IMPACTS OF FERRY TERMINALS ON JUVENILE SALMON MIGRATING ALONG PUGET SOUND SHORELINES PHASE II: FIELD STUDIES AT PORT TOWNSEND FERRY TERMINAL

WA-RD 480.1

Research Report
December 1999

**Washington State
Department of Transportation**

Washington State Transportation Commission
Planning and Programming Service Center
in cooperation with the U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 480.1		

4. TITLE AND SUBTITLE

Impacts of Ferry Terminals on Juvenile Salmon
Migrating Along Puget Sound Shorelines
Phase II: Field Studies at Port Townsend Ferry Terminal

5. REPORT DATE

December 1999

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

David K. Shreffler and Russell A. Moursund

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Battelle Marine Sciences Laboratory
1529 West Sequim Bay Road
Sequim, WA 98382

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

GCA-1723

12. SPONSORING AGENCY NAME AND ADDRESS

Washington State Department of Transportation
Transportation Building, MS 47370
Olympia, Washington 98504-7370
Program Manager, Jim Schafer 360-705-7403

13. TYPE OF REPORT AND PERIOD COVERED

Final Research Report

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration and the U.S. Army Corps of Engineers, Seattle District.

16. ABSTRACT

The University of Washington (UW) and Battelle Marine Sciences Laboratory (MSL) are jointly conducting a multiyear, three-phased research program to determine whether ferry terminals affect migrating juvenile salmon, and if so, how future design of ferry terminals and modifications to both terminals and operations can mitigate those impacts. Phase I resulted in a report synthesizing the technical knowledge regarding the potential effects of shoreline structures on migrating juvenile salmon. This report summarizes our results from Phase II pilot field studies at the Port Townsend ferry terminal in spring 1999 and provides recommendations for proposed on-site tests of the effects of a range of different WSDOT ferry terminals and vessel activity patterns in Phase III (spring-winter 2000). The overall goal of Phase II was to perform pilot field experiments with releases of hatchery chum and chinook fry to test whether the Port Townsend terminal stops or delays the natural migration of juvenile salmon. Monitoring methods included diving surveys, beach seining surveys, single-beam and split-beam hydroacoustics, remote underwater video, and *in situ* light sensors.

River otters directly and indirectly resulted in mortalities to approximately 29,000 of the 30,000 chinook fry and 39,700 of the 40,000 chum fry that we were holding in net pens for experiments. We released the remaining fish 30 m from the southern edge of the Port Townsend ferry terminal on June 11, 1999. On the basis of this one-time experiment, we found no evidence that the Port Townsend ferry terminal was a barrier to the migration of the 1000 chinook that we released. We have no data or observations for the 300 chum fry after their release. The released chinook fry stayed in a school and did not disperse upon encountering the Port Townsend ferry terminal. The chinook fry did not divert their migratory route into deeper water or around the offshore perimeter of the terminal. Surface observations, underwater video, and the single-beam and split-beam hydroacoustics confirmed that the chinook migrated from the release point directly to the shadow line underneath the terminal. The chinook fry stopped at the shadow line and then displayed a consistent behavior of swimming from the darkness of the shadow line and near the bottom into the light to feed at the surface. As the sun set and the shadow line progressed further underneath the terminal, the chinook school appeared to follow the shadow line under the terminal and, we assume, out the other side. **However, we caution that it is neither prudent nor valid to conclude that ferry terminals either do or do not have an effect on juvenile salmon migration, on the basis of these preliminary findings.** The loss of the majority of our fish for experiments, the hard-drive crash on the navigation computer, and the malfunctioning of some of the single-beam transducers compromised this study. The fundamental question of whether ferry terminals are a "barrier" to juvenile salmon migration remains unanswered.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Salmon migration, over-water structure, hydroacoustics, underwater video, light sensors, chum salmon, chinook salmon	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	79	

Research Report
Contract GCA-1723

IMPACTS OF FERRY TERMINALS ON JUVENILE SALMON MIGRATING ALONG PUGET SOUND SHORELINES
PHASE II: FIELD STUDIES AT PORT TOWNSEND FERRY TERMINAL

by

David K. Shreffler
Battelle Marine Sciences Laboratory
1529 West Sequim Bay Road
Sequim, Washington 98382

Russell A. Moursund
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland, Washington 99352

Washington State Department of Transportation
Paul J. Wagner, Technical Monitor
James A. Schafer, Research Program Manager

Prepared for

Washington State Transportation Commission
Department of Transportation
and in cooperation with the
U.S. Army Corps of Engineers
Seattle District

December 1999

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

EXECUTIVE SUMMARY viii

INTRODUCTION 1
    Problem Description 3
    Goals and Objectives 4
    Assumptions 8

REVIEW OF PREVIOUS WORK 9

RESEARCH APPROACH 10
    Field Preparations and Coordination 10
    Diving Survey 15
    Beach Seining Survey 17
    Split-Beam Hydroacoustics 17
    Single-Beam Hydroacoustics 25
    Underwater Video 29

FINDINGS 36
    Field Preparations and Coordination 36
    Diving Survey 37
    Beach Seining Survey 37
    Split-Beam Hydroacoustics 37
    Single-Beam Hydroacoustics 43
    Underwater Video 51

DISCUSSION 60
    Field Preparations and Coordination 60
    Diving Survey 61
    Beach Seining Survey 62
    Split-Beam Hydroacoustics 63
    Single-Beam Hydroacoustics 65
    Underwater Video 66
    Light Measurements 70

CONCLUSIONS 71

RECOMMENDATIONS 73

ACKNOWLEDGMENTS 76

REFERENCES 78

LIST OF FIGURES

Fig. 1 Organization of research phases in UW-MSL studies on ferry terminal impacts on juvenile salmon migrating through Puget Sound 2

Fig. 2 Physical setting and shoreline features in the vicinity of the Port Townsend ferry terminal, Port Townsend, Washington 5

Fig. 3 Researcher Barb Nightingale transfers chinook fry from the hatchery truck to the floating net pen in May, 1999 12

Fig. 4 Following transfer of chinook fry from the hatchery truck into our floating net pen in May 1999, the net pen was towed from Port Townsend boat ramp to a moorage slip next to the commercial boat dock at the Port Townsend marina 13

Fig. 5 The net pen was moored at the commercial boat dock at the Port Townsend marina from mid-May to late-May 1999 14

Fig. 6 Locations of six diving transects at the Port Townsend ferry terminal 16

Fig. 7 Installation of a slotted pvc pipe, which contains two sing-beam transducers attached to a sealed pvc float, at the Port Townsend ferry terminal in June 1999 18

Fig. 8 Locations of two beach seine sets near the Port Townsend ferry terminal, June 8, 1999 19

Fig. 9 Locations of split-beam mobile transects and stationary sampling locations at buoys near the Port Townsend ferry terminal, June 9-11, 1999 22

Fig. 10 Salmon tracking boat and salmon release boat just prior to releasing the chum and chinook fry approximately 30 m south of the southern edge of the Port Townsend ferry terminal on June 11, 1999 24

Fig. 11 We held an estimated 1000 chinook fry and 300 chum fry in a circular net inside a rectangular fish tote supplied with ice and bubble oxygen, prior to their release near the Port Townsend ferry terminal on June 11, 1999 26

Fig. 12 Multiplexed hydroacoustics array of 16 single-beam transducers paired at eight stations for sampling migrating juvenile chum and chinook salmon at the Port Townsend ferry terminal, June 1999 27

Fig. 13 Researcher Russ Moursund in the Ryder truck operations center verifying the proper functioning of the array of 16 single-beam transducers along the southern edge of the Port Townsend ferry terminal 30

Fig. 14 Real-time display of hydroacoustic "targets" detected by the single-beam transducers at the Port Townsend ferry terminal 31

Fig. 15 The underwater video system deployed at the Port Townsend ferry terminal from June 9 to 11, 1999 33

LIST OF FIGURES (continued)

Fig. 16 The LI-COR LI-193SA spherical quantum sensor that we used to measure photosynthetically-active radiation (PAR) at the edge and underneath the Port Townsend ferry terminal 35

Fig. 17 Hydroacoustic tracking of juvenile chum and chinook salmon released 30 m from the southern edge of the Port Townsend ferryterminal, 1833 h - 1838 h on June 11, 1999 40

Fig. 18 Echogram and plot of range versus time data for fish tracking with split-beam hydroacoustics at the Port Townsend ferry terminal, 1833 h-1838 h on June 11, 1999 41

Fig. 19 Hydroacoustic tracking of juvenile chinook salmon underneath the Port Townsend ferry terminal, 1919 h-1955 h June 11, 1999 42

Fig. 20 Echogram and plot of range versus time data for tracking of juvenile salmon underneath the Port Townsend ferry terminal, 1919 h-1926 h on June 11, 1999 44

Fig. 21 Echogram and plot of range versus time data for tracking of juvenile salmon underneath the Port Townsend ferry terminal, 1928 h-1946 h on June 11, 1999 45

Fig. 22 Echogram for tracking of juvenile salmon underneath the Port Townsend ferry terminal, 1947 h-1955 h on June 11, 1999 46

Fig. 23 Fish detections at Stations 2 and 3 at 1831 h on June 11, 1999 at the Port Townsend ferry terminal 48

Fig. 24 Fish detections at Stations 2 and 4 at 1841 h on June 11, 1999 at the Port Townsend ferry terminal 49

Fig. 25 No fish detections at 1851 h on June 11, 1999 at the Port Townsend ferry terminal 50

Fig. 26 Average instantaneous PAR each hour during the duration of the light monitoring from 1700 h on June 7, 1999 to 2100 h on June 11, 1999 at the edge and midpoint under the Port Townsend ferry terminal 54

Fig. 27 Integrated hourly PAR versus time of day, average instantaneous PAR each hour showing values less than 100 $\mu M/m^2/hr$, and values less than 10 $\mu M/m^2/hr$ at the Port Townsend ferry terminal, June 7-11, 1999 55

Fig. 28 Relationship between average instantaneous PAR each hour at the edge and midpoint sensors at the Port Townsend ferry terminal, June 7-11, 1999 57

Fig. 29 Differences in average instantaneous PAR each hour between the edge and midpoint sensors at the Port Townsend ferry terminal, June 7-11, 1999 58

Fig. 30 Illustration of the observed and videotaped chinook fry orientation within the shadow line underneath the Port Townsend ferry terminal 68

LIST OF TABLES

Table 1 DT 6000 scientific digital split-beam echosounder characteristics as applied at Port Townsend ferry terminal from June 9-11, 1999 20

Table 2 Summary of split-beam stationary and mobile sampling efforts at Port Townsend ferry terminal, June 9-11, 1999 23

Table 3 Fish species collected during qualitative beach seine surveys near the Port Townsend ferry terminal on June 7, 1999 38

Table 4 Summary of positive fish identifications in the vicinity of the southern edge of the Port Townsend ferry terminal between June 10 and June 11, 1999, based on analysis of color underwater video footage 52

EXECUTIVE SUMMARY

The University of Washington s (UW) School of Fisheries and School of Marine Affairs and Battelle Marine Sciences Laboratory (MSL) are jointly conducting a multiyear, three-phased research program to determine whether ferry terminals affect migrating juvenile salmon, and if so, how future design of terminals and modifications to both ferry terminals and operations can mitigate those impacts. In early 1998, Washington State Department of Transportation (WSDOT) initiated support of this comprehensive research program.

A previous report by our research team provided a synthesis of the Phase I state of technical knowledge regarding the potential effects of shoreline structures such as ferry terminals on migrating juvenile salmon (Simenstad et al. 1999). We concluded in Phase I that shoreline structures, such as WSDOT ferry terminals, do represent potential behavioral barriers to juvenile salmon migrating along shallow water habitats of Puget Sound during their outmigration to the Pacific Ocean. This report summarizes our results from Phase II pilot field studies at the Port Townsend ferry terminal in spring 1999 and provides recommendations for planning the proposed on-site tests of the effects of a range of different WSDOT ferry terminals and vessel activity patterns in Phase III (spring-winter 2000).

Phase II research was conducted by a collaborative team of fisheries biologists from the MSL, UW, and the United States Army Corps of Engineers (USACE), Seattle District. The overall goal of Phase II was to perform pilot field experiments with releases of hatchery chum and chinook fry to test whether the Port Townsend ferry terminal stops or delays the natural migration of juvenile salmon. We designed several field experiments that were intended to be a proof of concept for several potential methods of documenting juvenile salmon behavior in the vicinity of ferry terminals. Those methods included diving surveys, beach seining surveys, single-beam and split-beam hydroacoustics, remote underwater video, and *in situ* light sensors. We designed these experiments to determine which of these monitoring methods, or what combination of methods, would be the most effective for the full-scale implementation of field studies at multiple WSDOT ferry terminals in year 2000. We also applied the above methods to observe and document for the first time whether one representative ferry terminal at Port Townsend caused juvenile chum or chinook salmon to stop or delay their natural migration.

Unforeseen problems with river otters at the Port Townsend marina led to considerable expense, enormous frustration, and complete rethinking of our original experimental design. River otters directly and indirectly resulted in the mortality or escape of approximately 29,000 of the 30,000 chinook fry and 39,700 of the 40,000 chum fry that we were holding in net pens for experiments. As a result, we were only able to do a one-time release of all the remaining fish 30 m from the southern edge of the terminal, rather than replicate day and night releases at varying distances from the edge of the terminal and at various tidal regimes as originally planned.

On the basis of this one-time experiment, we found no evidence that the Port Townsend ferry terminal was a barrier to the migration of the 1000 chinook that we released. We have no data or observations for the 300 chum fry after their release. The chinook fry stayed in a school and did not disperse upon encountering the Port Townsend ferry terminal. We also found no evidence that the terminal caused the released chinook fry to divert their migratory route into deeper water or around the offshore perimeter of the terminal. Surface observations, underwater video, and the single-beam and split-beam hydroacoustics confirmed that the released chinook fry migrated from the release point directly to the shadow line underneath the terminal. The chinook fry stopped at the shadow line and then displayed a consistent behavior of swimming from the darkness of the shadow line and near the bottom into the light to feed at the surface. As the sun set and the shadow line progressed further underneath the terminal, the chinook school appeared to follow the shadow line under the terminal and, we assume, out the other side.

However, we caution that it is neither prudent nor valid to conclude that ferry terminals either do or do not have an effect on juvenile salmon migration, on the basis of these preliminary findings at Port Townsend. The loss of the majority of our fish for experiments, the hard-drive crash on the computer that was compiling global positioning systems (GPS) and flux-gate compass data, and the malfunctioning of some of the single-beam transducers compromised this study. The fundamental question of whether ferry terminals are a "barrier" to juvenile salmon migration remains unanswered.

The following recommendations are offered in the hope of facilitating rigorous Phase III field investigations at several different WSDOT ferry terminals:

1) conduct mark-recapture experiments "above" and "below" several ferry terminals
2) minimize the amount of time that hatchery salmon fry must be held in floating net pens, or rely solely on natural outmigrants
3) include Washington Department of Fish and Wildlife (WDFW) as a partner help to ensure the availability of marked fish at appropriate times, the avoidance of ESA permitting delays, and assistance with field experiments from experienced staff biologists
4) use a remote-controlled underwater video camera to obtain images of salmon behavior around ferry terminals
5) document minimum light levels during periods of salmon migration and threshold levels for specific behavioral responses
6) address differences in prey resources along shading and tidal elevation gradients within and adjacent to ferry terminals

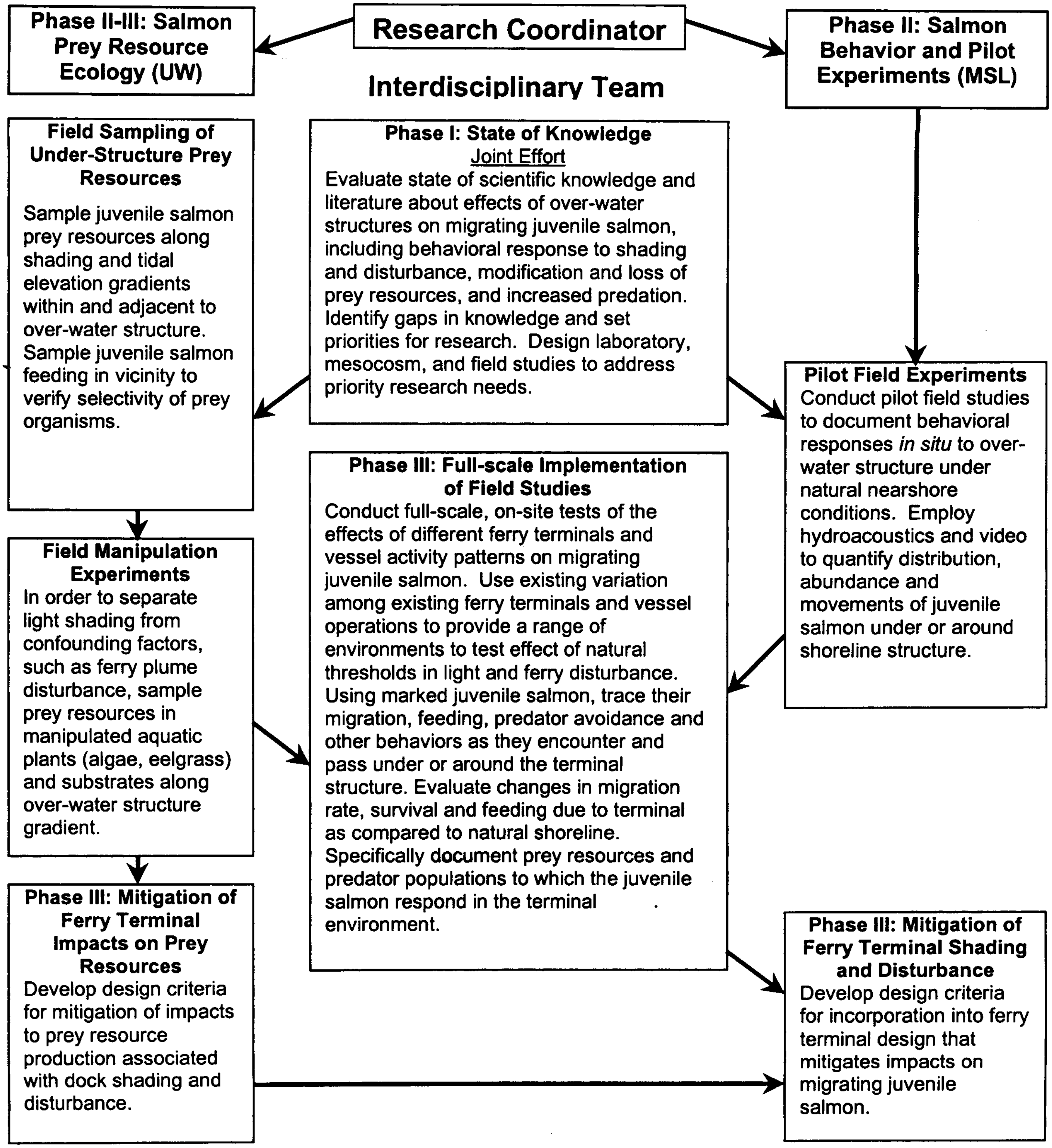
7) explore the possibility of tracking individuals and schools of juvenile salmon in real time with the Limpet Mine Imaging Sonar (LIMIS) system to assess short-term variability in juvenile salmon responses to ferry terminals.

INTRODUCTION

In January 1998, Washington State Department of Transportation (WSDOT) initiated support of a comprehensive research program to evaluate the nearshore effects of its ferry terminals on migrating juvenile salmon. The research team, comprised of the University of Washington's (UW) School of Fisheries and School of Marine Affairs and the Battelle Marine Sciences Laboratory (MSL), were asked to assess three primary topics of concern to WSDOT:

1) ferry terminals as barriers to estuarine nearshore migration of juvenile salmon
2) the effects of terminals in reducing estuarine secondary productivity that supports juvenile salmon foraging
3) the effects of terminals in attracting or concentrating populations of predators on migrating juvenile salmon.

We are presently addressing these concerns through a multiyear, three-phase research program **(Figure 1)**. Phase I, a comprehensive synthesis of the state of knowledge regarding the potential effects of over-water structures on migrating juvenile salmon, was completed in June 1999 with UW as the lead. Phase II, conducted in spring and summer 1999 with MSL as the lead, consisted of pilot field studies at the Port Townsend ferry terminal to test the feasibility of using hydroacoustics, underwater video, and *in situ* light sensors to better understand and document the behavior of migrating juvenile salmon in the vicinity of the terminal. This report summarizes the findings of those field studies. Phase III, scheduled to begin in spring 2000 with UW as the lead, is expected to involve on-site tests of the effects of multiple different ferry terminals and vessel activity patterns on migrating juvenile salmon and field sampling of under-



Research Coordinator

Interdisciplinary Team

Phase II-III: Salmon Prey Resource Ecology (UW)

Phase II: Salmon Behavior and Pilot Experiments (MSL)

Phase I: State of Knowledge
Joint Effort
Evaluate state of scientific knowledge and literature about effects of over-water structures on migrating juvenile salmon, including behavioral response to shading and disturbance, modification and loss of prey resources, and increased predation. Identify gaps in knowledge and set priorities for research. Design laboratory, mesocosm, and field studies to address priority research needs.

Field Sampling of Under-Structure Prey Resources

Sample juvenile salmon prey resources along shading and tidal elevation gradients within and adjacent to over-water structure. Sample juvenile salmon feeding in vicinity to verify selectivity of prey organisms.

