MNI for different prey species. Data are presented strictly as percent frequency of occurrence (FO). FO is an index of presence or absence that indicates the proportion of time a certain taxon is consumed but not the number taken (MNI). Sample size (s) does not include "empty" scat samples that contained no prey hard parts, but does include samples that contained prey that was heavily eroded and could not be identified ("unidentifiable").

Frequency of Occurrence (FO_i):

$$FO_i = \frac{\sum_{k=1}^{s} O_{ik}}{s}$$

where

O_i = 0 if taxon i is absent in fecal k
1 if taxon i is present in fecal k

s = total number of fecal samples that contained prey

Bill Walker (NMFS) identified salmon otoliths and rare Cephalopad beaks to species. Additional beaks were identified using published keys (Iverson and Pinkas 1971, Wolff 1982, Clarke 1986) and reference specimens from the National Marine Mammal Laboratory collection. In order to examine additional food habits parameters, such as age and prey size, otoliths collected in 1999 and 2000 were measured, however those data have not been analyzed, and are pending collaboration with ground fish and forage fish biologists from WDFW to develop age-length regressions specific to Puget Sound, Washington.

Results

Observation of Surface Predation

A total of 817 hours of surface observation were conducted at Quilcene Bay, Dosewallips River, Duckabush River, Hamma Hamma River and Skokomish River in Hood Canal from 5 September to 20 November 1998, 1,212 hours (includes additional Quilcene Bay and Duckabush River observation sites) from 15 August to 11 November 1999 and 600 hours of observation from 20 August to 29 October 2000. Harbor seal predation on salmonids was observed at all five sites and on a few occasions, California sea lion predation on salmonids was observed off the Hamma Hamma River. The estimates of salmonid predations presented here only include predation attributed to harbor seals. The majority of predations observed were only identifiable as a salmonid, however when possible observers did note the species of salmon. Harbor seals were observed preying on chum and coho salmon in Quilcene Bay; chum, coho, pink (1999) and steelhead (1999) at the Duckabush River; chum, coho and pink (1999) at the Dosewallips River; chum, pink (1999) and chinook (1999) at the Hamma Hamma.

1998-2000 Predation Estimates

Estimates of weekly salmonid predation at each site were determined using the two-stage sampling estimator (Cochran 1977). The estimated total daytime predation at each observation area in 1998 was: Quilcene Bay (242 salmon); Dosewallips River (113 salmon); Duckabush River (96 salmon); Hamma Hamma River (278 salmon).

Predation estimates for 1999 were also done using the two-stage sampling estimator as in 1998. The estimated total predation at each observation area in 1999 was: Quilcene Bay (80 salmon); Dosewallips River (185 salmon); Duckabush River (Up River-69 salmon and Mouth- 201 salmon); and Hamma Hamma River (119 salmon). Weekly run size and predation estimate data for 1998 and 1999 are presented in Figures 3-4, 6-7, 9-10, and 12-13, with fish return data provided by the WDFW Fisheries Management Group.

Table 3. Estimates of the percentage of summer chum consumed by harbor seals at four river mouths in 1998 and 1999 under two allocation scenarios.

Quilcene Bay	**1998**		**1999**	
	Numbers	Percentage	Numbers	Percentage
	Scenario 1 - Based on Abundance			
High 95% CI	74	4.9%	71	2.4%
Estimate	**53**	**3.5%**	**41**	**1.4%**
Low 95% CI	31	2.1%	10	0.4%
	Scenario 2 - Based on ID			
High 95% CI	419	21.8%	157	5.0%
Estimate	**296**	**16.4%**	**90**	**2.9%**
Low 95% CI	173	10.3%	23	0.8%
Dosewallips	**1998**		**1999**	
	Numbers	Percentage	Numbers	Percentage
	Scenario 1 - Based on Abundance			
High 95% CI	104	35.7%	29	8.3%
Estimate	**85**	**29.1%**	**20**	**5.6%**
Low 95% CI	62	21.1%	9	2.7%
	Scenario 2 - Based on ID			
High 95% CI	194	39.9%	194	35.6%
Estimate	**144**	**33.0%**	**127**	**26.6%**
Low 95% CI	94	24.3%	59	14.5%
Duckabush	**1998**		**1999**	
	Numbers	Percentage	Numbers	Percentage
	Scenario 1 - Based on Abundance			
High 95% CI	32	11.1%	14	14.6%
Estimate	**21**	**8.3%**	**10**	**11.2%**
Low 95% CI	8	5.2%	7	7.6%
	Scenario 2 - Based on ID			
High 95% CI	58	21.3%	250	72.9%
Estimate	**42**	**16.3%**	**185**	**66.6%**
Low 95% CI	26	10.6%	120	56.4%
Hamma Hamma	**1998**		**1999**	
	Numbers	Percentage	Numbers	Percentage
	Scenario 1 - Based on Abundance			
High 95% CI	13	13.0%	8	3.5%
Estimate	**7**	**6.8%**	**6**	**2.4%**
Low 95% CI	0	0%	3	1.3%
	Scenario 2 - Based on ID			
High 95% CI	0	0.0%	39	14.4%
Estimate	**0**	**0.0%**	**27**	**10.4%**
Low 95% CI	0	0%	15	6.0%

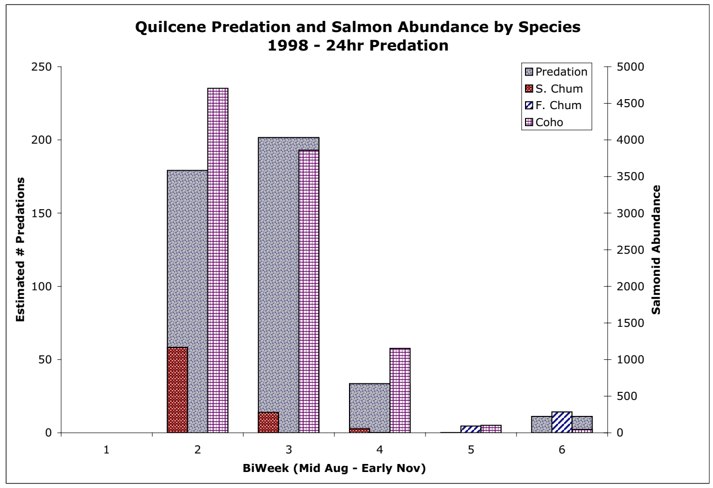

Figure 3. BiWeekly 24hr predation estimates and abudance for three salmonid species in Quilcene Bay, 1998.

