DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights**. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.

PNNL-13635-(3)

Effects of Shoreline Hardening and Shoreline Protection Features on Fish Utilization and Behavior at Washaway Beach, Washington (Final Report)

M.C. Miller
G.D. Williams
L.K. O'Rourke
S.L. Sargeant
J.A. Southard

December 2002

Prepared for
The Washington State Department of Transportation
Under a Related Services Agreement
With the U.S. Department of Energy
Under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Sequim, Washington 98382

Contents

Executive Summary iii

1.0 Introduction 1

1.1 Problem Statement 2
1.2 Objectives 2
1.2 Overview of Survey Methods and Study Area 3

2.0 Predator Surveys 6

2.1 Methods 6
2.2 Results 6

3.0 Beach Seines 12

3.1 Methods 12
3.2 Results 13

4.0 Stomach Content Analysis 18

4.1 Methods 18
4.2 Results 18

5.0 Mark-Recapture 21

5.1 Methods 21
5.2 Results 22

6.0 Snorkel Observations 23

6.1 Methods 23
6.2 Results 23

7.0 Summary of Results 24

8.0 Summary of Previous Studies 26

8.1 Splitbeam Hydroacoustic Surveys 26
8.2 Drift Buoy Deployments 31
8.3 Commercial Fishing Interviews and Observations 32
8.3.1 Interviews 32

8.3.2 Field Observations 33
8.4 Bird and Mammal Observations 33
8.5 Snorkel and SCUBA Dive Surveys 34
8.6 Stomach Content Analysis 36
8.7 Beach Seines 36
9.0 Discussion and Conclusions 39
9.1 Predation 39
9.2 Migration 42
9.2.1 Physical Processes Affecting Migration 42
9.2.2 Fish Migration Impacts 42
9.3 Discussion of Methods 44
9.4 Conclusion 45
10.0 References 47

Figures

1. Location of Jacobson's Jetty Project Site at Washaway Beach, Washington 2
2. Beach Seine and Predator Survey Stations at Washaway Beach, May 2002 5
3. Relative Abundance of Gull Taxa During Predator Surveys at Washaway Beach Groin and Reference Stations, May 2002 9
4. Relative Abundance of Piscivores other than Gulls during Predator Surveys at Washaway Beach Groin and Reference Stations, May 2002 10
5. Deploying the Beach Seine and Examining the Catch after a Haul, Washaway Beach, May 2002 .. 13
6. Total Number of Fish Captured at Four Sample Stations, Washaway Beach, May 2002 16
7. Percentage of Species Abundance during Day and Night Sampling, Washaway Beach, May 2002. 17
8. Size Class of Predator Species and Salmonids Captured at Washaway Beach, May 2002 (does not include 376-mm subadult coho captured at East Groin) 17
9. Marking Juvenile Chinook Salmon with Elastomer Tags, Washaway Beach, May 2002 21
10. *F/V Tricia Rae.* (The diagonal bar attached to the life rail is used for the hydroacoustic tranducer mount.)... 27
11. Typical Track Line for Split-Beam Hydroacoustic Surveys 27

12. Hydroacoustic Survey during High Slack Tide on October 19, 2001 28

13. Hydroacoustic Survey during an Ebb Tide Changing to Low Slack on October 20, 2001 29

14. Drift-Buoy Tracks Recorded on Flood Tides at Washaway Beach, Washington 31

15. Salmon Smolt, Feeding Near the Rock Groin 36

16. Juvenile Salmon, often Observed in Small Groups 36

17. Five-Year Trends and Trend Lines (2-Period Moving Average) in Terminal Run Size of Willapa Bay and Gray's Harbor Chinook 44

Tables

1. Survey Methods and Study Objectives during Field Studies at Washaway Beach, 2001-2002 4

2. Bird and Marine Mammal Taxa Observed during Sampling Efforts at Washaway Beach, May 2002 7

3. Mean Number of Individuals per Study Area of Marine Mammals and Avian Taxa Documented during Predator Surveys at Washaway Beach Groin and Reference Stations, May 2002 8

4. Number of Beach Seine Sets Conducted at Washaway Beach Groin and Reference Stations, May 2002 12

5. Fish Species Captured at Washaway Beach Groin and Reference Stations, May 2002 14

6. Catch Per Unit Effort (CPUE) at Four Sample Stations, Washaway Beach, May 2002 16

7. Stomach Contents of Potential Fish Predators Captured at Washaway Beach, May, 2002 19

8. Elastomer Marking Patterns Used at Washaway Beach Groin and Reference Stations, May 2002. ... 21

9. Mark-Recapture Data for the Four Seining Areas at Washaway Beach, May 2002 22

10. Species Netted in Beach Seines at Washaway Beach, June 11-14, 2001 38

11. Study Conclusions of the Potential Effect of Washaway Beach Groin and Dike on Migratory Movement and Predation on Juvenile and Adult Salmonids 46

Executive Summary

In 1998, the Washington State Department of Transportation (WSDOT) with funding assistance from the Federal Highway Administration, constructed a groin and underwater dike adjacent to State Route 105 on the north side of Willapa Bay in the vicinity of North Beach. The structure was designed to arrest the northward migration of a deep ebb tidal channel that, if continued to move northward, threatened to erode the only transportation link connecting Tokeland and the Shoalwater Indian Reservation with Grayland and Westport. The structure was built in two segments: an above-water portion, generally referred to as the groin (locally known as Jacobson's Jetty), and an underwater portion, referred to as the dike. As a condition of the emergency construction authorization, WSDOT agreed to conduct a biological monitoring program to evaluate the effect of the structure on the habitat and migration habits of salmonids that pass through the estuary and coastal area on their way in or out of Willapa Bay. The specific concerns expressed by the regulatory agencies were as follows:

- The dike, constructed of large diameter, dumped rock, could provide habitat for predators that would feed on the migrating juvenile salmon.
- The dike could change the flow pattern within the nearshore migration pathway and force the juvenile fish into deeper water where they would be more vulnerable to avian predators.
- The structure could become a gathering place for piscivorous avian species that would deplete the already stressed salmon stocks.
- The altered circulation patterns around the dike could also hinder the out-migration of salmonids by trapping them in downstream eddies or causing them to congregate on the upstream side of the structure.
- The dike could alter the migration path of returning adults such that fish holding near the dike would become easy prey for seals or sea lions.

Responding to these concerns, the WSDOT supported a habitat evaluation study conducted by scientists from the Battelle Marine Sciences Laboratory from spring 2001 through fall 2002. The study was carried out in three phases to determine the effect of the structure on juvenile salmon (June 2001 and May 2002) and returning adult salmon (October 2001). Reports of the 2001 field monitoring programs have been completed. This document provides a summary of these reports and the results of the May 2002 field survey.

The following methods were used to observe fish behavior or to document predation on salmonids by fish predators, birds, and mammals:

- fish sampling using beach seine and gillnet;
- split-beam hydroacoustic surveys;
- direct observation by divers using snorkel and scuba;
- stomach content analysis;
- observation of bird and mammal predators;
- interviews with fishermen and Washington Department of Fish and Wildlife personnel;
- current pattern observation using passive drifter buoys; and
- fish migration tracking using mark and re-capture.

Although these methods have been used successfully in other studies and were considered appropriate, not all were effective in this environment, nor were all methods used for all surveys.

The following conclusions were drawn from the field observations:

- The jetty and dike provide substrate and habitat for a large variety of aquatic species, both flora and fauna. Only the latter are documented in this study. During the second spring sampling (May 2002), the numbers of individual fish and the variety of species were significantly greater at the structure site than at the control sites. Stomach content analysis of large piscivorous predators did not reveal salmonids or their remains. Sport and subsistence fishers use the jetty all year.
- The echo sounder surveys were conducted in spring and fall 2001. The spring survey showed large schools of small fish, believed from the seine catch to be shiner perch and/or forage fish, to be widely distributed in the study area, including at the structure. The fall survey indicated that large fish, probably salmon, based on the corresponding results of commercial fishing, were observed throughout the study area during the flood tide but were not widespread during the low slack tide. Not all phases of the tide were sampled because of the extreme currents during periods of flooding and ebbing. Commercial fishers took advantage of this behavior and fished on the flooding tide.
- Commercial fishers revealed in interviews that the structure did not seem to affect either the magnitude or location of their catch. Comparison of Grays Harbor and Willapa Bay catch statistics show similar trends in terminal run size, suggesting that factors within Willapa Bay have not independently influenced the run. Data on this issue are not conclusive because of the short time that the structure has been in place and because data were averaged to remove seasonal spikes.
- Observations of the distribution of birds and mammals do not suggest that they preferentially concentrate and feed around the structure. Predator aggregation is often observed in habitat patches where prey availability and density is higher. This aggregative response may increase mortality rates of prey species relative to habitat areas with lower prey densities. Though more predator species of birds were observed at the structure site relative to the reference sites, we did not observe what could be termed an aggregative response of predators to these habitats.
- Juvenile salmons were observed individually and in small groups (3 to 5 individuals) during snorkel and dive surveys on both sides and on top of the structure during both high and low slack tides. Fish were behaving normally, e.g., feeding, and did not appear confused or disoriented around the structure.
- Turbulence and eddies downstream of the structure were observed and documented using drift buoys. These were also predicted by the numerical model studies conducted by the Corps of Engineers and were measured by current meters and synoptic current surveys conducted during physical monitoring. The degree to which these eddies influence salmon behavior could not be determined.
- These studies do not provide evidence that this single structure has adversely impacted salmon populations through alteration in behavior or predation in Willapa Bay.

Because of the variability of natural biological systems, long-term studies would be required to conclusively demonstrate whether a cause-and-effect relationship exists between the structure and salmonid population and behavior. The specific amount of time required to establish or deny causal inference at this site has not been determined. The inability to conduct before and after impact studies at the construction site means that differences in population and behavior must be compared by reference with analogs of the preconstruction site. Because analogs are always imperfect and trends in environmental data are common, it may be impossible to unambiguously ascribe effects to the salmon population that are solely due to the structure.

1.0 Introduction

This report is the third and final in a series detailing the procedures used and the results obtained from studies designed to determine the impacts of erosion control structures on nearshore habitat and salmonids at Washaway Beach, Washington. This area of shoreline near Cape Shoalwater in Pacific County has been undergoing extreme erosion for nearly a century. With a shoreline retreat rate that has averaged between 100 and 130 feet per year (Terich and Levenseller 1986), the site has been identified as having the most severe erosion rate of any location on the US West Coast (Komar 1998). In 1998, the Washington Department of Transportation (WSDOT) constructed a groin and dike along the North Channel at North Cove in an attempt to halt and possibly reverse the erosion trend and to protect State Route 105, which was threatened by the northward migration of the channel. The structures placed on the site consisted of a 1600-ft rock groin and an attached 930-ft underwater dike that were designed to slow erosion and facilitate accretion of sediments along the most vulnerable section of the highway. In addition, a beach nourishment was undertaken in which 350,000 cy of sand was placed on the beach along the existing riprap wall immediately seaward of the highway and to the east of the structure. The project background is more fully described in Phillips and Pierce (1999). The location and general layout of the area surrounding the rock groin, locally known as "Jacobson's Jetty," is shown in Figure 1.

In the "Finding of No Significant Impact (FONSI)" filed prior to construction of the groin and dike, the State noted:

> The urgency of the project does not allow for the establishment of clear environmental resource baseline conditions, given seasonal, annual, and possibly cyclic variations in the quantity and quality of habitats. Instead of delaying the implementation of the project to acquire this information, an alternative approach is used to establish baseline conditions and to set mitigation thresholds. This approach as addressed in the Monitoring and Mitigation Agreement relies on establishing baseline conditions using existing information; information collected prior to and concurrent with the project construction; and information collected over a period of time following construction.
>
> State Route 105
> North Cove Emergency Stabilization
> Project ER-96-3, Approved 7/31/97

The Federal Highway Administration (FHWA) and WSDOT entered into an agreement with the other state and federal resource agencies and the Shoalwater Tribe to pursue environmental issues in an adaptive framework. To this end, the Pacific Northwest National Laboratory (PNNL), Battelle Marine Sciences Laboratory (MSL) was engaged to conduct a series of field studies.

At the close of this report, we summarize the findings from all previous field efforts and make some general conclusions about likely impacts of the groin structure on salmon habitat, opportunity, and function.

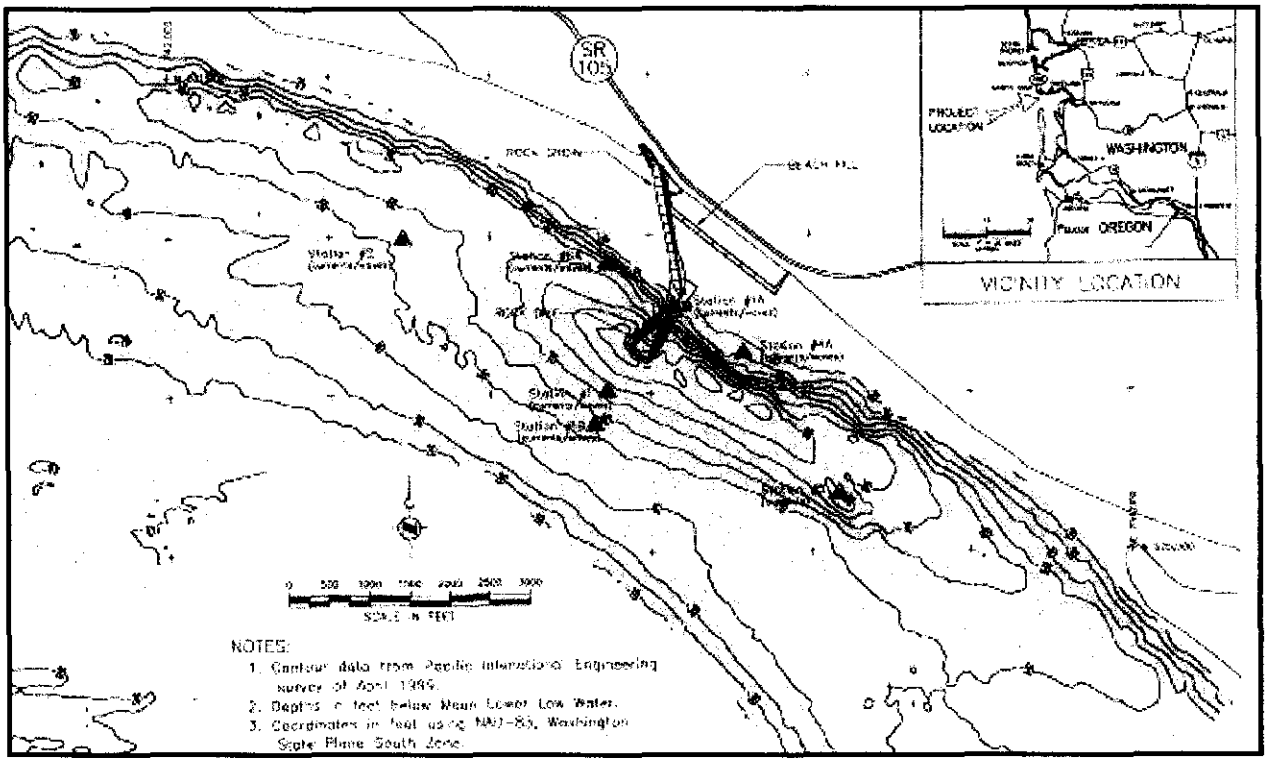

Figure 1. Location of Jacobson's Jetty Project Site at Washaway Beach, Washington

1.1 Problem Statement

Armor used for erosion control structures in Washington waters has both physical and biological effects (MacDonald et al. 1994; Williams and Thom 2001). Though the physical effects of shoreline armoring have been studied somewhat, the specific ecological effects of shoreline and habitat modification are often poorly documented. To better understand the impacts of various armoring strategies and to devise least damaging alternatives, it is critical to acquire systematic data on ecological impacts from these structures. This study is directed at determining the impact of the groin structure on habitat characteristics and species composition at Washaway Beach.

1.2 Objectives

The objectives of the study were to develop an understanding about whether groin-type structures on the outer coast can alter migratory movement or predation pressure on juvenile and adult salmon. The Washaway Beach dike and groin structure is an example of such a feature and provides an opportunity to conduct coupled studies on the physics and associated ecology of these structures in this environment.

Specific questions addressed were the following:

1. What are the differences in predator abundance and predation pressure between the armored site and nearby unarmored sites?

2. What are the differences in juvenile and adult salmon migratory behavior between the armored site and nearby unarmored sites?

3. What are the physical conditions and processes (substrata, currents, sedimentation, erosion, wave energies) that could contribute to differences in predation and migration between armored and unarmored sites?

1.2 Overview of Survey Methods and Study Area

The first field survey of the site was conducted from June 11 through 15, 2001 during the outmigration window of juvenile salmon from Willapa Bay (Miller et al., 2001). Five survey methods (splitbeam hydroacoustics, beach seines, snorkel and dive survey, analysis of stomach contents, and observations of birds and mammals near the groin) were used to locate juvenile salmonids and potential predators, and to assess the impact of the groin on the distribution, activity, and migration pathway of the salmon (Table 1).

The fall survey, conducted from October 14 through 21, 2001, was aimed at assessing the influence of the groin on the migration pathway of the returning adult salmon. These surveys consisted of gillnetting, passive drifter surveys, interviews with fishers and Washington Department of Fish and Wildlife (WDFW) personnel, bird and mammal surveys, and splitbeam hydroacoustic surveys (Miller et al., 2002) (Table 1).

The third and final survey, conducted from May 13 through 17, 2002, built upon successful field techniques used in previous efforts and focused on outmigrating juvenile salmonids. In this field effort, surveys of potential bird and mammal predators associated with the groin structure were intensified, beach seines were used to gather data on fish species composition and abundance, stomach contents of potential fish predators were analyzed, and limited mark-recapture of juvenile salmon was conducted to investigate nearshore residence time and movement patterns. The following sections provide details of the methods and results used in the survey.

Field sampling centered on the groin structure itself (groin) and on two reference stations (East and West Reference) with unarmored shorelines (Figure 2). These reference stations were established at a sufficient distance from the groin and dike as to be minimally impacted by its effect on sediment dynamics and currents. East Reference (Lat. 46° 43.527 N, 124° 03.074 W) was located approximately 600 m southeast (inside) of the groin, adjacent to the decommissioned section of SR105. This station within the bay was relatively protected from wind and wave action. West Reference (Lat. 46° 44.111 N, 124° 04.817 W) was located approximately 1800 m northwest (outside) of the groin, on a more open coastal shoreline exposed to full wind and wave action.

Visual surveys of bird and mammals considered potential salmon predators were conducted at all three stations (groin, East Reference and West Reference) and encompassed a 100-m stretch of beach centered on each station. Collections of juvenile salmonids and their potential fish predators were conducted with beach seines at all three stations, although the groin was more intensively sampled, with collections made on both the east and west sides (Figure 2).