Pilot Field Experiments
Conduct pilot field studies to document behavioral responses *in situ* to over-water structure under natural nearshore conditions. Employ hydroacoustics and video to quantify distribution, abundance and movements of juvenile salmon under or around shoreline structure.

Field Manipulation Experiments
In order to separate light shading from confounding factors, such as ferry plume disturbance, sample prey resources in manipulated aquatic plants (algae, eelgrass) and substrates along over-water structure gradient.

Phase III: Full-scale Implementation of Field Studies
Conduct full-scale, on-site tests of the effects of different ferry terminals and vessel activity patterns on migrating juvenile salmon. Use existing variation among existing ferry terminals and vessel operations to provide a range of environments to test effect of natural thresholds in light and ferry disturbance. Using marked juvenile salmon, trace their migration, feeding, predator avoidance and other behaviors as they encounter and pass under or around the terminal structure. Evaluate changes in migration rate, survival and feeding due to terminal as compared to natural shoreline. Specifically document prey resources and predator populations to which the juvenile salmon respond in the terminal environment.

Phase III: Mitigation of Ferry Terminal Impacts on Prey Resources
Develop design criteria for mitigation of impacts to prey resource production associated with dock shading and disturbance.

Phase III: Mitigation of Ferry Terminal Shading and Disturbance
Develop design criteria for incorporation into ferry terminal design that mitigates impacts on migrating juvenile salmon.

Figure 1. Organization of research phases in UW-MSL studies on ferry terminal impacts on juvenile salmon migrating through Puget Sound (from Simenstad et al. 1999)

structure prey resources. The eventual product of the overall research program will be recommendations to WSDOT on how to mitigate the impacts of its ferry terminals and operations on juvenile salmon in the estuarine and marine waters of Washington state.

Problem Description

We know as a result of our Phase I literature synthesis (Simenstad et al. 1999) that shoreline structures, such as WSDOT ferry terminals, represent potential behavioral barriers or inhibitors to juvenile salmon traveling along shallow water habitats of Puget Sound during their outmigration to the Pacific Ocean. Findings presented at the August 25, 1998 WSDOT-UW-MSL workshop on impacts of over-water structures on juvenile salmon established that over-water structures *can cause juvenile salmon to stop or delay their natural migration*, and led to the recommendation that this impact should be evaluated at WSDOT ferry terminals.

There are no natural analogues to ferry terminals within the evolutionary experience of migrating juvenile salmon. Ferry terminals may especially be a barrier for chum (*Oncorhynchus keta*) and ocean-type chinook (*O. tshawytscha*), that preferentially migrate within a narrow, shallow-water zone along Puget Sound shorelines. Fry and fingerlings of these species enter Puget Sound at approximately 30 mm-80 mm in length, after no or brief residence in their natal freshwater spawning sites. Thus, juveniles of chum and ocean-type chinook are especially vulnerable, because they must meet energy, growth, and survival requirements during the critical nearshore life history stage (Healey 1991; Salo 1991). The importance of our research program was magnified by 1999 Endangered Species Act (ESA) listings of several chum and chinook stocks in Washington state. WSDOT continues to demonstrate its commitment to identifying and mitigating the effects of ferry terminals on migrating juvenile salmon.

Goals and Objectives

Phase II research was conducted by a collaborative team of fisheries biologists from the MSL, UW, and USACE at the WSDOT ferry terminal in Port Townsend, Washington. The overall goal of Phase II was to perform pilot field experiments to test whether the Port Townsend ferry terminal stops or delays the natural migration of juvenile salmon. In consultation with WSDOT, we selected the Port Townsend ferry terminal for the pilot experiments for several reasons: 1) the terminal position within the likely migratory pathway of ESA-listed species; 2) the existence of data and information from previous diving surveys (Simenstad et al. 1997; 1999) and eelgrass mapping at this terminal (Norris and Hutley 1997); 3) the concrete-pile construction used at this terminal; and 4) the moderate shoreline development adjacent to the terminal (i.e., the shoreline immediately to the north of the terminal is developed and rip-rapped; the shoreline immediately to the south of the terminal is mostly undeveloped, natural beach) **(Figure 2).**

Based on the results of the August 25, 1998 WSDOT-UW-MSL workshop on the impacts of over-water structures on juvenile salmon, there was sufficient evidence to formulate the following testable hypothesis regarding the impacts of ferry terminals on juvenile salmon migratory behavior:

H_0 = ferry terminals cause juvenile salmon to stop or delay their natural migration.

Our underlying assumption is that a change, stop, or delay in the natural migration direction or rate of juvenile salmon could result in increased stress, reduced growth, or increased mortality. Although the exact mechanisms are unknown, Simenstad et al. (1999) suggested that over-water structures could increase mortality of juvenile salmon fry by 1) introducing a "behavioral barrier" that deflects fish into deeper waters without refugia or delays their migration; 2) dispersing schools; 3) decreasing growth and residence times because of limited prey resource

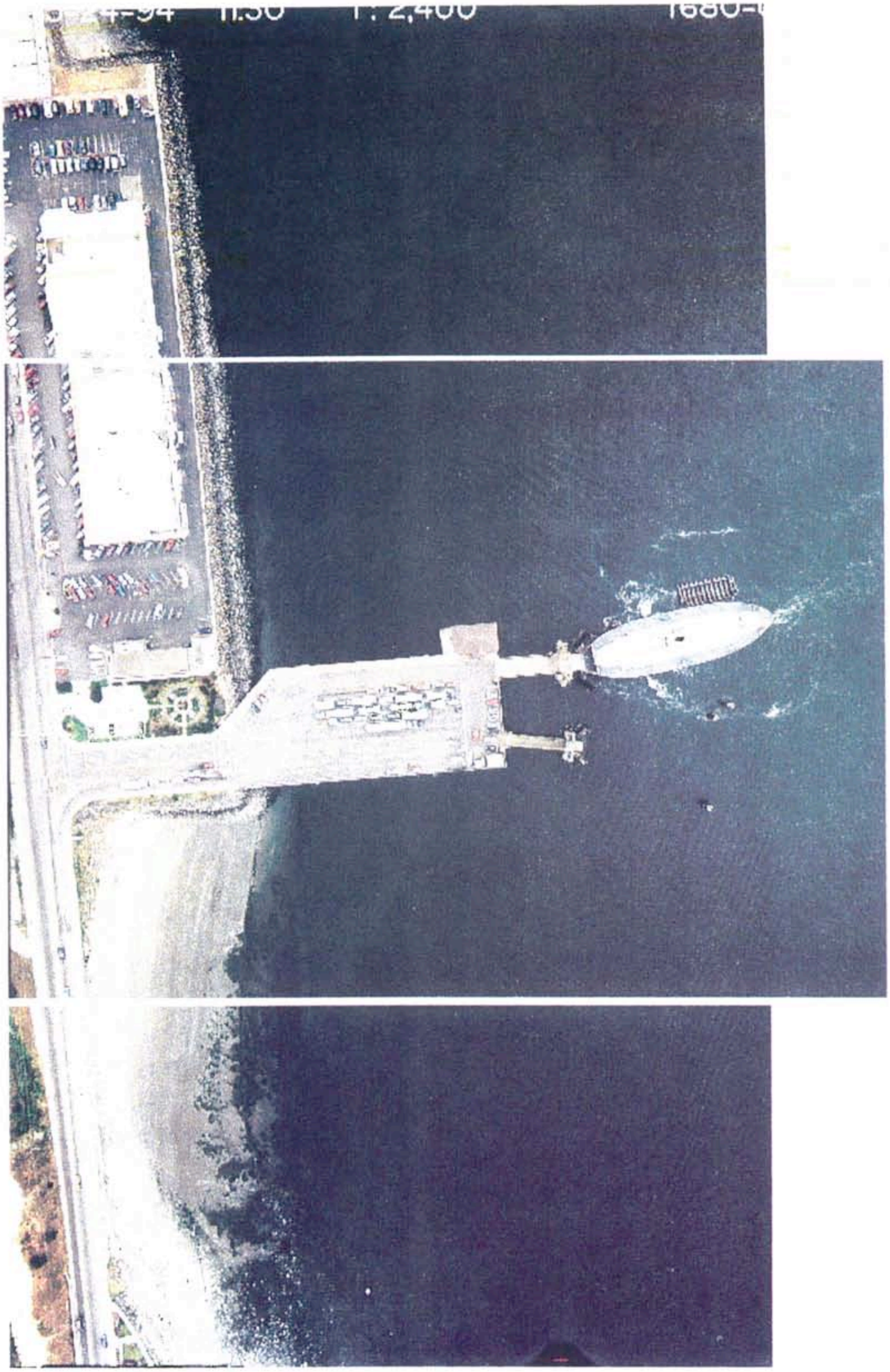


Figure 2. Physical setting and shoreline features in the vicinity of the Port Townsend ferry terminal, Port Townsend. Washington

production and availability; and 4) increasing predation by aggegating predators or heightening the predation rates of predators associated with over-water structures.

We did not expect to evaluate the absolute effect of ferry terminals on total survival because of the complexity of factors that affect salmon survival across all life history stages (Simenstad et al. 1999). Rather, we designed our experiments in Phase II to test whether one ferry terminal at Port Townsend resulted in a short-term delay in the natural migration rate or direction of juvenile salmon. We suspect that the effects of over-water structures are cumulative over the entire shoreline migration of juvenile salmon. Thus, quantifying a "barrier" effect on ultimate survival was beyond the scope of our research.

To test the null hypothesis stated above, we designed several pilot field experiments that were intended to be a "proof of concept" for several potential methods of documenting juvenile salmon behavior in the vicinity of ferry terminals. Those methods included diving surveys, beach seining surveys, single-beam and split-beam hydroacoustics, underwater video, and *in situ* light sensors. We designed these experiments to determine which of these monitoring methods, or what combination of methods, would be the most effective for the full-scale implementation of field studies at multiple WSDOT ferry terminals in year 2000. We also applied the above methods to observe and document for the first time whether one representative ferry terminal at Port Townsend caused juvenile chum or chinook salmon to stop or delay their natural migration.

The specific objectives and subobjectives for our research were as follows:

Objective 1.1: Coordinate with resource agencies and mobilize for the field effort. Develop a project strategic plan and implementation schedule.

Objective 1.2: Perform a diving survey with an underwater video camera to document the presence or absence of juvenile salmon and potential predators underneath the Port Townsend terminal and in the immediate vicinity.

Objective 1.3: Conduct qualitative beach seining surveys along the shoreline to the south of the Port Townsend terminal to characterize the species of fish in the vicinity of the terminal.

Objective 2.1: Determine fish behavior at the release site approximately 500 m up-current from the ferry terminal at Port Townsend, and fish behavior and distribution between the release site and the ferry terminal, using split-beam hydroacoustics.

Subobjective 2.1.1: Determine stationary background fish behavior at three strategic locations between (and including) the release site and the ferry terminal.

Subobjective 2.1.2: Determine the distribution of prerelease fish targets between the release site and the ferry terminal.

Subobjective 2.1.3: Track juvenile chum and chinook salmon from the up-current release site to the ferry terminal.

Objective 2.2: Monitor fish passage on the up-current side of the ferry terminal and the up-current outer corner of the terminal, using single-beam hydroacoustics.

Subobjective 2.2.1: Characterize the distribution of migrating chum and chinook salmon at the up-current approach to the ferry terminal.

Subobjective 2.2.2: Characterize the behavior of migrating juvenile salmon in the vicinity of the up-current side of the ferry terminal (milling, actively migrating through and under the terminal, or skirting the terminal).

Subobjective 2.2.3: Estimate the swimming speed of schools or individual chum and chinook salmon as they approach and either pass through or go around the end of the terminal.

Objective 3.0: Use underwater video to record the behavioral responses of natural and released juvenile salmon as they encounter the terminal and/or move underneath the terminal.

Objective 4.0: Record continuous light measurements *in situ* at two locations: the edge of the terminal, and the center or darkest point underneath the terminal.

Objective 5.0: Produce a technical report that documents the results of Objectives 1-4 and provide recommendations for Phase III full-scale implementation of field studies.

Assumptions

Several assumptions were implicit in the design and execution of this study. Below we have listed those assumptions:

- we assumed that a change, stop, or delay in the natural migration direction or rate of juvenile salmon could result in increased stress, reduced growth, or increased mortality
- we did not expect to evaluate the absolute effect of ferry terminals on total salmon survival
- we assumed that the outmigration behavior of the hatchery fry we released for our experiments would differ from the behavior of naturally outmigrating nonhatchery fry
- we assumed that once the single-beam transducers, light sensors, and underwater video cameras were in place that our equipment would not affect fish behavior
- we assumed that placing divers in the water, beach seining, and monitoring that required boats, such as the split-beam hydroacoustics, could affect juvenile salmon behavior, but measuring any such effect was beyond the scope of our research.

REVIEW OF PREVIOUS WORK

In Phase I of this research program, we evaluated the state of technical knowledge about the effects of shoreline structures on migrating juvenile salmon and performed a preliminary characterization of the existing light environment and biological communities associated with ferry terminals of different sizes, ages, and construction materials. The results of Phase I are contained within a research report titled "Impacts of Ferry Terminals on Juvenile Salmon Migrating Along Puget Sound Shorelines. Phase I: Synthesis of State of Knowledge" (Simenstad et al. 1999).

The Phase I report addressed three potential effects of over-water structures on juvenile salmon: 1) alteration in migratory behavior; 2) reduction in prey production and availability; and 3) increased predation. An assessment of over 60 direct sources of information indicated that shoreline structures can alter natural migratory behavior of nearshore dependent juvenile chum and ocean-type chinook salmon and can also reduce prey production and availability. The authors found no quantitative evidence for significant increases in predation on salmon associated with over-water structures. The effects of shoreline structures on the migration behavior of juvenile salmon may vary, depending on the design and orientation of the structure, extent of alteration of the underwater light field, and presence of artificial light. However, no definitive conclusions could be drawn about the significance of short-term delays in the salmons' migration, reduced food supply, or cumulative or synergistic effects. Field studies were recommended for Phase II.

RESEARCH APPROACH

Field Preparations and Coordination

Prior to initiating any field work, the team of fisheries biologists from MSL, UW, and USACE held a kick-off conference call on April 20, 1999 to determine the number of juvenile salmon required for the experiments, the timing of the experiments, the exact methods to be used, the logistics for deploying field equipment, and action items and responsibilities for each individual on the team. The product of this conference call was a strategic plan and implementation schedule, which we submitted to WSDOT and USACE for approval.

With the help of Larry Telles and Dave Zajac from the United States Fish and Wildlife Service (USFWS), we were able to obtain an estimated 40,000 fall chum fry (800/lb x 50 lb) from the Quilcene National Fish Hatchery. Dave Zajac also worked with staff at the Washington Department of Fish and Wildlife (WDFW) to secure the transfer permit required to move fish from the hatchery to a saltwater release site. The fry were delivered to the boat ramp at the Port Townsend marina in a USFWS transfer truck on May 7, 1999 during a morning high tide. We then transferred the fry from the transfer truck to a net pen tied to an aluminum frame that was suspended between two inflatable pontoons. The rationale for using this pontoon system was that we could easily tow the net pen to various locations when we were ready to release the fry for our experiments. We divided the net pen into two approximately equal compartments, one for holding the chum fry and one for holding chinook fry that we received at a later date. We rigged the net pen so that either end of the net could be easily released from the frame and dropped into the water, allowing fish to volitionally escape at the time of an experiment.

At high tide, we were able to position the net pen in an optimal position at the Port Townsend boat ramp to receive the fry. We transferred the fry to the net pen in the transfer truck's holding tank water using gravity flow through a 25.4-cm diameter, flexible hose (**Figure 3**). We were successful in transferring the fry with minimal mortality, estimated at 100-200 fish. We then towed the net pen to a boat moorage slip and tied it securely to cleats on the end of the floating dock near the inlet to the marina (**Figures 4 and 5**).

Working in cooperation with Thom Johnson and Andy Appleby from WDFW, we were able to obtain an estimated 30,000 fall chinook fry (75/lb x 400 lb) from the Samish Hatchery and the required transfer permit. The fry were delivered to the Port Townsend marina in a WDFW transfer truck on May 24, 1999 during an afternoon high tide. We were successful in transferring the fry to our floating net pen with minimal losses (estimated at 200-300 fish) using the same gravity-transfer method as with the chum fry.

A predator net was secured with ropes and cable ties across the top of the submerged net pens to keep out avian predators. Later, chicken wire was added across the top of the predator net as another barrier to potential predators. The chum and chinook fry were fed daily using an automatic feeder, which slowly released known amounts of food over a 12-hour period. The amount of food, general appearance of the fish, number of mortalities, net pen and predator net conditions, evidence of predators, and any other relevant observations were recorded each day in a log book stored on the mooring dock next to the net pen.

We held the chum and chinook fry in the floating net pen system in order to acclimate these hatchery fish to the natural conditions near the Port Townsend ferry terminal. Unfortunately, we had to hold the fish for 3 to 4 weeks because the required hydroacoustics equipment for our planned experiments was in use on the Columbia River through the end of May 1999. Hence, we had to get the chum and chinook fry from the hatcheries when they were available to us in early to mid-May and hold the fish in net pens much longer than desirable. By the time we were

Figure 3. Researcher Barb Nightingale (top) transfers chinook fry from the hatchery truck to the floating net pen in May 1999, using gravity flow through a 25.4-cm diameter, flexible hose. This method minimized mortality of the chinook fry (bottom) that we held for pilot field experiments in June 1999 at the Port Townsend ferry terminal.

Figure 4. Following transfer of chinook fry from the hatchery truck into our floating net pen in May 1999, the net pen was towed from the Port Townsend boat ramp to a moorage slip next to the commercial boat dock at the Port Townsend marina

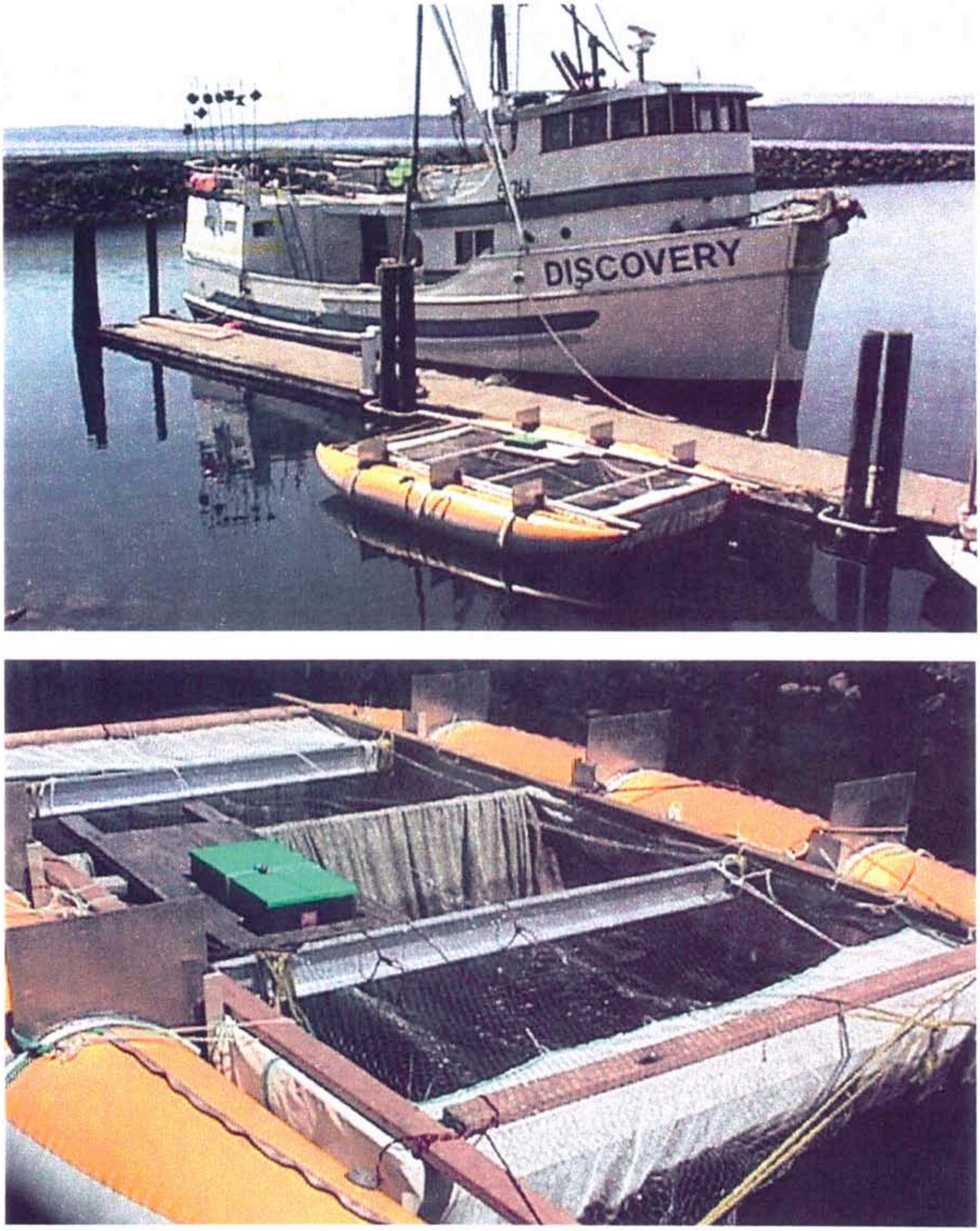


Figure 5. The net pen was moored at the commercial boat dock at the Port Townsend marina from mid-May to late May 1999 (top). The green box sitting on top of the net pen is an automatic feeder (bottom). The chicken wire was intended to keep predators out of the net pen.

prepared to initiate our experiments, river otters had caused the mortality or release of 39,700 chum fry and 29,000 chinook that we were holding in the net pens. The problems we experienced with river otters are reported in greater detail in the findings section of this report.