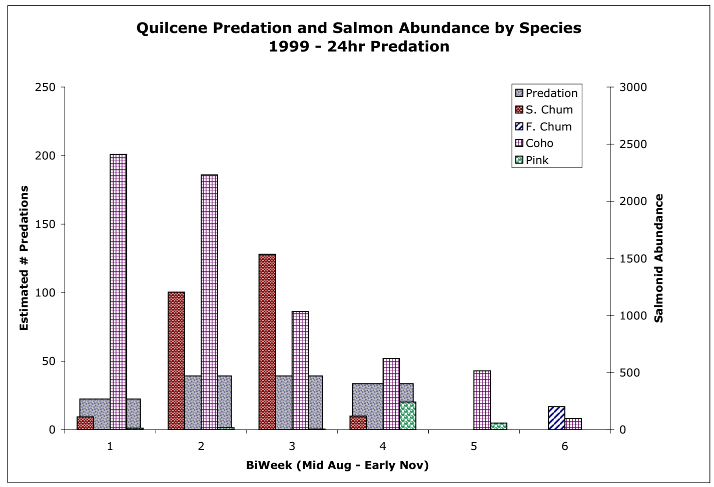

Figure 4. BiWeekly 24hr predation estimates and abudance for three salmonid species in Quilcene Bay, 1999

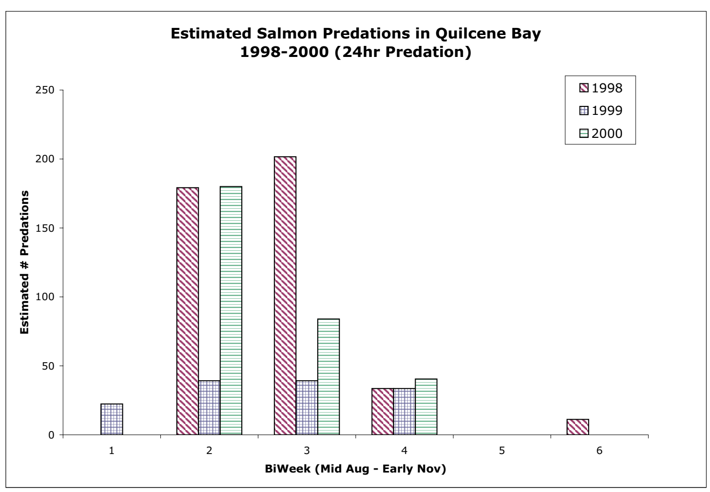

Figure 5. BiWeekly 24hr predation estimates for Quilcene Bay, 1998-2000

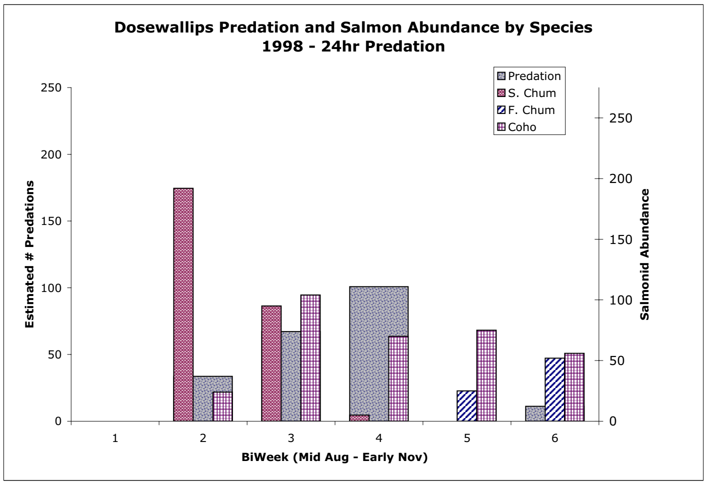

Figure 6. BiWeekly 24hr predation estimates and abudance for three salmonid species in the Dosewallips River, 1998.

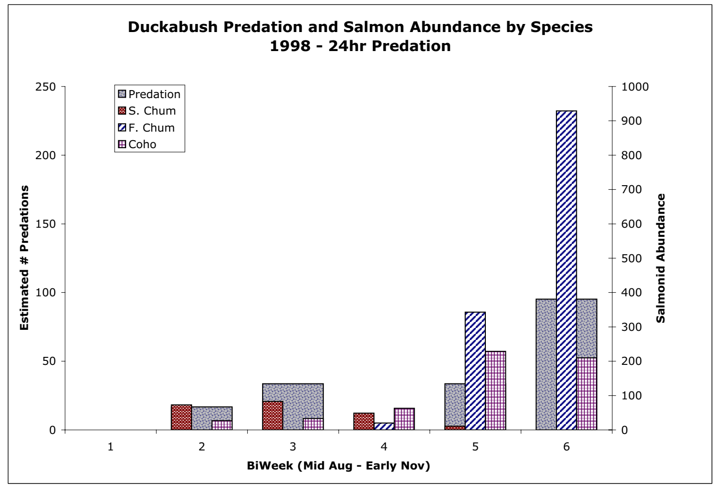

Figure 9. BiWeekly 24hr predation estimates and abudance for three salmonid species in the Duckabush River, 1998.

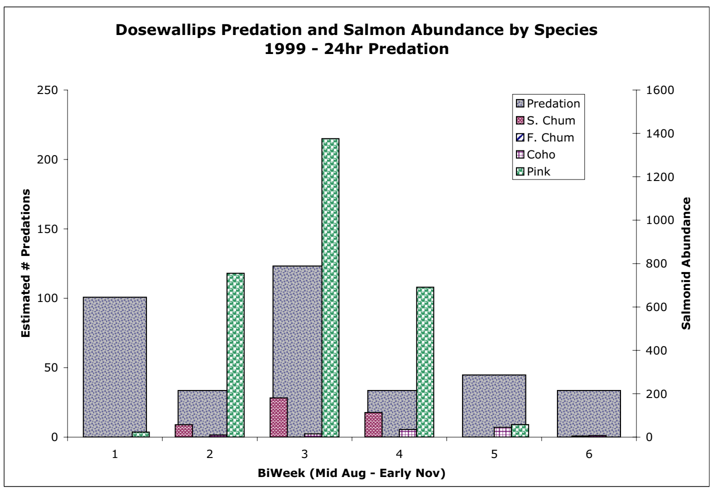

Figure 7. BiWeekly 24hr predation estimates and abudance for three salmonid species in the Dosewallips River, 1999.

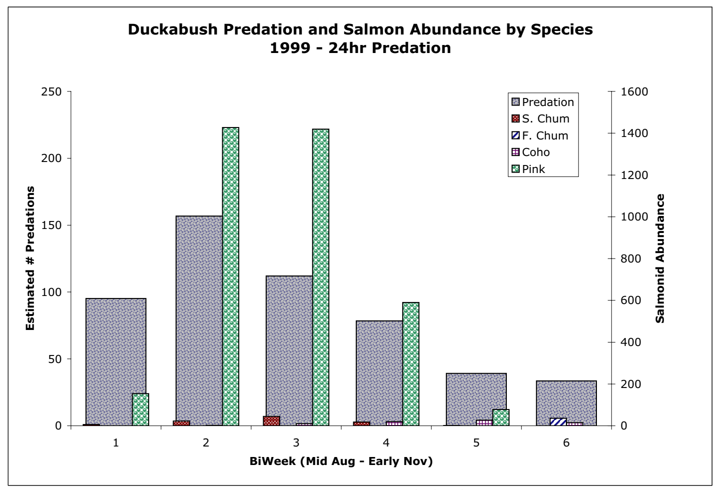

Figure 10. BiWeekly 24hr predation estimates and abudance for three salmonid species in the Duckabush River, 1999.