Table 1. Survey Methods and Study Objectives during Field Studies at Washaway Beach, 2001-2002

Survey Method	Fish species composition	Migratory behavior of juvenile salmonids	Utilization of groin vs. natural reference sites by juvenile salmonids	Potential predator species composition	Predation on juvenile salmonids	Migratory pathway of returning adult salmonids	Physical conditions and processes near groin
Beach seine	***a,c***		***c***	***c***			
Split beam hydroacoustic						***b***	
Snorkel & Dive		***a,b,c***	***a,c***	***a,c***			***a,c***
Stomach content analysis					***a,c***		
Bird & mammal predators				***b,c***	***b,c***		
Fishermen & WDFW interviews						***b***	
Gillnet						***b***	
Passive drifter buoy							***b***
Mark and re-capture		***c***	***c***				

a = June 2001, *b* = Oct 2001, *c* = May 2002

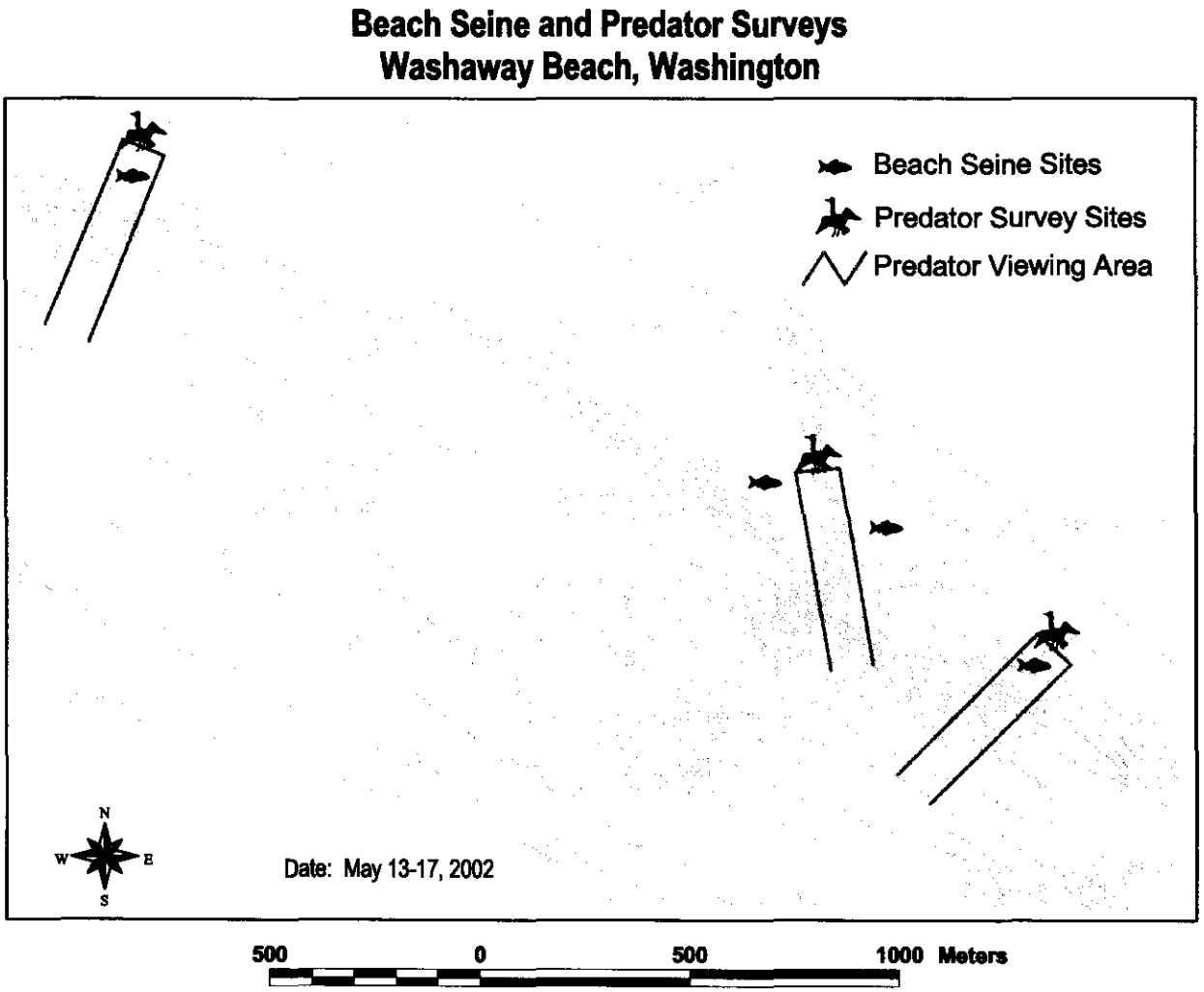

Figure 2. Beach Seine and Predator Survey Stations at Washaway Beach, May 2002

2.0 Predator Surveys

2.1 Methods

Quantitative fixed-point-count surveys of birds and marine mammals were conducted to document both the presence and feeding behavior of potential salmon predators at the groin relative to "unaltered" reference sites.

Over a five-day period, May 13 through 17, 2002, seven surveys were simultaneously conducted at random start times at all three stations. These surveys comprised a variety of times and tidal stages (Table 1). Each fixed-point-count survey involved a 20-min station visit, wherein all taxa and numbers of birds and marine mammals observed within the station boundaries (from shore to maximum viewing distance seaward) were counted and recorded over a period of five successive counts in 5-min intervals. General behavior (e.g., diving, foraging, perching) of birds and marine mammals was also recorded. To account for possible redundant counts of the same subjects over the course of each 20-min (5-count) period, the mean number of individuals recorded per 20-min survey was calculated for each species. These mean counts were then used to estimate total mean densities of potential salmon predators across stations (groin vs. East Reference vs. West Reference). The ratio of potential salmon predators to non-predators was also compared for each station.

Qualitative observations of unusual or noteworthy marine mammal and/or piscivorous bird activity relevant to potential salmonid predation during other sampling efforts were also recorded.

2.2 Results

A total of 16 bird and marine mammal taxa were observed at the study locations during the course of both quantitative surveys and qualitative observations during other field sampling activities (Table 2). Of these taxa, 2 were marine mammals and 14 were bird taxa. Based on a review of the literature, the following groups were classified as piscivores ("fish-eaters") that could be considered potential salmon predators: seals, sea lions, gulls, loons, cormorants, grebes, terns, and bald eagles. Piscivorous birds employ various foraging methods, such as underwater pursuit diving, plunge diving, surface feeding, and aerial feeding in pursuit of their fish prey: Nonpiscivorous avian taxa were predominantly shorebirds and scoters, which feed on benthic invertebrates. In general, more bird and mammal species (13) were observed at the groin than at the reference stations; more piscivorous taxa (10) were observed at the groin as well.

Pacific harbor seals (*Phoca vitulina*) were recorded at each station but with greater frequency at the groin (three of seven surveys) than at each of the reference stations (one of seven surveys) (Table 3). Qualitative sightings of Pacific harbor seals around the vicinity of the groin and East Reference were fairly common. Likewise, California sea lions (*Zalophus californianus*) were seen near the groin on two different occasions in groups of two and three. Foraging by seals or sea lions was not observed. However, since smaller prey can be consumed underwater (NMFS 1997), quantifying pinniped predation based solely on observations of surface feeding is unreliable.

Thirteen avian taxa were documented during the course of quantitative predator surveys. Two species of gull (*Larus* spp.) were seen in greater numbers than the other piscivorous birds recorded in the surveys, although we observed no incidence of gulls feeding on fish during any survey. The frequency of gulls at each station was similar, but the mean number of individual gulls per survey was greater at West Reference (45.9 versus 1.6 and 3.2 at the groin and East Reference, respectively) (Figure 3). Gulls, particularly *Larus* spp., are often highly predatory, and are omnivorous and opportunistic feeders

Table 2. Bird and Marine Mammal Taxa Observed during Sampling Efforts at Washaway Beach, May 2002

Common Name	Scientific Name	East Reference	Groin	West Reference
Marine Mammals				
Pacific Harbor Seal *	*Phoca vitulina*	•	•	•
California Sea Lion*	*Zalophus californianus*		•	
Birds				
Gull (Western, Glaucous-winged or hybrid) *	*Larus* spp.	•	•	•
Bonaparte's Gull *	*Larus philadelphia*	•	•	•
Surf Scoter	*Melanitta perspicillata*	•	•	•
Common Loon *	*Gavia immer*	•	•	•
Pacific Loon *	*Gavia pacifica*		•	
Cormorant *	*Phalacrocorax* spp.		•	•
Northwestern Crow	*Corvus caurinus*		•	•
Tern *	*Sterna* spp.	•	•	•
Western Grebe *	*Aechmophorus occidentalis*		•	•
Bald Eagle *	*Haliaeetus leucocephalus*	•	•	
Plover sp.	*Charadrius* spp		•	•
Western Sandpiper	*Calidris Mauri*			•
Canada Goose	*Branta Canadensis*	•		
Cliff Swallow	*Hirundo pyrrhonota*			•
No. of Bird/Marine Mammal Taxa Observed (16 possible)		8	13	12
No. of Predator Species Observed (10 possible)		6	10	7

* Piscivore

Table 3. Mean Number of Individuals per Study Area of Marine Mammals and Avian Taxa Documented during Predator Surveys at Washaway Beach Groin and Reference Stations, May 2002

Station	Date	Time	Tide	Harbor seal *	Gull (Glaucous-winged/Western/hybrid) *	Gull - Bonaparte's *	Surf Scoter	Northwestern Crow	Common Loon *	Cormorant spp *	Tern spp *	Western Sandpiper	Western Grebe *	Plover spp	Bald Eagle *	Canada Geese	Cliff Swallow	Total mean number of mammals per survey	Total mean number of birds per suvey
E. Ref	5/13/02	12:45	Flood	0	12	0	25.4	0	0	0	0	0	0	0	0	0	0	**0**	**37.4**
E. Ref	5/14/02	11:35	Flood	0	0	0	8	0	0.4	0	0	0	0	0	0	0	0	**0**	**8.4**
E. Ref	5/15/02	10:27	Ebb/Slack	0	0	0	22	0	0.4	0	0	0	0	0	0	0	0	**0**	**22.4**
E. Ref	5/15/02	20:24	Ebb	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	**0**	**0.8**
E. Ref	5/16/02	10:35	Low Slack	0	1	3	63.2	0	0.2	0	0	0	0	0	0.2	0	0	**0**	**69.6**
E. Ref	5/16/02	21:08	Ebb	0	5	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**5**
E. Ref	5/17/02	7:00	Ebb	2	1.4	0	7.4	0	0	0	0	0	0	0	0	0	0	**2**	**8.8**
Mean no. of individuals per survey				**0.3**	**2.8**	**0.4**	**18.1**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.3**	**21.8**
Groin	5/13/02	12:45	Flood	0.2	1.4	0	0	0.4	0	0	0	0	0	0	0	0	0	**0.2**	**1.8**
Groin	5/14/02	11:35	Flood	0	0.2	0	0	0	0.4	0	0	0	0	0	0	0	0	**0**	**0.6**
Groin	5/15/02	10:27	Ebb/Slack	0.4	0.4	1.6	0	0	0	0.4	0	0	0	0	0	0	0	**0.4**	**2.4**
Groin	5/15/02	20:24	Ebb	0	0	0	2.8	0	0	0	0	0	0	0	0	0	0	**0**	**2.8**
Groin	5/16/02	10:35	Low Slack	0	4.6	0	60	0	0	2.6	0	0	0	0	0	0	0	**0**	**67.2**
Groin	5/16/02	21:08	Ebb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
Groin	5/17/02	7:00	Ebb	1.6	1.4	2.2	29.8	0	0	0	0	0	0.4	5	0	0	0	**1.6**	**38.8**
Mean no. of individuals per survey				**0.3**	**1.1**	**0.5**	**13.2**	**0.1**	**0.1**	**0.4**	**0.0**	**0.0**	**0.1**	**0.7**	**0.0**	**0.0**	**0.0**	**0.3**	**16.2**
W. Ref	5/13/02	12:45	Flood	0.2	13.8	0	0	0.4	0.4	0.2	0	0	0	0	0	0	0	**0.2**	**14.8**
W. Ref	5/14/02	11:35	Flood	0	29.2	0	2.4	0	0	0	0	0.2	0.2	0	0	0	0	**0**	**32**
W. Ref	5/15/02	10:27	Ebb/Slack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
W. Ref	5/15/02	20:24	Ebb	0	0.4	4.8	0	0.2	0	0	0.2	0	0	0	0	0	0	**0**	**5.6**
W. Ref	5/16/02	10:35	Low Slack	0	0.2	0	0	0	0	0	0	0	0.4	0	0	0	0	**0**	**0.6**
W. Ref	5/16/02	21:08	Ebb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
W. Ref	5/17/02	7:00	Ebb	0	266	7	0	0.6	0	0	0	0	0	1.8	0	0	0.4	**0**	**276**
Mean no. of individuals per survey				**0.0**	**44.2**	**1.7**	**0.3**	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.3**	**0.0**	**0.0**	**0.1**	**0.0**	**47.0**

* Piscivore

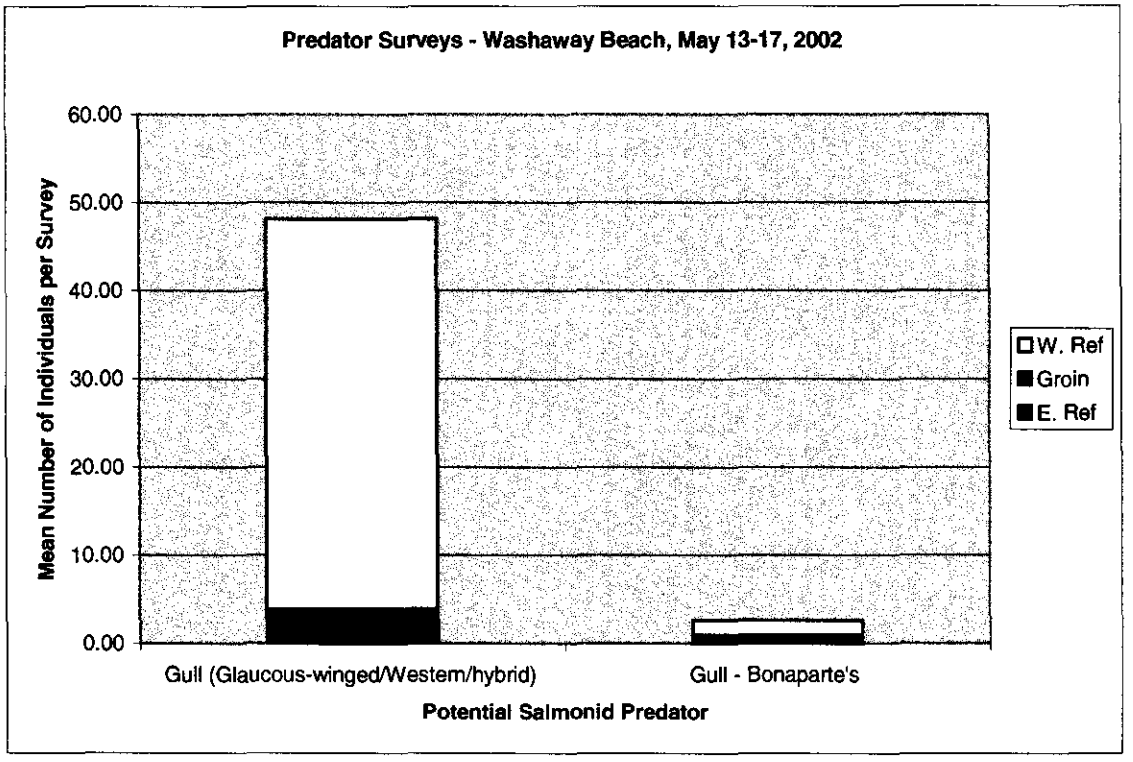

Figure 3. Relative Abundance of Gull Taxa During Predator Surveys at Washaway Beach Groin and Reference Stations, May 2002

(Nelson 1979). For example, during the survey at the groin on May 16, one adult and two juvenile gulls were seen swallowing seastars. Scavenging can also play a significant role in their foraging methods (Nelson 1979).

Common loons (*Gavia immer*) were recorded at each site but with greater frequency at East Reference (three of seven surveys) than at the groin and West Reference (one survey each) (Figure 4). These loons were solitary, with the exception of one survey when two were seen together at East Reference. On all occasions, this species was seen diving. A group of five Pacific loons was also observed approximately 20 m off the end of the groin on May 15 during other sampling operations. All four species of loons are evidently almost exclusively piscivorous in both breeding and wintering areas (Johnsgard 1987). Like the harbor seal, successful foraging is difficult to determine because most prey are swallowed underwater although larger fish may be brought to the surface (Cornell 2000).

Cormorants (*Phalacrocorax* spp.) were recorded only at the groin and West Reference stations, however, the single observation at West Reference was of a sole cormorant flying through in a southwesterly direction (Table 3). Cormorants were seen on two of the seven surveys at the groin. On the first occurrence, a solitary cormorant was observed diving approximately 10 m directly off the end of the exposed rocks. On the second occurrence, three cormorants were observed catching small fish from between submerged rocks directly over the groin. Over the course of the 20-min survey, the cormorants were seen feeding during three of the 5-min interval counts and resting on the rocks during two of the interval counts. Identity of the prey could not be confirmed, however, the observer reported that the prey species looked smelt- and sculpin-like. After the 20-min survey period had ended, the cormorants were

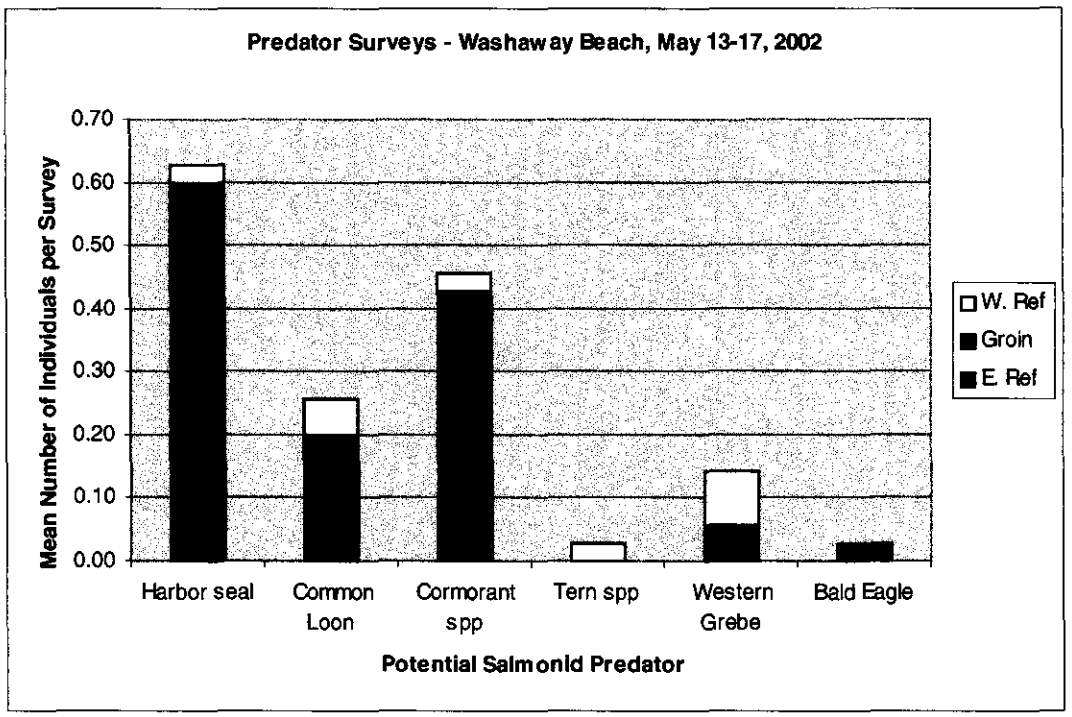

Figure 4. Relative Abundance of Piscivores other than Gulls during Predator Surveys at Washaway Beach Groin and Reference Stations, May 2002

seen to continue feeding at greater success rates, with prey being swallowed almost every time the birds surfaced. According to Robertson (1974, in CDFG 2002), cormorants prefer to feed off rocky bottoms in relatively shallow water. Unlike the loon, a cormorant commonly brings its catch to the surface before swallowing it (Landsborough Thompson 1964, in University of Michigan 2000).

The western grebe (*Aechmophorus occidentalis*) was recorded on only one survey at the groin and during two surveys at the West Reference station (Table 3). Although no direct observations of feeding were made, the western grebe is considered to be the only one of four North American grebe species that is almost exclusively a fish-eater. According to Johnsgard (1987), such specialization on optimal foods may indicate that foods are easy to find, as grebes that live under relatively poor foraging conditions tend to exploit all the available potential foods.