Diving Survey

On June 7, 1999 three divers from the MSL conducted a diving survey to make qualitative observations and record underwater video footage of the fish community underneath and adjacent to the Port Townsend ferry terminal. The focus of the diving effort was to determine 1) whether juvenile salmon or potential predators were present in the vicinity of the terminal, and 2) whether other species of size similar to that of juvenile salmon, which might look like a juvenile salmon "target" on the hydroacoustic echograms, were present. Two divers recorded their observations underwater on waterproof datasheets. The third diver operated the underwater video camera. We surveyed a total of six transects during the bottom time available to each diver on a single tank of compressed air (**Figure 6**). Three transects were surveyed parallel to the main axis of the ferry terminal from the offshore edge of the terminal to shore: one transect along the outer, southern edge of the pilings, one transect along the first set of pilings in from the southern edge, and one transect approximately 5 m south of the southern edge. Underwater video footage was only recorded for the transect along the southern edge of the terminal. Three transects were also surveyed parallel to shore from the southern edge of the terminal to approximately 50 m south into an adjacent eelgrass (*Zostera marina*) bed. These three transects started at the fourth, fifth, and sixth pilings out from shore, respectively. Underwater video footage was recorded only along the transect that started at the fifth piling.

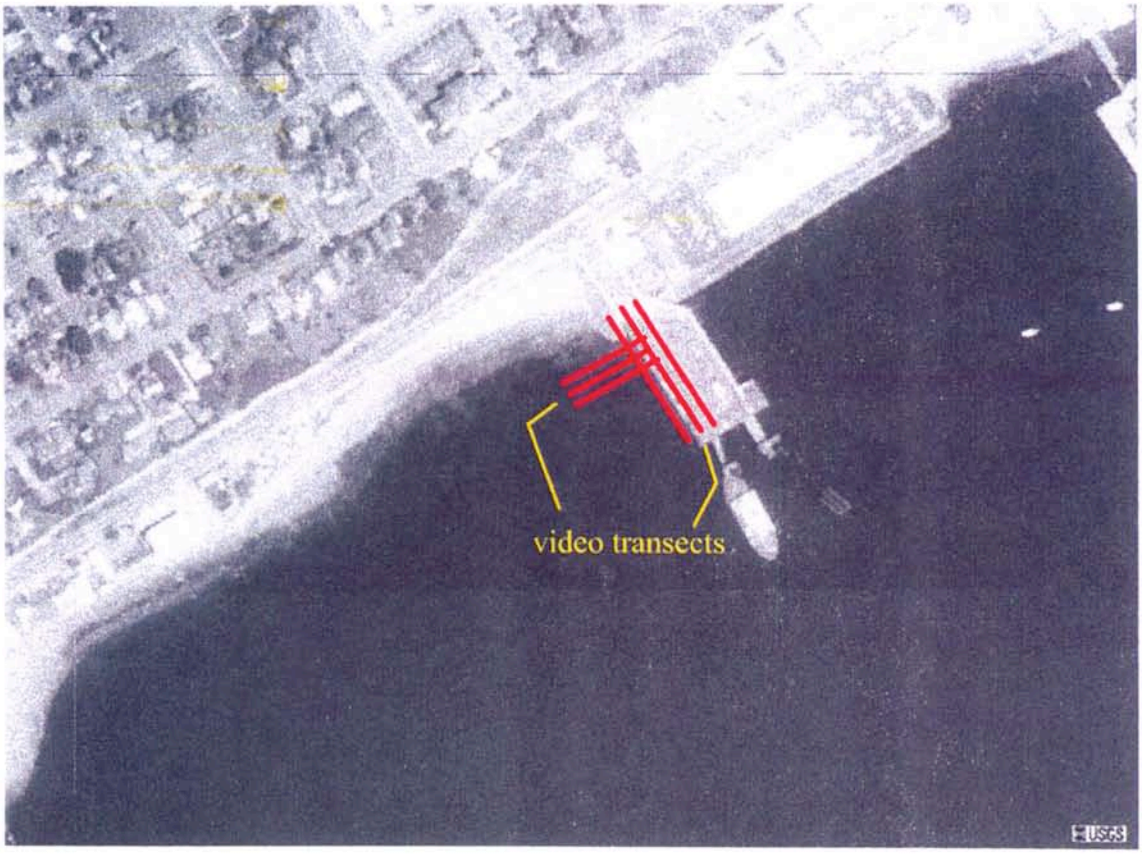


Figure 6. Locations of six diving transects (red) at the Port Townsend ferry terminal, June 7, 1999

Following the diving surveys, two of the three divers remained in the water to assist with scraping barnacles and other attached plants and animals off the faces of the pilings and affixing the single-beam transducer housings to the appropriate pilings with hose clamps (**Figure 7**).

Beach Seining Survey

Similar to the diving survey, the goal of the beach seining survey was to make a one-time, qualitative assessment of the species and sizes of fish in the vicinity of the Port Townsend ferry terminal. Characterizing the fish community was important in order to have background data that might later enable us to distinguish among different "targets" that might look like salmon on the single-beam or split-beam echograms. At low tide on June 8, 1999, we performed two nonoverlapping beach seine sets with a floating 30-m beach seine along the shoreline to the south of the terminal edge (**Figure 8**). Both beach seine sets were over the top of an eelgrass bed. The first set at 1427 was just north of the Bayview Restaurant, where a cobble beach and sand beach met. The second set at 1500 was along the sand beach adjacent to the southern edge of the Port Townsend ferry terminal. All nonsalmonid fish collected were immediately transferred from the net to buckets with battery operated air stones, identified to species, and released alive. Salmonids that were captured in the net were also transferred to well-oxygenated buckets, identified to species, counted, and a subset of the total number were measured (fork length to the nearest millimeter). We did not preserve voucher specimens of any of the fish species for subsequent confirmation of our field identifications.

Split-Beam Hydroacoustics

The purpose of Objective 2.1 was to determine fish behavior within approximately 500 south of the southern edge of the ferry terminal at Port Townsend, and fish behavior and distribution

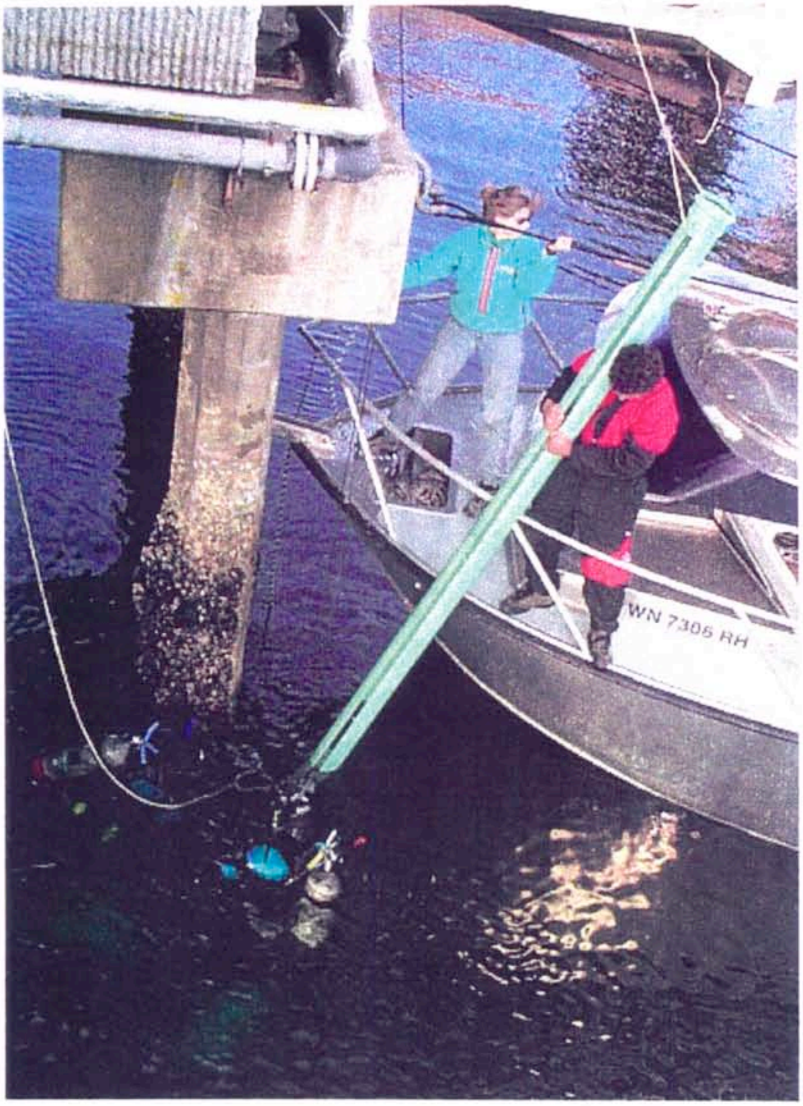


Figure 7. Installation of a slotted polyvinyl chloride (pvc) pipe, which contains two single-beam transducers attached to a sealed pvc float, at the Port Townsend ferry terminal in June 1999

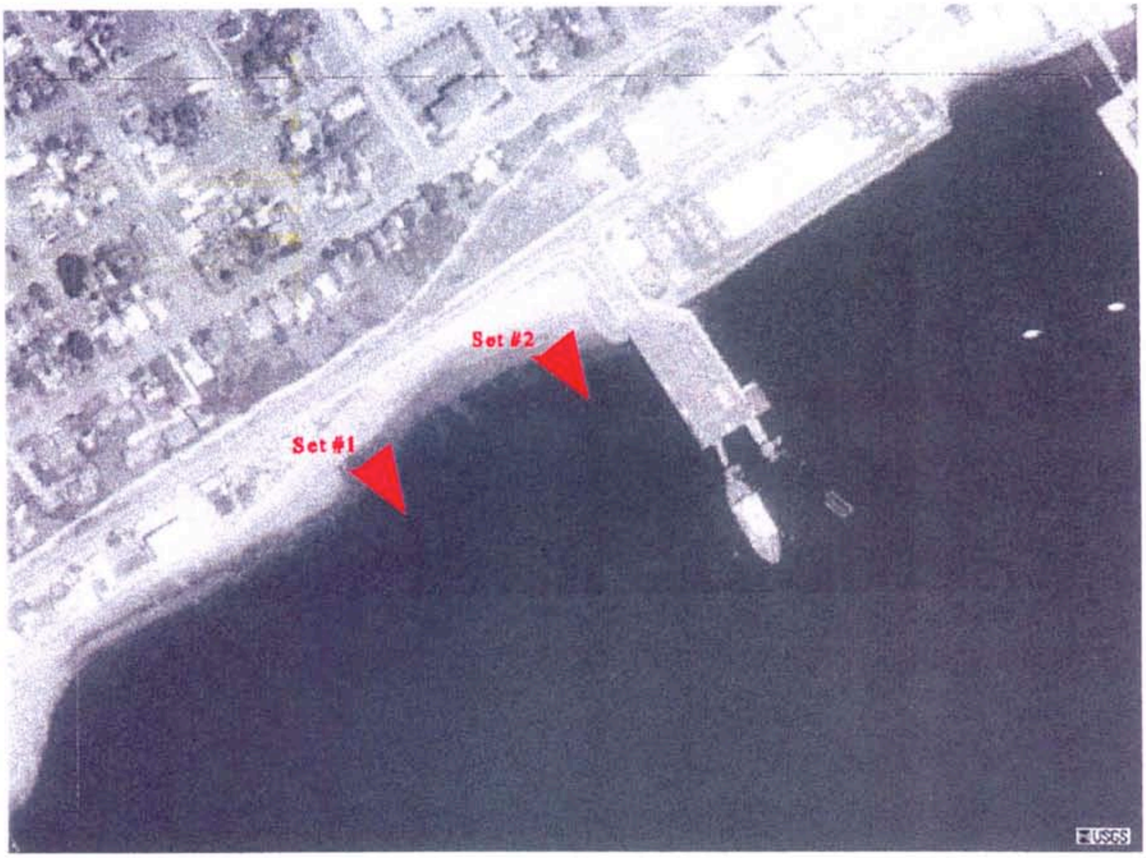


Figure 8. Location of two beach seine sets near the Port Townsend ferry terminal, June 8, 1999

between the release site and the ferry terminal. We proposed to accomplish this objective by monitoring fish behavior at three stationary sites (buoys) between and including the release site and the ferry terminal, determining the distribution of prerelease fish targets between the release site and the ferry terminal, and finally, tracking juvenile chum and chinook salmon individuals or aggregations from the release site to the ferry terminal.

The tool we chose to accomplish this objective was a scientific digital split-beam hydroacoustic system contributed to the project at no cost by Battelle's Pacific Northwest National Laboratory in Richland, Washington. The system we used for this work was a BioSonics DT6000 split-beam echo sounder operating at 201 kHz. The DT6000 was well suited to this application because of its high dynamic range (>100 dB) permitting it to sense targets ranging in size from plankton to large fish and low side lobes (-27 dB), which were ideal for the shallow water side-looking deployment necessary for this study. The system as deployed was characterized by the parameters listed in **Table 1**.

Table 1. DT6000 scientific digital split-beam echosounder characteristics as applied at Port Townsend ferry terminal from June 9-11, 1999

	VALUE	UNITS
Serial Number	DT697054	
Beam Width	6.3	degrees
Transmit Frequency	201000	Hz
Transmit Source Level	223.6	dB//μPa
Receive Sensitivity	-56.4	dB/μPa
Beam Pattern Factor	0.001093	

We operated the split-beam system at 2 pings per second with a pulse width of 0.4 milliseconds and minimum and maximum ranges set at 1.0 m and 18.11 m, respectively. We measured salinity to be 28 ppt, which yielded a corrected absorption coefficient of 0.004469 dB/m and sound velocity of 1491.44 m/s. We also coupled a GPS and flux-gate compass to the split-beam transducer mount to provide location and direction information.

We accomplished stationary monitoring by mooring the boat equipped with the DT6000 to buoys anchored at three locations approximately 50 m, 250 m, and 500 m south of the southern edge of the ferry terminal at Port Townsend (**Figure 9**). We collected data for approximately 10 min at each location from June 9 through June 11, 1999. We aimed the transducer away from shore or toward shore depending on whether fish activity was seen near the surface in either direction.

We also conducted mobile transects both parallel and perpendicular to the southern edge of the ferry terminal from June 9 through June 11, 1999 (**Figure 9**). We ran parallel transects were run with the transducer aimed both toward the terminal and away from the terminal. We ran perpendicular transects with the transducer aimed both toward shore and away from shore. The log of stationary and mobile sampling efforts that preceded the release of the hatchery chum and chinook fry is summarized in **Table 2**.

In preparation for the release of a combined group of hatchery chum and chinook fry, we positioned two boats near the southern edge of the Port Townsend ferry terminal (**Figure 10**). We temporarily tied off the tracking boat with the split-beam transducer to a mooring line extending from Buoy 3 to a piling near the middle of the southern edge of the terminal, and then

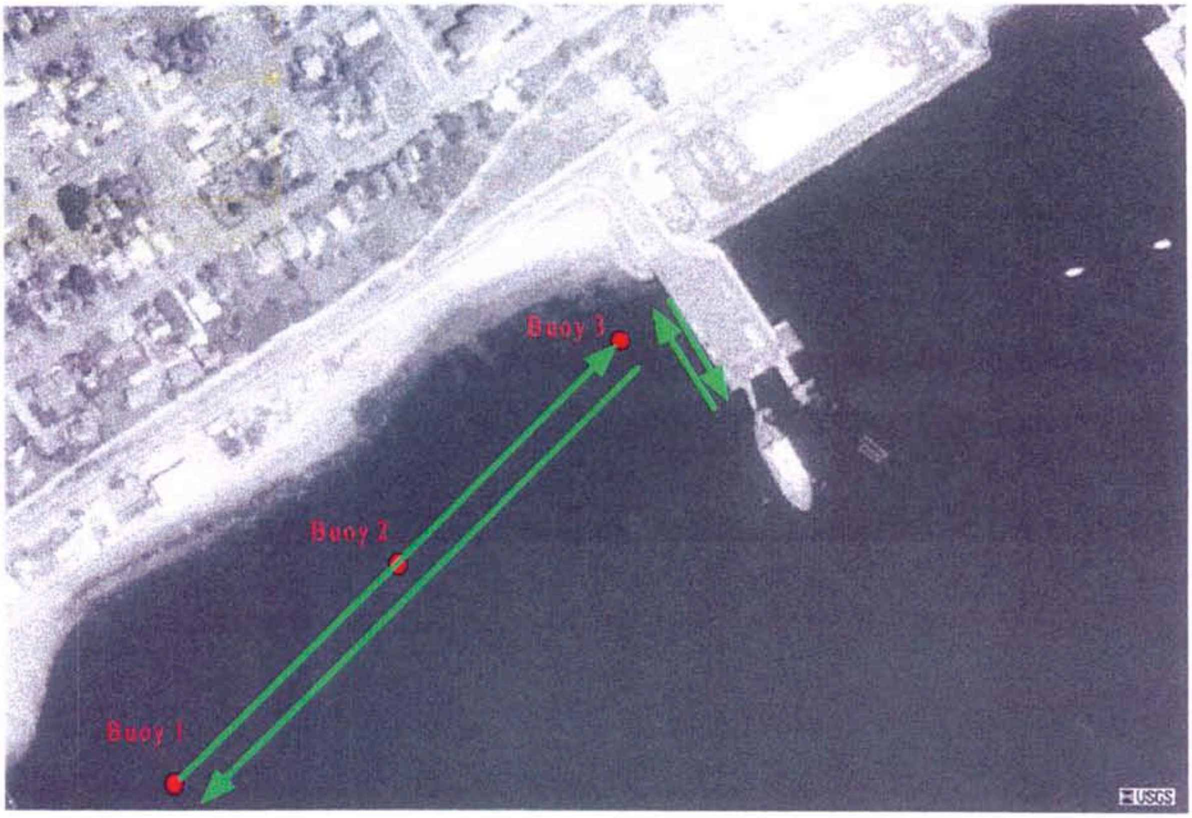


Figure 9. Locations of split-beam mobile transects (green) and stationary sampling locations at buoys (red) near the Port Townsend ferry terminal, June 9-11, 1999

Table 2. Summary of split-beam stationary and mobile sampling efforts at Port Townsend ferry terminal, June 9-11, 1999

DATE	START TIME	SAMPLING LOCATION	TRANSDUCER ORIENTATION
June 9	2306 h	Stationary at Buoy 1	Away from shore
June 9	2324 h	Stationary at Buoy 2	Away from shore
June 9	2352 h	Stationary at Buoy 3	Away from shore
June 10	2400 h	Mobile transect from Buoy 3 to Buoy 1	Away from shore
June 10	0025 h	Mobile transect from midterminal to Buoy 1	Away from shore
June 10	1716 h	Mobile transect from shore along edge of terminal	Aimed underneath the terminal
June 10	1723 h	Same transect as 1716 but further away from terminal edge	Aimed underneath the terminal
June 10	1735 h	Same transect as 1725 but further away from terminal edge	Aimed underneath the terminal
June 10	1903 h	Stationary at Buoy 1	Away from shore
June 10	1924 h	Stationary at Buoy 2	Away from shore
June 10	1952 h	Stationary at Buoy 3	Away from shore
June 10	2005 h	Mobile transect from Buoy 3 to Buoy 1	Away from shore
June 10	2028 h	Mobile transect from Buoy 1 to Buoy 3	Toward shore
June 10	2044 h	Mobile transect from Buoy 3 to Buoy 1	Away from shore
June 10	2110 h	Mobile transect from midterminal to Buoy 1	Away from shore
June 11	0509 h	Mobile transect from shore along edge of terminal	Aimed underneath the terminal
June 11	0524 h	Mobile transect from Buoy 3 to Buoy 1	Away from shore
June 11	0535 h	Mobile transect from Buoy 1 to Buoy 3	Toward shore
June 11	0601 h	Mobile transect from midterminal to Buoy 1	Away from shore
June 11	0621 h	Stationary at Buoy 1	Toward shore
June 11	0639 h	Stationary at Buoy 2	Toward shore
June 11	0719 h	Stationary at Buoy 3	Toward shore

Figure 10. Salmon tracking boat (middle right) and salmon release boat (farther away) just prior to releasing the chum and chinook fry approximately 30 m south of the southern edge of the Port Townsend ferry terminal on June 11, 1999

anchored the salmon release boat approximately 12 m offshore from the tracking boat. We held the chum and chinook fry in a circular net inside a rectangular fish tote supplied with ice and bubbled oxygen, prior to releasing them near the Port Townsend ferry terminal.

At approximately 1830 h on June 11, 1999, we released an estimated 1000 chinook (approximately 100 mm fork length) and 300 chum (approximately 70 mm fork length) together in one experimental group approximately 30 m south of the southern edge of the Port Townsend ferry terminal (**Figure 11**). After the fish were released, the salmon release boat remained anchored and we slowly pulled the tracking boat with the motors off along the mooring line to follow the migration of the released salmon fry.

Single-Beam Hydroacoustics

The purpose of Objective 2.2 was to monitor fish passage south of the southern edge of the Port Townsend ferry terminal and the outer corner of the southern edge of the terminal. We proposed to accomplish this objective by characterizing the distribution of released hatchery chum and chinook salmon at the southern edge of the ferry terminal, characterizing the behavior of natural (nonhatchery) migrating juvenile salmon in the vicinity of the southern edge of the terminal, and estimating the swimming speed of schools or individual chum and chinook salmon as they approached and either passed through or migrated around the end of the terminal.