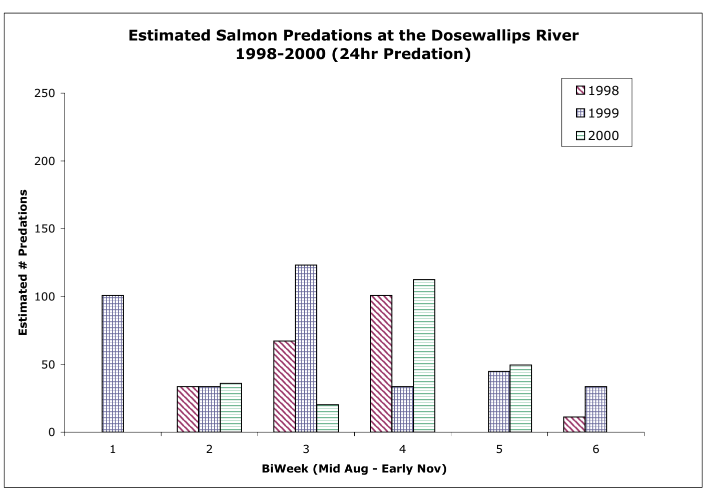

Figure 8. BiWeekly 24hr predation estimates for the Dosewallips River, 1998-2000

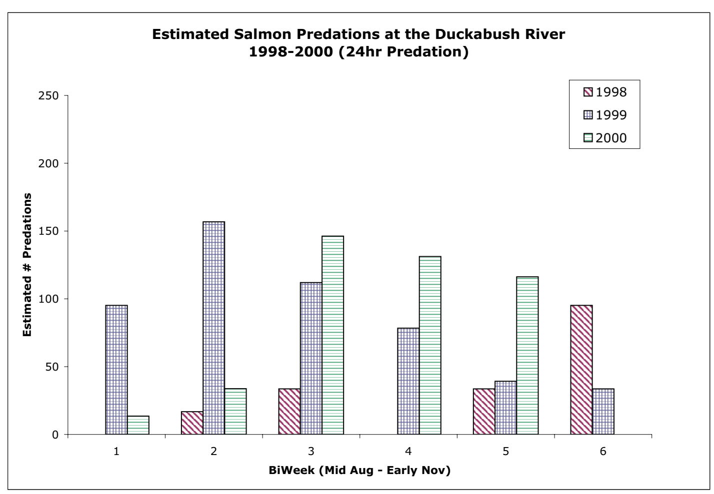

Figure 11. BiWeekly 24hr predation estimates for the Duckabush River, 1998-2000

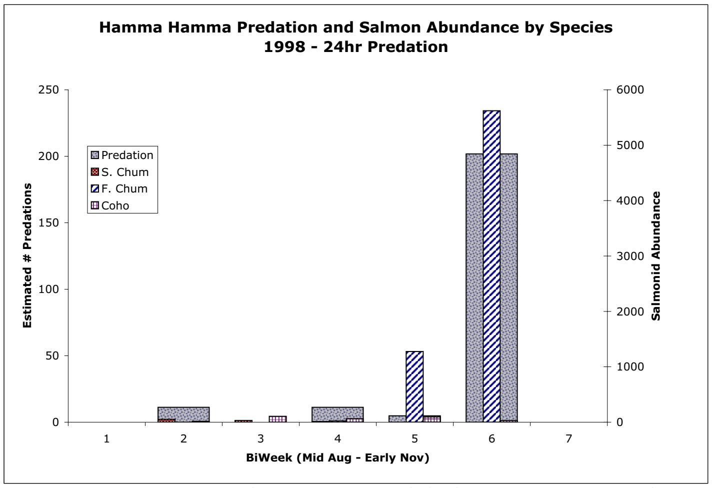

Figure 12. BiWeekly 24hr predation estimates and abudance for three salmonid species in the Hamma Hamma River, 1998.

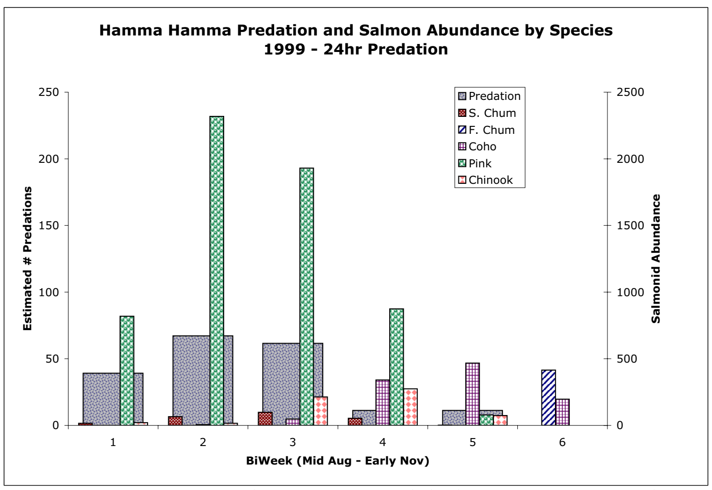

Figure 13. BiWeekly 24hr predation estimates and abudance for three salmonid species in the Hamma Hamma River, 1999.

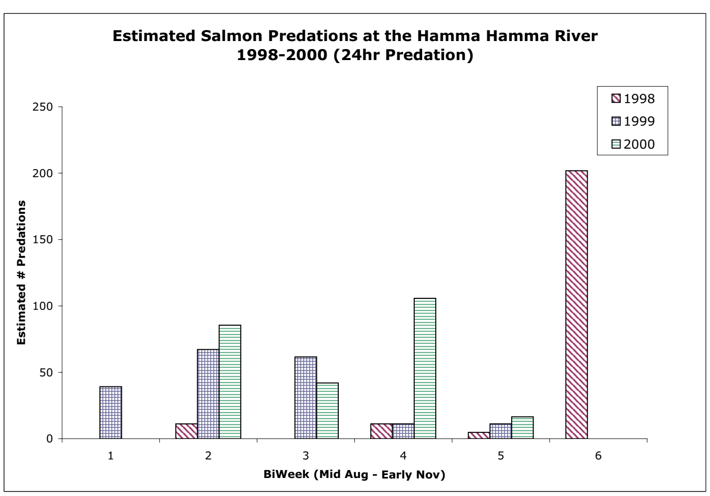

Figure 14. BiWeekly 24hr predation estimates for the Hamma Hamma, 1998-2000

Predation estimates for 2000 are still in a preliminary state of calculation. The estimates shown in Figures 5, 8, 11 and 14 are rough estimates and only presented to provide general comparisons of the year to year patterns in predation over time. Estimates will be finalized once salmonid abundance data for 2000 is available.