A single tern (*Caspia* spp.) and bald eagle (*Haliaeetus leucocephalus*) were recorded at the West Reference and East Reference, respectively (Table 3). In each of these circumstances, the individual was in flight: the tern was flying eastward approximately 100 m offshore, whereas the eagle made a low circle over the nearshore and flew inland.

Surf scoters (*Melanitta perspicillata*) were second to gulls in overall abundance (mean number of individuals per survey 10.6) (Table 3). They were often observed floating in large rafts of twenty to seventy, most frequently at the East Reference station (three of seven surveys) approximately 200 to 300 m offshore. A raft of around sixty scoters was observed 200 m off the groin during one survey. Surf scoters are listed as facultative benthivores with a primary diet of mollusks, crustaceans, and aquatic insects (Simenstad et al., 1979) and, therefore, were not considered to be a predator species for the purpose of our evaluation.

Shorebirds, considered a non-predator species, were recorded infrequently and in low numbers (Table 3).

The mean number of potential avian predators observed per survey was greatest at West Reference (46.1), followed by East Reference (3.3) and, lastly, the groin (2.2) (Figures 3 and 4). It should be noted, however, that approximately 85% of this variance is accounted for during a single survey, during which 273 gulls were observed resting on the beach at West Reference. The percentage of potential salmon predators out of the total birds observed at each of the survey sites was 25% (i.e., one predator to four non-predators), 51%, and 97% at the East Reference, groin, and West Reference, respectively.

Data were also analyzed to differentiate between specific activities associated with active foraging (e.g., diving, feeding, swimming, searching) and non-foraging activities (e.g., resting, perching, preening, flying in transit). The percentage of predators that were potentially or actively foraging to those not foraging at each of the survey stations was 59% (i.e., three potentially or actively foraging to five not foraging), 59%, and 23% at East Reference, groin, and West Reference, respectively.

In summary, 27 individual, piscivorous marine mammals and birds were observed exhibiting foraging behavior at the groin over 140 minutes of continuous observations made over a 5-day period. A total of 61 and 131 individuals were observed over a similar period of time at the East and West Reference stations, respectively. These data indicate that predators were foraging at both the groin and the unmodified shoreline reference stations, but do not appear to indicate that more potential predators were using the groin as compared with reference stations.

3.0 Beach Seines

3.1 Methods

Beach seining was conducted to gather data on the species composition and relative abundance of fish associated with the groin and unaltered reference stations. These data included information on the relative abundance of juvenile salmonids and their potential predators in these habitats. Salmon collected in seines were marked in an effort to ascertain simple movement patterns and timing (Section 5). The stomach contents of potential predators collected in the seine were examined to confirm food habits and confirm predatory behavior (Section 4).

The seine utilized was constructed according to EPA standard methods (Simenstad et al. 1991). It was designed as a floating beach seine, used for capturing motile fish, with floating line on top and a lead line on the bottom. The 37-m-long net composed of 3-cm mesh consisted of two 18-m long wings that were 0.9 m high at the ends and 2 m high where the wings attached to the central bag. The bag was 2 m high by 2.4 m wide by 2.3 m deep and made of 6-mm mesh.

Seining methods were adapted to local conditions and focused on evasive macrofauna associated with shallow (<1.5 m) nearshore waters. The seine was not deployed by boat because of generally rough surface conditions (breaking waves) at some stations, variable bottom substrate, and strong tidal currents. Rather, the seine was deployed by hand, which involved walking it out perpendicular to the shore to a maximum depth of about 1.5 m. The seine was deployed parallel to shore with the prevailing tidal current, then pulled shoreward onto the beach (Figure 5). The distance from shore ranged from approximately 10 m to 30 m, depending on the slope of the beach and tidal stage. The area swept during each seine ranged from approximately 370 m^2 to 1110 m^2.

A total of 22 beach seine sets were conducted at four stations during both day and night sampling periods (Table 4). Six sets were conducted at each of the stations associated with the groin structure and five sets were conducted at each of the reference stations.

Table 4. Number of Beach Seine Sets Conducted at Washaway Beach Groin and Reference Stations, May 2002

Site	Day	Night
East Reference	3	2
East Groin	4	2
West Groin	5	1
West Reference	3	2

After each seine haul, the identity, number, and size of fish and macro-invertebrate species were quantified. All of the salmon captured were measured for fork length (FL). When a non-salmonid species numbered greater than 20 individuals per seine, a subset of 20 individuals was measured for total length (TL). In addition, juvenile salmon captured during the first 72 hours of sampling were marked with fluorescent elastomer tags injected as a liquid into the fins of the fish (Section 5) and potential predators were anaesthetized and subjected to gastric lavage (Section 4).

Figure 5. Deploying the Beach Seine and Examining the Catch after a Haul, Washaway Beach, May 2002

To simplify comparisons of fish distribution between groin and reference stations, fish taxa were classified by life history, morphology, and behavior into seven general categories: flatfish, forage fish, greenling, salmon, sculpin, surfperch, and other. An additional category comprising all species documented as known predators of juvenile salmon was also created. Summaries of mean catch per unit effort (CPUE) were tabulated by these categories across stations to highlight biologically meaningful patterns. When appropriate, a chi-square test was also used to examine the null hypothesis that the CPUE for each fish category was equally distributed across all stations. When too few fish within a category were caught at each site (CPUE <6), that category was excluded from analysis (e.g., flatfish, greenling, sculpin, other). Also, too few salmon were caught at the West Reference; therefore, the two reference stations were combined for analysis. Graphical summaries were also created of relative abundance by day and night samples of each species.

3.2 Results

A total of 34,754 fishes comprising 24 species were netted during the study period (Table 5). Catches were dominated numerically by surf smelt (*Hypomesus pretiosus)* (87.5%), followed by shiner surfperch (*Cymatogaster aggregata)* (6.1%) and silver surfperch (*Hyperprosopon ellipticum*) (3.6%). Juvenile salmon made up just 1.2% (n=414) of the total catch. Species that could be considered top predators, or piscivores, included staghorn sculpin (*Leptocottus armatus*), lingcod (*Ophiodon elongatus*), kelp greenling (*Hexagrammos decagrammus*), sand sole (*Psettichthys melanostictus),* and subadult coho salmon (*Oncorhynchus kisutch*). Of these, staghorn sculpin, lingcod, and subadult coho salmon have been validated from the literature as predators of juvenile salmon (noted by asterisk in Table 5) (Simenstad et al. 1999; Nightengale and Simenstad 2001; Jeff Christiansen, personal communication 2002). Combined, these three species made up 0.2% of the total catch. In addition to fish, 31 Crangon shrimp *(Crangon spp.)* and 63 Dungeness crab *(Cancer magister)* were captured in the beach seine; both taxa were captured at all four sampling stations.

Species richness (i.e., the number of species in a given sample) was higher at the groin (18 and 21 spp.) than at either of the reference stations (11 and 15 spp.) (Table 5). Seven species were unique to the groin stations, including kelp greenling and striped surfperch, species that are generally associated with habitats that contain vertical structures. Two species, spotfin surfperch (*Hyperprosopon anale*) and topsmelt

Table 5. Fish Species Captured at Washaway Beach Groin and Reference Stations, May 2002

Common Name	Scientific Name	Fish Present at Sample Stations				
		E. Ref (n=5)	E. Groin (n=6)	W. Groin (n=6)	W. Ref (n=5)	Total
Flatfish						**32**
English sole	*Pleuronectes vetulus*	-	12	-	-	12
Sand sole	*Psettichthys melanostictus*	-	4	2	3	9
Speckled sanddab	*Citharichthys stigmaeus*	-	1	-	-	1
Starry flounder	*Platichthys stellatus*	3	5	2	-	10
Forage Fish						**30419**
Northern anchovy	*Engraulis mordax*	1	1	2	-	4
Pacific herring	*Clupea harengus pallasi*	-	3	4	-	7
Pacific sand lance	*Ammodytes hexapterus*	1	2	2	2	7
Pacific sardine	*Sardinops sagax*	-	3	2	-	5
Surf smelt	*Hypomesus pretiosus*	1424	8542	13951	6478	30395
Topsmelt	*Atherinops affinis*	-	-	-	1	1
Greenling						**52**
Kelp greenling	*Hexagrammos decagrammus*	-	3	6	-	9
Lingcod*	*Ophiodon elongatus*	3	37	3	-	43
Salmon						**414**
Chinook salmon (smolt)	*Oncorhynchus tshawytscha*	38	11	318	3	370
Chum salmon (smolt)	*Oncorhynchus keta*	5	27	9	2	43
Coho salmon (subadult)*	*Oncorhynchus kisutch*	-	1	-	-	1
Sculpin						**40**
Pacific staghorn sculpin*	*Leptocottus armatus*	8	23	9	-	40
Surfperch						**3591**
Pile perch	*Damalichthys vacca*	1	182	1	1	185
Redtail surfperch	*Amphistichus rhodoterus*	2	-	22	26	50
Shiner perch	*Cymatogaster aggregata*	137	1215	662	90	2104
Silver surfperch	*Hyperprosopon ellipticum*	759	373	96	12	1240
Spotfin surfperch	*Hyperprosopon anale*	6	-	-	-	6
Striped surfperch	*Embiotoca lateralis*	-	1	-	-	1
Walleye surf perch	*Hyperprosopon argenteum*	1	1	2	1	5
Other Fish						**206**
Threespine stickleback	*Gasterosteus aculeatus*	2	2	202	-	206
No. of Fish Species Captured (24 possible)		15	21	18	11	**24**

* Documented predators of juvenile salmon.

(*Atherinops affinis*), were unique to samples collected at the reference stations. It should be noted that the collection of spotfin surfperch in Willapa Bay represents a northern range extension for this species, which previously had only been recorded to Seal Rock, Oregon (Miller and Lea 1972; Eschmeyer et al. 1983).

The chi-square analysis rejected the null hypothesis of equal distribution of fish (salmon, forage fish, surfperch) at the east and West Groin and the combined reference stations ($p<<0.001$).

Juvenile salmon were collected at all stations, although CPUE was highest at the West Groin station (Table 6, Figure 6). Samplers generally observed large numbers of juvenile salmon periodically jumping out of the water in this region. Fewer numbers of salmon than expected (based on the statistical test) were caught at the East Groin and reference. Very few salmon were collected during night samples made at any sampling station (Figure 7).

The majority of salmon captured were identified as chinook smolts *(Oncorhynchus tshawytscha)* (370), with a mean FL of 127 mm. Of the total chinook captured, 65 (= 18%) were confirmed hatchery fish (adipose fin clipped). The other salmon species captured were chum fry *(O. keta)*, mean FL 55 mm (43). None of the chum had clipped adipose fins. Approximately 200,000 chum fry and 7 million subyearling fall chinook were released from the Willapa Bay hatchery system during March and May-June 2002, respectively (personal communication, WDFW hatchery personnel). The release dates of hatchery fish overlap with the wild salmon outmigration window, which generally ranges from February to August, depending on species.

As previously noted, three species (subadult coho salmon, staghorn sculpin, lingcod) validated in previous studies as predators of juvenile salmon were collected by beach seine. The single coho salmon *(O. kisutch)* captured at the West Groin site during the night, was a fin-clipped subadult (FL 376 mm). Both staghorn sculpin (mean TL = 86 mm) and juvenile lingcod (mean TL = 78 mm) were collected at every station except the West Reference, and were most abundant at the East Groin (Table 6, Figure 6). Most of these individuals were small juveniles that would be unable to effectively feed on outmigrating salmon (chum: mean FL = 55 mm; chinook: mean FL = 127 mm) (Figure 8). No lingcod were collected in samples made during the night, whereas the sculpins were collected at all times of day (Figure 7). Both staghorn sculpins and lingcod are demersal ambush predators that feed on crustaceans and small fish (Emmett et al. 1991). The relatively high abundance of juvenile lingcod at this site is noteworthy, and suggests that lingcod are recruiting to groin-associated habitats. Larval lingcod settle out of the plankton to shallow-water benthic areas in late spring-early summer, often in vegetated (kelp or eelgrass) habitats (Buckley et al., 1984). Age 1-2+ juveniles are commonly observed in high-current, soft bottom, or shell-hash habitats near the mouths of bays and estuaries (Doty 1993).

Other species groups displayed unique distribution patterns associated with the groin, as well. Forage fish were not equally distributed between unmodified shorelines and the groin, with more than expected collected at the West Groin and fewer than expected at East Groin and Reference (Table 6, Figure 6). Despite their apparent abundance across all stations, surf smelt (within the forage fish guild) were only collected during daylight sampling efforts (Figure 7). Surfperch were also collected at all stations but were more abundant than expected at the East Groin and less than expected at the other areas (Table 6, Figure 6). Conversely, surfperch of all species were more abundant in night collections despite the lower relative sampling effort expended during these times (night: n = 7, day: n = 15) (Figure 7).

Table 6. Catch Per Unit Effort (CPUE) at Four Sample Stations, Washaway Beach, May 2002

Fish Category	East Reference	East Groin	West Groin	West Reference
Flatfish	0.6	**3.7**	0.7	0.6
Forage Fish	285.2	1425.2	**2326.8**	1296.2
Greenling	0.6	**6.7**	1.5	0.0
Salmon	8.6	6.5	**54.5**	1.0
Sculpin	1.6	**3.8**	1.5	0.0
Surfperch	181.2	**295.3**	130.5	26.0
Other Fish	0.4	0.3	**33.7**	0.0
Salmon Predators	2.2	**10.2**	2.0	0.0

Bold indicates highest CPUE for each fish category.

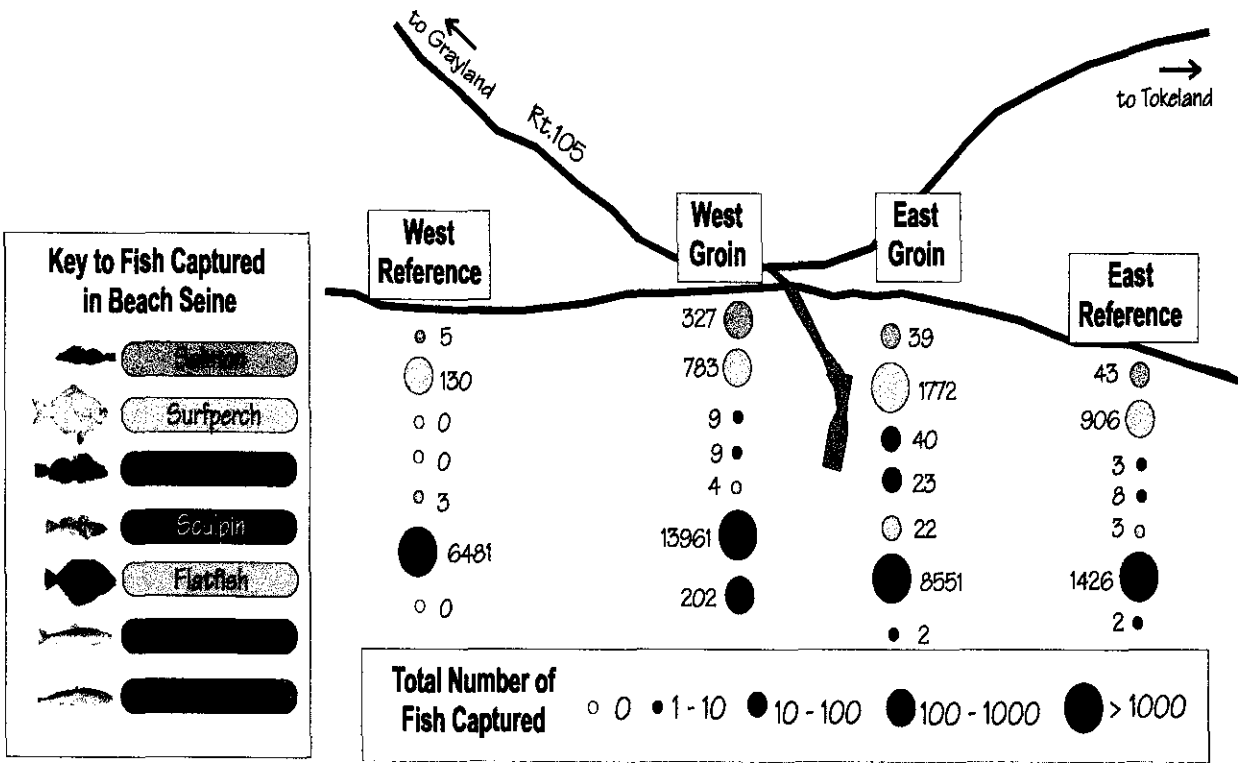

Figure 6. Total Number of Fish Captured at Four Sample Stations, Washaway Beach, May 2002

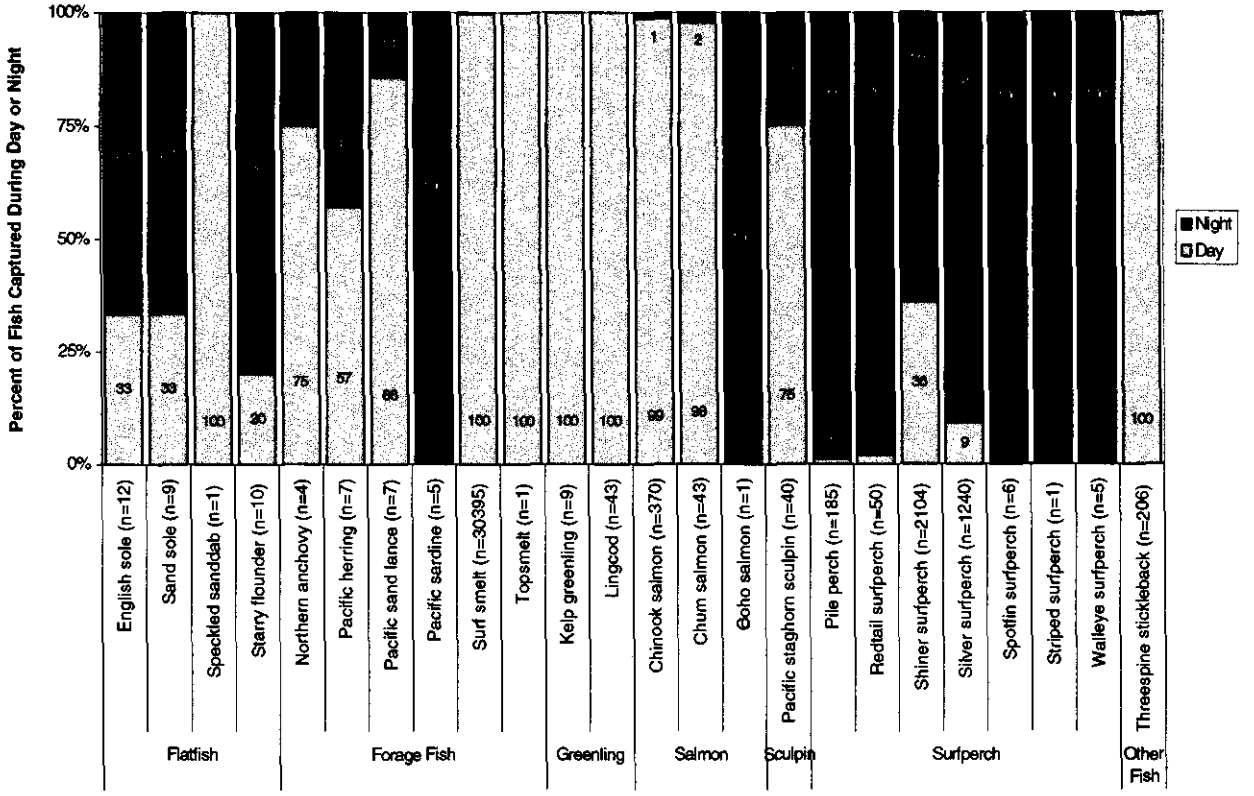

Figure 7. Percentage of Species Abundance during Day and Night Sampling, Washaway Beach, May 2002