The tool we chose to accomplish this objective was a multiplexed array of 16 single-beam transducers (**Figure 12**). We used two echosounders to drive the single-beam transducers in an eight-station paired array. We aimed one of the transducers of each pair at 45-degrees away from the terminal and the other almost parallel to the pilings, forming a hydroacoustic “curtain”

Figure 11. We held an estimated 1000 chinook fry and 300 chum fry in a circular net inside a rectangular fish tote supplied with ice and bubbled oxygen, prior to their release near the Port Townsend ferry terminal on June 11, 1999

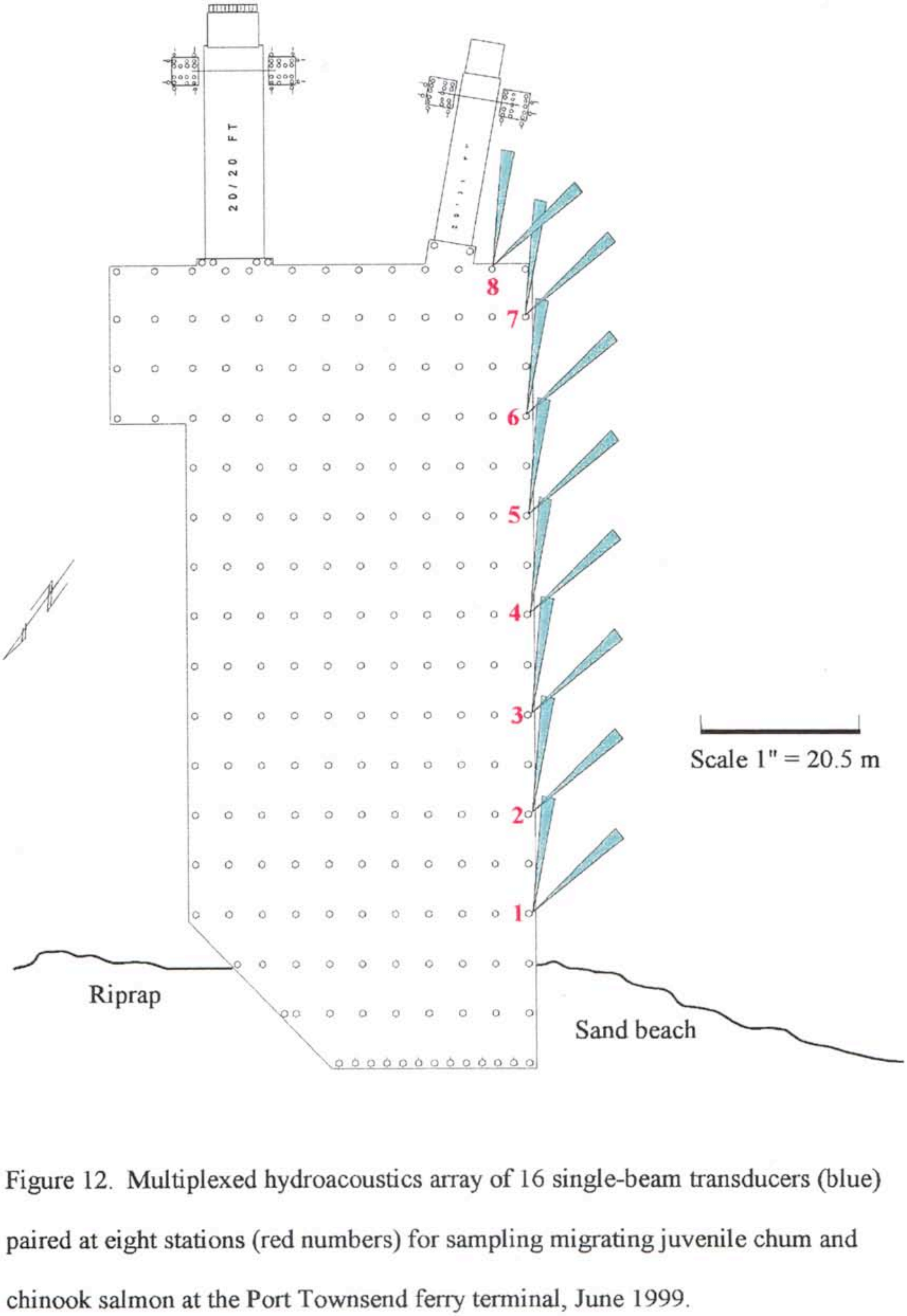


Figure 12. Multiplexed hydroacoustics array of 16 single-beam transducers (blue) paired at eight stations (red numbers) for sampling migrating juvenile chum and chinook salmon at the Port Townsend ferry terminal, June 1999.

that extended the entire length of the southern edge of the terminal. This paired transducer configuration was a modification of the pseudosquinted pair, which is commonly used for hydroacoustic studies at hydroelectric dams (e.g., Johnson et al. 1998; Johnson et al. 1999a, 1999b). A true squinted pair uses two beams that are transmitted simultaneously and have slightly overlapping sample volumes. Over time, the directionality of a target may be deduced by the differential detection between the two transducers. For example, a fish may be detected on only one transducer when entering a detection area, then on both for a period of time, then on only one again when leaving. The pseudosquinted pair used in hydropower fisheries research is a two single-beam transducer pair that is fast multiplexed; that is, the pair does not transmit simultaneously. Rather, each member of the pair transmits on an every-other-ping basis at rates of 20 to 40 pings per second.

We used two BioSonics Model 101 Echosounders, two BioSonics Model 151 Equalizer-Multiplexers, and two computers with Echo Signal Processor boards to drive eight transducers each. The echosounders had been recently calibrated by BioSonics because of their use on a study immediately prior to this one. We collected data on a third computer, and the entire system was connected via a local area network.

Using this equipment and transducer configuration, we attempted to mimic a typical hydropower deployment for fish passage studies. However, because of the low velocity of the water and our expectation that large schools of fish could be present around the ferry terminal, the type of data we collected was not of the sort typically collected for fish passage studies. We decided that an echo integration technique was more appropriate than the usual single-target tracking. The echo integration technique sums the intensity of the acoustic return within a given range. With proper calibration, this technique can be used to determine the density of schools. This system was not calibrated in the manner described, but was used instead to determine the relative density of schools within range bins over a finite sample period. Thus, the units of the data we collected were not significant, because all measurements were relative.

On June 7 and 8, 1999 we deployed and tested both the “dry gear” (i.e., sounder, multiplexers, and computers) located in the Ryder truck (**Figure 13**) and the “wet gear” located underwater (i.e., underwater cables, mounts, and transducers). Each pair of transducers, one "out" and one "along," was fast-multiplexed (ping to ping) at 10 pings per second each (20 total for the pair). We designated each pair a station. Sampling occurred for 2.5 minutes at each station before switching to the next pair. All 16 of the transducers were sampled within a 10-minute cycle. Data were collected continuously, 24 h/day, from June 9 at 0900 h to June 11 at 2000 h (**Figure 14**).

Underwater Video

Simultaneously with the hydroacoustic monitoring of juvenile salmon described above, we deployed two video cameras inside separate, waterproof, underwater housings. Our goal was to record the following: 1) the behavioral responses of natural juvenile salmon and hatchery juvenile salmon that we released as either group encountered the terminal, 2) the behavior of natural and released juvenile salmon that swam underneath the terminal, and 3) any potential predators on juvenile salmon.

We used one COHU CCD black-and-white camera with a 25-mm lens and one PC-33C color camera with a 28-mm, wide-angle lens. The two cameras were mounted to an aluminum frame

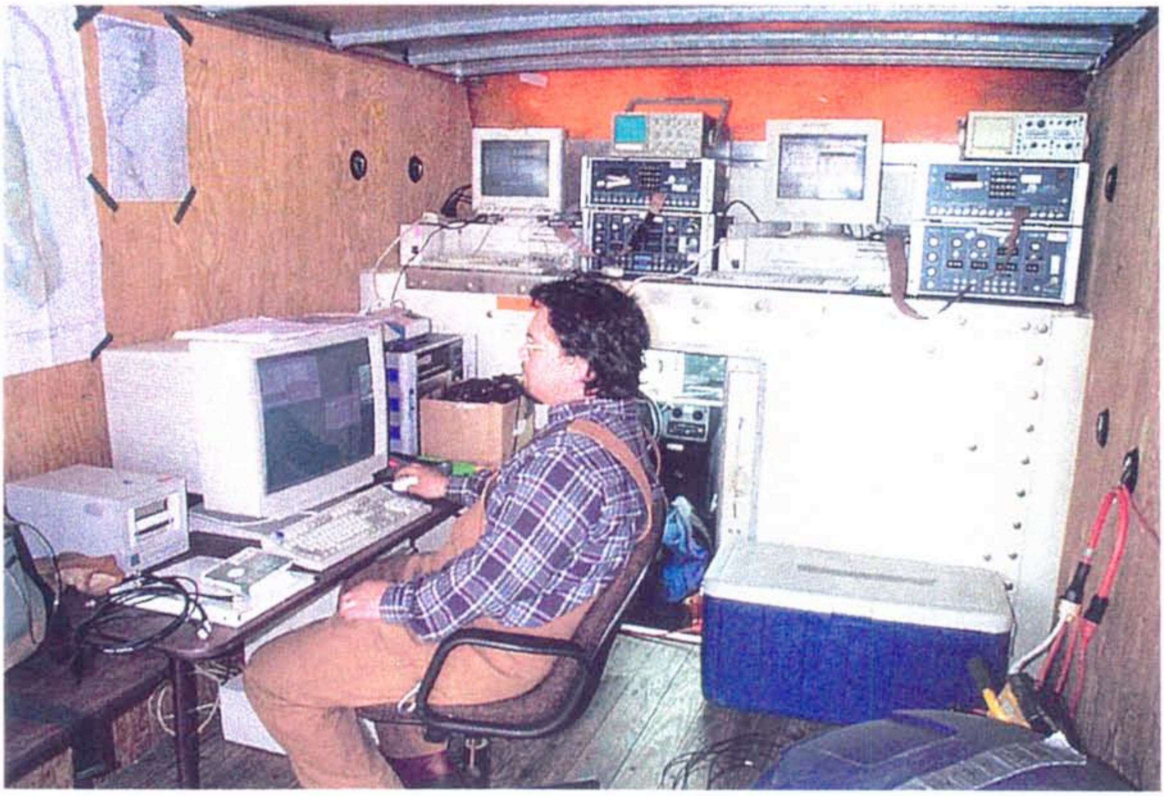


Figure 13. Researcher Russ Moursund in the Ryder truck operations center verifying the proper functioning of the array of 16 single-beam transducers along the southern edge of the Port Townsend ferry terminal

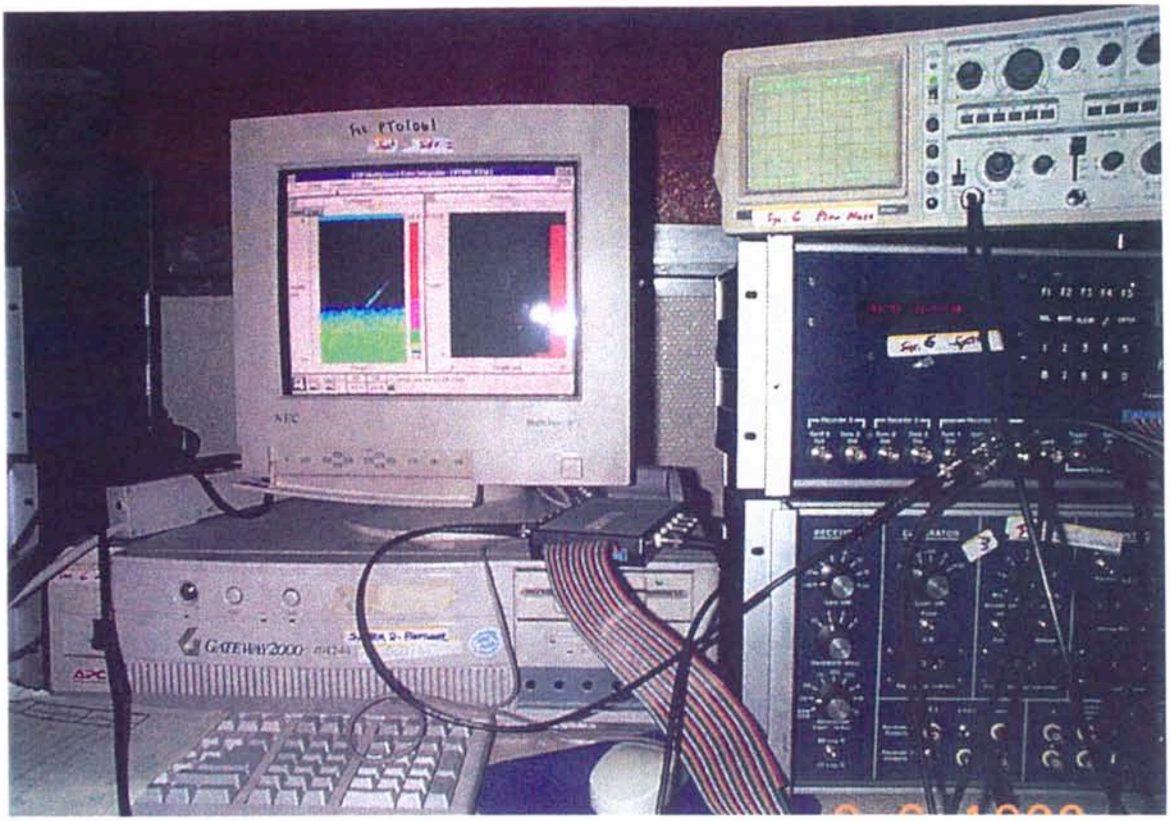


Figure 14. Real-time display of hydroacoustic "targets" detected by the single-beam transducers at the Port Townsend ferry terminal

that was suspended approximately 1 m below twin pontoons that floated on the water surface. We affixed the twin pontoons to a rope and pulley system that spanned the entire length of the southern edge of the terminal (**Figure 15**). Using the pulley system, we were capable of manually moving the video cameras anywhere along the southern edge of the terminal. Heavy-duty electronics cables designed specifically for underwater use connected the cameras to video monitors that were housed in a Ryder truck on the deck of the terminal.

We aimed both video cameras parallel to the terminal edge to intercept fish moving from the eelgrass bed adjacent to the terminal underneath the terminal or vice versa. The black-and-white camera had a field of view of 0.5 m, and was intended to allow us to make positive identification of individual fish. The color camera had a field of view of approximately 3 m, which under some tidal situations encompassed the entire water column from the water surface to the bottom. With this wide field of view, we hoped to capture footage of the behavior of salmon schools, as well as individual fish. We configured the video monitors so that time stamps were recorded directly on all video footage for both cameras. We recorded video footage only during the day with ambient light.

On June 11, 1999, approximately 1 h after the release of the chinook and chum fry for our experiment, the cameras were disconnected from the pulley system, so that we could manually maneuver the cameras underneath the ferry terminal. Two people watched the video screens in the Ryder truck and communicated via hand-held very high frequency (VHF) radios to team members on two boats to direct them where to locate the salmon. The crew on the two boats then maneuvered the cameras with boat hooks and lines in and around the pilings to document the salmon movements and behavior. Following the field effort, we viewed all the underwater

Figure 15. The underwater video system deployed at the Port Townsend ferry terminal from June 9 to 11, 1999

videos to ascertain the exact time, relative location in the water column, and direction of travel of all fish that could be positively identified to species.

Objective 4.0: Light Measurements

We collected light data using a LI-COR LI-1000 data logger with two LI-COR LI-193SA spherical quantum sensors that measure photosynthetically-active radiation (PAR). We attached one light sensor to a weighted aluminum frame and positioned the frame at the southern edge of the terminal near the seventh piling out from shore. The second light sensor we affixed to a weighted wood frame. We positioned the frame at what we perceived to be the darkest point underneath the terminal, near the midpoint of the terminal in line with the first sensor. The LI-COR data logger recorded light measurements continuously from 0900 h on June 7, 1999, through 2300 h on June 11, 1999, but logged as integrated PAR over each hour. A frame and sensor configuration similar to the one we used at Port Townsend is shown in **Figure 16**. However, this photo was taken at the Edmonds ferry terminal during previous research we conducted for WSDOT in 1997 (Simenstad et al. 1997).

Figure 16. The LI-COR LI-193SA spherical quantum sensor that we used to measure photosynthetically-active radiation (PAR) at the edge and underneath the Port Townsend ferry terminal (Photo taken at Edmonds ferry terminal)

FINDINGS

Field Preparations and Coordination

We held chum fry in the floating net pen system at the Port Townsend marina from May 8, 1999 through May 29, 1999, and chinook fry from May 24, 1999 through May 29, 1999. During that time period, we fed and checked on the health of the fry daily. On numerous occasions field staff observed river otters either in the vicinity of the net pen or inside of it. Repeated attacks by the river otters resulted in torn nets, damage to the net pen system, and loss of our experimental fish to mortality and escape. We attributed the mortality to direct predation, as well as otter-induced stress and possible subsequent disease.

On the morning of May 28, 1999, we made an attempt to rescue most of the fry and move them to flowing seawater tanks at the MSL. All of the fish died in transit. In the evening on May 29, we successfully transferred all the remaining fish by truck to the MSL, using a 2-m^3 tank with ice bags and bubbled oxygen. In the end, we were left with an estimated 1000 chinook fry and 300 chum fry to use for experiments.

The river otters at the Port Townsend marina directly and indirectly resulted in the mortality or release of an estimated 29,000 chinook fry and 39,700 chum fry between May 8 and May 29, 1999. On June 1, 1999, the authors participated in a conference call with other team members, WSDOT, and the USACE to determine whether the proposed field effort should be cancelled. The unanimous decision was that despite the fish losses, there was still benefit to be gained from the following: 1) deploying all the single-beam and split-beam hydroacoustics, underwater video cameras, and light sensors as originally planned; 2) spending more time than originally planned gathering background data on any natural salmon migrating through the terminal area; and 3) doing a one-time experimental release of all the remaining chum and chinook fry, as opposed to the replicate day and night releases originally proposed. Between June 1 and June 4, 1999, our extensive efforts to acquire additional chum or chinook fry from all possible state, federal, tribal, and private sources were unsuccessful.

Diving Survey

The three divers observed no juvenile salmonids during their diving survey on June 7, 1999. In the eelgrass beds adjacent to the southern edge of the terminal, the divers sighted and/or videotaped schools of shiner perch (*Cymatogaster aggregata*), pile perch (*Damalichthys vacca*), and tubesnouts (*Aulorhynchus flavidus*), as well as one copper rockfish (*Sebastes caurinus*) and several unidentified sculpins. Underneath the terminal, the divers sighted and/or videotaped schools of shiner perch and pile perch, one kelp greenling (*Hexagrammos decagrammus*), and several unidentified sculpins.

Beach Seining Survey

In the first beach seine set, we captured 10 chum salmon ranging in size from 45 mm to 80 mm fork length and one chinook salmon that was 120 mm fork length. The other 12 fish species we collected were typical species one would expect to find in an eelgrass bed (**Table 3**). In the second beach seine set, we collected 35 chum fry (60-90 mm fork length visually estimated), no chinook, two steelhead (*Oncorhynchus mykiss*), and one cutthroat trout (*Salmo clarkii*). Careful handling and well-oxygenated holding buckets helped to minimize stress and damage to the fish. Few known mortalities resulted from our beach seining efforts.

Split-Beam Hydroacoustics

The hard-drive of the laptop computer that was compiling the GPS and flux-gate compass data failed and most of the data were not retrievable. Due to this unfortunate event, we focused our

Table 3. Fish species collected during qualitative beach seine surveys near the Port Townsend ferry terminal on June 7, 1999

Beach Seine Set #1	**Fish Sizes (mm) measured**	**Beach Seine Set #2**	**Fish Sizes (mm) visually estimated**
Shiner perch	nd [(1)]	Shiner perch	nd
Pile perch	nd	Pile perch	nd
Striped perch	nd	Striped perch	nd
Saddleback gunnel	nd	Saddleback gunnel	nd
Penpoint gunnel	nd	Penpoint gunnel	nd
Juvenile flatfish	nd	Juvenile flatfish	nd
Snake prickleback	nd	Snake prickleback	nd
Pacific staghorn sculpin	nd	Pacific staghorn sculpin	nd
Tubesnout	nd	Tubesnout	nd
Pipefish	nd	Pipefish	nd
Juvenile greenling	nd	Juvenile greenling	nd
Starry flounder	nd	Starry flounder	nd
Chum salmon (n=10)	70, 45, 80, 80, 55, 65, 60, 65, 75, 70	Chum salmon (n=35)	60-90
Chinook salmon (n=1)	120	Steelhead (n=2)	300, 400
		Cutthroat trout (n=1)	300

(1) Nd = no data collected.

data analysis on the time period immediately following the release of the known group of hatchery chum and chinook fry. The released fish were located on echograms produced by the Visual Analyzer software, which accompanies BioSonics DT6000 echosounders.

We were successful in tracking the released salmon fry from the release point to the southern edge of the Port Townsend ferry terminal (**Figure 17**). We do not know whether the chum and chinook fry migrated together or split into separate species-specific aggregations. The released fish traveled the 30 m from the release boat to the terminal edge in 5 mins (1833-1838 h), a migration speed of 0.1 m/sec. The released salmon fry stayed in a fairly tight school, rather than migrating as individuals. The echogram and range versus time plot for this migration period indicate that the center of the strongest fish aggregations was always within 3 to 6 m from the tracking boat (**Figure 18**). The aggregations of migrating fish also appear to have been in the midwater region, because the echogram traces did not blend with the surface or bottom.