Preliminary estimates of harbor seal predation impacts on 1998 and 1999 Hood Canal summer chum runs were calculated under two scenarios (i.e., Scenario 1-estimates assume predations proportional to salmon species abundance and timing; and Scenario 2-estimates assume predations based on proportion of salmon kills identified to salmon species) at each site (Table 3). Of these two scenarios, we feel Scenario 1 is the most probable with the other scenario presented as and alternative to better understand the range of possible predation impacts. Predation impacts for 2000 are not presented, pending final completion of predation estimates and run size data for returning salmonids.

Under Scenario 1, predation estimates at most sites ranges from 1-10%. The predation estimate for the Dosewallips River in 1998 is a notable exception, with an estimated 29% of the summer chum run potentially consumed. Differences between 1998 and 1999 at the Dosewallips River (29% versus 8%) illustrates the effect an abundant species such as pink salmon can have as a potential buffer to predation on summer chum under this scenario.

Variance Calculation and Confidence Intervals

Variance calculations and 95% confidence intervals were calculated for the total predation estimate during the summer chum run at each site in 1998 and 1999 (Table 3). It should be noted that this does not include any variance that might be associated with the salmonid abundance estimates. Ranges presented here only represent the variance associated with the estimated total predation based on surface observations. Including variance estimates for salmonid abundance will increase the variance and, therefore, increase the range of the 95% confidence intervals.

Table 4. Comparison of observed predation events during day and night observations at the Duckabush River. Means and and Paired t-test p-values are shown for the comparison of salmon predations and the maximum number of foragers.

Salmon Preds	Mean	T-test Paired for Sample Means (alpha 0.05)			
Mouth Day	1.61538		Mouth Night	Upper Night	Combo Night
Mouth Night	0.38461	Mouth Day	0.05899		0.16540
Upper Day	0.76923	Upper Day		0.08209	
Upper Night	0.30769	Combo Day			0.0221
Combo Day	2.38461				
Combo Night	0.69230				

Max Foragers	Mean	T-test Paired for Sample Means (alpha 0.05)			
Mouth Day	5.30769		Mouth Night	Upper Night	Combo Night
Mouth Night	3.92307	Mouth Day	0.17384		0.16349
Upper Day	1.46153	Upper Day		0.00167	
Upper Night	3.07692	Combo Day			0.8479
Combo Day	6.76923				
Combo Night	7.00000				

Nighttime Predation

Nighttime predation observations at the Duckabush River were paired with scheduled daytime observations in order to provide preliminary information on the potential differences in the number of predations between daytime and nighttime. Paired t-tests for sample means were performed to evaluate any differences. Both number of predations observed and maximum number of foragers were evaluated. Resulting p-values from the t-tests and various pairings are presented in Table 4. When comparing the combined number of predations between the upper and lower and day and night observations, there is a significant difference in the number of predations observed (p=0.022). However, nighttime observations were conducted from the Highway 101 Bridge and the area above the bridge was rarely bright enough to observe with any confidence. Therefore, a more appropriate test may be to compare combined estimates for the upper and lower at night with just the lower estimates during the day. Under this scenario, the difference in means is not significant (p=0.165).

Given the inherent differences in observability between day and night, even with advanced night vision goggles, a comparison was made between the maximum number of foragers observed during the day and at night. The ability to detect a seal engaged in foraging activities such as chasing or patrolling is more consistent between day and night than the ability to recognize a predation event. Comparing the maximum number of foragers may provide a better index for comparing predation activity between day and nighttime periods. The only significant difference detected was in the number of foragers present at the upper location; however, this is likely due to issues discussed earlier with respect to the different observation locations.

Table 5. Number of Pacific harbor seal scats collected at each study haul out site in Hood Canal, Washington during fall (late July–mid November), 2000.

Location	Collected	Empty	w/ Remains
Quilcene Bay	245	1	244
Dosewallips River	156	7	149
Duckabush River	127	2	125
Hamma Hamma River	80	2	78
All Sites	**608**	**12**	**596**

2000 Food Habits Analysis

Harbor seal scat samples were collected in Quilcene Bay from oyster racks and salmon net pens and from haulout locations at the Dosewallips, Hamma Hamma, and Duckabush River mouths from late July through mid November (Table 5). Of 608 scat samples collected, 596 contained prey.

Fourteen species of fish and two cephalopods were identified, with an additional seven prey identified to genus or family level (scientific and common names provided in Appendix A). Overall, Pacific hake (78.9), Pacific herring (48.8), and salmon species (24.5) were the three most important prey species based on frequency of occurrence (FO) in harbor seal scat collected during fall of 2000 (Table 6). Three additional prey species important in harbor seal diet based on FO varied in their importance by location. Shiner surfperch was a primary prey species found in samples collected at

Table 6. Percent frequency of occurrence (FO) of prey species identified using all structures (bone and otoliths) in Pacific harbor seal scats collected in Hood Canal, Washington, overall and by river system during fall (late July-mid November) 2000.

	Overall n=596		**Quilcene Bay** n=244		**Dosewallips** n=149		**Duckabush** n=125		**Hamma Hamma** n=78	
Prey species	n	FO	n	FO	n	FO	n	FO	n	FO
Pacific hake	470	78.9	210	86.1	119	79.9	83	66.4	58	74.4
Pacific herring	291	48.8	107	43.9	68	45.6	81	64.8	35	44.9
Salmon species[a]	146	24.5	66	27.0	27	18.1	24	19.2	29	37.2
Shiner surfperch	81	13.6	38	15.6	12	8.1	27	21.6	4	5.1
Cephalopod species[b]	59	9.9	31	12.7	7	4.7	10	8.0	11	14.1
Threespine stickleback	53	8.9	52	21.3	1	0.7	0	0	0	0
Pacific tomcod	26	4.4	15	6.1	4	2.7	5	4.0	2	2.6
Clupeid species	23	3.9	6	2.5	3	2.0	8	6.4	6	7.7
Gadid species	14	2.3	6	2.5	3	2.0	2	1.6	3	3.8
Pacific staghorn sculpin	14	2.3	12	4.9	0	0	2	1.6	0	0
Plainfin midshipman	13	2.2	4	1.6	1	0.7	5	4.0	3	3.8
Skate (Family Rajidae)	9	1.5	5	2.0	2	1.3	2	1.6	0	0
Northern anchovy	8	1.3	2	0.8	3	2.0	3	2.4	0	0
Pile surfperch	4	0.7	3	1.2	0	0	1	0.8	0	0
Rockfish species	4	0.7	3	1.2	0	0	1	0.8	0	0
English sole	3	0.5	3	1.2	0	0	0	0	0	0
Pacific sandlance	2	0.3	2	0.8	0	0	0	0	0	0
Pacific lamprey	1	0.2	0	0	0	0	0	0	1	1.3
Osmerid species	1	0.2	0	0	1	0.7	0	0	0	0
Starry flounder	1	0.2	0	0	0	0	1	0.8	0	0
Pleuronectid species	1	0.2	1	0.4	0	0	0	0	0	0
Walleye pollock	1	0.2	1	0.4	0	0	0	0	0	0
Unidentified fish species	15	2.5	3	1.2	10	6.7	1	0.8	1	1.3