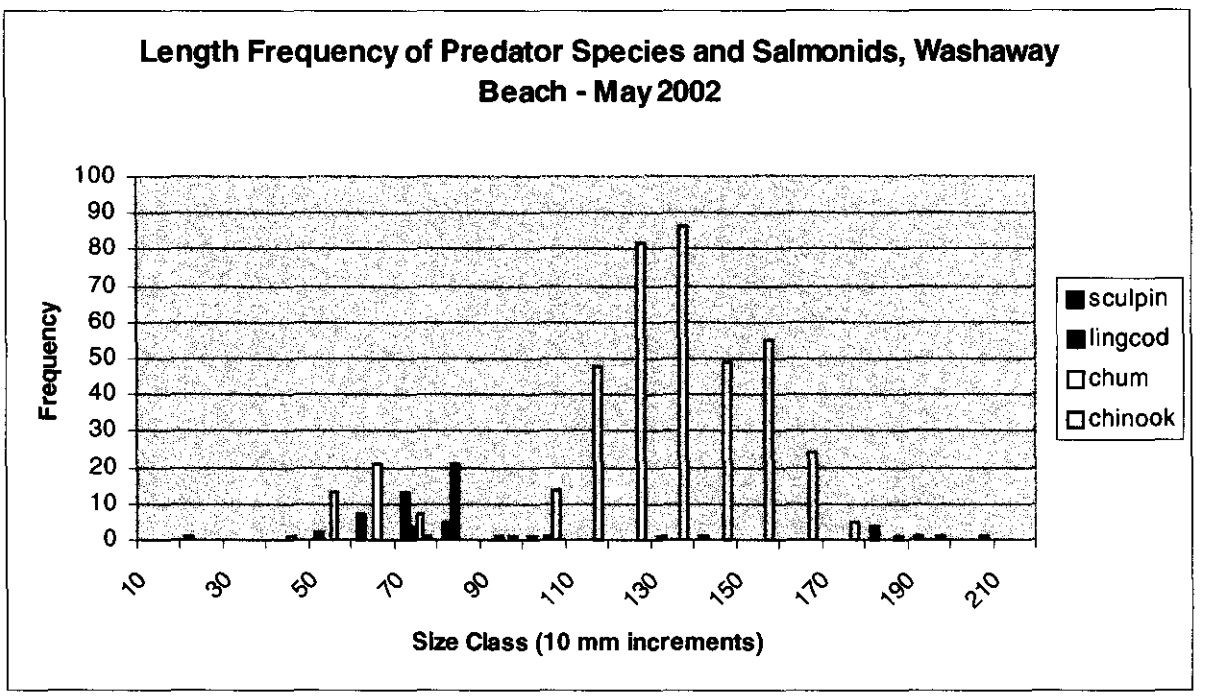

Figure 8. Size Class of Predator Species and Salmonids Captured at Washaway Beach, May 2002 (does not include 376-mm subadult coho captured at East Groin)

4.0 Stomach Content Analysis

4.1 Methods

Potential predators were captured for stomach content analysis in an effort to determine whether salmonids were a significant component of the prey base in the structure site. Fish capture methods included beach seining (previously described), which focused on species documented from previous studies as juvenile salmon predators. Hook-and-line sampling with artificial lures that imitated small forage fish was also conducted from both the beach and a small boat in the vicinity of the dike and groin. All species collected with this method were considered piscivorous and subjected to stomach content analysis. The fish were anesthetized in a solution of MS-222 (tricaine methanesulfonate). A pump was used to flush stomach contents from the fish with water (Giles 1980). After pumping, fish were placed in an oxygenated bath and then released upon recovery. Stomach contents were preserved in 70% ethanol and examined quantitatively in the laboratory.

4.2 Results

Fourteen individual fish comprising five species were subjected to quantitative analyses of stomach contents (Table 7). No identifiable salmonids were observed in the diet of any individual.

As previously described, potential fish predators collected in shallow habitats targeted by the beach seine included subadult coho salmon, Pacific staghorn sculpin, and lingcod. Gastric lavage techniques were only used on larger individuals (>120 mm TL), the minimum size judged to be able to consume the smallest chum salmon (mean FL 55 mm) in our samples. These criteria reduced the pool of potential predators to one coho salmon and six staghorn sculpin; all lingcod were substantially smaller than 100 mm TL. The stomach of the coho salmon was empty and no contents were retrieved during lavage efforts. The six staghorn sculpins had consumed predominantly macroinvertebrates, including *Crangon* shrimp, Dungeness crab, and clam siphons. However, the stomach of one 180-mm individual captured at the West Groin also contained eleven surf smelt (*Hypomesus pretiosus*) ranging from 50 to 70 mm in length.

Five kelp greenling, one adult lingcod, and one red Irish lord were collected from deeper waters of the groin and dike area using hook and line (Table 7). The stomach contents of all five kelp greenling (*Hexagrammos decagrammus*) contained large numbers of caprellid and gammarid amphipods. However, two greenling had also consumed small fishes: one partially digested, unidentified surf perch (family Embiotocidae), and two juvenile gunnels (family Pholididae). The contents of the 250-mm red Irish lord (*Hemilepidotus hemilepidotus*) were too digested for positive identification. The 530-mm lingcod (*Ophiodon elongatus*) contained two partial fish spines that appeared to be from a large sculpin (family Cottidae).

Habitat preferences and diets of these species follow information reported in a number of previous publications. Staghorn sculpins are one of the most ubiquitous species in shallow sublittoral habitats of Puget Sound and are distributed throughout most Pacific Coast estuaries (Emmett et al. 1991; Simenstad et al. 1979). Juveniles and adults are found primarily in sandy habitats, but are also common over substrates ranging from soft mud, eelgrass, and rock. Common dietary items for juveniles (to 120 mm TL) include primarily benthic and epibenthic organisms, such as amphipods, isopods, burrowing shrimp, decapod crustaceans (shrimp and Dungeness crab), bivalve siphons, and polychaetes (Armstrong et al., 1995; Emmett et al. 1991; Simenstad et al. 1979, Williams 1994). Large juveniles and adults also may consume fish (including herring, juvenile sculpin, surfperch, and juvenile salmon) and larger crustaceans (*Crangon* shrimp, crab).

Table 7. Stomach Contents of Potential Fish Predators Captured at Washaway Beach, May, 2002

Species Analyzed	Size (mm)	Catch Method	Location	Date	Time	Stomach Contents / Size / Weight
coho salmon	376	beach seine	East Groin	5/13/02	2100	none
staghorn sculpin	180	beach seine	East Groin	5/13/02	0850	1 Crangon shrimp (not retained)
staghorn sculpin	180	beach seine	East Groin	5/15/02	2235	2 Crangon shrimp / 0.98 g crab parts / 0.72 g clam siphon / 2.07 g
staghorn sculpin	190	beach seine	East Groin	5/15/02	2235	none
staghorn sculpin	140	beach seine	East Groin	5/15/02	2235	none
staghorn sculpin	180	beach seine	West Groin	5/14/02	0845	11 surf smelt / 50-70mm / 8.72 g 1 crab megalops / .0348 g
staghorn sculpin	180	beach seine	East Reference	5/15/02	2335	1 crab claw / 4.91 g 3 Crangon shrimp / 3.74 g
kelp greenling	355	hook and line	near/over dike	5/14/02	~1700	2 postlarval gunnels/55mm/0.204g 1 juvenile fish (UID)1 / 0.0434 g 1 isopod 0.0566 g [~ 450 caprellid and gammarid (*Corophium* sp.) amphipods - ratio ~ 2.5 caprellid/1 gammarid, ~4 g] 2
kelp greenling	290	hook and line	near/over dike	5/14/02	~1700	2 postlarval fish (UID) / 0.223 g 1 partial fish spine/ 45 mm /0.127g 1 crab megalops / 0.0095 g 1 crab (*H.* oregonensis) / 0.02 g animal tissue (UID) / 6.063 g [255 caprellid and gammarid (Corophium sp.) amphipods – ratio ~1.7 caprellid/1 gammarid, 1.6g] 2
kelp greenling	290	hook and line	near/over dike	5/16/02	~1800	1 digested fish (UID) / 0.183 g 1 crab (*H. oregonensis*) / 0.057 g 1 isopod / 0.029 g [480 caprellid and gammarid (*Corophium* sp.) amphipods - ratio ~ 2.5 caprellid/1 gammarid, 4.5g] 2
kelp greenling	310	hook and line	near/over dike	5/16/02	~1800	4 Crangon shrimp / 0.967 g crab claw & leg parts / 0.351 g 1 parasitic amphipod / 0.059 g 1 well digested fish (partial spine) [~250 caprellid and gammarid (Corophium sp.) amphipods – ratio ~1.7 caprellid/1 gammarid,~1.6g] 2
kelp greenling	325	hook and line	near/over dike	5/16/02	~1800	1 UID surf perch / 3.89 g 1 clam siphon / 0.73 g [110 caprellid and gammarid (*Corophium* sp.) amphipods – ratio ~1.8 caprellid/1 gammarid, 1.23g] 2
red Irish lord	250	hook and line	near/over dike	5/14/02	~1700	unidentifiable remains – very well digested
ling cod	530	hook and line	near/over dike	5/14/02	~1700	2 fish spines / 1 @ > 90mm / 0.30g, other partial only 1 maxillary

[1] unidentified

[2] count, ratio, and weight is based on approximately one-quarter of the sample contents

Kelp greenling, lingcod, and red Irish lord are bottom-oriented carnivores most typically associated with rocky/kelp bed or gravel-cobble habitats (Simenstad et al. 1979). Besides anecdotal reports of lingcod feeding on hatchery-raised salmon at the Seattle aquarium (Jeff Christiansen, personal communication), no previous studies have documented juvenile salmon in the diets of these species. Diet analyses of kelp greenling (n=31) in the Strait of Juan de Fuca show that they have a diverse prey spectrum comprised principally of amphipods, crabs, and isopods; unidentified fish made up less than 2% (total index of relative importance [IRI]) of the diet (Simenstad et al. 1979). Red Irish Lord prey items typically include isopods (42% of total IRI), brachyuran crabs (39.9%), unidentified fish spp. (13.4%), and shrimp (1.3%) (Simenstad et al. 1979). Lingcod are primarily piscivorous. Small juveniles feed on crustaceans, but concentrate their feeding on small fish as they grow (Emmett et al. 1991). Adults feed on Pacific herring, sand lance, flounders, rockfishes, and large crustaceans (Emmett et al. 1991; Simenstad et al. 1979).

Maturing subadult and adult coho salmon are generally found in offshore pelagic habitats. One study by Fresh et al. (1981) documented predation by adult coho salmon on juvenile chinook salmon, although they made up a small relative proportion (1.7%) of the prey biomass in the larger coho (600 mm to 699 mm FL) diets. Coho diets (n = 172, mean FL = 350 mm to 386 mm) collected by purse seine in Puget Sound showed that euphausids, fish (primarily herring), gammarid amphipods, and decapod larvae were the dominant prey (Fresh et al. 1981). Diets of larger coho, collected by anglers in Puget Sound (n = 142, mean FL = 451 mm) and at the mouth of the Columbia River (n = 471, mean FL = 556 mm), were comprised primarily of fish (by biomass) (Fresh et al. 1981). Identifiable fish in coho stomachs included herring, northern anchovy, surf smelt, juvenile chinook salmon, sand lance, gadids (cods), and cottids (sculpins).

5.0 Mark-Recapture

5.1 Methods

Juvenile salmon captured during the first 72 hours of beach-seine sampling were marked with fluorescent elastomer tags injected as a liquid into the fins of the fish (Figure 9). Chum salmon collected in the seine were too small (55 mm mean FL) to mark using this technique without the possibility of causing injury or fin loss. The two objectives of this method were to 1) track movement of juvenile salmon relative to the groin, and 2) determine temporal patterns of habitat use. Four different marking patterns (based on ink color and injection site) were used to associate fish with their initial capture at one of the four sample sites (Table 8). Subsequent beach seines were assessed for recapture of marked fish.

To provide an estimate of the probability that fish are staying within a specific sampling station, the number marked in the population was divided by the number recaptured on a later date. Nighttime captures were generally too unsuccessful (i.e., only six salmonids were captured during night seines) to analyze separately. Because the intention was not to characterize the population of the entire nearshore area, the mark-recapture data were not designed to estimate population size.

Figure 9. Marking Juvenile Chinook Salmon with Elastomer Tags, Washaway Beach, May 2002

Table 8. Elastomer Marking Patterns Used at Washaway Beach Groin and Reference Stations, May 2002.

Sample Site	Color	Injection Site
East Reference	Green	Anal fin
East Groin	Orange	Anal fin
West Groin	Orange	Caudal fin
West Reference	Green	Caudal fin

5.2 Results

A total of 227 juvenile chinook salmon were captured, marked, and released at all four sampling stations over the course of 3 days (Table 9). Most fish were captured at the West Groin.

Two marked fish were recaptured at the West Groin on May 15, 2002 (Table 9). The first fish, a 130-mm chinook, had an orange mark on the base of its anal fin, indicating it was one of nine fish originally marked at the East Groin from May 13 to May 14, 2002. The second fish, a 145-mm chinook, had an orange mark on the base of its caudal fin, indicating it was one of 94 fish originally marked at the West Groin on May 13, 2002.

The single chinook salmon that was marked at the East Groin and recaptured at the West Groin provides evidence that at least one chinook survived initial capture and marking, then successfully swam over or around the rock groin structure. The individual originally marked and later recaptured at the West Groin shows that there was an extremely low probability that salmon remain within this station for a protracted period of time (p=0/94, 1/94, 0/177, mean p= 0.004). All other sites had too few marked fish (all less than seven) that could be recaptured to make reliable estimates of the probability of remaining at the site.

As a further note, 33 chinook (size range 63 to 159 mm) marked at East Reference were observed by snorkelers upon release. The snorkelers were able to track the fish for approximately 60 secs, during which time the fish remained in a school in the middle-to-lower water column at a water depth of approximately 2 meters. The fish traveled in a southeast direction, parallel to the shoreline.

Table 9. Mark-Recapture Data for the Four Seining Areas at Washaway Beach, May 2002

	East Reference			East Groin			West Groin			West Reference		
Date	Captured	Marked	Recaptured	Captured	Marked	Recaptured	Captured	Marked	Recaptured	Captured	Marked	Recaptured
5/13/02	5	5	0	8	8	0	173	94	0	0	0	0
5/14/02	0	0	0	1	1	0	6	0	0	0	0	0
5/15/02	33	33	0	0	0	0	85	83	2 (1 from the East Groin)	3	3	0
5/17/02	--	--	--	0	0	0	54	0	0	--	--	--
Total	38	38	0	9	9	0	318	177	2	3	3	0

6.0 Snorkel Observations

6.1 Methods

Snorkel observations were conducted to further clarify the presence, movement, and behavior of juvenile salmon and their potential predators relative to the groin. Two snorkelers entered the water from shore on either side of the groin during a flood tide at 10:45 hrs on May 15, 2002. The plan called for swimming a transect parallel to the groin, crossing over it, and returning on the opposite side. Snorkelers made qualitative observations and recorded their findings upon return to shore.

6.2 Results

Throughout the survey, visibility was less than 2 feet. On the west side of the groin, aggregations of small (<120 mm) staghorn sculpin (*Leptocottus armatus*) were observed amongst the rocks and tide pools at the water's edge. One chinook salmon (~110 mm) jumped upon the snorkelers entering the water. On the east side of the groin, both snorkelers observed schools of juvenile surf smelt (*Hypomesus pretiosus*) in an eddy formed during the flood tidal flow. Unidentified salmonid (~120 to 150 mm) were also seen jumping from the water.

Severe currents and waves prevented one snorkeler from crossing over the groin. These factors and poor visibility prompted the cancellation of further snorkel and dive surveys.

7.0 Summary of Results

Physical conditions of groin and reference stations:

- Eastern sites are more protected; western sites are more exposed to wind and wave action.
- All stations are steep sloped, except for the East Groin, which is gradual and appears to be a site of sediment deposition.
- Groin substrate is composed of rocky material filled with sand; both reference sites contain exclusively sand.
- Both groin stations appear to be areas of detritus and organic matter accumulation, which were entrained in back-eddies on either side of the groin.

Bird/mammal surveys:

- The number of potential predators observed at the groin was similar to reference sites.
- There were no confirmed observations of predation on juvenile salmon by birds or marine mammals.

Fish seines:

- Species richness and relative abundance of all fish categories were higher at groin stations as compared with Reference stations. Seven species were unique to the groin, including kelp greenling and striped surfperch, species that are generally associated with highly structured habitats.
- Salmon made up a relatively small proportion (1.4%) of the total catch, but were significantly more abundant adjacent to the groin, suggesting they may use this as a temporary resting, feeding, or transition area. During previous site visits, divers observed juvenile salmon individually and in small groups (3 to 5 individuals) on both sides and on top of the structure during all phases of the tide. Fish were behaving normally, e.g., feeding, and did not appear confused or disoriented around the structure.
- Fish species documented as predators of salmon, staghorn sculpin, lingcod, and subadult coho salmon, were more abundant at groin stations than at reference stations (73 and 11 individuals, respectively) and made up only 0.2% of the total catch. Most of these individuals were juveniles (<120 mm) with a mean TL of 71 mm.
- Shallow water habitats associated with the east side of the groin likely serve as a nursery area for juvenile lingcod.
- Particularly high densities of surfperch and forage fish were observed at the groin stations, which complements previous diver and snorkel observations.

Stomach content analyses:

- Fourteen individual fishes, comprising five species, were subjected to quantitative analyses of their stomach contents.

- No identifiable salmonids were observed in the diet of any individual. However, staghorn sculpins, kelp greenling, and adult lingcod did have the remains of other fish species in their stomachs.

- Most of the potential salmon predators (lingcod and staghorn sculpin) collected by seine were too small to effectively feed on outmigrating juvenile salmon.

Fish movement:

- A total of 227 juvenile chinook salmon were marked at all stations, two of which were recaptured at the West Groin.

- Most salmon were collected at the West Groin, including one marked individual that was originally marked at the East Groin. Combined, these observations show that individual fish can successfully swim over or around the rock groin, and suggest that the groin does not inhibit movement of most juvenile salmon past this structure.

- The low recapture rate of fish marked on either side of the groin indicates that juvenile salmon are not remaining at the groin for long periods of time (>1 day).

8.0 Summary of Previous Studies

The field methods used in each of the surveys are summarized in Table 1. All methods were not used for all three field studies because of differing objectives and highly variable environmental conditions. This section summarizes, for continuity purposes, the methods and results from the field sampling surveys of June 11 through 15, 2001, and October 14 through 21, 2001. Additional details may be found in those individual reports.

8.1 Splitbeam Hydroacoustic Surveys

The splitbeam hydroacoustic surveys were conducted during both spring and fall field-sampling periods of 2001. The objective of the June survey was to observe out-migration of juvenile salmonids and other fish species, whereas the fall survey was directed at the return migration of the adults.

The hydroacoustic data were collected using a BioSonics DT6000 Scientific Splitbeam Echo Sounder operating at 200 kHz. The transducer and underwater electronics package were attached to a rigid 10-ft pole located approximately midship on the fishing vessel *Tricia Rae* (Figure 10) to minimize the motion of the transducer during rough-water conditions. Data were collected and displayed in real time using BioSonics proprietary software (VISACQ) and were stored on a hard disk. Data analysis was performed using BioSonics proprietary software (ANALYZER). First-pass analysis was performed with 20 depth intervals and 20 longitudinal intervals.