At the southern edge of the terminal, we lost track of the released fish for a period of approximately 10 min. Subsequently, we observed salmon fry rippling the surface underneath the ferry terminal at the light to dark transition formed by the dock shadow. After repositioning the boat parallel to the southern edge of the terminal near single-beam transducer Station 4, we relocated the released fish with the split-beam hydroacoustics and the video pontoon at 1919 h (**Figure 19**). From 1919 h to 1955 h, we were successful in continuing to track the locations and movements of the released fish underneath the terminal with the split-beam system and the video pontoon. The estimated locations of the dock shadow lines at 1919 h and 1955 h are shown on Figure 19. We determined the locations of these lines based on visual observations and surface video footage.

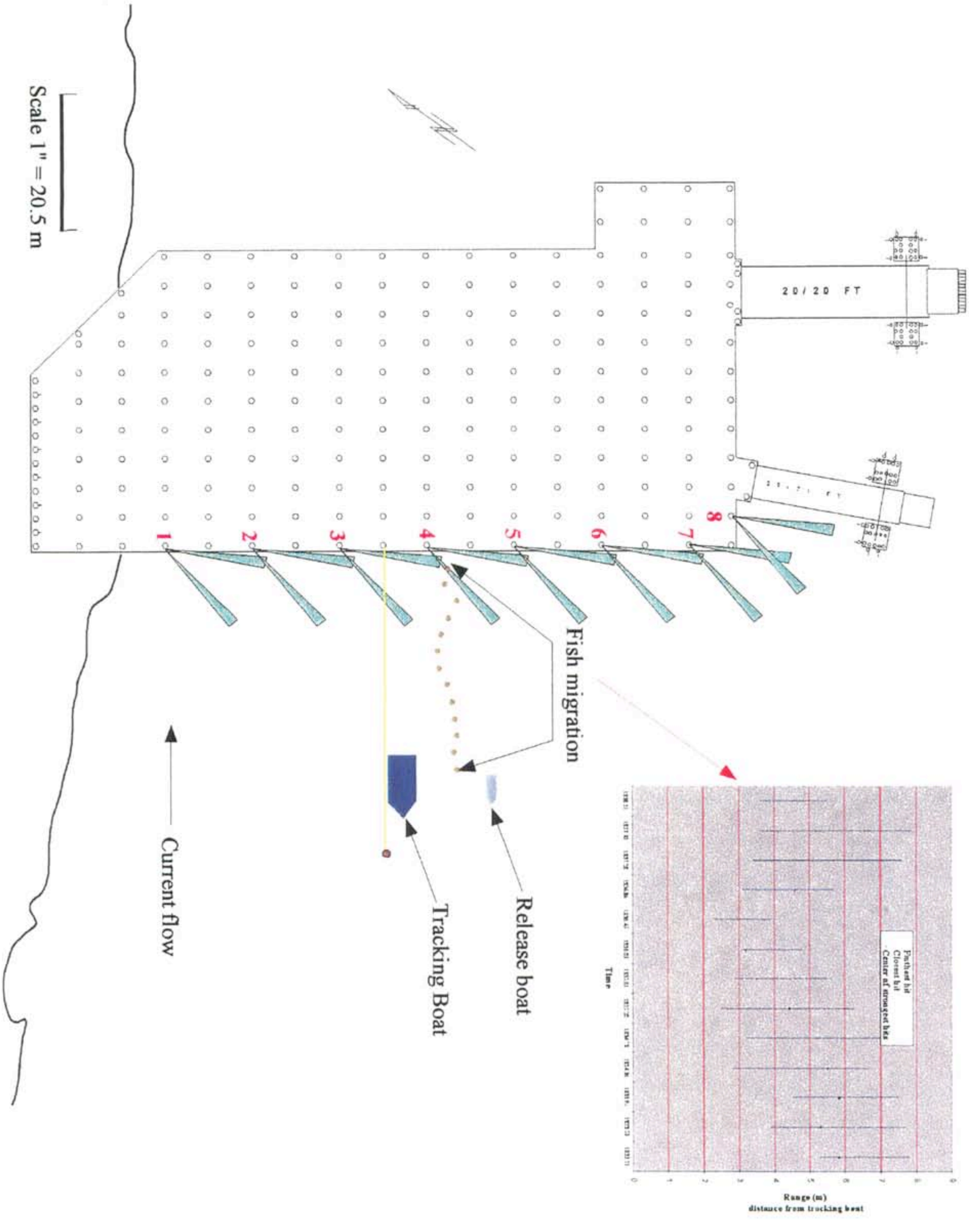


Figure 17. Hydroacoustic tracking of juvenile chum and chinook salmon released 30 m from the southern edge of the Port Townsend ferry terminal, 1833 h-1838 h June 11, 1999

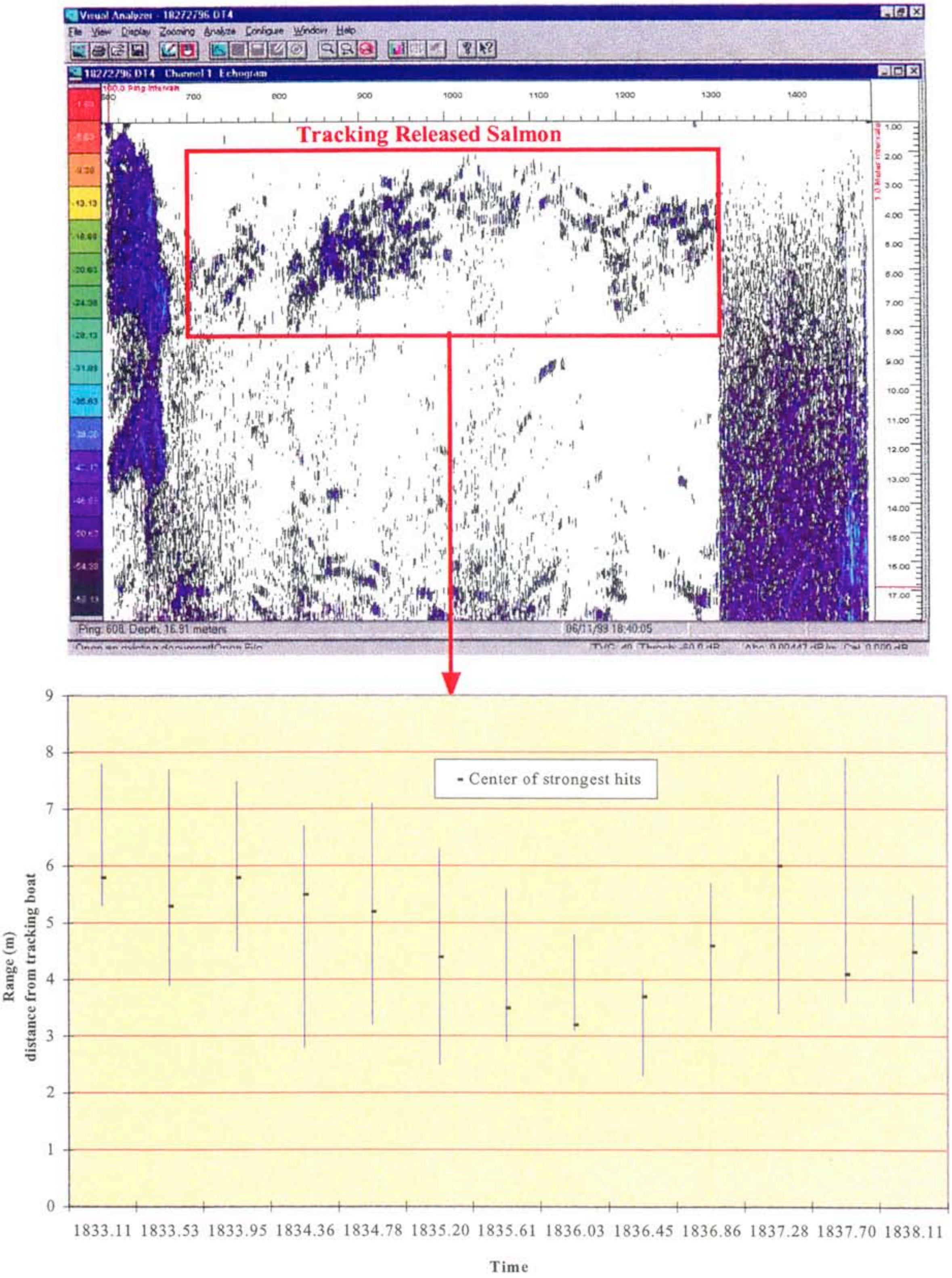


Figure 18. Echogram (top) and plot of range versus time data (bottom) for fish tracking with split-beam hydroacoustics at the Port Townsend ferry terminal, 1833 h - 1838 h on June 11, 1999.

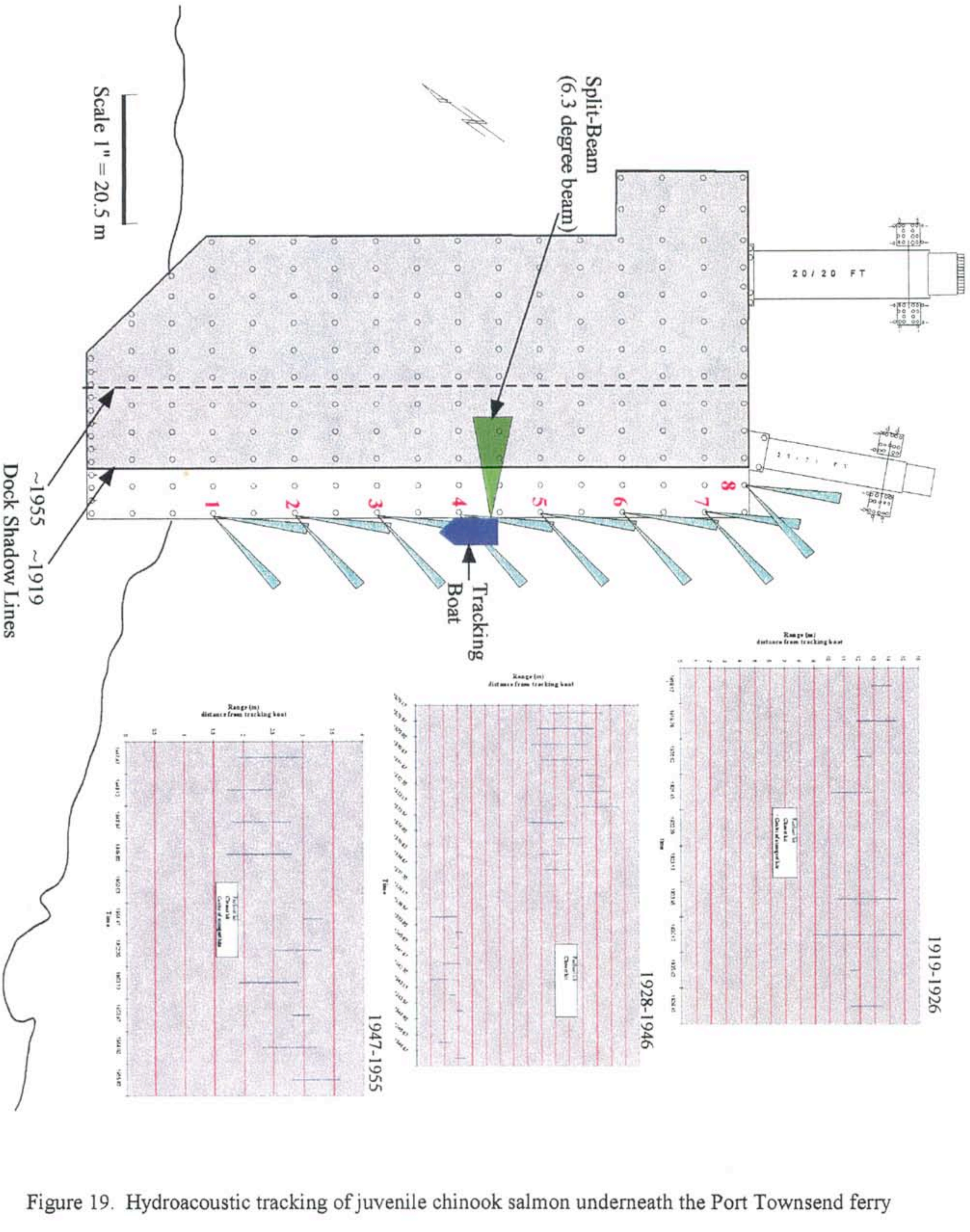


Figure 19. Hydroacoustic tracking of juvenile chinook salmon underneath the Port Townsend ferry terminal, 1919 h-1955 h June 11, 1999.

The echogram and range versus time plot for 1919 h to 1926 h show that the salmon fry were aggregated approximately 9 m to 15 m away from the tracking boat (**Figure 20**). The center of the strongest fish aggregations was 9.8 m to 13.2 m from the tracking boat; these fish were aggregated in the darkness created by the dock shadow, between the second and third set of pilings underneath the terminal from the southern edge. The echogram and range versus time plot for 1928 h to 1946 h show that from approximately 1928 h to 1937 h, the center of the strongest fish aggregations was 9.6 m to 13.3 m from the tracking boat (**Figure 21**). From 1939h to 1946 h, the video camera pontoon was visible at a range of 1 m-3 m from the tracking boat. The echogram for 1947 to 1955 h shows the video camera pontoon creating stronger acoustic returns as we manually move it further underneath the terminal and as it intercepts more of the acoustic energy from the split-beam at a distance of 1-3 m (**Figure 22**). After 1955 h, we lost track of the fish. We assume based on visual observations that the chinook fry moved beyond the range of our hydroacoustics as they followed the shadow line further underneath the terminal. At the time we lost track of the chinook fry on the echograms, we could see fish rippling the dark surface at about the midpoint underneath the terminal.

Single-Beam Hydroacoustics

We used a software package called Tecplot to create spatially appropriate representations of the sampling volumes for the single-beam data analysis [Tecplot is a registered trademark of Amtec Engineering, Inc: Bellevue, Washington, USA]. Each frame generated by Tecplot covered a single 10-min cycle. Each cycle, as noted previously, is the shortest period in which all 16 transducers (two pairs at eight stations) were sampled. Lastly, we created an animation of the sampled volumes over time that visually displayed the spatial and temporal aspects of the entire data set.

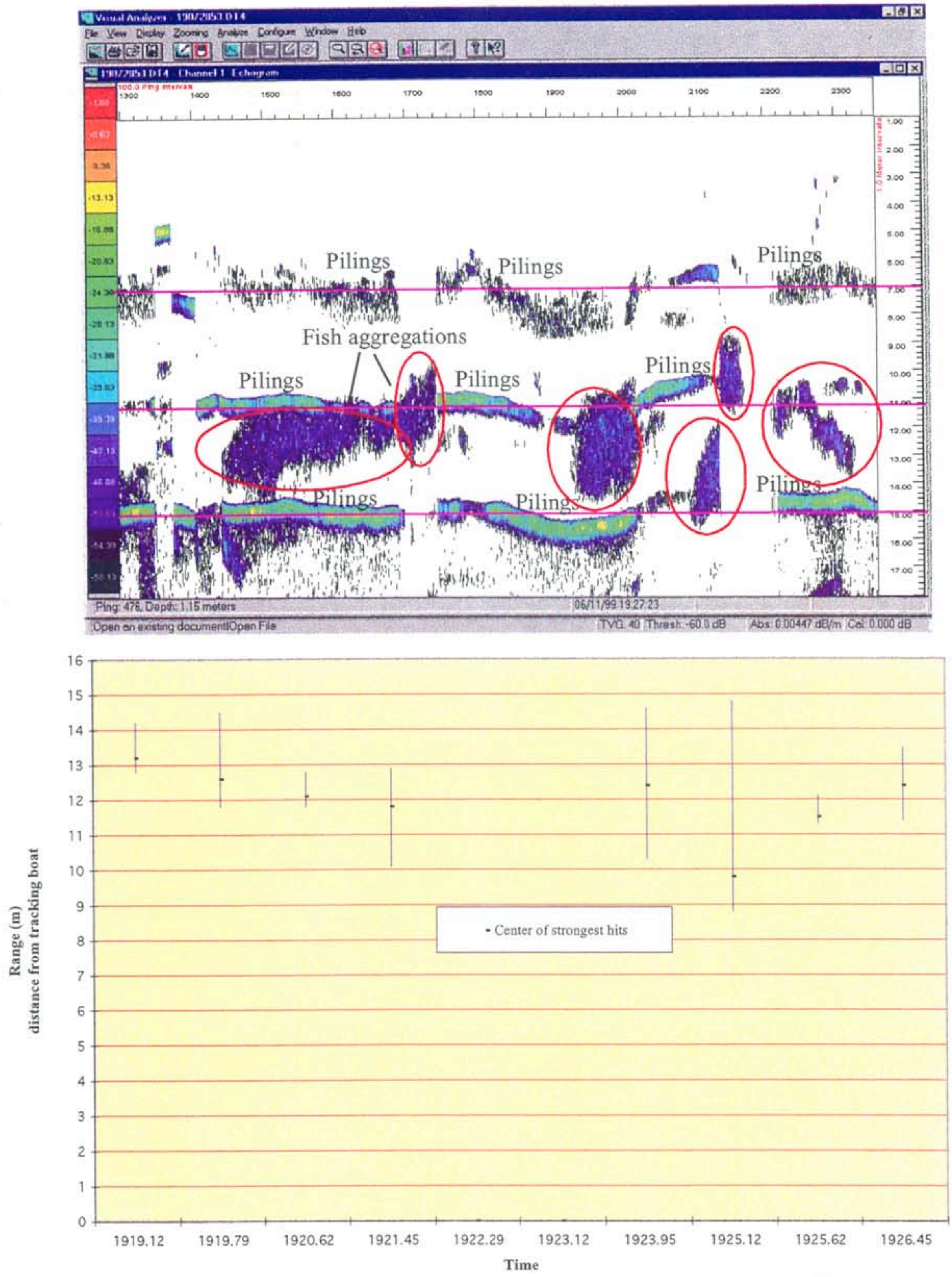


Figure 20. Echogram (top) and plot of range versus time (bottom) for tracking of juvenile salmon underneath the Port Townsend ferry terminal, 1919 h-1926 h on June 11, 1999. Pilings are located at approximately 7 m, 11 m, and 15 m. Fish aggregations are circled in red on the echogram.