[a] see table 9 for species composition based on otolith identification

[b] see table 7 for species composition based on beak identification

Quilcene Bay (15.6) and the Duckabush River (21.6); cephalopod species were important prey at the Hamma Hamma River (14.1) and Quilcene Bay (12.7); and Threespine stickleback was a common prey species in Quilcene Bay (21.3), but not at other locations except one sample collected at the Dosewallips River (Table 6).

Cephalopod species were present in 59 samples overall, however 20 of those samples contained only statoliths and species identification is not possible. Beaks were identified to two species in the remaining 39 samples represented by, *Loligo opalescens* (71.8 FO) and *Berryteuthis magister/Gonatopsis borealis* species (33.3). One beak was unidentifiable to species (Table 7).

Quantifying salmon consumption was the primary focus of this study and identification of salmon remains in scat samples is one way to measure its importance in the diet of harbor seals. Salmon species are the third most commonly occurring prey species based on frequency of occurrence (24.5) in the diet over the entire sampling period and for all collection sites combined. Changes in the FO of salmon (Table 8) occurred over the course of our fall sampling period. In general, presence of salmon species in samples (FO) increased over time with the greatest percentage of samples containing salmon overall occurring at the end of October and early November (36.9). FO of salmon in samples increases over the sampling period at each collection location if examined individually as well.

Of 146 scat samples that contained salmon remains, 14 samples contained otoliths (Table 9). Six samples collected from Quilcene Bay contained chinook and coho salmon otoliths. Four samples collected at the Dosewallips River contained chum salmon, coho salmon, coho or chum salmon, and an unidentified salmonid (not chinook salmon) otolith. Two samples collected from the Duckabush River area contained chum or steelhead salmon and chinook salmon otoliths. Two samples collected from the Hamma Hamma River contained *Oncorhynchus spp*, (most likely coho salmon), and an unidentifiable *Oncorhynchus spp.* otolith.

In this study, all bones recovered from scat were identified to the lowest possible taxon to determine diet composition. Using bones in addition to otoliths to reconstruct the diet of seals varies by prey species in its importance for identification due to biases associated

Table 9. Identification of salmon to species based on otoliths recovered from Pacific harbor seal scats collected in Hood Canal, Washington, overall and by river system during fall (late July-mid November) 2000.

Location	Date	Otolith 1	Otolith 2
Quilcene Bay	10/09	Chinook salmon	
	10/09	Chinook salmon	Coho salmon
	10/17	Chinook salmon	
	10/17	Coho salmon	
	11/15	Coho salmon	c.f. Coho salmon
	11/15	Chinook salmon	c.f. Chinook salmon
Dosewallips	09/16	*Oncorhynchus spp.* (not Chinook)	
	11/13	Chum salmon	
	11/13	c.f. Coho salmon or Chum salmon	
	11/13	Coho salmon	
Duckabush	09/25	Chum salmon or Steelhead salmon	
Fulton Creek	10/31	Chinook salmon	
Hamma Hamma	10/13	*Oncorhynchus spp.* (c.f. Coho)	
	11/02	*Oncorhynchus spp.* (c.f. Coho)	*Oncorhynchus spp.*

Table 7. Percent frequency of occurrence (FO) of cephalopod species found in Pacific harbor seal scats based on beak identification collected in Hood Canal, Washington, overall and by river system during fall (late July-mid November) 2000.

	All sites n=596		**Quilcene Bay** n=244		**Dosewallips** n=149		**Duckabush** n=125		**Hamma Hamma** n=78	
	n	FO	n	FO	n	FO	n	FO	n	FO
Cephalopod species	59	9.9	31	12.7	7	4.7	10	8.0	11	14.1
statoliths only[a]	20		10		1		6		3	
beaks present:	39		21		6		4		8	
Loligo opalescens	28[b]	71.8	13[b]	61.9	5	83.3	4	100.0	6	75.0
Berryteuthis/Gonatopsis borealis species	13[b]	33.3	11[b]	52.4	0	0	0	0	2	25.0
Ommastrephes bartramii	1[c]	2.6	1[c]	4.8	0	0	0	0	0	0
unidentified	1	2.6	0	0	1	16.7	0	0	0	0

[a]presence of cephalopod, no species identification possible

[b]two samples contained both *L. opalescens* and *B. magister/G. borealis* species

[c] one sample contained both *L. opalescens*, *B. magister/G. borealis*, and *O. bartramii*

Table 8. Percent frequency of occurrence (FO) of Pacific harbor seal scats collected with salmon remains (n^s) by collection date in Hood Canal, Washington, overall and by river system during fall (late July-mid November) 2000.

	Overall			**Quilcene Bay**		**Dosewallips**		**Duckabush**		**Hamma Hamma**	
Collection dates	n	n^s	FO	n	n^s	n	n^s	n	n^s	n	n^s
07/18-08/02	21	1	4.8	`	`	12	0	2	1	7	0
08/28-08/30	16	1	6.3	`	`	7	1	9	0	`	`
09/16	28	7	25.0	`	`	28	7	`	`	`	`
09/23-09/29	76	7	9.2	`	`	45	2	31	5	`	`
10/03-10/09	113	22	19.5	30	8	`	`	52	9	31	5
10/12-10/17	50	18	36.0	16	7	`	`	15	1	19	10
10/22-10/25	59	17	28.8	40	9	3	0	3	0	13	8
10/31-11/02	111	41	36.9	56	18	34	9	13	8	8	6
11/13-11/15	122	32	26.2	102	24	20	8	`	`	`	`

Table 10. An annual comparison of the percent frequency of occurrence (FO) of primary prey species identified using all structures (bone and otoliths) found in Pacific harbor seal scats by river system in Hood Canal, Washington during fall (late July-mid November) of 1998, 1999, and 2000.