Sample and transect locations were collected simultaneously using a Trimble differential global positioning system (DGPS). Differential lock was maintained; thus, positions are expected to have submeter accuracy for the entire survey period. Location information was logged independently and stored with the hydroacoustic records during the survey. Subsequently, geographical information system (GIS) maps were developed showing the location of each transect during every survey of the region. A typical map of transect lines is shown in Figure 11. All transects were conducted at or near the times of high or low tide to better control the boat's speed through the water and reduce stress and vibration on the echo sounder (sonar) support boom.

Five hydroacoustic surveys were conducted in June 2001 during the outmigration of juvenile salmon. The processed data/echograms from the surveys were qualitatively evaluated to determine the location, relative size (i.e., small, medium, large), and approximate placement in the water column (i.e., upper, middle, lower) of schools and individual fish detected by sonar. The echo sounder returns signals from a fish swim bladder but, unfortunately, there is no way to determine the species of fish. Considering the large numbers of shiner perch and forage fish caught in the beach seine during spring sampling in 2001 and 2002, it is likely that the echoes were from these types of fish.

The greatest numbers of schools were detected on the north side of the channel (where the groin is located). No discernable pattern was observed with respect to size of school or location in the water column. The greatest assemblage of fish detected on the south side of the channel was at the shallowest depth surveyed (~30 to 50 feet), directly across the channel from the dike and ranging up to 1500 feet in either along channel direction.

Schools of all sizes located throughout the water column were assembled around the dike on all transects evaluated. It should be noted, however, that during each transect, the dike area was surveyed more frequently relative to the remaining area. Individual fish were consistently present over the deepest area

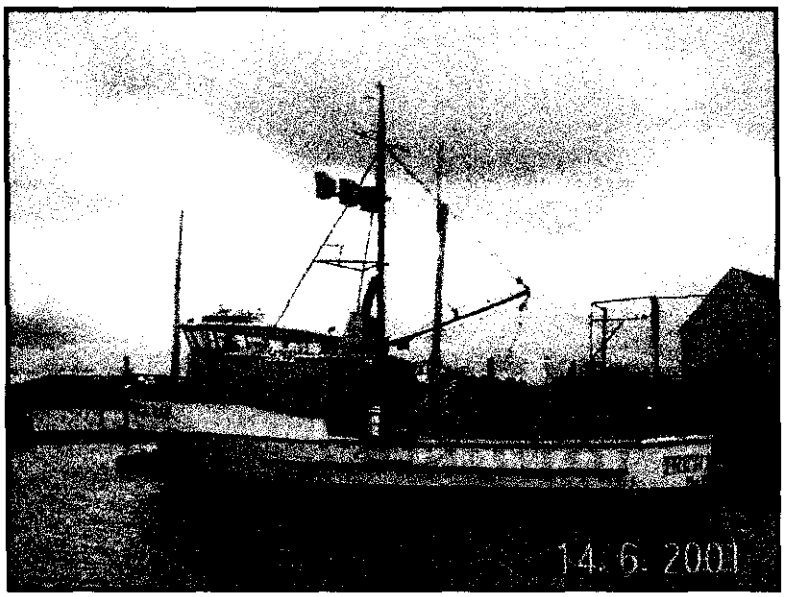

Figure 10. *F/V Tricia Rae*. (The diagonal bar attached to the life rail is used for the hydroacoustic tranducer mount.)

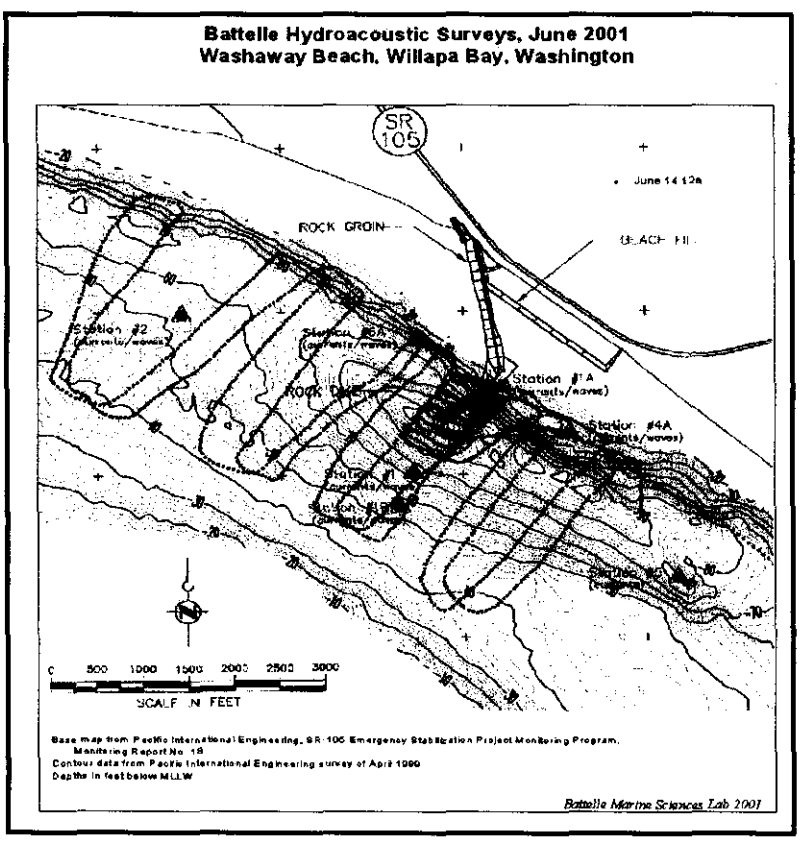

Figure 11. Typical Track Line for Split-Beam Hydroacoustic Surveys

of the channel, typically several meters off the bottom. These were detected from the strong individual return echo but could not be identified by species and none is speculated.

The same echo sounding survey technique was used during October 2002. Because target signal strength for fish with air bladders has been related to length of individuals (Love 1971), return echoes were filtered to relate to fish of approximately 30 cm or longer. According to the algorithms of Love (1971), this size relates to target strength of greater than –38 decibels (dB).

Other factors, such as ship's rolling or the angle of the sonar beam relative to the fish, could also affect the strength of the return echo, so the minimum threshold of –38 dB was used only as a general guideline and was not considered an absolute indicator of size class. The target data were also categorized according to position in the water column: upper one-third, middle one-third, lower one-third, and 1 m or less off the bottom. GIS maps were developed showing the location and relative depth of selected targets for each survey. Examples for the high-slack tide of October 19 and low-slack tide of October 20 are shown in Figures 12 and 13.

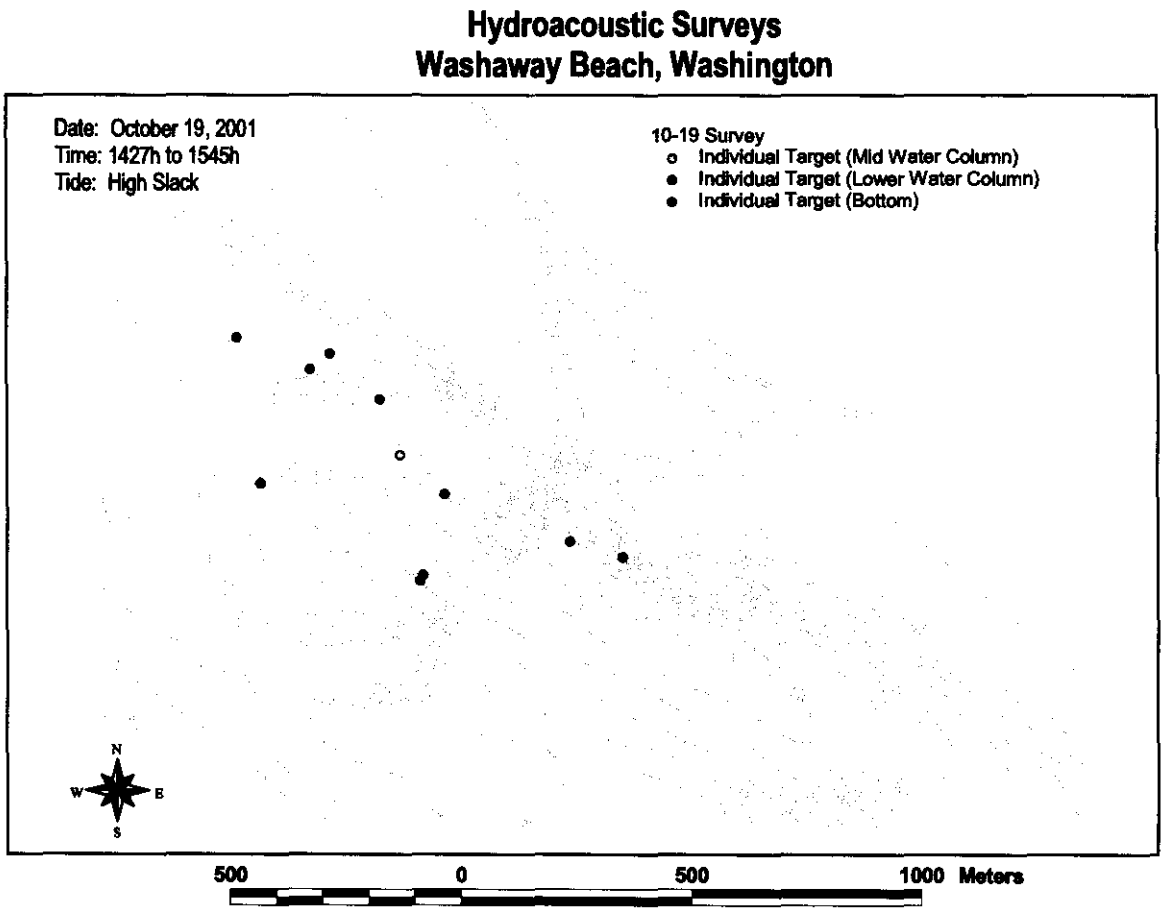

Figure 12. Hydroacoustic Survey during High Slack Tide on October 19, 2001

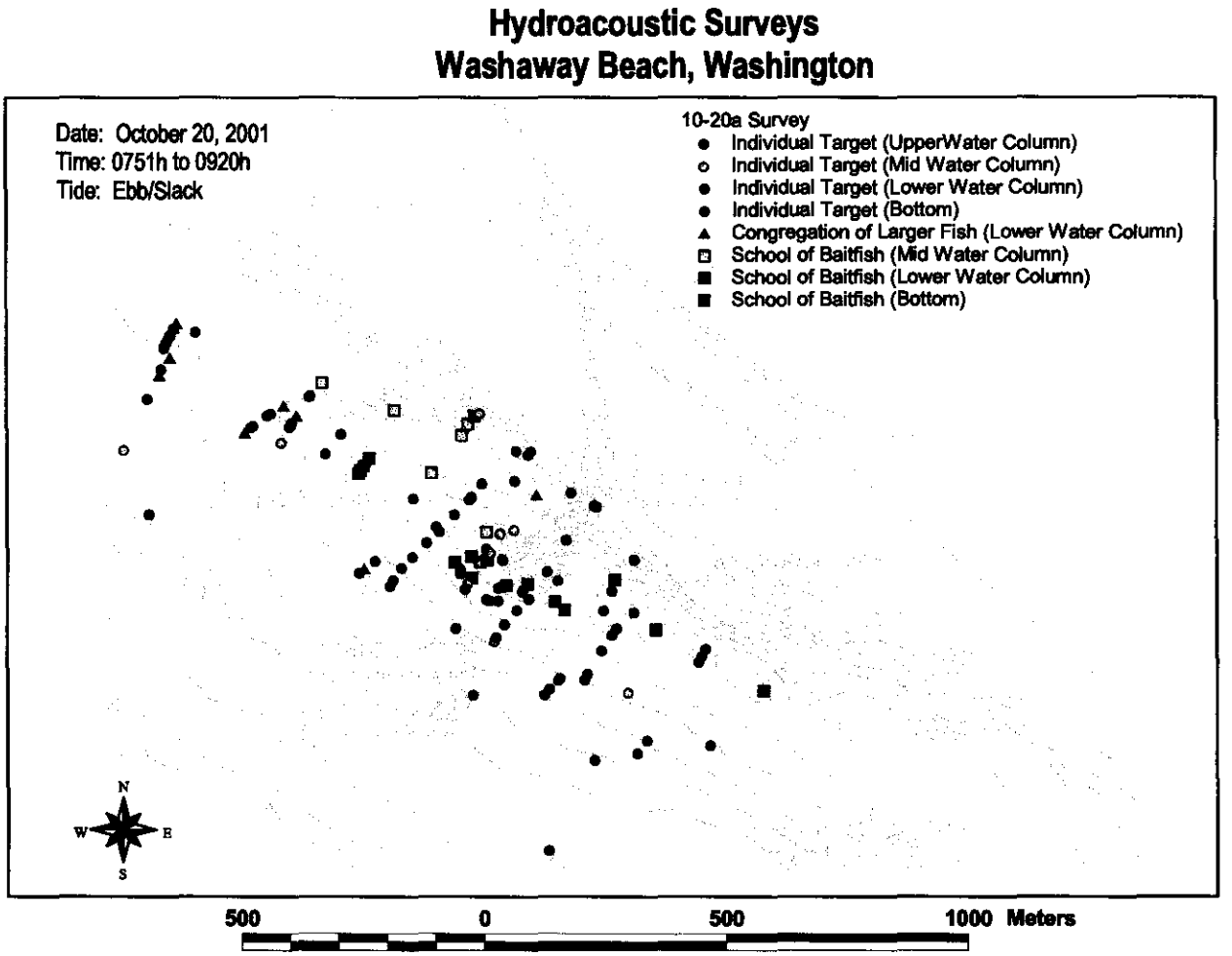

Figure 13. Hydroacoustic Survey during an Ebb Tide Changing to Low Slack on October 20, 2001

Surveys during high slack and flood tides on October 19 and 20 (p.m.), respectively, showed a predominance of individual targets in the lower water column and near bottom. No aggregations of larger individuals were recorded during either of these surveys, and one school of baitfish was recorded October 20. There appeared to be some orientation of bottom targets to the dike October 20. This observation could be an indication of demersal species, such as cabezon (*Scorpaenichthys marmoratus*), kelp greenling (*Hexagrammos decagrammus*), or surf perch (family *Embiotocidae*) that are typically associated with reef-like structures.

Surveys during an ebbing tide (becoming slack) on October 20 (a.m.) and October 21 showed greater occurrence of all target categories, as well as more variable spatial distribution. Relatively few targets were observed in the upper water column. It is possible that targets nearer the surface were mixed with acoustic noise frequently associated with turbulence, and were therefore removed from analysis. Aggregations of larger-sized fish were recorded during both ebb tide surveys. All of the aggregations

were positioned in the lower water column. Additionally, during the October 20 survey, all aggregations were detected on the downstream side (westward) of the groin. The majority of all selected targets surveyed on October 21 were located on the upstream side (eastward) of the groin. In general, there was greater activity of larger biota and schooling baitfish in the survey area when the ebb flow was decreasing into slack tide.

The hydroacoustic surveys conducted near high and low slack tides perhaps provided the best evidence of spatial differences in fish abundance and distribution relative to the groin structure. Although it is not possible to determine species of fish with hydroacoustic equipment, concurrent observations by commercial fishermen showed that chum and coho salmon were the most likely targets identified by this technique. An explanation of salmon distribution and abundance relative to the tidal phase was offered by Terry Larson, the captain of the F/V *Tricia Rae*, and was supported by the hydroacoustic survey and the observed fishing methods. Captain Larson suggested that the fish begin to school in the channel near the mouth of Willapa Bay as the tide approaches the low stand. According to his explanation, the fish ride the currents in last stages of the falling tide from the shoal areas surrounding the channel to the deeper, higher velocity region that will develop as the tide rises. It is also likely that the fish aggregation also includes newly arrived individuals from the open ocean. As the flood tide progresses, the fish ride the inflowing tide upstream. This behavior allows the fish to minimize energy expenditure as they migrate upstream into the bay.

The commercial fishermen also take advantage of this apparent behavior, because they were observed to begin fishing at the low tide near the seaward edge of the designated area, and they rode the incoming tide into the estuary. As the tide approaches the high water stand, the fish appear to disperse from the deeper channels and move onto the shallow tidal banks and network of channels, where they rest and wait through the ebb cycle for the next incoming tide.

Whether fish are as plentiful in the shallow water areas as in the channel during the flooding tide is not known. Most fishermen remain in deeper waters for the safety of their boats and nets. Based on direct observations, adult salmon were also present in shallow nearshore waters (<6 ft depth) in the East Reference site. However, no confirmation could be made of adult salmon very near to the groin because of the inherent difficulties of sampling highly mobile fish in turbid waters associated with these structurally complex habitats.

Hydroacoustic technologies are useful for looking at spatial patterns; however, there are inherent limitations in its application to in-depth analysis of highly mobile marine species. For instance, the directional movement of fish targeted during the surveys cannot be determined, nor can the species targeted be identified from the echo. A review of commercial fisheries data from the week prior to the hydroacoustic surveys indicates that the majority of salmonids migrating towards Willapa Bay during this time period were chum salmon. It is believed that chum salmon originating in Washington streams migrate north, then east, then southward along the coast to their natal streams. The pattern of formation of aggregations and the movement inshore, however, is not well known. The approach by chum salmon to the estuaries of their natal streams is usually fairly rapid (Groot et al. 1991). The total chum salmon catch of approximately 9000 in area 2G during the commercial fishery of October 16 through 18 (Patrick Verhey, Washington Department of Fish and Wildlife, personal communication, 2001-2002) indicates this to be true, with large numbers of adult chum migrating in a southeasterly direction.

All species of anadromous salmonids may delay their entry into freshwater or into terminal spawning areas as they approach the mouths of their natal rivers at the end of the marine phase of their life cycle. Also known as "milling," this behavior makes certain species such as chum particularly vulnerable to fisheries and natural predation during this period. The cause of milling is not certain, but it is believed

that maturation may play a role (Johnson et al. 1997). Although it is possible that the groin/dike presents an attractive location for milling salmonids returning to natal rivers in Willapa Bay, commercial fish catch data provide evidence that large numbers of salmonids, particularly chum, are progressing in an "upstream" direction beyond the dike.

8.2 Drift Buoy Deployments

The drift-buoy experiments were conducted only during the October 2001field survey and were conducted to observe eddies formed on the downstream side of the structure that had been predicted by numerical model results presented in previous reports (USACE Research and Development Center 2000). The drift buoys were designed and built by the MSL. The floating portion was constructed of foam-filled 36-in. by 8-in. polyvinyl chloride (PVC) pipe fitted with solid end caps. Attached to one end of the pipe were two webbing straps that facilitated attachment of a waterproof case that contained a Garmin III-Plus global positioning system (GPS) unit. Additional construction details can be found in Miller et al. (2002).

Drift buoys were deployed in groups of two or three, perpendicular to shore and upstream of the submerged portion of the structure. Following recovery of the buoy, the position data in the GPS were transferred to a lap-top computer and displayed on a base map of the study area. The tracklines of deployments made during flood tides from October 17 through 19, 2001, are shown in Figure 14.