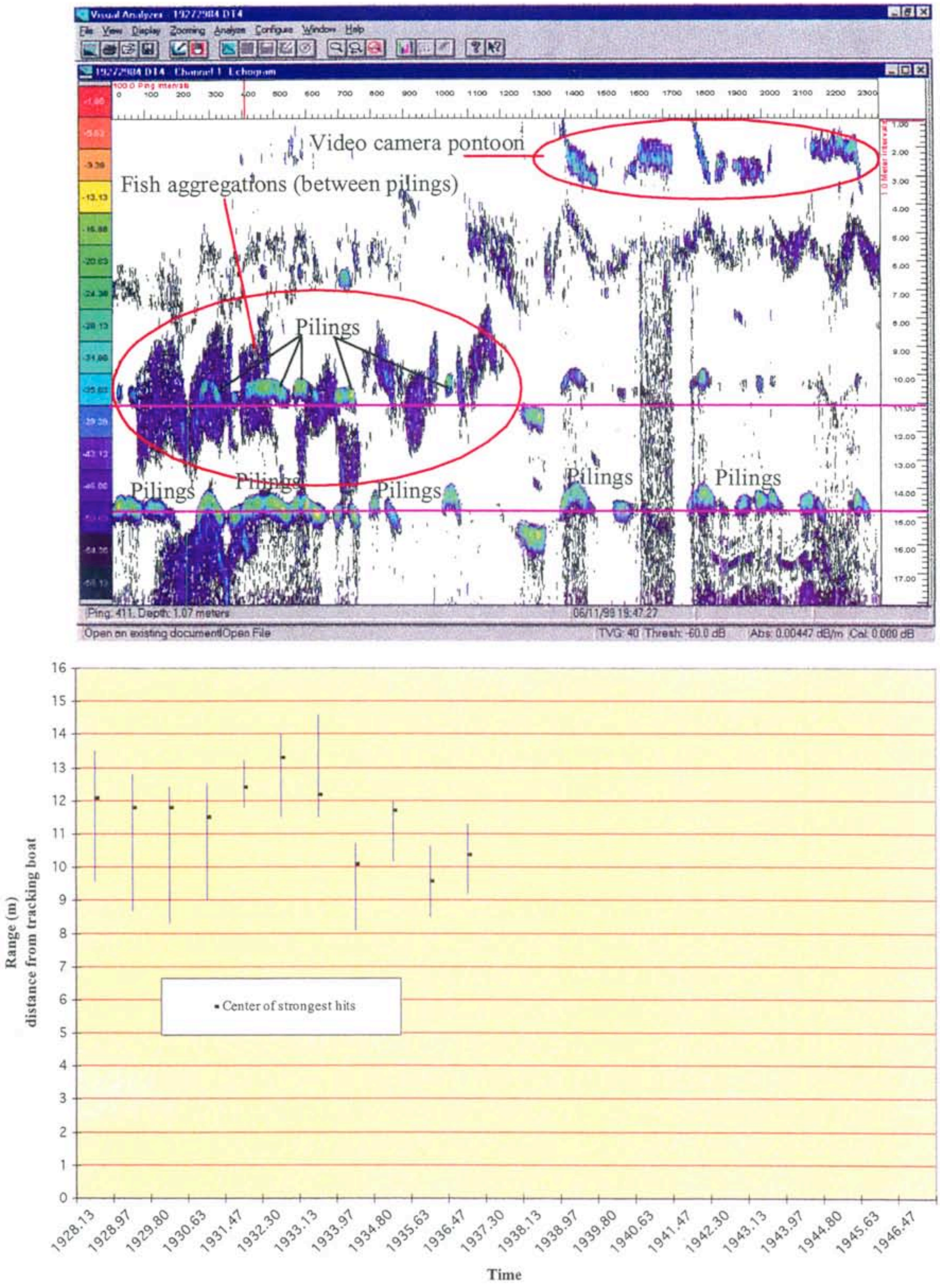
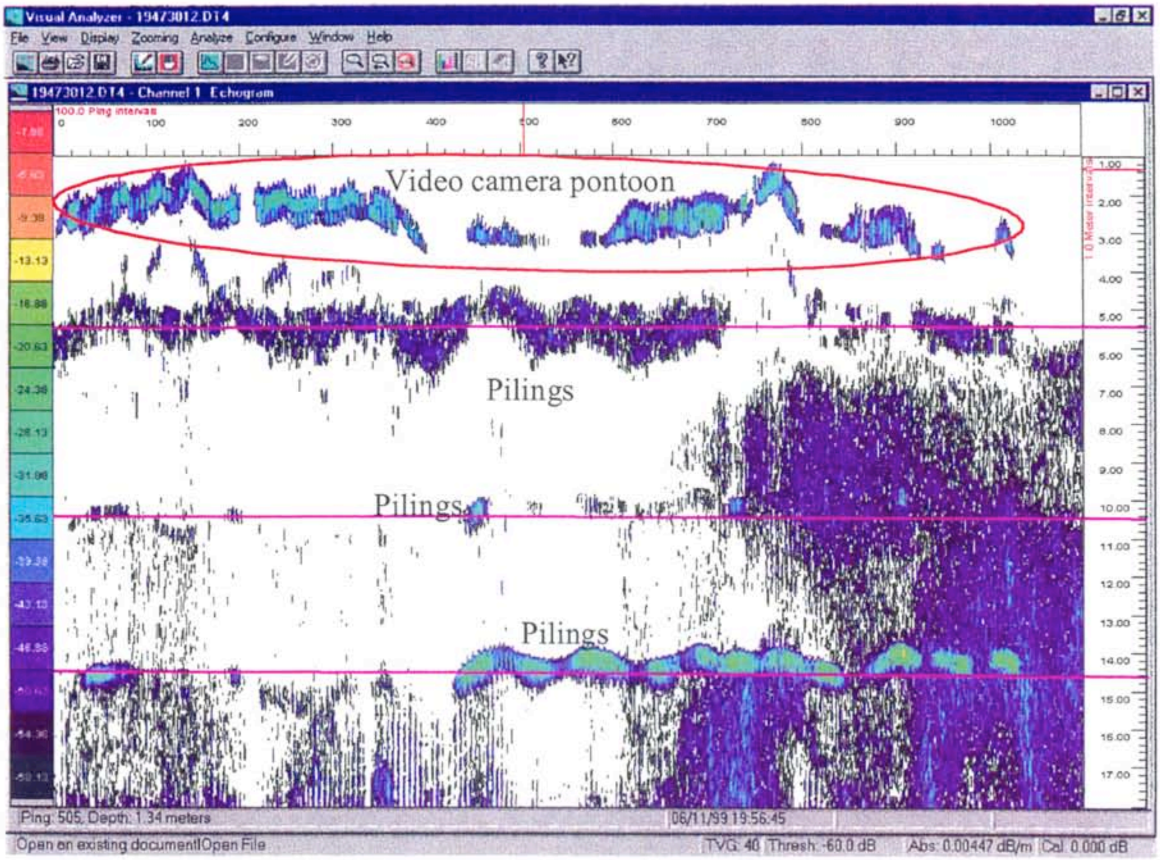


Figure 21. Echogram (top) and plot of range versus time data (bottom) for tracking of juvenile salmon underneath the Port Townsend ferry terminal, 1928 h-1946 h on June 11, 1999. Fish aggregations are circled in red on the echogram.



Ping: 505, Depth: 1.34 meters

06/11/99 19:56:45

Open an existing document!Open File

TVG: 40 Thresh: -60.0 dB Abs: 0.00447 dB/m Cal 0.000 dB

Figure 22. Echogram for tracking of juvenile salmon underneath the Port Townsend ferry terminal, 1947 h-1955 h on June 11, 1999

Background prerelease data showed that fish of unknown species were detected 24 h/day at all stations, although the sample size was too small for us to make any inferences regarding the diel distribution of fish at the ferry terminal. The L-shaped diagrams we show below depict fish detections at each of the eight stations for the three 10-min cycles closest to the time of the fish release at 1830 h on June 11, 1999 (**Figures 23, 24, 25**). We have positioned each L-diagram with the southern edge of the terminal oriented horizontally across the page. At each of the eight stations there were two pairs of transducers. One transducer was aimed "along" the edge of the terminal and is represented by the horizontal leg of each L-diagram. A second transducer was aimed "out" at approximately a 45-degree angle away from the terminal edge and is represented by the vertical leg of each L-diagram. Based on visual identification, we believe that detections at Stations 2 to 4 for the period 1830 h to 1845 h are the salmon fry from the single release.

We believe that Stations 5-8 did not record data correctly and that the lack of detections at these stations is anomalous. As stated previously, we used two complete single-beam systems with eight transducers apiece. Stations 1-4 and Stations 5-8 were separate systems. During data collection, both systems appeared to collect data. Echograms were reasonable and agreed with each other, and files of the same size and format were collected. Only after we completed our data analysis did we detect an apparent problem. Observations and notes from the data collection period show that detection did occur, and echograms were produced on the Echo Signal Processing computers. We suspect that the echo integration software installed in the field was at fault, but we have not definitively identified the problem to date. The echo integration technique is not one typically used in fish passage research, and we assume that

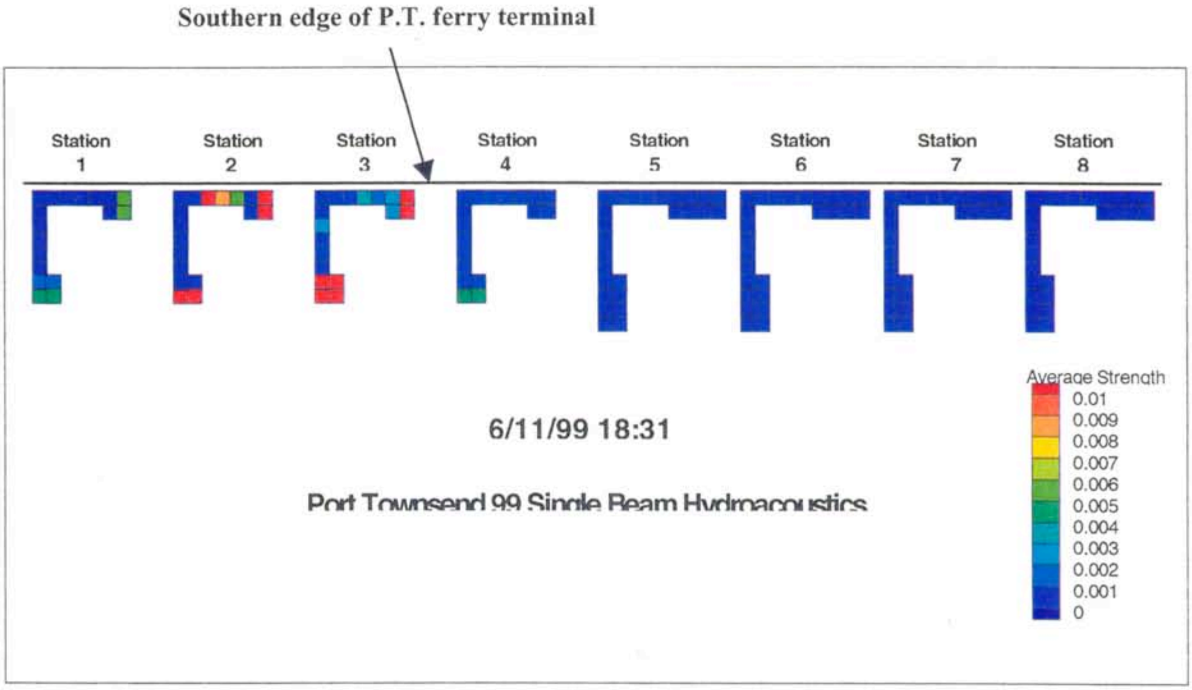

Southern edge of P.T. ferry terminal

Figure 23. Fish detections at Stations 2 and 3 at 1831 h on June 11, 1999, at the Port Townsend ferry terminal. We believe that Stations 5-8 did not record data correctly and that the lack of detections at these stations is anomalous.

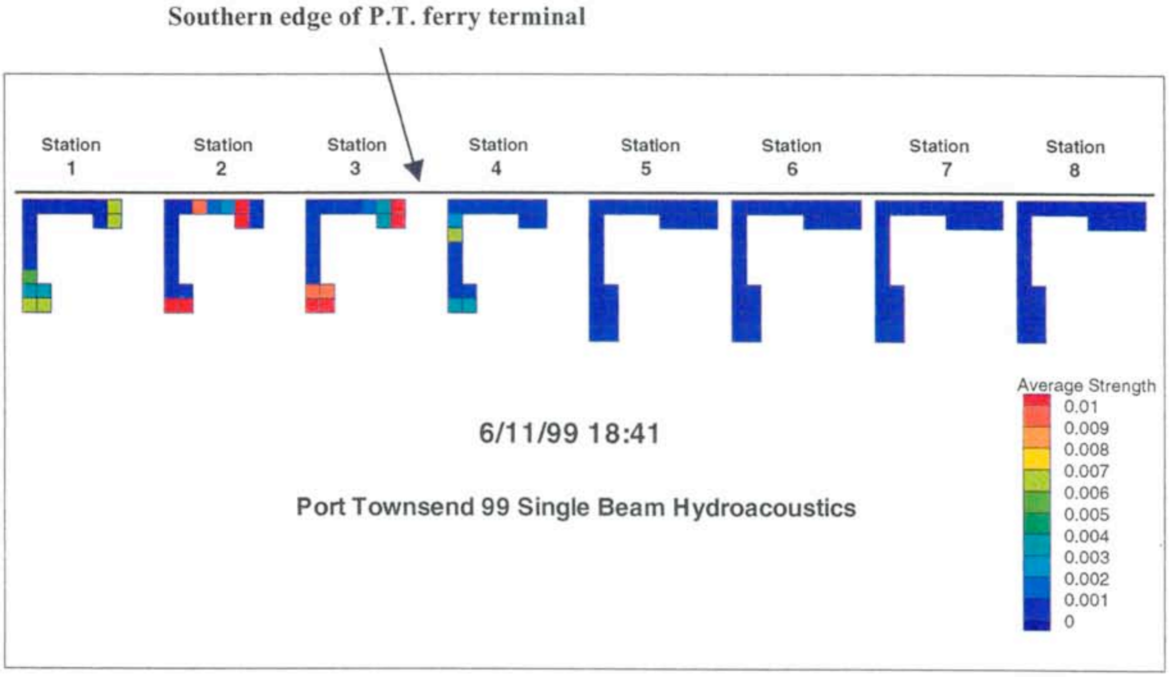


Figure 24. Fish detections at Stations 2 and 4 at 1841 h on June 11, 1999 at the Port Townsend ferry terminal. We believe that Stations 5-8 did not record data correctly and that the lack of detections at these stations is anomalous.

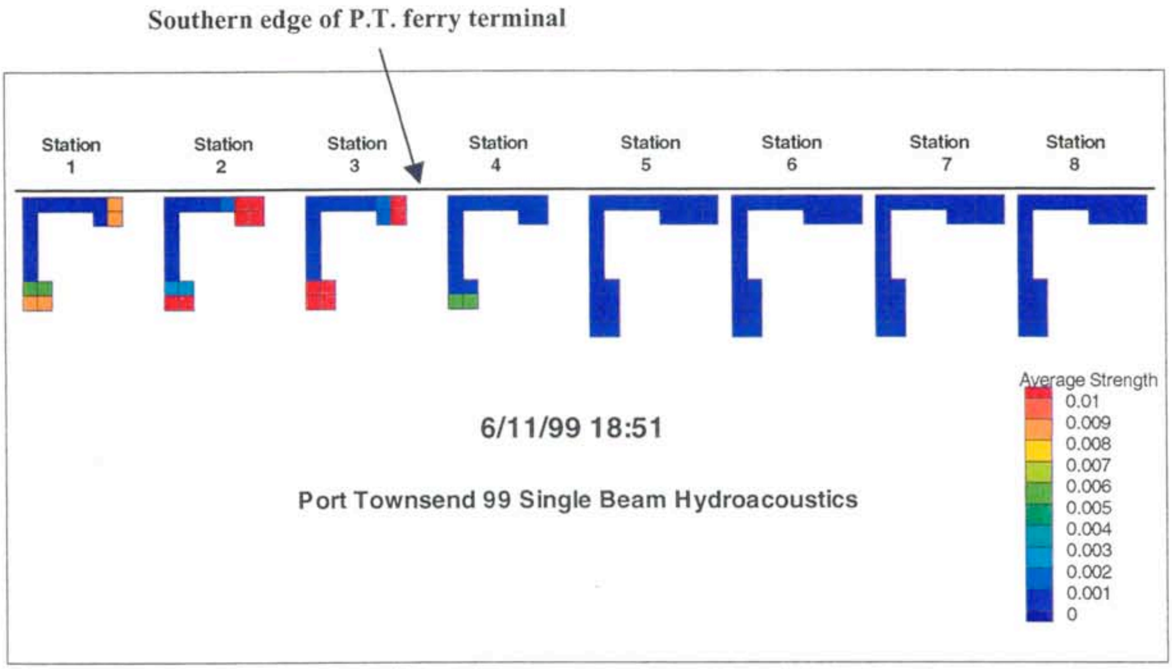


Figure 25. No fish detections at 1851 h on June 11, 1999 at the Port Townsend ferry terminal. We believe that Stations 5-8 did not record data correctly and that the lack of detections at these stations is anomalous.

inexperience with the echo integration software may explain why we did not detect this error in the field.

Underwater Video

Video footage from the black-and-white camera was analyzed for two time periods: 1) the period from 0541 h to 1210 h on June 11, 1999, and 2) following the salmon release from 1935 h on June 11, 1999 to 0203 h on June 12, 1999. During the first time period, we could make eight positive identifications of a large school of shiner perch milling around the southern edge of the Port Townsend terminal between 0544 h and 0907 h. Also during the first time period, we could identify a school of sand lance on five occasions between 0944 h and 0955 h. During the second time period, post-salmon release, we were able to make 14 positive identifications of both individual chinook salmon (approximately 100 mm length) or a school of chinook salmon. We are confident that these fish were the same chinook salmon that we released at approximately 1830 h for our experiments, based on the relative number of fish in the school, the uniform size of the fish, and the timing of their appearance at the southern edge of the terminal.

Video footage from the color camera was analyzed for 11 different time periods between 0910 h on June 10 and 2006 h on June 11, 1999 (**Table 4**). On Tape 1 for June 10, 1999, we were able to make positive identification of a large school of shiner perch, and tentative identification of a school of sand lance (*Ammodytes hexapterus*). Salmon were recorded by the color video camera on only two occasions on June 10, 1999: 1) a school of salmon (most likely chinook) that was moving in and out of camera view between approximately 1210 h and 1310 h (Tape 2); and 2) one individual chinook salmon at 1650 h (Tape 3). No other salmon were recorded on the seven tapes for June 10, 1999. We could make no positive identifications of any fish species between

Table 4. Summary of positive fish identifications in the vicinity of the southern edge of the Port Townsend ferry terminal between June 10 and June 11, 1999, based on analysis of color underwater video footage

Date, Tape Number, Recording Period	**Time and Description of Fish Observation**
June 10, 1999 (Tape 1) 1055 h	1004 h school of shiner perch 1035 h school of sand lance (not a positive identification) 1045 h unidentifiable school
June 10, 1999 (Tape 2) 1208 h-1310 h	~1210 h - 1310 h, school of salmon (most likely chinook) moving in and out of camera view
June 10, 1999 (Tape 3) 1610 h -1712 h	~1650 h, one individual chinook salmon swimming rapidly from right to left
June 10, 1999 (Tape 4) 1718 h -1820 h	no positive fish identifications
June 10, 1999 (Tape 5) 1823 h -1926 h	no positive fish identifications
June 10, 1999 (Tape 6) 1941 h -2043 h	no positive fish identifications
June 10, 1999 (Tape 7) 2121 h -2143 h	no positive fish identifications
June 11, 1999 (Tape 1) 0544 h -0646 h	no positive fish identifications
June 11, 1999 (Tape 2) 0841 h -0943 h	0841-0943 h, large school of shiner perch moving in and out of camera view
June 11, 1999 (Tape 3) 1809 h -1911 h	~1815 h, four individual salmon swimming by near water surface
June 11, 1999 (Tape 4) 1934 h -2006 h	~1934 h -1956 h, school of chinook salmon that we released

1710 h on June 10, 1999 and 0646 h on June 11, 1999. Between 0841 h and 0943 h on June 11, 1999, there was a large school of shiner perch milling around the terminal edge. Later that same day, during the tenth recorded time period (1809 h to 1911 h), the camera recorded four chinook salmon very close to the water surface at 1815 h. At approximately 1915h, we determined, based on visual observations of salmon feeding at the water surface underneath the terminal, that we needed to move the camera system closer to where we were observing the feeding.

During the final time period (1934 h to 2006 h on June 11, 1999), we removed the camera from the pulley system and manually maneuvered the camera in and around the pilings underneath the terminal. A school of chinook salmon was positively identified seven times between 1935 h and 2000 h. We believe that these were the same chinook fry that we released at 1830 h, recorded on the black-and-white video footage (1935 h -1957 h), and also captured on the split-beam echograms (Figures 21, 22). The school appeared to be fairly stationary at the shadow line created by the terminal edge, and oriented facing south into the ebbing current most of the time. We observed no directed swimming on the videos. However, we know from visual observations that individual fish were rising to the surface to feed. As the sun set and the shadow line moved further north and underneath the dock, the chinook fry tracked the shadow line until they were eventually beyond the range of our cameras. After 1957 h on June 11, 1999, we observed no more chinook fry on the videos. No video footage of potential predators of juvenile salmon was recorded by either the black-and-white or color camera system between June 10 and June 11, 1999.