Quilcene Bay

Prey species	1998 n=152 n	FO	1999 n= 115 n	FO	2000 n=244 n	FO
Pacific hake	135	88.8	89	77.4	210	86.1
Pacific herring	59	38.8	50	43.5	107	43.9
Salmon species	37	24.3	41	35.7	66	27.0
Shiner surfperch	15	9.9	8	7.0	38	15.6
Cephalopod species	9	5.9	12	10.4	31	12.7
Threespine stickleback	7	4.6	5	4.3	52	21.3

Hamma Hamma River

Prey species	1998 n=67 n	FO	1999 n=38 n	FO	2000 n=78 n	FO
Pacific hake	56	83.6	26	68.4	58	74.4
Pacific herring	27	40.3	16	42.1	35	44.9
Salmon species	16	23.9	13	34.2	29	37.2
Shiner surfperch	3	4.5	2	5.3	4	5.1
Cephalopod species	2	3.0	6	15.8	11	14.1

Dosewallips River

Prey species	1998 n=240 n	FO	1999 n=196 n	FO	2000 n=149 n	FO
Pacific hake	204	85.0	156	79.6	119	79.9
Pacific herring	113	47.1	75	38.3	68	45.6
Salmon species	51	21.3	42	21.4	27	18.1
Shiner surfperch	15	6.3	14	7.1	12	8.1

Skokomish River

Prey species	1998 n=125 n	FO	1999 n=43 n	FO
Pacific hake	99	79.2	14	32.5
Pacific herring	56	44.8	16	37.2
Salmon species	45	36.0	18	41.9
Shiner surfperch	6	4.8	5	11.6

Duckabush River

Prey species	1998 n=7 n	FO	1999 n=9 n	FO	2000 n=125 n	FO
Pacific hake	7	100.0	5	55.6	83	66.4
Pacific herring	3	42.9	6	66.7	81	64.8
Salmon species	1	14.3	0	0	24	19.2
Shiner surfperch	0	0	1	11.1	27	21.6
Northern anchovy	2	28.6	0	0	2	0.8

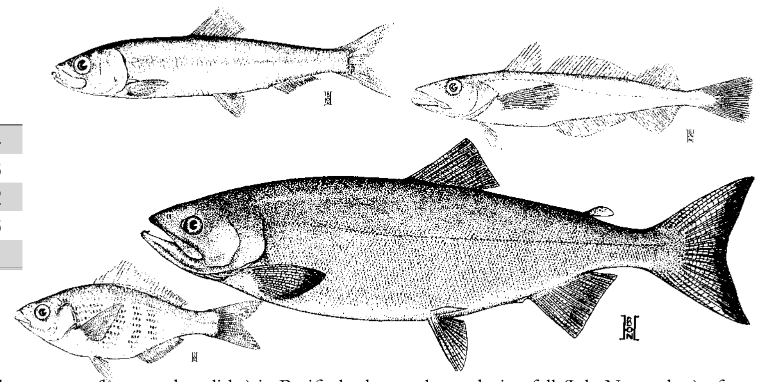

Table 11. Percent frequency of occurrence (FO) of prey species identified using all structures (bone and otoliths) in Pacific harbor seal scat during fall (July-November) of 1998, 1999, and 2000 in Hood Canal, Washington.

Prey Species	1998 n=591 n	FO	1999 n=393 n	FO	2000 n=596 n	FO	Total n=1580 n	FO
Pacific hake	501	84.8	289	73.5	470	78.9	1260	79.7
Pacific herring	258	43.7	164	41.7	291	48.8	713	45.1
Salmon species	150	25.4	114	29.0	146	24.5	410	25.9
Shiner surfperch	39	6.6	30	7.6	81	13.6	150	9.5
Cephalopod species	23	3.9	32	8.1	59	9.9	114	7.2
Threespine stickleback	7	1.2	6	1.5	53	8.9	66	4.2
Pacific tomcod	15	2.5	7	1.8	26	4.4	48	3.0
Plainfin midshipman	14	2.4	15	3.8	13	2.2	42	2.7
Northern anchovy	14	2.4	19	4.8	8	1.3	41	2.6
Pacific staghorn sculpin	16	2.7	9	2.3	14	2.3	39	2.5
Skate species	3	0.5	3	0.8	9	1.5	15	0.9
Clupeid species	0	0	33	8.4	23	3.9	56	3.5
Gadid species	0	0	7	1.8	14	2.3	21	1.3
Rockfish species	3	0.5	3	0.8	4	0.7	10	0.6
Pile surfperch	4	0.7	3	0.8	4	0.7	11	0.7
Pacific sandlance	0	0	2	0.5	2	0.3	4	0.3
Walleye pollock	2	0.3	1	0.3	1	0.2	4	0.3
Osmerid species	1	0.2	0	0	1	0.2	2	0.1
Slender Sole	0	0	2	0.5	0	0	2	0.1
English sole	2	0.3	0	0	3	0.5	5	0.3
Starry flounder	0	0	0	0	1	0.2	1	0.1
Pleuronectid species	0	0	0	0	1	0.2	1	0.1
American shad	0	0	1	0.3	0	0	1	0.1
Roughback sculpin	1	0.2	0	0	0	0	1	0.1
Pacific lamprey	0	0	0	0	1	0.2	1	0.1
Unidentified fish	29	4.9	18	4.6	15	2.5	62	3.9

with type of prey consumed. Bone identification is particularly important for adult salmon, which have small and fragile otoliths relative to their size. For example, overall FO of salmon was very low (2.3) when only otoliths were used for identification and considerably higher (24.5) when all structures (e.g. teeth, gill rakers, vertebrae) were used for identification (Table 10). This difference in FO of salmon based on identification techniques is also apparent for each river system individually (Table 10).

1998, 1999, and 2000 Food Habits Analysis

Scats were collected in Quilcene Bay from oyster racks and salmon net pens and from haulout locations at the Dosewallips, Hamma Hamma, Duckabush, and Skokomish River mouths in 1998, 1999, and 2000. Scat collections were stopped at the Skokomish River in 2000 due to the lack of complete salmonid abundance data. In 1998, 601 scat samples were collected and in 1999, 412 were collected.. In 2000, 608 scat samples were collected.

From scat samples collected in 1998, 1999, and 2000 (n=1,580), seventeen species of fish and two cephalopods were identified, with an additional seven prey identified to the genus, or family level (scientific and common names provided in Appendix A). For all three years combined, Pacific hake (79.7), Pacific herring (45.1), and salmon species (25.9) were the three most important prey species based on FO in harbor seal scat collected during the fall in Hood Canal (Table 11). Three additional prey species were important in harbor seal diet based on FO and include shiner surfperch (9.5) cephalopod species (7.2), and threespine stickleback (4.2). Those three species (surfperch, cephalopods, and stickleback) varied more among years than did the top three species (hake, herring, and salmon).