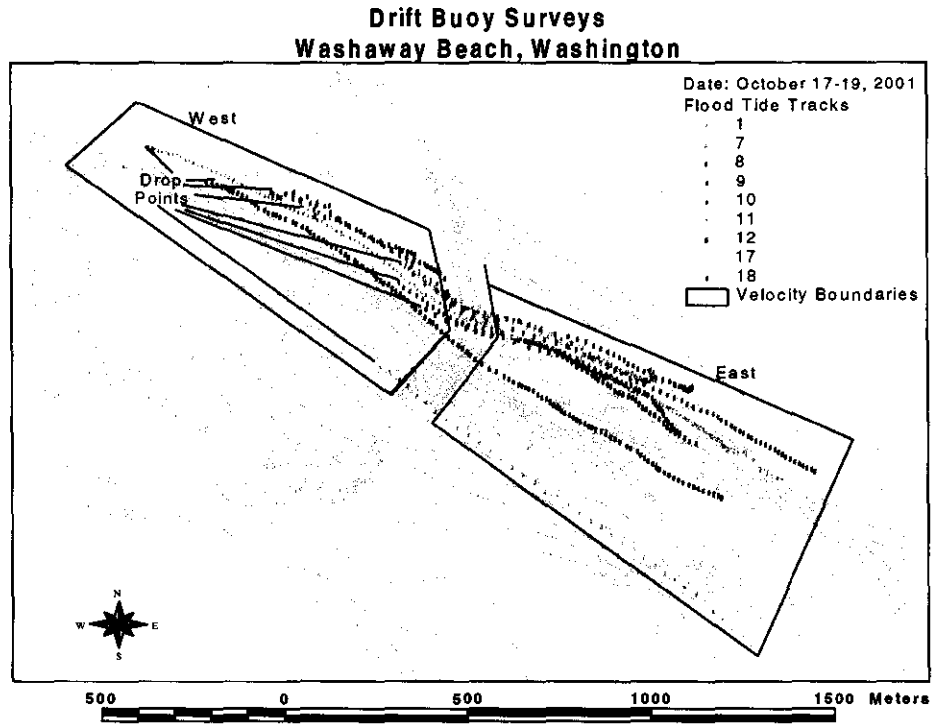

Figure 14. Drift-Buoy Tracks Recorded on Flood Tides at Washaway Beach, Washington

Most of the buoys showed acceleration over the top of the groin as would be expected in shallow water conditions. The flow pattern also shows a displacement along the groin in the offshore direction. In most

cases, the buoys decelerate on the down-drift side of the groin. The maximum current velocity measured by this method was about 2.5 knots. During the flood tide, all drift buoys decreased in speed after crossing the rock groin, except for the one released furthest offshore, which increased in speed. The drift buoys provided an indication of the circulation of the near-surface water surrounding the structure. The drogue section of the device could be set for various depths but was maintained at about 6 ft.

None of these drift patterns recorded by the GPS illustrated the eddy on the downstream side of the groin predicted by the numerical model. One of the buoys (No. 16) was observed circulating, indicating the presence of an eddy, but GPS data were not returned, and the details of the pattern could not be reconstructed. The buoys do illustrate the acceleration over the top of the structure and the component of flow parallel to the structure.

8.3 Commercial Fishing Interviews and Observations

Interviews with commercial gillnet fishers were conducted at Tokeland Marina on October 16 and 17, 2001. We note that this is not a scientific survey, but rather a reflection of the opinions of the respondent. There may be some inherent bias in the responses, based on the perception that our inquiry might be politically motivated. The surveys were conducted only during the October 2001 period, because that particular field deployment corresponded with the commercial fishing season in Willapa Bay.

8.3.1 Interviews

On October 16, 2001, at 1645 h, prior to the 1800 h start of the commercial gillnet fishery, two fishermen at the Tokeland Marina dock were informally interviewed about the impact of the groin on fisheries since its construction in 1998. The general feeling about the groin was a positive one. They felt that the channel was now easier and safer to navigate. One of the fishermen said, "It's working well and fisheries have been good." They intended to fish the flooding tide. When asked whether they fish shallow, they replied, "We don't like to tangle our nets *[in shallow water snags]*, but we fish everywhere."

On October 17, 2001, following the high slack tide, fishers were interviewed at Tokeland Marina as they waited to offload their catch. Four commercial fishers were interviewed singly and in small groups of as many as three. At first they were skeptical that their observations would be treated objectively (decisions are politically driven), and noted that sports fishers were likely the source of potential complaints about reduced catches at the jetty location because of likely changes in the shoreline.

- ***Q*** - Has the presence of the groin changed your fishing patterns?

  A - In general, fishers noticed no changes in catches that would be related to the groin and did not think the groin was having any adverse effect on adult salmon migration. They mentioned a rock pile that had been in the same location in the past and doubted that migratory pathways of fish would be appreciably affected by any similar type of structure. They noted that the Columbia River was "full of groins and fish got around them okay."

- ***Q*** - Are there differences in catches close to versus far from groin?

  A – It is not clear. Most fishers did not fish close to the groin because of the potential for "hanging up" their nets. Also, this is the outer limit of the zone within which they are allowed to fish.

- ***Q*** - Do you fish in shallow water close to shore (i.e., <10 ft of water)? Why or why not?

A - In general, no, but this is more related to fears of entangling on bottom debris, such as the submarine netting, old cars, and foundations of houses lost to erosion.

- *Q* - What are net dimensions and where in the net are fish concentrated?

  A - Fish are found throughout the net. No dimensions given, although they appear to be of heavy monofilament.

- *Q* - What is the timing of your fishing and why?

  A - Generally they fish on a flooding tide. No reason given, but thought to be when fish are actively moving into the estuary.

- *Q* - What species were commonly caught, including those taken as by-catch (i.e., species that could easily be confused by hydroacoustics)?

  A - Predominantly chum salmon (*Oncorhynchus keta*) were caught during the day (October 17, 2001), but a number of coho (*O. kisutch*) were also taken the night before. They noted that coho were more generally associated with the shallow water, which might be the reason that certain fishers were targeting these areas. They generally have few problems with by-catch, although spiny dogfish (*Squalus acanthius*) are caught occasionally.

On October 17, the Tokeland dock attendant reported that there were a total of 14 commercial boats participating in the October 16 through 18 fishery. The initial information indicated "good" catches; for example, the catch of one particular boat had been approximately 2500 pounds, composed mostly of chum salmon, as well as some coho. The average weight of an adult chum salmon in Washington State is 9 to 11 pounds, according to information provided by the WDFW. This would equate to an approximate catch of 220 to 270 fish.

8.3.2 Field Observations

On October 17, 2001, between 0700 and 1000 h, the following observations were made about the commercial gillnet operations:

The tide was ebbing until about 0830. Approximately 11 boats were observed setting drift gill nets in various positions relative to the jetty, some using the shore/surf zone as edge of set. As the flood current increased, boats lined up at the outer edge of the fishing area (groin) and set nets perpendicular to the current, then drifted back into Willapa Bay. Nets were set in a zigzag fashion, with boats backing out as the net-reel in the bow spooled out netting. Most nets were approximately 500 m or more in length. One boat (No. 0835) deployed a net ~150 m in length directly from the shore in less than 3 min; his net was pulled in almost every time he caught a fish (which was frequently). The fishing activity was observed to continue through the flood cycle as the boats moved upstream in the estuary. At slack or ebb tide, most boats retrieved nets and headed into port.

8.4 Bird and Mammal Observations

Quantitative surveys of birds and marine mammals were conducted to document the presence of potential salmon predators and to determine whether they were found at higher numbers at the groin relative to reference sites. Observations were made during all field deployments.

The methods used during October 2001 and May 2002 were identical, with the exception of combining the two stations at the groin for the May 2002 survey, and provided quantitative information on species and their activities. The observation methods of June 2001 were more qualitative in nature and provided the following observations:

- The largest congregation of piscivorous birds was observed on the shore about 100 meters south of the groin. This group of about 60 individuals was composed of two species of gulls.
- At no time were more than 10 individual birds observed feeding near the groin.
- The greatest attraction for the gulls appeared to be when fishers were active on the rock groin.
- Though birds were observed over the groin, only three successful strikes by herring gulls were observed. The prey species could not be identified.

During the in-migration of adult salmon, birds do not pose a predation threat but were observed to determine whether they preferred the location of the structure site relative to the control sites. Approximately the same numbers of birds were observed at the West Reference site and on the east and west sides of the groin. Fewer birds (about one quarter the total number) were observed at the East Reference site. Though seven taxa were observed, gulls were by far the most abundant.

Marine mammals (e.g., killer whales, harbor seals), land mammals (e.g., bears during spawning migration), and large predatory birds (e.g., osprey, eagles) are known to prey on salmonids (Monaco and Emmett 1998, cited in CMI 1998). Although both osprey and bald eagle were observed during the site visit, neither was seen in large numbers or in particular association with the groin. Two species of pinnipeds, harbor seals (*Phoca vitulina*) and sea lions (Stellar, *Eumetopius jubatus* or California, *Zalophus californianus*), were observed during the site visit. Harbor seals were seen regularly and more frequently than the sea lion, both around the immediate vicinity of the structure and eastward. Two mammal carcasses, one harbor seal and one sea lion, were beached approximately 150 m west of Station A. No marine mammals were seen at the West Reference site (Station D). However, seas were generally higher there relative to those at the groin and East Reference sites, making sighting of the mammals more difficult. On only one occasion was a marine mammal observed feeding. While conducting drifter buoy surveys, we observed a sea lion feeding on a sturgeon in the channel approximately 1500 m southeast of the groin.

Bird and mammal observations made during the May 2002 field survey are given elsewhere in this report.

8.5 Snorkel and SCUBA Dive Surveys

Observation and documentation of fish abundance and behavior were conducted during all three surveys, and dives were attempted by the MSL dive team during all surveys. Diving and snorkeling surveys were not effective in October 2001 or May 2002, because high waves, strong currents, and turbidity combined to produce extremely low visibility.

In June 2001, however, diving conditions were more favorable and produced both qualitative and quantitative information concerning the behavior of juvenile salmon near the groin. MSL scientists conducted eight snorkel surveys over the course of four days (June 11 through 14, 2001). Two of the surveys were complemented with photography using a Nikonos V underwater camera, and one survey with underwater videography. During two of the surveys, snorkelers quantitatively recorded the depth, substrate type, and species and numbers of fish and macro-invertebrates at 10-m intervals along 100-m

transects extending from the shore on the west side of the groin for 100 m and returning to shore on the east side. This method was then repeated in the reverse direction. Because of significant turbidity resulting in insufficient visibility, the west side transect was aborted during the final leg of the survey.

Scientific divers performed seven SCUBA surveys over the course of three days (June 12, 13, and 14, 2001). Because of severe currents in the study area, dives were of limited duration and were scheduled only during slack tides. Observations of species, substrate, and general conditions were recorded for all dives. Photographs and video were used to further document a dive on June 13. On June 14, three divers performed nine quantitative 360° surveys by descending to the bottom at stratified random points located along the groin, and observing and recording all fish visible within a 360° rotation. Nine, 10-m strip transects were conducted by attaching a pre-measured 10-m line to the bottom in the location of the 360° surveys and counting fish within half of the visibility distance from each side of the survey lines that ran parallel to the groin.

The 360° dive surveys recorded the following fish species and numbers at depths ranging from 14 to 20 feet mean lower low water (MLLW): 8 lingcod (*Ophiodon elongatus*), 2 cabezon (*Scorpaenichthys marmoratus*), 163 kelp greenling (*Hexagrammos decagrammus*), 44+ pile surf perch (*Damalichthys vacca),* 6 striped surf perch (*Embiotoca lateralis*), ~95 shiner perch (*Cymatogaster aggregata*), and 2 juvenile black rockfish (*Sebastes melanops*). Invertebrate species included sea stars (*Pisaster* spp.), anemones (*Urticina* spp.), and red rock crab (*Cancer productus*). Small boulders (3 to 4 ft) were noted at a depth of 14 ft MLLW on the west side of the groin. Large boulders (8 to 12 ft) with large crevices were noted at a depth of 17 ft MLLW.

During the 100-meter band transect snorkel survey, four chinook (*Oncorhynchus tshawytscha*) were recorded, two on the west side of the groin and two on the east side. Large schools of silver surfperch (*Hyperprosopon ellipticum)* ranging in size from >20 to >100 individuals were observed on the east side of the groin. Other species recorded included surfperch (other species), staghorn sculpin (*Leptocottus armatus*), kelp greenling (*Hexagrammos decagrammus*), starry flounder and other species of flatfish, and crabs (*Cancer* spp).

Juvenile salmonids, predominantly chinook (*Oncorhynchus tshawytscha*), were observed during snorkel and dive surveys. They were documented in groups, generally of five or fewer individuals, in the size range of 85 mm to 110 mm (Figures 15 and 16). Seen at all locations adjacent to and over the groin in the upper one meter of the water column, they were often observed feeding on plankton or on barnacles. They also exhibited a back-and-forth darting behavior along the periphery of the groin at the sand-rock interface at a depth of less than one meter.

Kelp greenlings (*Hexagrammos decagrammus*), both juvenile and adult, were present in relatively large numbers. Lingcod (*Ophiodon elongatus*) were also observed, but in fewer numbers, and ranged in size from approximately 120 mm to 900 mm. Other species documented during dive surveys, in addition to the species netted during the seines, include possible predator species that are commonly associated with rocky habitat: black rockfish (*Sebastes melanops*), cabezon (*Scorpaenichthys marmoratus*), and the great sculpin (*Myoxecephalus polyacanthocephalus*).

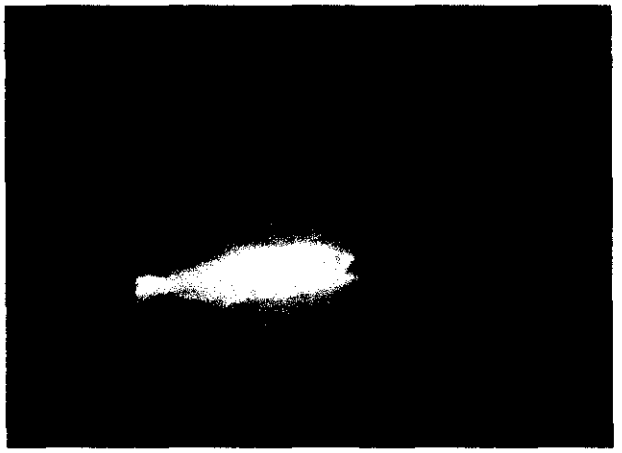

Figure 15. Salmon Smolt, Feeding Near the Rock Groin

Figure 16. Juvenile Salmon, often Observed in Small Groups.

8.6 Stomach Content Analysis

To investigate predation on salmonids in the groin area, known piscivores were captured for stomach content analysis during both the June 2001 and May 2002 surveys. Methods employed for fish capture included beach seining, hook and line from the beach, and hook and line from a boat approximately 100 meters southeast of the groin. A pump was used to flush stomach contents from the fish with water (Giles 1980). Stomach contents were preserved in 70 percent ethanol. All of the species analyzed represent potential salmonid predators; however, none contained identifiable fish remains; only invertebrates were identified.

Two staghorn sculpins measuring 145 mm and 150 mm were netted during beach seines and analyzed on June 12 and 13. Hook and line methods were used on June 14 from shore. A silver surfperch and walleye surfperch were landed and their stomachs were pumped. The stomach contents were well digested and therefore not identifiable. The hook-and-line method was used again on June 15 from a MSL boat, approximately 150 meters offshore at a depths between 14 and 19 feet. A cabezon, measuring 310 mm and weighing 440 grams (less stomach contents), was found to contain a small Dungeness crab and two *Crangon* shrimp. A kelp greenling, measuring 330 mm and weighing 460 grams (less stomach contents), contained a small crab and partial bivalve siphons (>1).

The stomach contents of more and larger fish were obtained during the May 2002 survey but, again, no salmon remains were identified. Details are provided elsewhere in this report.

8.7 Beach Seines

Beach seines were conducted during the June 2001 and May 2002 surveys to gather baseline data of species composition and relative abundance. Data collected on either side of the groin and at a reference site approximately 500 m south of the groin were compared during both ebb and flood tides. The seine used during the June 2001 survey was a standard beach seine with a floating line on top and lead line on bottom, and was 15 m in length by 2 m in depth. Specifically, the net consisted of two 6-m wings (1-cm^2 diamond mesh) and a 3-m center bag (2- by 6-mm mesh). A new seine was obtained for the May 2002 survey. The method of fishing was essentially the same for all surveys.

At each site, the seine was walked out perpendicular to the shore to a maximum depth of 1.5 m. The seine was deployed parallel to shore and then pulled shoreward onto the beach. The distance from shore ranged from approximately 20 m to 35 m, depending on the slope of the beach. After each seine haul, quantitative information was recorded on the species, numbers, and size of fish and macroinvertebrates netted.

A total of 21 beach seines were conducted at three sites in June 2001: West Groin, East Groin, and Reference site (approximately 500 meters south of groin) during both ebb and flood tides. The breakdown was as follows:

	No. of Seine Samples	
Station	**Ebb**	**Flood**
West Groin	3	3
East Groin	3	4
Reference	3	5

A total of 3,305 fish and macroinvertebrates, comprising a total of 24 species, were netted during the 21 beach seines conducted during the June 2001 study period. Fifty-two salmonid smolts were netted from the three sites. The majority of smolts netted were identified as chinook (*Oncorhynchus tshawytscha*), with a mean FL of 93 mm. It should be noted, however, that smolting salmonids are often difficult to identify. The other salmonid species netted were identified as coho (*O. kisutch*), mean FL 106 mm, and one steelhead (*O. mykiss*), FL 270 mm.

Three juvenile lingcod (*Ophiodon elongatus*) were captured during seining, one at the East Groin site and two at the reference site. Two juvenile kelp greenling (*Hexagrammos decagrammus*) were netted, one from West Groin and one from East Groin.

The most abundant fish netted were surfperch (1,894) and included the following species: shiner surfperch (*Cymatogaster aggregata*), silver surfperch (*Hyperprosopon ellipticum*), red-tailed surfperch (*Amphistichus rhodoterus*), walleye surfperch (*Hyperprosopon argenteum*), and pile surfperch (*Damalichthys vacca*). Three species of forage fish comprised the next most abundant group of fish (614): surf smelt (*Hypomesus pretiosus*), Pacific herring (*Clupea pallasi*), and Pacific sandlance (*Ammodytes hexapterus*). A total of 118 flatfish, composed of four species, were also collected: starry flounder (*Platichthys stellatus*), English sole (*Pleuronectes vetulus*), sanddab (*Citharichthys spp.*), and sand sole (*Psettichthys melanostictus).* Also netted were the following: 262 staghorn sculpins (*Leptocottus armatus*), 179 threespine sticklebacks (*Gasterosteus aculeatus*), 145 crangon shrimp (*Crangon* spp.), and 35 crab (*Cancer magister, Cancer productus*, and hermit crab spp.). A one-way ANOVA was run on the total catch at each site and on the number of salmonids caught at each site. There was no significant difference in either category. There was also no significant difference in the species richness between the three sites. A list of all species netted or observed during snorkel and dive surveys can be seen in Table 10.

Table 10. Species Netted in Beach Seines at Washaway Beach, June 11-14, 2001

Common Name	Scientific Name	East Groin	West Groin	Reference
Fish				
Chinook salmon	*Oncorhynchus tshawytscha*	*	*	*
Coho salmon	*Oncorhynchus kisutch*	*	*	*
Steelhead	*Oncorhynchus mykiss*			*
Pile surfperch	*Damalichthys vacca*	*		
Silver surfperch	*Hyperprosopon ellipticum*	*	*	*
Shiner surfperch	*Cymatogaster aggregata*	*	*	*
Walleye surfperch	*Hyperprosopon argenteum*		*	*
Red-tailed surfperch	*Amphistichus rhodoterus*	*	*	*
Staghorn sculpin	*Leptocottus armatus*	*	*	*
Kelp greenling	*Hexagrammos decagrammus*	*	*	*
Lingcod	*Ophiodon elongates*	*		
Pacific tomcod	*Microgradus proximus*	*		
Starry flounder	*Platichthys stellatus*	*	*	*
Sand sole	*Psettichthys melanostictus*	*	*	*
English sole	*Pleuronectes vetulus*	*	*	*
Sanddab	*Citharichthys* spp.	*		*
Surf smelt	*Hypomesus pretiosus*	*	*	*
Threespine stickleback	*Gasterosteus aculeatus*	*	*	
Pacific herring	*Clupea pallasi*	*	*	
Pacific sandlance	*Ammodytes hexapterus*		*	
Macroinvertebrates				
Dungeness crab	*Cancer magister*	*	*	
Red rock crab	*Cancer productus*			*
Hermit crab	Various species.		*	
Crangon shrimp	*Crangon* spp.	*	*	*

9.0 Discussion and Conclusions

9.1 Predation

Observations of marine mammals during surveys at Washaway Beach provided no evidence of predation on juvenile salmon. In most cases in which pinnipeds and salmonid smolts co-occur, it is assumed that the pinnipeds are feeding on smolts (NMFS 1997). However, because the smolts are consumed underwater, it is unknown to what extent the seals and sea lions exploit that resource. Predation on juvenile salmonids is affected by their size during outmigration. With respect to salmonid species in the Willapa Bay river system, chum and most fall and summer chinook salmon migrate either as fry soon after hatching (chum) or as subyearlings (chinook) and, therefore, may be too small to be pinniped prey. Spring chinook, coho, and steelhead migrate to the ocean as yearlings or older, at a size where they are most vulnerable to predation (NMFS 1997).