Light Measurements

PAR varied throughout the day at the edge and midpoint of the terminal; much greater light occurred at the edge (**Figure 26**). The dashed horizontal line in **Figures 26 and 27** indicates the

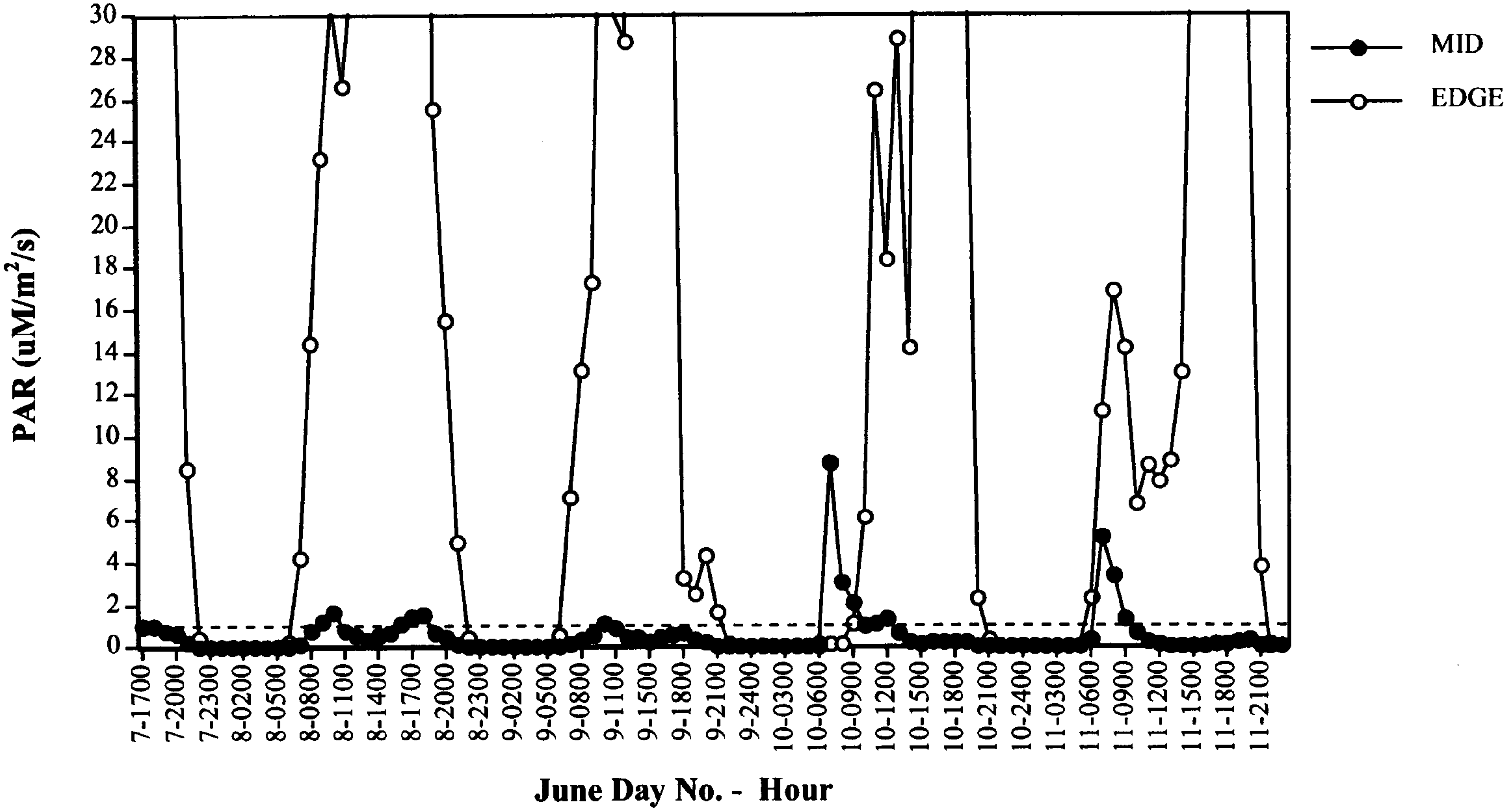


Figure 26. Average instantaneous PAR each hour during the duration of the light monitoring from 1700 h on June 7, 1999 to 2100 h on June 11, 1999 at the edge and midpoint under the Port Townsend ferry terminal

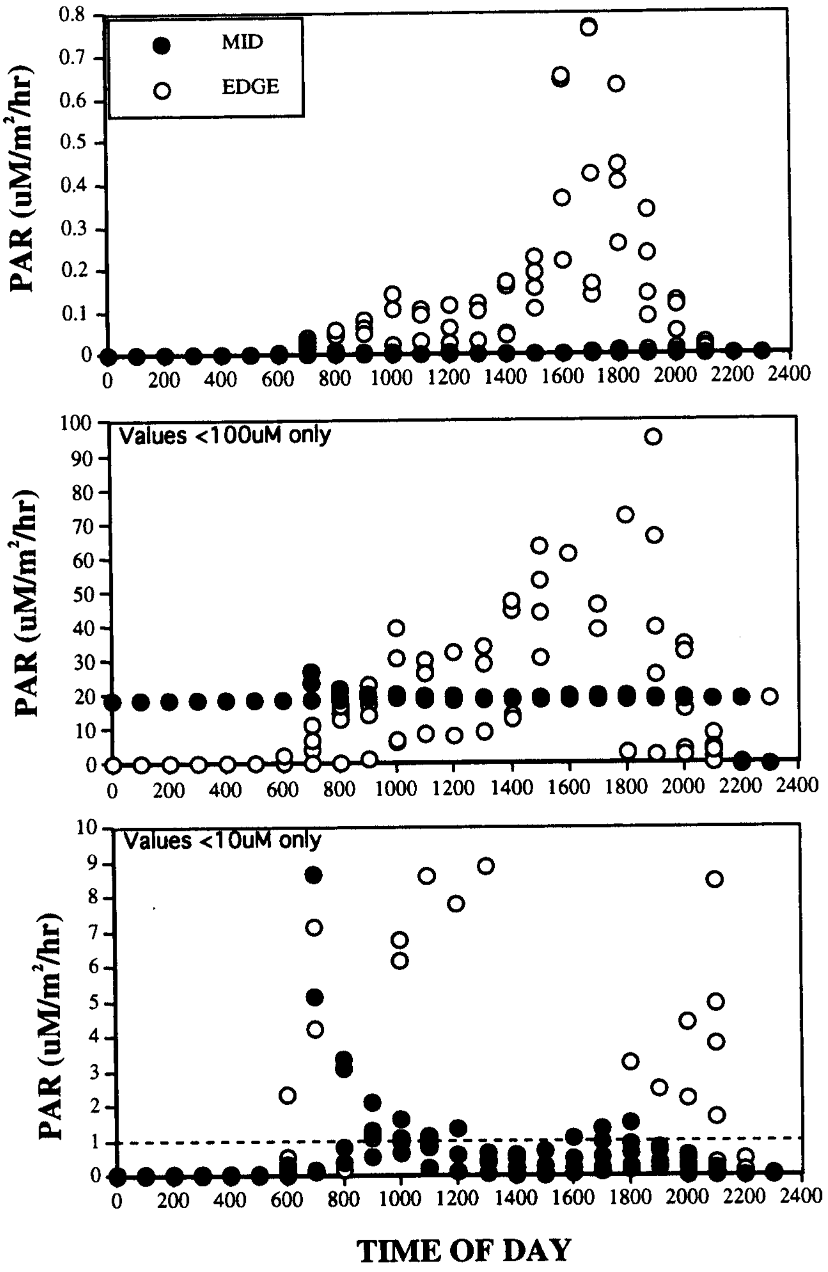


Figure 27. Integrated hourly PAR versus time of day (top), average instantaneous PAR each hour showing values less than 100 μM/m²/hr (middle), and values less than 10 μM/m²/hr (lower) at the Port Townsend ferry terminal, June 7-11, 1999. Values from all five days are shown for each hour of the day.

1 μM/m^2/s light level, which was identified in our Phase I report as a tentative threshold response for juvenile salmon (Simenstad et al. 1999). Below a light level of 1 μM/m^2/s, juvenile salmon schools disperse and fish have been observed to stop feeding (Ali 1959).

Typically, there was a pattern of rapid increase in light between 0600 h and 0900 h and a rapid decline between 1700 h and 1900 h. Light at the midpoint under the terminal showed an early morning increase, decreased after about 0900 h to very low levels, and a slight increase in late afternoon. This pattern may be related to tide level and sun angle. Low sun angle in the morning and late afternoon allows for more light to reach further under the terminal. In addition, low tides occurred in the morning and late afternoon. The height of the increase appeared to be related to the tide level also. The lowest morning low tides occurred on June 10 and 11, in correspondence with peaks in PAR (**Figure 26**).

The variability in PAR at each hour over the five days of monitoring is illustrated in **Figure 27**. Both light sensors showed variation between days in light levels, with maximum variation of up to about six times (e.g., 0.12 to 0.78 M at 1700 h). Between-day variations can be attributed to changes in tide level, cloud cover, wind chop on the water surface, suspended matter, and occasional coverage of the light sensors with drifting seaweed (noted by divers). Light increased to a maximum between 1600 h and 1800 h. This late afternoon peak is likely related to the occurrence of low tides at this time, which had a greater effect on light at the edge than midway under the terminal.

There was no correlation between light at the edge and light at the mid-point (**Figure 28**). This is largely because light at the edge continued to increase during the day, whereas light at the mid- point decreased after a brief early morning peak. The differences between edge and mid-point PAR are illustrated by subtracting the midpoint values from the edge values (**Figure 29**).

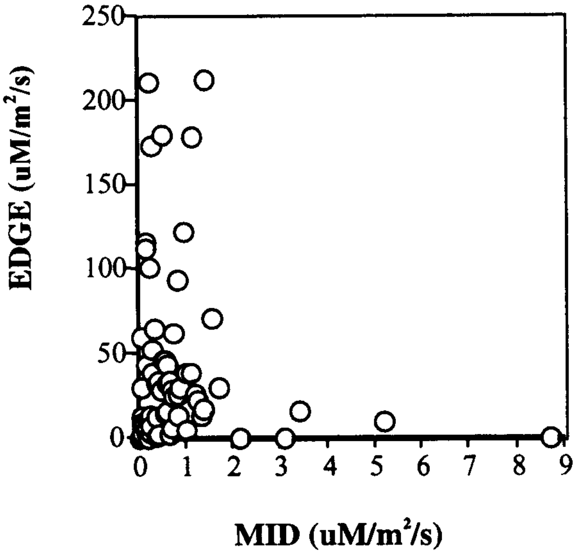


Figure 28. Relationship between average instantaneous PAR each hour at the edge and midpoint sensors at the Port Townsend ferry terminal, June 7-11, 1999

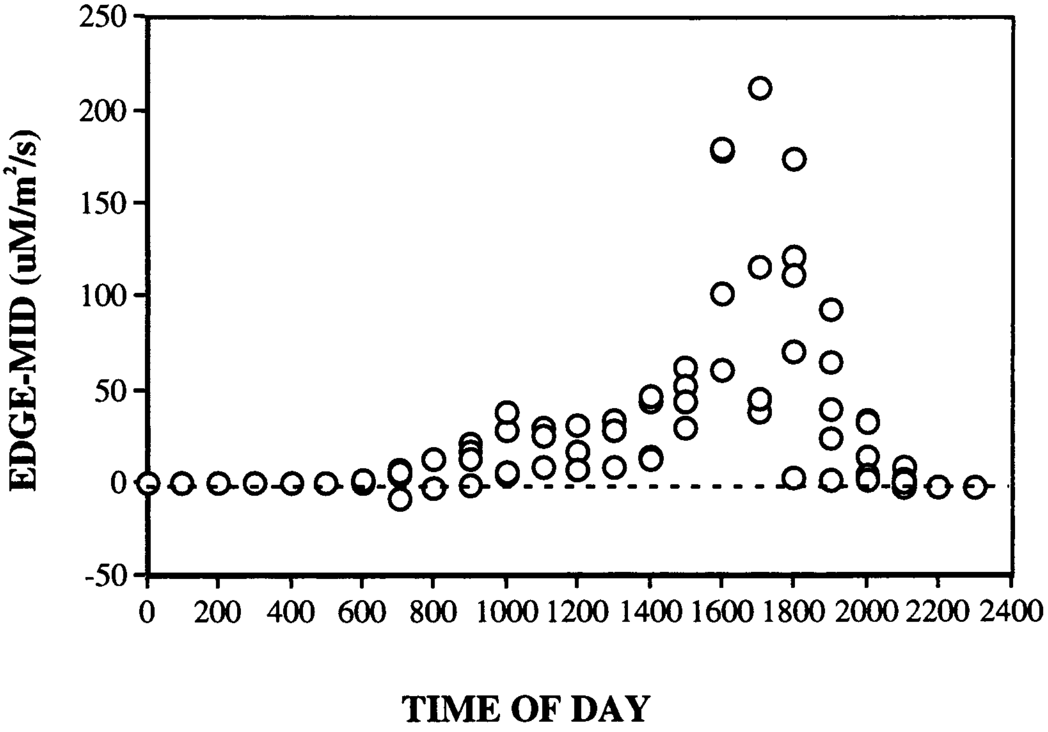


Figure 29. Differences in average instantaneous PAR each hour between the edge and midpoint sensors at the Port Townsend ferry terminal, June 7-11, 1999

Before 0600 and after 2000 h, PAR was essentially the same between the edge and midpoint. The edge received more light after about 0600 h, again with a maximum between about 1600 h and 1800 h.

DISCUSSION

Field Preparations and Coordination

We were successful in constructing, deploying, and testing all of the planned hydroacoustic equipment, underwater video cameras, and light sensors at the Port Townsend ferry terminal. With the help of WDFW and USFWS, we were also successful in obtaining 40,000 chum fry and 30,000 chinook fry for experiments, and transferring those fish from hatchery trucks to a floating net pen system at the Port Townsend marina. However, because the split-beam and single-beam transducers and all associated cables, computers, oscilloscopes, and hardware were unavailable to us until early June 1999, we were forced to shift our experiments until the end of the typical March-June outmigration window for juvenile chum and chinook salmon in Puget Sound. The result was that we had to hold the hatchery fry for the experiments longer than we desired, and the fish were thus larger at release than our planned target sizes of 30-50 mm chum and 50-70 mm chinook. These target sizes were determined based on typical sizes of natural (nonhatchery) outmigrating chum and chinook fry reported in the literature (Simenstad et al. 1999).

Instead, the chinook we released were an estimated mean size of 100 mm and the chum were approximately 70 mm. The effect that releasing these larger fish may have had on the results of our experiment is unknown. The sizes of our released hatchery chum were within the reported size range (60 mm-90 mm) of the chum captured in beach seine samples on June 8, 1999. Only one 120 mm chinook was captured in the beach seines, so we do not know how the size of the released hatchery chinook compares to other chinook (hatchery or natural) that may have been migrating along the Port Townsend shoreline at the time of our experiment.

Aside from these unanticipated but not uncommon hurdles associated with mounting an intensive field effort of this scale, the major problem we encountered was the persistent river otter attacks on our floating net pen system. River otters directly and indirectly contributed to losses of approximately 29,000 chinook fry and 39,7000 chum fry that we were holding for experiments. The unforeseen problems with river otters led to considerable expense, enormous frustration, and complete rethinking of our original experimental design. Because we had so few fish to release for our experiments, we were only able to do a one-time release of all the remaining fish rather than replicate day and night releases at varying distances from the edge of the terminal and at various tidal regimes as originally planned.

Diving Survey

We suspect that part of the reason that no juvenile salmon were observed during our one-time diving surveys on June 7, 1999 was poor visibility, estimated to be 1 m to 3 m. Although the degree to which juvenile salmon are scared off by divers is unknown, we successfully observed and videotaped juvenile salmon at two ferry terminals (Kingston and Vashon) during the Phase I preliminary diving and light surveys (Simenstad et al. 1999). Anecdotal observations made while looking down at the water surface from the Port Townsend terminal deck suggest that juvenile salmon were present in the vicinity of the terminal throughout our June 7-11 field efforts.

Among the six fish species observed or videotaped by divers, only shiner perch are of the approximate same size and general body shape as juvenile salmon; therefore shiner perch could have appeared as similar "targets" on the hydroacoustics echograms. One copper rockfish was the only potential predator on juvenile salmon that we observed and videotaped at the Port

Townsend terminal. Copper rockfish have previously been reported to be predators on juvenile salmon around over-water structures (Simenstad et al. 1999).

Beach Seining Survey

Our beach seining survey on June 8, 1999 indicated that small numbers of chum and chinook were present in the vicinity of the Port Townsend ferry terminal, prior to initiating our hydroacoustic and video monitoring. We reiterate that this survey was only intended to provide an indication of whether any salmonids were present in the area, and was not designed to systematically quantify the species, numbers, or sizes of salmonids migrating through the area. We do not know whether the 45 captured chum salmon and one chinook salmon were hatchery or natural outmigrants. The two steelhead and one cutthroat trout that we collected could be considered potential predators on juvenile chum or chinook salmon.

A volunteer salmon restoration group, Wild Olympic Salmon, released into Chimacum Creek an estimated 40,000 chum fry (~600-700/lb) on March 27, 1999, and another 40,000 chum fry (~500/lb) on April 23, 1999. These fish had no external markings or means of identifying them as Chimacum Creek chum (e.g., adipose removed, fin clipped). The mouth of Chimacum Creek is approximately 6 miles from the Port Townsend ferry terminal, and it is conceivable that some of the chum fry we captured near the terminal were outmigrants from Chimacum Creek. The Port Townsend shoreline has been documented to have extensive eelgrass beds (Norris and Hutley 1997) that are known to support some of the preferred prey organisms of migrating juvenile chum salmon, such as harpacticoid copepods (Simenstad et al. 1999). However, if the chum we collected were from Chimacum Creek, these fry would have been residing along the Port Townsend shoreline for a period of 7 to 10 weeks, much longer than the longest estuarine residence times of up to 2 weeks reported in the literature (Shreffler et al. 1990).

As with the diving survey, shiner perch were the only species that we identified as a potential hydroacoustic "target" on the echograms that could be confused with juvenile salmon, because of their similar body length, school size, and common occurrence around over-water structures and in nearshore habitats, especially eelgrass.

Split-Beam Hydroacoustics

Although we gathered continuous single-beam data and periodic (dawn and dusk) split-beam data from June 9 to 11, 1999, we restricted our data analysis to only those periods of time when identified salmonids were in the vicinity of the Port Townsend ferry terminal. We know that the salmon fry that we released at 1830 h on June 11, 1999 moved from the release site to the ferry terminal without hesitation at an average speed of 0.1 m/s on an ebbing tide. We do not know whether this documented migration behavior is attributable simply to the released fish moving with the outgoing tide or some other combination of factors. Our original intent had been to release fish at both flood and ebb tides and at various times of the day and night. This was not possible due to otter predation on the majority of the chum and chinook fry that we were holding for experiments.

After temporarily losing track of the released fish, we relocated them underneath the ferry terminal at the light-dark transition (i.e., shadow line) and monitored their movements with the split-beam system for nearly an hour. The fish appeared to be aggregated between the second and third group of pilings in from the southern edge of the terminal. As discussed below in the underwater video section, we believe that these fish were using the darkness of the shadow line as a refuge from potential predators.

The data from the stationary and mobile split-beam hydroacoustic transects provided little useful background information on fish locations and movements prior to the release of the known group of chum and chinook fry. Few fish aggregations were identified for any of the sampling periods (listed in Table 2) prior to the salmon fry release. In general, the field log indicates that we observed very little fish activity on the surface during these stationary and mobile sampling events. The echograms for the stationary and mobile monitoring were quite "noisy," because the system was able to only sample at 2 pings per second. We attempted to ping at higher rates, but the Visual Acquisition software could not acquire data at faster rates. The split-beam system we used is vendor rated at up to 30 pings per second, and we are uncertain why the system would not function properly at higher ping rates. A higher ping rate would have smoothed the motion of the boat and given greater definition to the fish schools we observed on the echograms.

Despite the shortcomings of the split-beam hydroacoustics monitoring, we did learn several valuable lessons that have implications for the proposed Phase III research:

- split-beam technology is complex, but we now have a clear understanding of the deployment and data processing requirements to track juvenile salmonid releases in Puget Sound
- split-beam technology is also expensive, and our efforts to trim costs by using Battelle equipment, rather than leased equipment, resulted in delays. Delaying our experiments until June when the Battelle split-beam system was available meant that we had to hold the chum and chinook fry too long. The end result was high mortality from otter predation and a compromised study design. For future studies, all necessary hydroacoustic equipment needs to be available at the time of the peak outmigration of the salmon species being tracked.

Single-Beam Hydroacoustics

The plan for the fixed-location, single-beam systems was to detect and possibly track schools of fish near the Port Townsend ferry terminal using an equipment deployment that was developed for hydropower fish passage evaluations. Using this deployment, we were able to detect both individual fish and schools in the water column; however, we did not have sufficient spatial or temporal resolution to track fish movements. We used data visualization to show and mitigate the effects of structural components (e.g., the bottom return, pilings) and how they varied over time due to the tidal influence. At night the split-beam mobile surveys found few fish aggregations, yet we continued to log detections with the single-beam hydroacoustic array. We suspect, based on these preliminary data and professional opinion, that a variety of fish species may use the terminal as a refuge at night. We have no underwater video or visual observations to confirm or disprove this hypothesis.

Hydroacoustic passage studies near hydropower installations assume that fish are entrained in the acoustic sampling volume. In other words, fish enter and exit the ensonified portion of the water column once and only once. Based on this assumption, the squinted-pair configuration was created to track the direction of travel of individual fish using single target tracking. The entrainment assumption, as predicted, is not valid in a more dynamic marine setting such as the Port Townsend ferry terminal. The spatial resolution due to beam spreading inherent in active sonar systems limits the detection of individuals to locations where fish are relatively isolated in space and time. Thus, we were obligated to use an echo integration technique for data processing.

An important limitation that hydroacoustics will never overcome is the speciation of fish targets. We saw that both individual fish and schools were detected with the single beam system during the day and at night. We could not and will not be able to determine the species of those fish strictly from the acoustic output. The Tecplot examples shown in Figures 17, 18, and 19 are believed to be the chinook salmon fry from the release; however, we know this only because these fish were tracked and visually identified to be at that location at that time. An examination of the single-beam data collected over the entire sample period shows the presence of other fish targets near the ferry terminal. We also know from the beach seine data and video records that many fish species were present in the vicinity of the ferry terminal throughout our study. The presence of so many fish species severely limits the potential benefit of a fixed-location hydroacoustic deployment without concurrent intensive efforts to identify the fish targets.

Underwater Video

The underwater video cameras confirmed our surface observations that the chinook salmon we released for our experiments preferred to stay in the darkness of the Port Townsend ferry terminal shadow. Following the experimental fish release, no chum salmon were ever recorded on either the black-and-white or color camera. The chinook that we released appeared to aggregate underneath the terminal at the dock shadow line, initially at a distance of 11 to 14 m north of the southern edge of the terminal near the second set of pilings underneath the terminal. For 1 h we were able to sit along the pilings at the southern edge of the terminal and monitor the behavior of the fish with the underwater video system, the split-beam hydroacoustics, and surface observations. On several occasions the fish surfaced within 1 m-5 m from the boat, and we were able to make positive identification that what we were seeing on the video monitors and split-beam echograms were chinook fry. Although we cannot say definitively that these were the same fish we released, we are confident that they were, based on their body size, and on the fact that we tracked the release group with the split-beam hydroacoustics to this exact location.

The chinook fry demonstrated a very consistent pattern of rising from the darkness of the dock shadow line into the light and then immediately diving down and back into the dark again (**Figure 30**). We assume that the fish were rising to the surface to feed. However, we cannot make a definitive determination, because we did not take surface water samples of potential prey organisms, nor did we collect any of the chinook fry for gut-content analysis. The fry appeared to be using the shadow line created by the terminal as a refuge before and after they darted to the surface. As the sun dropped lower in the sky and the shadow line moved further underneath the dock, the chinook fry appeared, based on our surface observations, to move with the shadow line.