Pacific hake, Pacific herring, salmon species, and shiner surfperch are the four most commonly occurring prey species (>10 FO) at each individual river system for each year (Table 11). Cephalopod species are the fifth most commonly occurring species in Quilcene Bay and at the Hamma Hamma River; Northern anchovy is the fifth most commonly occurring species at the Duckabush River. Threespine stickleback is the sixth most commonly occurring species in Quilcene Bay primarily due to its high occurrence in the diet in 2000. Sample sizes do vary widely among locations and years, particularly at the Duckabush River.

Discussion

Predation on Salmonids

Determining impacts of harbor seals on the recovery of summer chum in Hood Canal will require the combined efforts of marine mammal and fisheries biologists. While further analysis is still needed, it seems plausible that in those situations where summer chum returns are already depleted and seals are consuming 10-20% of the returning adults, they are having a negative impact. Whether this impact is significant remains unanswered, and should be considered in conjunction with the numerous other causes of salmon mortality.

To date, our work in Hood Canal has focused on predation occurring in and around the estuarine and lower reaches of summer chum natal rivers. The presumption has been that these areas provide seals the best opportunity to catch and consume salmonids with consistency. Observations during this study certainly indicate that this is true. However, analysis of salmonid otoliths found in scats has revealed a larger than expected number of chinook salmon. Chinook are extremely rare in all of the river systems where our observations have occurred, with the exception of the Hamma Hamma River where a relatively small number returned in 1999 and 2000. This would indicate that there is a larger than expected component of seal diet in Hood Canal coming from open water predation on salmonids.

Potential differences in the number of predation events occurring in daylight and nighttime hours was examined in 2000 with a series of paired observations. Results of this work, unfortunately, still remain inconclusive. This is do in large part to the somewhat obvious fact that our ability to observe predation events at night is not as good as during the day. This fact will continue to cloud any comparison from a conclusive answer. However, clues from other more visible indices, such as number of foragers or number of chase events, may provide a clearer picture. Indeed, initial examination of data from 2000 at the Duckabush does seem to indicate that there are not significant differences in the number of seals in the river actively foraging between day and night. It is for this reason that we are assuming a 24 hour predation rate based on our daytime observations.

Food Habits and Scat Analysis

Food habits data reported here indicate that Hood Canal harbor seals are opportunistic predators feeding on a variety of prey species, primarily schooling fishes, adult salmonids, and cephalopods. Pacific hake, Pacific herring, salmon, shiner surfperch, and two cephalopod species were the five most commonly occurring species for each year and for all years combined. The frequency of each prey species did vary among location, most notably the large percentage of two cephalopod species and threespine stickleback in Quilcene Bay. A high frequency of shiner surfperch was also observed in Quilcene Bay and Dosewallips River. Through collaborative work with WDFW fisheries biologists we hope to overlap and incorporate information on distribution and abundance of these prey species with our knowledge about distribution and abundance of harbor seals in Hood Canal to better understand their foraging ecology.

Describing pinniped food habits using scat analysis has numerous limitations and potential biases and they are described in detail in the literature (Pitcher 1980, Bigg and Fawcett 1985, Tollit et al. 1997, DaSilva and Neilson 1985, Harvey 1989, Cottrell et al. 1996) and have also been the subject of several formal and informal workshops (Riemer and Lance 2000). Differential recovery rates of fish hard parts vary with prey species. Captive feeding studies currently taking place at University of British Columbia (Dr. Dominic Tollit) and Moss Landing Marine Laboratories (Dr. Jim Harvey) are addressing crucial questions including determining the effects of the amount of prey consumed, composition and frequency on passage rates and recovery rates of diagnostic skeletal remains. Answers to these questions are crucial because they directly affect assumptions and models used to reconstruct diet.

Salmonid consumption and impacts on specific salmon runs by pinnipeds are the drivers for this study. Salmon species are the third most frequently occurring species based on scat analysis. Identification of salmon to species from otoliths is the first step, however this only accounts for a small percentage of the samples collected. Development of molecular genetic techniques to identify salmon to species using bone recovered from fecal samples is an important tool for identifying salmon species and we hope will compliment predation estimates based on surface observations as a quantifiable next step.

Recommendations for Future Work

Summer Chum Spawner-Recruit Relationship

Estimates of predation rates and percentage of returning adults consumed for 1998-2000 indicate that levels of seal predation on returning salmonids is higher than initially expected. However, a key factor currently missing from the analysis is an assessment of the impact observed levels of predation are having, or could have, on recovery of Hood Canal summer chum.

An important component of determining the level of significance is the spawner-recruit relationship. This relationship describes the number of additional recruits (future spawners) that will result from one additional spawner. Factors such as density dependence, habitat quantity and quality, sex ratios and ocean survival all play a role in the characterization of this relationship. Spawner-recruit curves for salmonids typically exhibit a greater than 1:1 relationship at low population levels, and as the population increases the slope becomes less steep and eventually flattens out to a point where an additional spawner does not result in additional recruits. The key question to understanding the impacts of seal predation is to determine the slope of the spawner-recruit curve at current population levels of Hood Canal summer chum.

To our knowledge, the spawner-recruit relationship for summer chum in Hood Canal is not well understood. Characterization of the spawner-recruit relationship requires both accurate estimates of number of returning spawners and estimates of age distribution. Summer chum have never been the focus of widespread commercial harvest, and detailed research into this summer chum salmon population has only begun in the last 5-10 years.

With these limitations it may not be possible to accurately determine the level of significance seals may be having on summer chum. However, we believe steps should be taken to begin this process in the immediate future. This may initially require assumptions and extrapolation of data from other summer chum and/or fall chum populations in Washington and British Columbia. This should provide managers with an initial estimate of seal predation levels that should raise concern with respect to the recovery of summer chum in Hood Canal.

Extent of Open-water (non-river) Salmonid Predation

Our work has focused on estimating 'in-river' predation rate of seals in Hood Canal. Existence of 'open-water' predation has been presumed, however, no efforts have been made to quantify and/or characterize the extent to which this predation is occurring throughout the seal population. We know from scat analysis that salmonid remains are present in roughly 25% of scats and of those scats where identifiable otoliths are present, chinook salmon is consumed. Chinook are non-existent or extremely rare in the Quilcene, Dosewallips and Duckabush river systems, and have recently been re-introduced to the Hamma Hamma River. Chinook are a significant component of hatchery salmon returning to both the Hoodsport Hatchery and other hatcheries located on the Skokomish River. Therefore, presence of chinook otoliths in scats collected at Quilcene Bay, Dosewallips and Duckabush would suggest that salmonid predation in 'open-water' is occurring at some level.

Deployment of Time-Depth Recorder Archival Tags (TDRs)

Quantification of 'open-water' predation will not be possible at levels of precision we have attained with 'in-river' predation. However, use of time-depth recorder archival tags (TDRs) and head-mounted VHF radio tags may provide a means to characterize the extent to which 'open-water' salmonid predation is occurring within the population of seals. We plan to deploy TDRs on seals observed foraging within the river mouths and more 'generic' seals found at the main haulouts. We hope a comparison of dive profile data from the two seal types can provide insight into the foraging activity away from the river mouths.