The underwater feeding behavior of pinnipeds, combined with fragility and rapid digestion rate of salmon prey, exemplify the difficulty of estimating salmon consumption rates by pinnipeds in any study. Although all of the above-mentioned salmon species have been documented as prey of pinnipeds in Washington, food-habit studies show varying rates of occurrence of salmonids as prey depending on location (e.g., seals forage near haul-out areas), season, prey availability, and data collection methods used. For example, a food-habit study of 211 Pacific harbor seals in Willapa Bay using scat and otolith analysis during March to September in 1980 to 1982 showed that 55% of the seals consumed flatfish, 40% consumed anchovy, 35% consumed sculpin, 17% consumed surf perch, and 11% consumed crustaceans. A similar study of 197 seals during June to September only, showed 28% to have consumed salmonids (NMFS 1997). Although extensive analysis of harbor seal diets in Washington coastal estuaries have shown that they consume some adult salmonids, there is no evidence that smolts were eaten (Beach et al.1985 in Schroder and Fresh 1992). It is believed, however, that smolt predation is either not represented or underrepresented in most studies, because the otoliths of juvenile salmonids are fragile and quickly digested and, therefore, may not be identified in stomachs or scats (NMFS 1997).

Likewise, we did not observe evidence of juvenile salmon predation by seabirds or large aggregations of seabirds feeding at the groin during surveys at Washaway Beach. The location of seabird foraging areas is governed by a combination of factors, such as foraging techniques, breeding locations, and availability of prey (Furness and Monaghan 1984). It is known that seabirds predictably associate with a wide range of physical marine features, which are assumed to increase prey abundance or availability. According to Ballance et al. (2001), it is generally concluded that seabirds associate with small-scale oceanic features, in addition to large-scale currents and regimes that affect prey abundance through primary production. Such features serve to concentrate prey in space and time and often occur under predictable circumstances.

Topographic features, such as the Washaway Beach groin and dike, may also deflect currents and can be sites of strong horizontal and vertical changes in current velocity (Miller et al. 2002). These features may similarly concentrate prey through a variety of mechanisms (e.g., physically trapping prey in a downstream eddy or forcing a transition between stratified and well-mixed water). The composition of seabird species documented during our predator surveys may indicate that this is true of the Washaway Beach groin and dike. Three of the predator species present (loons, grebes, and cormorants) sacrifice wide-area search capabilities in exchange for diving adaptations and, therefore, are limited to areas of

high prey availability (Ballance et al. 2001). The number and abundance of fish species, forage fish in particular, captured in beach seines near the groin supports this suggestion (Table 5).

Seabirds may have a significant impact on outmigrating juvenile salmonids in some locations. For example, a study of the colony size and diet composition of piscivorous seabirds on the lower Columbia River (Collis et al. 2002) showed that juvenile salmonids were an important diet component of birds nesting in the Columbia River estuary. On Rice Island (river km 34), salmonids accounted for 74% (by mass) of the diet of Caspian terns (*Sterna caspia*), 46% for double-crested cormorants (*Phalacrocorax auritus*), and 11% for glaucous-winged and/or western gulls (*L. glaucescens, L. occidentalis*).

However, the greater availability of marine forage fish may serve to reduce the relative rate of predation on juvenile salmonids in lower estuarine habitats, such as those found near the groin at Washaway Beach. Collis et al. (2002) found significantly lower proportions of juvenile salmonids in the diets of birds nesting lower in the Columbia River estuary at river km 8 (East Sand Island) compared with those nesting at river km 34 (Rice Island). The proportion of juvenile salmonids in the diet of double-crested cormorants nesting at river km 8 was approximately one-third that of cormorants nesting further upriver, at river km 34. Marine forage fishes, e.g. herring (*Clupea* spp.), smelt (Osmeridae), shiner perch (*Cymatogaster aggregata*), and Pacific sand lance (*Ammodytes hexapterus*), became more prevalent in the diets of cormorants in the lower estuary. Similar trends were seen in the diets of glaucous-winged and western gulls and Caspian terns. Marine forage fish comprised 52% of identifiable prey items in the diets of terns foraging in downriver locations, versus only 8% of those foraging in upriver locations. The authors attributed this to a greater availability of marine forage fish lower in the estuary.

Seabird predation on hatchery-raised pink salmon (*O. gorbuscha*) between April and June of 1995 in Prince William Sound, Alaska, similarly indicated that salmon fry just entering the marine environment were not especially susceptible to avian predation (Scheel and Hough 1997). The authors attributed this decline in vulnerability to the presence of other attractive food patches and to a decline in the number of seabirds foraging along the shoreline later in the study.

Declines in the numbers of some piscivorous seabird species along coastal Washington also coincide with outmigration periods of juvenile salmonids in Willapa Bay, further reducing potential predation pressure on salmon in these habitats. Western grebes begin inland migration in March, leaving the ocean by the later part of April, whereas common loons begin spring migration northward usually in April and May (Terres 1956). According to the Washington Ornithological Society (2001), common and Pacific loons, western grebes, and Bonaparte's gulls become considerably less common in western Washington by the end of May to the beginning of June. Other predatory species documented (e.g., cormorant, glaucous-winged and western gulls, bald eagle) are fairly common in western Washington year-round. The Cape Shoalwater area is not a documented breeding location for any of the avian predator species recorded during MSL surveys (Smith et al. 1997). Therefore, greater numbers of avian predators would not be expected at the Washaway Beach area during the breeding season and, coincidently, peak juvenile salmonid outmigration.

Our analysis of fish diets at the structure provides conclusive evidence that juvenile salmon were not a major dietary component of any predatory fish species throughout the duration of our study. No identifiable salmonids were observed in the diet of larger piscivores, and when fish were identified in stomach contents, they included only forage fish (i.e., surf smelt), surf perch, and gunnels. As noted for seabirds, the high abundance and greater availability of other marine forage fishes in these habitats may serve to reduce the relative rate of fish predation on outmigrating juvenile salmonids. We should point out, however, that if the proportion of juvenile salmonids relative to forage fish was much greater, the rate

of predation on juvenile salmon would likely increase commensurately. Therefore, temporal variations in outmigrating salmon populations are likely a factor in overall predation-related mortality.

The evidence establishing whether significant numbers of potential predators were aggregated in the groin area is less conclusive and involves more interpretation. Piscivorous fish were somewhat more abundant at shallow groin habitats than at reference stations (Table 5). SCUBA observations and hook-and-line collections made in the deeper groin habitats also suggest that larger piscivorous species do preferentially associate with these rocky, sublittoral habitats. However, most individuals (specifically lingcod and staghorn sculpin) collected in shallow groin habitats were too small to effectively feed on outmigrating juvenile salmon, which generally exceeded the size of the "predator" species (Figure 7). Likewise, demersal predators in deeper groin habitats consumed primarily benthic prey taxa, further suggesting that salmon oriented in the top 2 m of the water column would be unlikely prey items.

Part of the complexity in resolving the distribution question is based upon our inability to separate between basic habitat preferences of a particular species and volitional aggregation to specifically feed on outmigrating salmon. Increased fish abundance in structurally complex habitats has usually been attributed to the combined benefits of enhanced food supply and refuge from predators. In fact, habitat structure is often manipulated to enhance or aggregate specific faunal groups for human benefit (e.g. artificial reefs) (Seaman and Sprague 1991). Similarly, the groin structure itself provides features (such as hard attachment substrate, structural complexity, and prey) that are similar to rocky sublittoral habitats in the region. Bottom-oriented carnivores, such as lingcod, kelp greenling, and red Irish lord, are typical species found in these steep and well-flushed habitats (Simenstad et al. 1979).

The preferential distribution near the groin of potential fish predators typically oriented to rocky sublittoral habitats is to be expected. Determining whether they are preferentially aggregating there to feed on juvenile salmon requires evidence of predation (stomach contents), as well as knowledge of prey (salmon) distributions. From our field studies, it is apparent that juvenile salmon concentrate on the west side (outside) of the groin, although the behavioral mechanisms for this are still unclear. Eddies formed on either side of the groin may be an important concentrating mechanism; however, we cannot definitively conclude this based on the existing data. However, the benthic orientation of these large potential predators generally does not overlap with surface-oriented salmon (<2 m). Diet analyses confirm these observations.

Aggregative responses to uneven prey distributions have previously been quantified in terms of predator numbers, or time spent by a predator, per unit areas of different prey density (Hassell and May 1974). Studies to date have shown that salmon predators (e.g., northern squawfish [*Ptychocheilus oregonensis*], gulls [*Larus* spp.], and common mergansers [*Mergus merganser*]) aggregate in response to unnatural or exceptional circumstances, such as spawning channels, hatcheries, or dams, where juvenile salmon are concentrated relative to natural conditions. Thus, much of the predation may occur in upriver, freshwater regions of a study area as compared with tidal areas. It is known that large populations of squawfish aggregate below hydroelectric and irrigation diversion dams, where they prey upon small fish that are disoriented or injured. For example, Sims et al. (1977, 1978 in Brown and Moyle 1981) found that the percentage of squawfish consuming outmigrating salmonids below dams on the Columbia River during 1976 and 1977 varied from 20% to 88% respectively. Salmon consumption by squawfish has also often been correlated with periods of smolt release from hatcheries (Brown and Moyle 1981). However, other studies have indicated that under natural conditions, salmonids are not major prey items of squawfish. In free-flowing sections of the Willamette River, Buchanan et al. (1981) found that only 2% of 1127 squawfish examined during outmigration in 1976 and 1977 contained salmonids. Ruggerone (1986) documented aggregations (250 to 350) of gulls actively foraging for fish within 75 m of the Wanapum Dam tailrace on the Columbia River. During a 25-day peak outmigration period at the Wanapum Dam,

the number of salmonids consumed by gulls foraging below turbines was estimated to be 2% of actual spring outmigration. Wood (1987) found that merganser numbers were orders of magnitude higher below the Big Qualicum hatchery than in tidal waters during spring releases of salmon fry. He estimates that the mortality rate of salmon attributed to mergansers was unlikely to be above 8% during outmigration for any particular stock studied on coastal streams of Vancouver Island.

9.2 Migration

9.2.1 Physical Processes Affecting Migration

Prior to construction of the jetty and dike, flow through the channel was unobstructed. Current measurements made near the channel by PIE (1997) documented near-surface velocities as high as 1.95 m/sec (3.8 kts). Velocities depend on the tidal range (e.g., the difference between successive high and low tide), with swifter currents generated by greater tidal differences. Current velocities were regularly monitored at several locations around the structure following construction, and vertically averaged velocities as high as 2.4 m/sec (4.7 kt) were observed during ebb tide downstream of the dike. Near-surface velocities are not reported for that measurement date, but velocities as high as 2.5 m/sec (5 kt) were recorded near the end of the dike on August 27, 1999 (PIE 2000). These velocities, though strong for tidal currents, are probably no greater than those that would occasionally be developed without the dike present. Bathymetric surveys taken following construction indicate the dike and groin have arrested the northward migration of the channel and have altered the flow pattern of the tidal currents.

Numerical model studies conducted by the Army Corps of Engineers, Engineering Research and Development Center, predicted that large eddies are present on the downstream side of the jetty during both ebb and flood tidal phases (Figures 6-37 and 6-38 in Kraus 2000). The ADCIRC model used for this study is vertically integrated so the entire water column in a model grid moves only in the same horizontal direction, such that small scale eddies developed around rocks and vertical motions are not shown. The turbulence generated downstream of the dike/jetty by rapid flow over the rocks was noted on several occasions by MSL observers. Ducks were observed riding small eddies and remaining in the same general location behind the jetty while strong currents flowed in or out of the bay past the end of the jetty. The strength of the downstream eddies varies during the tidal cycle. Water in the eddies passes through and is transported in the downstream direction.

Current meter measurement made by PIE following construction showed that current velocities were comparable with those prior to construction. However, direct comparison cannot be made because of differences in the tidal elevation and possible changes in channel geometry. The drogue measurements made by the MSL during fall 2001 and the current meter measurements made by PIE showed that the velocity increased and was directed slightly offshore over the top of the structure. The drogue studies also indicated that currents were 2.5 kt, and that on one occasion (of 16), an eddy formed in the lee of the structure (Miller et al. 2002). Most of the drogues, however, traveled past the jetty and were retrieved downstream, indicating that large-scale strong eddies that could potentially entrain salmon were not present during these conditions.

9.2.2 Fish Migration Impacts

There is concern that shoreline armoring structures may inhibit or alter migration pathways of juvenile salmonids. Most directed research in Washington State on the effect of shoreline structures on biotic communities has involved breakwaters in the context of marinas (Williams and Thom 2001). Salmon fry and forage fish schools have been seen to concentrate in higher densities behind breakwaters in marina basins as compared with unaltered nearshore areas (Heiser and Finn Jr. 1970; Pentilla and Aguero 1978).

Fish movement and schooling behavior documented in these studies suggested that concentration in these areas was volitional. Reluctance of juvenile salmonids to leave the shoreline and travel along bulkheads or connected breakwaters is apparently related to size. Heiser and Finn (1970) found that 35-mm to 45-mm pink (*O. gorbuscha*) and chum fry would not venture along bulkheads or connected breakwaters until reaching a larger size (50 mm to 70 mm).

The design of the bulkheads or breakwaters also affect fry behavior. Steep, vertical designs inhibit migration potential, whereas low-slope structures (<45-degree angle) of natural material (e.g., riprap) with irregular surface configuration provided more protective cover, shallow water shelter, and predation refuge (Williams and Thom 2001). The Washaway Beach groin was designed to have a slope of 1:7 and so is considerably less steep than a 45-degree angle.

Although we can confirm that one chinook successfully traveled from east of the groin to the west side of the groin, it does not, of course, provide conclusive evidence that the physics of the groin structure do not alter migratory behavior of juvenile salmon. Our drift-buoy surveys during the fall sampling effort in October 2001 (Miller et al. 2002) showed that flow velocities can increase significantly over the groin. For instance, one buoy tracked over the groin on a flood tide increased in velocity from approximately 0.5 m/s west of the groin to 1.5 m/s over the groin. The highest recorded velocity was about 2.5 m/s. High velocities may prevent some juvenile salmonids from swimming over the groin at certain times. For example, studies involving the swimming capacity of juvenile salmonids have shown that a 70-mm chinook can maintain a home station facing velocities of 0.23 m/s, but lie under a layer of 0.45 m/s water and be surrounded by velocities of 0.6 m/s (Chapman and Bjornn 1968 in Beauchamp et al. 1983). Further, various laboratory studies on the swimming performance of juvenile salmonids were used to derive 30 cm/s as the threshold velocity to model the availability of low-velocity rearing habitat in the Columbia River estuary (Bottom et al. 2001). However, the duration of high velocities at the groin are periodic and thus would not be expected to prevent salmonids from moving past the groin in either direction for more than 6 hours. The low rate of recaptures of fish marked on either side of the groin perhaps provides the best indication that juvenile salmon are not remaining at the groin for long periods of time and suggests that the groin does not inhibit movement past this structure. However, the groin may create conditions conducive to volitional feeding, resting, and transition to marine waters.

An acute negative impact of the groin on outmigrating juveniles would return significantly fewer adults to spawn in the Willapa Bay river system after ocean residence. A majority of outmigrating juveniles in 1999 (post-groin construction) would return as spawning adults between 2001 and 2005. As the average age of adults returning to spawn is 3 to 4 years old, a majority of 1999 outmigrants would be expected to return in 2002 and 2003. With this in mind, it may be useful to continue to look at Willapa Bay salmon runs in 2002 and beyond. However, sorting out the effect of the groin versus other factors affecting salmon returns is problematic.

An impact of the groin construction on salmonids would be expected to affect salmon fisheries in Willapa Bay. Because of natural interannual variability in Pacific salmon fisheries, 5-year averages of the terminal run size (terminal commercial and sport catch plus spawning escapement) were calculated for chinook fisheries in Willapa Bay and Gray's Harbor (Figure 17). Both fisheries show a remarkable similarity in their five-year trend, with no significant deviation between fisheries in the last 5-year period. Although the overall decline in chinook fisheries is greater in Willapa Bay, the trend began prior to groin construction in 1998.

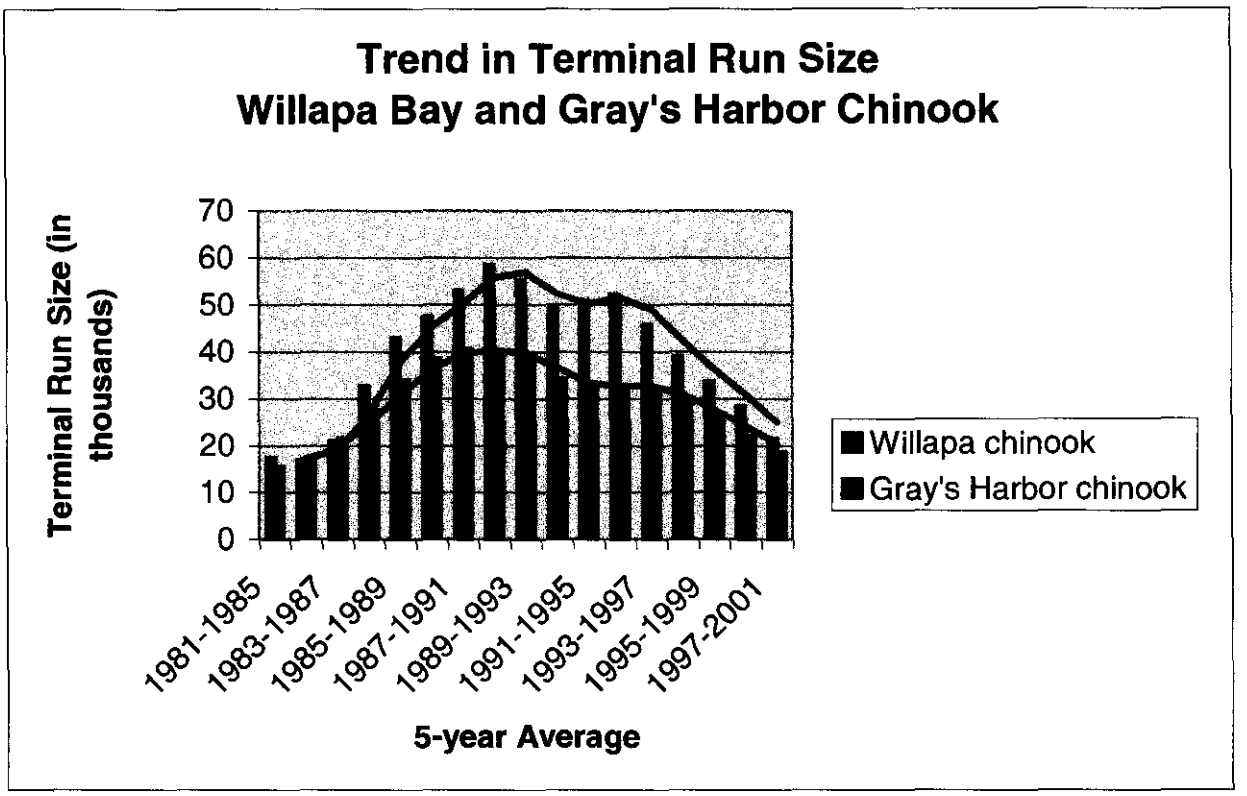

Figure 17. Five-Year Trends and Trend Lines (2-Period Moving Average) in Terminal Run Size of Willapa Bay and Gray's Harbor Chinook (adapted from the Review of 2001 Ocean Salmon Fisheries, Pacific Fishery Management Council)

9.3 Discussion of Methods

Determining the impact on a fish assemblage due to an event such as the placement of the structure at Washaway Beach is a typical problem in applied ecology, in which the effect of human interaction is to be separated from the natural temporal variability of the population. It is a particularly difficult problem because environmental systems are not static but change naturally over time, and this background variation must be taken into account. Assigning an effect due to the structure is made more difficult because it cannot practically be replicated in another site. Convincing statistical data that show the structure as the cause of an observed variable may, therefore, be difficult to obtain.