Similar preferences of migrating juvenile salmon for shaded areas have been reported in several other studies. Based on the Phase I literature review, there is some evidence, predominantly observational, that salmon fry tend to use both natural refuge (e.g., vegetation such as eelgrass) and darkness (e.g., shading from over-water structures, turbidity) as refuge from potential predators (Simenstad et al. 1999). The authors suggested that the physical design of an over-water structure can influence whether the shadow cast on the nearshore covers a sufficient area and level of darkness to constitute a barrier for migrating salmon. In laboratory experiments performed at the MSL in 1995, Jorgensen found that, in all 55 tests of juvenile coho (*Oncorhynchus kisutch*) preference for shaded versus unshaded areas, the fish (mean length =125mm) preferred areas of shade created by simulated over-water structures or the sides of the experimental tank (unpublished data, Jorgensen 1995). During dockside video and underwater observations of fish passage through the Pier 64/65 short-stay moorage facility, Taylor noted that juvenile salmon showed a distinct preference for the edges of over-water structures or the

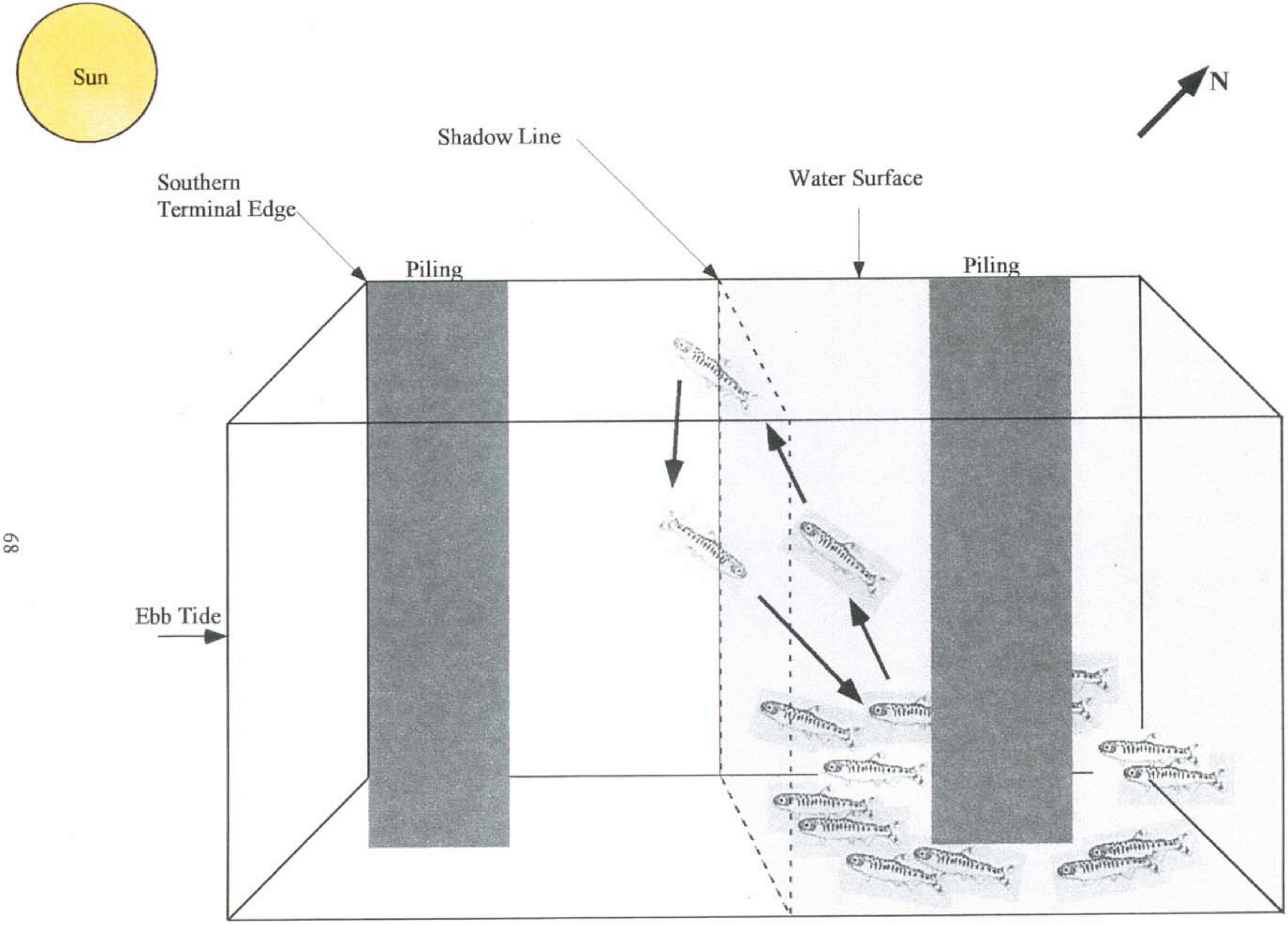


Figure 30. Illustration of the observed and videotaped chinook fry orientation within the shadow line underneath the Port Townsend ferry terminal, and their consistent surface-darting behavior, June 11, 1999

shade cast by these structures (Taylor 1997). Pentec Environmental (1997) also reported that juvenile salmon moving through the industrialized Everett Harbor used dark areas for predator refuge. Differences in behavioral responses of individual juvenile salmon to shaded areas or darkness may be a function of the size of the individuals and the size of the school (Simenstad et al. 1999).

In contrast, other studies of juvenile salmon behavior around over-water structures have suggested that juvenile salmon migration patterns may be more influenced by prey availability than predator avoidance (Prinslow et al. 1980; Cardwell et al. 1980; Weitkamp 1982, 1993; Dames & Moore Inc. and Biosonics 1994). Modifications to light, temperature, salinity, nutrient levels, and wave action beneath an over-water structure influence the rate of photosynthesis, plant distribution, and survival of specific plant species that directly or indirectly support prey resource composition and production (Simenstad et al. 1999). We suspect that any over-water structure that interferes with the availability of light may contribute to a decrease in the production of critical plant material essential to the detritus-based, copepod-salmonid food web system upon which juvenile chum and ocean-type chinook depend during their nearshore migration (e.g., Sibert et al. 1977; Healey 1982; Cordell 1986; Simenstad and Salo 1982; Wissmar and Simenstad 1988). A single over-water structure, such as the Port Townsend ferry terminal, may not have a direct, quantifiable effect on the food web. However, juvenile salmon migrating along Puget Sound shorelines encounter multiple over-water structures during their seward migration. The effect of cumulative loss and modification of juvenile salmon prey resources resulting from over-water structures has not been examined.

Light Measurements

Light monitoring provided an indication of the relative difference between the edge and middle (darkest) portion of the terminal, as well as an indication of how light varied at each of these points over the day. In summary, light is very low for most of the day under the terminal. Light along the southern edge is much greater, and remains high throughout the day. Incident solar irradiance, water depth, wind chop, and suspended matter all probably influence the level of light. There appears to be a period in early morning and late afternoon when light levels increase under the mid-point of the terminal, which was likely related to lower sun angle and low tides. Ultimately, as we gather more light data at a number of different terminals in Phase III, the light data can be compared with fish movement data to understand if there is a threshold light level to which fish respond.

CONCLUSIONS

One of the major limitations to interpreting the findings of our Phase II research is that we were only able to perform one release experiment. Without replication, there is no way to determine with certainty or statistical significance the meaning of the fish behavior we observed. For the one small group of fish we released on one ebbing tide, the Port Townsend ferry terminal did not appear to be a barrier to their migration.

In contrast to the Phase 1 finding that schools of salmon fry and and fingerlings often disperse upon encountering docks (Simenstad et al. 1999), the chinook fry in our Phase II experiment stayed in a school and did not disperse upon encountering the Port Townsend ferry terminal. We also found no evidence from the single-beam hydroacoustics that the terminal caused the released chinook to divert their migratory route into deeper water or around the offshore perimeter of the terminal. From the single-beam and split-beam hydroacoustics data, we know that the released chinook fry traveled approximately 30 m in a relatively straight line from the release point to the shadow line underneath the southern edge of the terminal. Within 5 min post-release, the chinook fry stopped their migration at the shadow line, rather than immediately continuing underneath the terminal. For approximately 1 h, we monitored individual chinook fry with underwater video and surface observations. The fry consistently swam from the darkness of the dock shadow line into the light and then immediately darted down and back into the dark again. We suggest, based on our best professional judgment, that the fish were rising to the surface to feed, but we have no gut-contents data to confirm or dismiss this contention. As the sun dropped lower on the horizon and the shadow line moved further underneath the terminal, the chinook school appeared to follow the shadow line staying near the light-dark transition.

Based upon our preliminary findings at Port Townsend, we caution that it is neither prudent nor valid to conclude that ferry terminals either do or do not have an effect on juvenile salmon migration. As previously noted, a number of hurdles and unexpected misfortunes jeopardized the Phase II 1999 field studies at the Port Townsend ferry terminal. The loss of the majority of our fish for experiments, the hard-drive crash on the navigation computer, and the malfunctioning of some of the single-beam transducers compromised this study. The fundamental question of whether ferry terminals are a "barrier" to juvenile salmon migration remains unanswered. Further salmon behavior studies at additional WSDOT ferry terminals are strongly recommended for Phase III.

We suggest that the mechanisms by which ferry terminals or other over-water structures could increase mortality of juvenile salmon need to be investigated further. As we stated in the introduction of this report, these potential mechanisms include 1) introducing a "behavioral barrier" that deflects fish into deeper waters without refugia or delays their migration, 2) dispersing schools, 3) decreasing growth and residence times because of limited prey resource production and availability, and 4) increasing predation by aggegating predators or heightening the predation rates of predators associated with over-water structures.

RECOMMENDATIONS

Drawing upon the successes and failures of the Phase II field effort, we offer the following recommendations in the hope of facilitating rigorous Phase III field investigations at several different WSDOT ferry terminals:.

- We recommend implementing controlled field experiments in Phase III to explore the effects of different ferry terminals and settings on responses by migrating juvenile salmon. Mark-recapture type experiments should be conducted "above" and "below" several ferry terminals to rigorously assess both behavior and consequences (e.g., survival, food consumption) of marked juvenile salmon. The number of released fish, distance from the release location to the terminal, time of day/night, and tidal cycle are all variables that should be taken into account in designing the mark-recapture experiments. Variability in dock structure and ferry operations, environmental setting, and seasonal and artificial lighting effects should also be considered.

- To avoid the problems that we encountered in Phase II with river otters, Phase III studies should minimize the amount of time that hatchery salmon fry must be held in floating net pens, or rely solely on natural outmigrants rather than hatchery fish that need to be acclimated to the conditions at the release site.

- Because of the difficulties we experienced in obtaining chinook and chum fry of the size we wanted at the time we wanted and the required transfer permits, we recommend starting this process much earlier (i.e., the winter before the spring field season). It would be especially beneficial to include WDFW as a partner in the Phase III studies. WDFW's involvement would help to ensure the availability of marked fish at appropriate times, the avoidance of

ESA permitting delays, and also assistance with field experiments from experienced staff biologists.

- A remote-controlled camera platform that could be maneuvered underneath a ferry terminal and around pilings at the same time the operator is viewing the video screen would be particularly useful for Phase III studies. The best video footage we obtained of juvenile salmon behavior in Phase II studies was during the time period when we were manually maneuvering the cameras underneath the terminal to locate the chinook fry we had released. Based on our experiences at the Port Townsend terminal, stationary cameras at fixed locations may not provide much useful data.

- We recommend that *in situ* light levels must be monitored in conjunction with any fish behavior studies proposed for Phase III. We know that juvenile salmon behavior is influenced by light. Light is necessary for spatial orientation, prey capture, schooling, predator avoidance, and migration navigation (Simenstad et al. 1999). However, the specific mechanisms by which light influences juvenile salmon behavior are unknown and will require documenting both minimum light levels during periods of migration and threshold levels for specific behavioral responses. Ultimately, what is needed is a statistical model for predicting light levels, which can then be translated into ferry terminal design parameters (e.g., dock height above water, width, orientation, construction materials, lighting,) to mitigate for potential impacts on migrating juvenile salmon.

- Phase III of the WSDOT research program should also address differences in prey resources (e.g., species, size, distribution, and abundance) along shading and tidal elevation gradients within and adjacent to ferry terminals. In conjunction with these prey studies, the gut contents of juvenile salmon that have been feeding in the vicinity of ferry terminals should be sampled to verify selectivity of prey organisms.

- We recommend exploring the potential for acquiring and deploying the Limpet Mine Imaging Sonar (LIMIS) system for Phase III studies. The LIMIS system was originally developed at the University of Washington's Applied Physics Laboratory as a diver-held sonar for detecting mines on ship hulls and had not been considered for fisheries research applications until after we completed this field study. LIMIS is a high resolution imaging sonar that best fits the description of an acoustic flashlight. It is unaffected by water clarity and can be deployed in zero-visibility conditions. The output of the LIMIS system is video-like images of fish or underwater structures at ranges up to 10 m. Recent tests of the LIMIS system at the Battelle-operated Pacific Northwest National Laboratory (PNNL) proved that it can provide an underwater view unattainable with conventional fisheries hydroacoustics. Results from the mobile split-beam system used in this study showed that the released juvenile salmon stayed within 8 m of the tracking boat, well within the operating range of a LIMIS sonar. Therefore, it would be possible to use a mobile LIMIS system to track released fish (schools or individuals) with the added benefits of a 20-degree field of view and no interference from structures. For example, a small mobile platform could be used to track salmon schools from a release point, underneath a terminal (between pilings and in shallow water) and out the opposite side.

- Finally, we advise against deploying fixed-location hydroacoustics of any kind (e.g., single-beam, split-beam, or multi-beam) as the costs outweigh the benefits.

ACKNOWLEDGMENTS

A project of this magnitude could not have succeeded without the support and enthusiasm of many individuals. Our sincere thanks to Jim Schafer of WSDOT and Pat Cagney of USACE-Seattle District for funding our research; without their perseverance, guidance, and creative cost-sharing agreement, this project may never have been carried out. Betsy Poulson and Jan Slater of Battelle and Nancy Walker of URS Greiner put in many extra hours to implement a complex, five-party contracting process. Rick Brater and Paul Wagner of WSDOT and Si Simenstad of UW provided critical input at various stages of the scoping and planning of our research. Steve Long, the terminal agent at Port Townsend, was very helpful in coordinating the location of our Ryder truck operations center, access to power supplies and fresh water, and other on-site logistics. Tom Jay and Bob Marett from Wild Olympic Salmon were kind enough to loan us several net pens, predator nets, and automatic fish feeders, which the resident river otters at the Port Townsend marina subsequently damaged.

The salmon fry for our experiments were provided by WDFW and USFWS. We are grateful for the efforts of Thom Johnson and Andy Appleby from WDFW and Larry Telles and Dave Zajac from USFWS in helping us locate, transport, and transfer chinook and chum fry to our floating net pens in the Port Townsend marina.

The Battelle-USACE-UW field crew worked long hours to complete the experiments. In particular, we want to recognize the contributions of Paul Farley and Bob Johnson from Battelle, Jeff Dillon, Dean Paron, and Fred Goetz from USACE-Seattle District, and Barb Nightingale from UW. Paul Farley deserves recognition for his intense efforts to get all of the hydroacoustics and underwater video equipment constructed, deployed, and operating smoothly, as well as for his boat-operating skills. Bob Johnson was instrumental in planning and

implementing several phases of the hydroacoustics monitoring effort, including study design, costing, and equipment deployment. Barb Nightingale is to be commended for her invaluable assistance with processing of the single-beam hydroacoustics data.

We also wish to acknowledge our many coworkers who contributed to this project: Steve Anglea, Liam Antrim, Pete Becker, Val Cullinan, Ann Drum, Bill Gardiner, Ron Thom, Amy Borde, and Eve Fagergren. The following volunteers provided vital help in our attempts to rescue the salmon fry from the relentless incursions of the river otters at the Port Townsend marina: Jim Hackman, Ann Soule, Chris Duff, Mike Kennedy, and Duffy Nightingale.

The clarity of this document was improved through diligent reviews by Susan Thomas, Ron Thom, Jim Schaefer, Pat Cagney, and Jeff Dillon. Finally, we are especially appreciative of the tireless efforts of Barb Nightingale, who spent many anxious, sleepless hours on the mooring dock trying to keep the river otters out of our salmon net pens.

REFERENCES

Ali, M.A. 1959. The ocular structure, retinomotor and photobehavioral responses of juvenile Pacific Salmon. *Can. J. Zool.* 37:965-996.

Cardwell, R.D., S.J. Olsen, M.I. Carr, and E.W. Sanborn. 1980. *Biotic, water quality, and hydrologic characteristics of Skyline Marina in 1978.* Tech. Rep. 54, Washington Department of Fisheries, Olympia, Washington.

Cordell, J.R. 1986. *Structure and dynamics of an epibenthic harpacticoid assemblage and the role of predation by juvenile salmon.* Master's thesis, University of Washington, Seattle, Washington.

Dames & Moore Inc., and Biosonics. 1994. *Salmon migration study: Manchester Naval Fuel Pier, Manchester, Washington. March 1993-June 1993.* Report to U.S. Navy, Seattle, Washington.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: the life support system. Pp. 315-341 *in* V.S. Kennedy (ed.), *Estuarine Comparisons*, Academic Press, New York, New York.

Healey, M.C. 1991. Life history of chinook salmon. Pp. 311-393 *in* C. Groot and L. Margolis (eds), *Pacific Salmon Life Histories*, UBC Press, Vancouver, Canada. 564 pp.

Johnson G.E., R.A. Moursund, and J.R. Skalski. 1998. *Fixed-location hydroacoustic evaluation of spill effectiveness at Lower Monumental Dam in 1997.* Prepared for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Johnson, R.L., R.A. Moursund, and M.A. Simmons. 1999a. *Fish behavior in front of the prototype surface collector at Bonneville Dam in 1998.* Final report submitted to Portland District, U.S. Army Corps of Engineers, January 1999 by Battelle Pacific Northwest National Laboratory, Richland, Washington.

Johnson, R.L., S.M. Anglea, S.L. Blanton, M.A. Simmons, R.A. Moursund, G.E. Johnson, E.A. Kudera, J. Thomas, and J.R. Skalski. 1999b. *Hydroacoustic evaluation of fish passage and behavior at Lower Granite Dam in spring 1998.* Final report submitted to Walla Walla District, U.S. Army Corps of Engineers, February 15, 1999 by Battelle Pacific Northwest National Laboratory, Richland, Washington.

Jorgensen, Kevin. 1995. *Effects of over-water structures on the behavior of juvenile coho salmon.* Final report prepared for AWU SERS internship program, Richland, Washington.

Norris, J.G., and T. Hutley. 1997. *Habitat utilization/water quality study: interim data report.* Prepared for the Port Townsend Marine Science Center,Fort Worden State Park, 532 Battery Way, Port Townsend, Washington.

Pentec Environmental. 1997. *Movement of juvenile salmon through industrialized areas of Everett Harbor.* Prepared for Port of Everett by Pentec Environmental, Edmonds, Washington.

Prinslow, T.E., E.O. Salo, and B.P. Snyder. 1980. *Effects of wharf lighting on outmigrating salmon, 1979, U.S. Naval Submarine Base-Bangor.* Report to U.S. Navy, FRI-UW-8007, Fisheries Research Institute, University of Washington, Seattle, Washington.

Salo, E.O. 1991. Life history of chum salmon. Pp. 231-309 *in* C. Groot and L. Margolis (eds), *Pacific Salmon Life Histories*, UBC Press, Vancouver, Canada. 564 pp.

Shreffler, D.K., C.A. Simenstad, and R.M. Thom. 1990. Temporary residence by juvenile salmon in a restored estuarine wetland. *Canadian Journal of Fisheries and Aquatic Sciences* 47 (11):2079-2084.

Sibert, J.R., T.J. Brown, M.C. Healey, B.A. Kask, and R.J. Naiman. 1977. Detritus-based food webs: exploitation by juvenile chum salmon (*Oncorhynchus keta*). *Science* 196:649-650.

Simenstad, C.A. and E.O. Salo. 1982. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (*Oncorhynchus keta*) in Hood Canal, Washington. Pp. 21-37 in B.R. Metleff and R.A. Neve (eds.). *Proc. North Pac. Aquaculture Symposium, 18-27 August 1980.* Anchorage, Alaska and Newport, Oregon. Alaska Sea Grant Rep. 82-2. University of Alaska, Fairbanks, Alaska. 372 pp.

Simenstad, C.A., R.M. Thom, and A.M. Olson. 1997. *Mitigation between regional transportation needs and preservation of eelgrass beds.* Report No. WA-RD 421.1. Washington State Transportation Center (TRAC), Seattle, Washington.

Simenstad, C.A., B. J. Nightingale, 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.

Taylor, W.S., and W.S. Willey. 1997. *Port of Seattle fish migration study. Pier 64/65 short-stay moorage facility: Qualitative fish and avian predator observations.* Draft report to the Port of Seattle prepared for Beak Consultants Inc., Seattle, Washington.

Weitkamp, D.E. 1982. Juvenile chum and chinook salmon behavior at Terminal 91, Seattle, Washington. Prepared for Port of Seattle by Parametrix, Seattle, Washington.

Weitkamp, D.E. 1993. Light and juvenile salmon under pier aprons: literature review. Prepared for Port of Seattle by Parametrix, Seattle, Washington.

Wissmar, R.C. and C.A. Simenstad. 1988. Energetic constraints of juvenile chum salmon migrating in estuaries. *Can. J. Fish Aquat. Sci.* 45:1555-1560.