Deployment of Head-mounted VHF Radio Transmitters

Harbor seals are generally characterized as highly localized 'central-place' foragers. Studies in British Columbia, Washington and California have shown the vast majority of foraging locations for adult seals to be within 15km of a haulout. Satellite PTT transmitters deployed on two seals in Hood Canal during the winter of 2002 appear to indicate a similar pattern. However, given the mobility and dynamic changes in density and location of returning salmonids, seals focusing on salmonids as a prey resource may diverge from the 'standard' foraging behavior. For this reason, it will be important to establish locations of foraging seals in the 'open-water' habitat of Hood Canal. By deploying head-mounted VHF transmitters and TDRs on the same individuals, we may also be able to provide verification of the hypothesized difference in dive profiles of those seals foraging for salmonids and non-salmonids. Seals are believed to bring captured salmonids to the surface for consumption. Use of the VHF transmitters to locate and identify foraging seals in 'open-water' will allow limited observation of surface activity. Any observed salmonid consumption can later be paired with dive information from the TDR to examine dive profiles for known salmonid foraging events.

Monitoring of Duckabush River for Return Foragers

During the 2001 field season, two seals were captured and fitted with flipper tags and streamers and a number of individual seals were captured on videotape. A key question for future mitigation and management options is whether or not predation events in the rivers involve the same group of seals not only within the same year, but also across years. Limited observations at the mouth of the Duckabush for the presence of Pv1409 and other video taped seals would provide an answer to this key question.

Establish Fish Age-Length Regression for Pacific hake

Pacific hake was found in nearly eighty percent of all harbor seal scat samples collected in Hood Canal during this study (1998, 1999, and 2000) and also composed more than eighty percent of the diet in food habit studies conducted by Cascadia Research in Hood Canal (Calambokidis et al. 1978; Calambokidis et al. 1989). Hake otoliths are frequently recovered in scat samples because they are relatively robust and length and width measurements can easily be taken. The Marine Fish Science Unit of WDFW is currently processing hake collected from mid-water trawls near Port Susan, Washington and will be collecting population data (length, weight, sex, and maturity) as well as ageing those otoliths. Collaboration with the Marine Fish Science Unit (WDFW) to develop an age-fish standard length regression for Puget Sound hake would provide additional information about the age composition of hake eaten by harbor seals in Hood Canal. Regression analysis would also allow us to determine potential differences in the relative age composition of hake in the diet of harbor seals in Hood Canal between the two time "windows" (late 1970s/1980s and late 1990s) through collaboration with Cascadia Research.

Genetic analysis of salmon bones

In order to understand the impact of predation on particular salmon runs, identification of salmon to species is critical. Direct surface observation is one way to quantify predation and scat analysis is another. Salmon remains were present in almost twenty five percent of the harbor seal scat samples collected in Hood Canal; however identification of salmon in the majority of those samples was based on bone identification, which does not allow identification to species level. Species identification is possible if otoliths are recovered, but because salmon otoliths are small and relatively fragile and may not be consumed, this is a rare occurrence.

The Conservation Biology Molecular Genetics Laboratory and the National Marine Mammal Laboratory collaborated on a study to develop molecular genetic techniques to identify salmonid bones recovered from pinniped scat samples where otoliths were not present to species.

WDFW's genetics laboratory would build on developmental work done by the NMFS-Montlake Genetics Lab (Purcell et al., 2001 and L. Park, NMFS, pers. comm.) to develop and implement a single-nucleotide polymorphism (SNP) based assay procedure to identify species-of-origin of salmonid bone fragments isolated from seal scats. They would utilize commercially available silica membrane technology, centrifuge-based kits to purify the DNA after decalcification and proteinase K digestion of bone samples previously isolated from scat samples. They would plan to focus their analysis on the same portion of the mtDNA genome that was used in the NMFS study: the cytochrome oxidase III, glycine-tRNA, and ND3 gene region. This region would be amplified from the isolated DNA using the polymerase chain reaction - PCR (Saiki et al., 1988). They would develop standard (e.g., ABI SnaPshot system) or a modified (three primer) SNP analysis to detect species-specific differences in nucleotide sequence in the target DNA. This way they would hope to avoid the lack of specificity sometimes encountered when using restriction endonucleases (RFLP analysis), and the high cost of direct sequencing. Their approach would be to try to utilize SNPs in such a way that several completely or partially diagnostic SNPs will be screened in each sample using an automated sequencer (ABI-377 or ABI-3100) to detect presence and approximate size of each amplification product. If possible, they would multiplex SNP markers at the PCR and/or electrophoresis stages to facilitate cost-effect analysis.

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Appendix A

Families and species names of Pacific harbor seal prey items identified from scat samples collected in Hood Canal, Washington during the fall (late July-November) of 1998, 1999, and 2000.

Family	Species	Common Name
Ammodytidae	*Ammodytes hexapterus*	Pacific sandlance
Batrachoididae	*Porichthys notatus*	Plainfin midshipman
Clupeidae	*Clupea pallasii*	Pacific herring
	Alosa sapidissima	Amercian shad
Cottidae	*Leptocottus armatus*	Pacific staghorn sculpin
	Chitonotus pugetensis	Roughback sculpin
Embiotocidae	*Rhacochilus vacca*	Pile surfperch
	Cymatogaster aggregata	Shiner surfperch
Engraulididae	*Engraulis mordax*	Northern anchovy
Gadidae	*Microgadus proximus*	Pacific tomcod
	Theragra chalcogramma	Walleye pollock
	Merluccius productus	Pacific hake
Gasterosteidae	*Gasteroseus aculeatus*	Threespine stickleback
Gonatidae	*Berryteuthis magister*	Schoolmaster gonate squid
	Gonatopsis borealis	Boreopacific gonate squid
Loliginidae	*Loligo opalescens*	Market squid
Octopodidae	*Octopus spp.*	Octopus
Ommastrephidae	*Ommastrephes bartramii*	Neon flying squid
Osmeridae	*Hypomesus pretiosus*	Surf smelt
Petromyzontidae	*Lampetra tridentata*	Pacific lamprey
Pleuronectidae	*Parophrys vetulus*	English sole
	Lyopsetta exilis	Slender sole
	Platicthys stellatus	Starry flounder
Rajidae	*Rajid spp.*	Skate
Salmonidae	*Oncorhyncus tshawytscha*	Chinook salmon
	Oncorhyncus kisutch	Coho salmon
	Oncorhyncus keta	Chum salmon
	Oncorhyncus mykiss	Steelhead
Scorpaneanidae	*Sebastes spp.*	Rockfish