One recommended procedure for detecting and quantifying effects of human intervention is to sample repeatedly and contemporaneously at the potential impact site and at one or more control sites during the periods before and after the impact has begun. The length of time required for statistical significance varies, but at least one year is typical because of the practical constraints of budgets and planning. The differences in the variant of interest, in this case abundance of salmonids, can be calculated between the impact and control sites on each survey. The averages of these differences can then be compared for the periods before and after the impact. A critical element in this design is that the control site and the impact site be sampled at about the same time, and that they track each other or vary in about the same way prior to the impact. The assumption is made that because of proximity or similarity, the background variability

is common to both the impact and control sites. A significant change between the means of the differences before the impact as opposed to after the impact is strong evidence of an ecological effect of the impact itself (Schroeter et al. 1993). This method is called Before-After/Control-Impact (BACI) sampling and has been applied with some variations in a number of monitoring and impact assessment studies (Green 1979; Guidetti 2001; Keough and Mapstone 1997; Lee and Pritchard 1996; Schmidt and Osenberg 1996; Smith 2002; Stewart-Oaten, Bence, and Osenberg 1992; Stewart-Oaten, Murdoch, and Parker 1986; Underwood 1991, 1992, 1993, 2000).

In systems where plants or animals are long lived, BACI sampling may be required for several years before statistically significant changes in population are detected. For instance, Schroeter et al. (1993) report that their studies of kelp forest organisms extended over nearly 6 years, yet the resulting statistical tests generally had power of <30% to detect a doubling or halving in density at a significance level of 0.05.

The data collected during the three collection periods is insufficient to determine with confidence whether or not the structure has had an adverse impact on salmon population in Willapa Bay. However, the data do allow evaluation of potential mesoscale effects on factors that could ultimately result in impacts to salmon populations in Willapa Bay. The BACI method of study allows the researcher to eliminate the natural variability between sites by synoptic sampling over a relatively short period of time. Future construction plans should consider biological sampling of this sort in assessing potential impacts.

9.4 Conclusion

Determining whether biologically relevant levels of salmon predation occur at the groin rests on our ability to clarify whether potential predators were distributed in significantly higher numbers here, and whether they were feeding on salmon. Likewise, it rests on how we define "biologically significant."

Our interpretation of fish predator abundance and diet suggest that juvenile salmon do not experience biologically significant levels of predation near the groin. We did not observe meaningful aggregations of any predator species at the groin. In circumstances in which piscivorous birds are abundant, literature suggests that no single species of avian predator is capable of inflicting compensatory mortality on juvenile salmonids during their brief period of seaward migration in coastal systems (Wood 1987). Furthermore, available literature does not support the notion that marine mammals are a significant source of smolt predation. To date, we have found no definitive examples of predator aggregation in response to alterations of marine shoreline habitats, although this issue is now receiving more attention.

Adult salmon returning to the estuary during spawning migration are most vulnerable to marine mammal predation as they travel through estuaries and river mouths, especially where salmonids concentrate or passage may be constricted. Ficus (1979 in NMFS 1997) suggests that mammal predation on free-swimming salmon in the open ocean probably has minimal impact on the overall stock. Our interviews with gillnet fishermen and review of the commercial fish-catch data during our field study in October 2001 provide evidence that large numbers of salmonids, particularly chum salmon, are progressing in an "upstream" direction beyond the dike. Also, our observations of marine mammals during peak returns of chum salmon suggested no particular association with the groin.

However, we temper our interpretation with acknowledgement of potential study weaknesses, including the limited duration of the study and inability to conduct pretreatment comparisons. An ideal study design would involve paired comparisons of predator abundance at the groin and unaltered reference stations both before and after the groin was put in place. An alternative design would compare predator aggregation during peak salmon abundance (this study) and at other times. Therefore, our conclusions

that address the concerns of the regulatory agencies rest upon our comparisons of the structure with unaltered reference stations during a short segment of the juvenile salmon outmigration and adult return migration periods (Table 11).

Table 11. Study Conclusions of the Potential Effect of Washaway Beach Groin and Dike on Migratory Movement and Predation on Juvenile and Adult Salmonids.

Concern	**Conclusion (1) ***	**Conclusion (2) ***
The dike provides habitat for predators **(1)** that would feed on the migrating juvenile salmon **(2)**	Yes	No evidence
The dike could change the flow pattern within the nearshore migration pathway **(1)** and force the juvenile fish into deeper water where they would be more vulnerable to avian predators **(2)**	Yes	Inconclusive
The structure could become a gathering place for piscivorous avian species **(1)** that would deplete the already stressed salmon stocks **(2)**	No evidence	No evidence
The structure could alter circulation patterns around the dike **(1)** and hinder the out-migration of salmonids by trapping them in downstream eddies or causing them to congregate on the upstream side of the structure **(2)**	Yes	No evidence
The dike could alter the migration path of returning adults **(1)** such that fish holding near the dike would become easy prey for seals or sea lions **(2)**	Inconclusive	No evidence

* Conclusions (1) and (2) refer to similarly highlighted concerns in each row of the table.

10.0 References

Armstrong, J. L., D. A. Armstrong, and S. B. Mathews. 1995. Food habits of estuarine staghorn sculpin, Leptocottus armatus, with focus on consumption of juvenile Dungeness crab, Cancer magister. *Fishery Bulletin* 93:456-470.

Ballance, L. T, D. G. Ainley, and G. L. Hunt, Jr. 2001. Seabird Foraging Ecology. Pages 2636-2644 in: J.H. Steele, S.A. Thorpe and K.K. Turekian (eds.) *Encyclopedia of Ocean Sciences*, vol. 5. Academic Press, London.

Beauchamp, D.A., M. F. Shepard, and G. B. Pauley. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest): Chinook Salmon. Report No. FWS/OBS-82/11-6. Division of Biological Services, U.S. Fish and Wildlife Service. 15pp.

Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. 2001. Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon. U. S. National Marine Fisheries Service.

Brown, L. R. and P. B. Moyle. 1981. The impact of squawfish on salmonid populations: A review. *N. Am. J. Fish. Mgmt.* 1:104-111.

Buchanan, D. V., R. M. Hooton, and J. R. Moring. 1981. Northern squawfish (*Ptychocheilus oregonensis*) predation on juvenile salmon in sections of the Willamette River Basin, Oregon. Can. J. Fish. Aquat. Sci. 38:360-364.

Buckley, R., G. Hueckel, B. Benson, S. Quinnell, and M. Canfield. 1984. *Enhancement research on lingcod (Ophiodon elongatus) in Puget Sound.* Progress Report #216. Washington Dept. Fish and Wildlife, Olympia, Washington.

CDFG (California Department of Fish and Game). 2002. *California Wildlife Habitat Relationships System.* Available online: http://www.dfg.ca.gov/whdab/B047.html

CMI (Conservation Management Institute). 1998. *Marine and Coastal Species Information System.* Virginia Technical University. Available online: http://fwie.fw.vt.edu/WWW/macsis/index.htm.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D.E. Lyons. 2002. Colony Size and Diet Composition of Piscivorous Waterbirds on the Lower Columbia River: Implications for Losses of Juvenile Salmonids to Avian Predation. *Transactions of the American Fisheries Society* 131:537-550.

Cornell Laboratory of Ornithology. 2000. Available online: http://www.birds.cornell.edu

Doty, D. C., R. M. Buckley, and J. E. West. 1995. Identification and Protection of Nursery Habitats for Juvenile Rockfish in Puget Sound, Washington. Pages 181-190. *Puget Sound Research '95 Proceedings Volume 1.* E. Robichaud, editor. Puget Sound Water Quality Authority: Olympia, Washington.

Emmett, R. L., S. A. Hinton, S. L. Stone, and M. E. Monaco. 1991. *Distribution and abundance of fishes and invertebrates in West Coast estuaries, Volume II: Species life history summaries.* ELMR Report No. 8. Strategic Envirnomental Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, Maryland. 329pp.

Eschmeyer, W. N., E. S. Herald, and H. Hamann. 1983. *A field guide to Pacific Coast fishes of North America.* Peterson Field Guide Series. Houghton Mifflin Co., Boston, MA.

Fresh, K. L., R. D. Cardwell, and R. R. Koons. 1981. *Food habits of Pacific salmon, baitfish, and their potential competitors and predators in the marine waters of Washington, August 1978 to September 1979.* Progress Report No. 145, WA State Department of Fisheries. 46 pp.

Furness, R.W., and P. Monaghan. 1984. *Seabird Ecology.* Chapman & Hall: New York.

Giles, N. 1980. *A stomach sampler for use on live fish.* Journal of Fish Biology, 16:441-444.

Green, R. H. 1979. In: *Sampling Design and Statistical Methods for Environmental Biologists.* Wiley and Sons, New York.

Groot, C., and L. Margolis. 1991. *Pacific Salmon Life Histories.* University of British Columbia Press, Vancouver, British Columbia.

Guidetti, P. 2001 Detecting environmental impacts on the Mediterranean seagrass *Posidonia oceanica* (L.) Delile: the use of reconstructive methods in combination with 'beyond BACI' designs. *Journal of Experimental Marine Biology and Ecology* vol. 260. pp.226-39.

Hassell, M., and R. May. 1974. Aggregation of predators and insect parasites and its effect on stability. J. *Anim. Ecol.* 43:567-594.

Heiser, D. W., and E. L. Finn Jr. 1970. *Observations of juvenile Chum and Pink salmon in marina and bulkheaded areas.* Management and Research Division, Supplemental Progress Report, Puget Sound Stream Studies. Washington Department of Fisheries, Olympia, Washington.

Johnsgard, P. 1987. *Diving Birds of North America.* University of Nebraska Press: Lincoln.

Johnson, O.W., W.S. Grant, R.G. Kope, K. Neely, F.W. Waknitz, and R.S. Waples. 1997. *Status Review of Chum Salmon from Washington, Oregon, and California.* U.S. Department of Commerce, NOAA Tech. Memo. NMFS-NWFSC-32. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington.280 pp.

Keough, M. J., and B. D. Mapstone. 1997. Designing environmental monitoring for pulp mills in Australia. *Wat. Sci. Tech.* 35, No 2-3, pp.397-404.

Komar, P. D. 1998. *The Pacific Northwest Coast: Living with the shores of Oregon and Washington.* Duke University Press. 195 p.

Kraus, N. C. (ed). 2000. *Study of Navigation Channel Feasibility, Willapa Bay, Washington.* U.S. Army Corps of Engineers ERDC/CHL TR-00-6. 440 pp.

Lee, R. S., and T. R. Pritchard. 1996. How do long-term patterns affect time-limited environmental monitoring programmes? *Marine Pollution Bulletin,* 33, Nos 7-12, pp. 260-268.

Love, R.H. 1971. Measurement of Fish Target Strength. *Fish. Bull.* 69(4): 703-715.

MacDonald, K. B., D. Simpson, B. Paulsen, J. Cox, and J. Gendron. 1994. *Shoreline armoring effects on the physical processes in Puget Sound, Washington.* Coastal Erosion Management Studies, Volume 5.

Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, Washington.

Miller, D. J., and R. N. Lea. 1972. *Guide to the coastal marine fishes of California.* Fish Bulletin of the California Department of Fish and Game 157:1--235.

Miller, M. C., R. M. Thom, G. D. Williams, J. A. T. Southard, S. L. Blanton, and L. K. O'Rourke. 2001. *Effects of Shoreline Hardening and Shoreline Protection Features on Fish Utilization and Behavior, Washaway Beach, Washington.* PNNL-13635-(1). WA-RD 521.1. Washington State Department of Transportation, prepared by Pacific Northwest National Laboratory, Sequim, Washington.

Miller, M. C., G. D. Williams, L. K. O'Rourke, J. A. Southard, S. L. Blanton. 2002. *Effects of Shoreline Hardening and Shoreline Protection Features on Fish Utilization and Behavior, Washaway Beach, Washington (Report 2).* PNNL-13635-(2). WA-RD 521.2. Washington State Department of Transportation, prepared by Pacific Northwest National Laboratory, Sequim, Washington.

Nelson, B. 1979. *Seabirds; their biology and ecology.* A & W Publishers, Inc.: New York.

Nightengale, B., and C. Simenstad. 2001. White paper--overwater structures: marine issues. Rept. no. WA-RD 508.1, Wash. State Transport. Center, Univ. Wash., Seattle, WA. 133 pp + append.

NMFS (National Marine Fisheries Services). 1997. *Investigation of Scientific Information on the Impacts of California Sea Lions and Pacific Harbor Seals on Salmonids and on the Coastal Ecosystems of Washington, Oregon, and California.* U.S. Department of Commerce, NOAA Tech. Memo. NMFS-NWFSC-28. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington. 172 pp.

Pacific Fishery Management Council. 2002. Review of 2001 Ocean Salmon Fisheries. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, Portland, Oregon.

Pentilla, D. and M. Aguero. 1978. *Fish usage of Birch Bay Village Marina, Whatcom County, Washington, in 1976.* Progress Report No. 39. Washington Department of Fisheries, Olympia, Washington.

Phillips, S. and B. Pierce. 1999. *Beach Erosion Control Project at North Cove, Washington (Construction and Preliminary Monitoring Program Results).* Washington State Department of Transportation, Vancouver, Washington.

PIE (Pacific International Engineering). 1997. SR-105 Emergency Stabilization Project, Monitoring Report #4, February 20, 1997.

PIE (Pacific International Engineering). 2000. SR-105 Emergency Stabilization Project, Monitoring Report #17, March 10, 2000.

Ruggerone, G. T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. *Trans. Am. Fish. Soc.* 115:736-742.

Scheel, D. and K. R. Hough. 1997. Salmon Fry Predation by Seabirds Near an Alaskan Hatchery. *Marine Ecology Progress Series* 150:35-48. Abstract available online: http://www.int-res.com/abstracts/meps.

Schmidt, R. J. and C. W. Osenberg (Editors). 1996. *Detecting Ecological Impacts: Concepts and Applications in Coastl Habitats.* Academic Press, San Diego. 401 pp.

Schroder, S., and K. Fresh. 1992. *Results of the Grays Harbor coho survival investigation 1987-1990.* Wash. State Dep. Fish. Tech. Rep. No. 118, 414 p.

Schroeter, S. C., J. D. Dixon, J. Kastendiek, and R. O. Smith. 1993. Detecting the ecological effects of environmental impacts: a case study of kelp forest invertebrates. *Ecological Applications.* 3(2). pp. 331-350.

Seaman W. & Sprague L. M. (eds). 1991. Artificial Habitat Practices in Aquatic Systems in *Artificial Habitats for Marine and Freshwater Fisheries.* Academic Press. California.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, K. Thornburgh, and L. J. Bledsoe. 1979. *Food web relationships of Northern Puget Sound and the Strait of Juan de Fuca.* EPA 600/7-79-259. Office of Engineering and Technology, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

Simenstad, C. A., C. D. Tanner, R. M. Thom, and L. L. Conquest. 1991. *Estuarine Habitat Assessment Protocol.* Puget Sound Estuary Program, EPA 910/9-91-037. Prepared for the US Environmental Protection Agency, Region 10, Office of Puget Sound, Seattle, Washington.

Simenstad, C. A., B. J. Nightengale, R. M. Thom, and D. K.Shreffler. 1999. *Impacts of ferry terminals on juvenile salmon migrating along Puget Sound shorelines. Phase I: synthesis of state of knowledge.* Report No. WA-RD- 472.1. Washington State Transportation Center (TRAC), Seattle, Washington.

Smith, E. P. 2002. BACI design, in El-Shaarawi, A.H. and W.W. Piegorsch, ed., *Encyclopedia of Environmetrics.* 1:141-148, John Wiley and Sons, Ltd.

Smith, M. R., P. W. Mattocks, Jr., and K. M. Cassidy. 1997. *Breeding Birds of Washington State,* Vol 4 in Washington State Gap Analysis: Final Report (K.M. Cassidy, C.E. Grew, M.R. Smith, and K.M. Dvornich, eds). Seattle Audubon Society Publications in Zoology No. 1. Seattle, 538 pp.

Stewart-Oaten, A., J. R. Bence, and C. W. Osenberg. 1992. Assessing effects of unreplicated perturbations: no simple solutions. *Ecology.* 73(4). pp. 1396-1404.

Stewart-Oaten, A., W. W. Murdoch, and K. R. Parker. 1986. Environmental impact assessment: "Pseudoreplication" in time? *Ecology.* 67(4). pp. 929-940.

Terres, J. K. 1956. *The Audubon Society Encyclopedia of North American Birds.* Wings Books: New York.

Terich, T. and T. Levenseller. 1986. The Severe Erosion of Cape Shoalwater, Washington. *Journal of Coastal Research,* (2)4: 465-477.

Underwood, A. J. 1991. Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research.,* 42:569-587.

Underwood, A. J. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Bilogy and Ecology.* 161:145-178.

Underwood, A. J. 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. *Australian Journal of Ecolog.* 18:99-116.

Underwood, A. J. 2000. Experimental ecology of rocky intertidal habitats: what are we learning? *Journal of Experimental Marine Biology and Ecology.* 250:51-76.

University of Michigan. 2000. *Animal Diversity Web.* Available online: http://animaldiversity.ummz.umich.edu/accounts.

U.S. Army Engineer Research and Development Center. 2000. Study of navigation channel feasibility, Willapa Bay. Nicholas C. Kraus, editor; Prepared for U.S. Army Engineer District, Seattle. ERDC/CHL TR-00-6, April 2000.

Washington Ornithological Society. 1999-2001. *Seasonal Occurrence of Washington Birds.* Available online: http://www.wos.org.

Williams, GD., and RM. Thom. 2001. *Development of Guidelines for Aquatic Habitat Protection and Restoration: Marine and Estuarine Shoreline Modification Issues.* PNWD-3087. Prepared for the Washington State Department of Transportation, Washington Department of Fish and Wildlife, and the Washington Department of Ecology, by Battelle Marine Sciences Laboratory, Sequim, Washington.

Williams, G. D. 1994. *Effects of habitat modification on distribution and diets of intertidal fishes in Grays Harbor Estuary, Washington* . M.S. Thesis. School of Fisheries, University of Washington, Seattle, Washington. 53pp.

Wood, C. C. 1987. Predation of juvenile Pacific salmon by the common merganser (Mergus merganser) on eastern Vancouver Island. I: Predation during the seaward migration. *Can. J. Fish. Aquat. Sci.* 44:941:949.