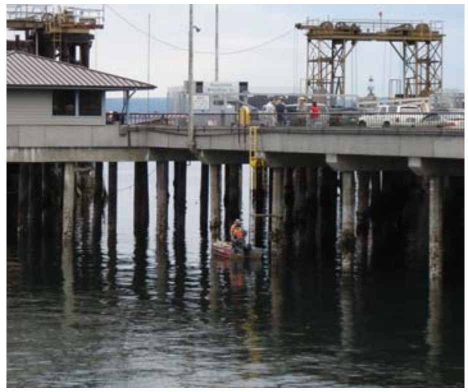
PNWD-3647

Impacts of Ferry Terminals on Juvenile Salmon Movement along Puget Sound Shorelines



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Battelle Memorial Institute
Pacific Northwest Division

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16. ABSTRACT

This study used both standardized surveys and innovative fish tagging and tracking technologies to address whether WSF terminals alter the behavior of migrating juvenile salmon, and if so, which attributes mediate abundance patterns or behavioral changes. Results showed that juvenile salmon were observed most frequently adjacent to ferry terminals, but were also observed far from and underneath the terminals. In some situations, juvenile salmon aggregated near the edge of the ferry terminal OWS (over-water structures). Variations in habitat, as mediated by tidal stage (affecting current magnitude and direction, light under structures, water level) and time of day (light level, sun angle, cloud cover), likely affect salmonid movement. Juvenile chum were observed to remain on the light side of a relatively sharp light-dark “edge” over a short horizontal distance (e.g., five meters). These observations demonstrate that the shading caused by ferry terminals and other OWS characteristics can deter or delay juvenile salmonid movement, and that this effect may be decreased at low tides when ambient light can better filter beneath the terminal structure. Recommendations are made concerning the design and operation of WSF terminals with regard to minimizing the undesirable impacts of OWS on juvenile salmonid movement as well as additional research.

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Executive Summary

This research was supported by the Washington State Department of Transportation, Washington State Ferries (WSF), which is interested in identifying and quantifying the possible impacts of ferry terminals and ferry operations on the marine resources of Puget Sound. Although WSF terminals constitute a very small fraction of the total shoreline structures, ferry terminals can be used as models to address questions concerning the effects of over-water structures (OWS) on aquatic species.

Over-water structures (OWS), such as ferry terminals, bridges, and temporary work trestles, may affect juvenile salmon, especially chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*), directly, by disrupting migratory behavior along the shallow-water nearshore zone. Although individual shoreline structures may not impose significant impacts on salmon species, populations, or stocks, the cumulative effect of dense, contiguous shoreline modifications is likely a contributor to the present decline of several Puget Sound salmon species and may inhibit the success of recovery actions (Williams and Thom 2001).

Residence times for salmonids in the Puget Sound region vary with species, location, time of year, and other factors. As the juvenile salmon move along the nearshore on their way to the ocean, they inevitably encounter OWS. However, few studies have actually assessed the influence of OWS on juvenile salmon aggregation or movement during peak out-migration periods. The research that has been reported has shown that the response of fish to OWS is complex. Individuals of some species readily pass under OWS, some pause and go around, schools may disband upon encountering OWS, and some schools pause and eventually go under OWS en masse (Nightingale and Simenstad 2001).

This study used both standardized surveys and innovative fish tagging and tracking technologies to address whether WSF terminals alter the behavior of migrating juvenile salmon, and if so, which attributes mediate abundance patterns or behavioral changes. To address these issues, visual surveys at 10 terminals (total of 30 surveys), light measurements at 10 terminals, a total of 160 snorkel surveys at two terminals, and enclosure net monitoring and acoustic tagging and telemetry at one terminal were used to investigate variables affecting juvenile salmon abundance and behavior.

Results showed that juvenile salmon were observed most frequently adjacent to ferry terminals (within 10 m of the edge of the OWS), but were also observed far from (10 to 50 m away) and underneath the terminals. This observation illustrates that, in some situations, juvenile salmon aggregate near the edge of the ferry terminal OWS. Variations in habitat, as mediated by tidal stage (affecting current magnitude and direction, light under structures, water level) and time of day (light level, sun angle, cloud cover), likely affect these movements. At the 22 m-wide Fauntleroy terminal, juvenile salmonids observed aggregating adjacent to the terminal were deeper in the water column, as opposed to nearer the surface at sites located away from the terminal. At the 24 m-wide Edmonds terminal, juvenile salmon were only observed underneath the dock during low tide. All other regions sampled had observations at both high and low tides, at similar densities for chinook and coho salmon. Juvenile chum were observed to remain on the light side of a dark/light shadow line at the 51 m-wide Clinton terminal when the decrease in light level was approximately 85%, which created a relatively sharp light-dark “edge” over a short horizontal distance (e.g., five meters). These observations demonstrate that the shading caused by ferry terminals and other OWS characteristics can deter or delay juvenile salmonid movement, and that this effect may be decreased at low tides when ambient light can better filter beneath the terminal structure.

The acoustic tagging study at Port Townsend indicated that the juvenile chinook and coho moved under and past the structures quickly during the late evening when there was a less distinct shadow boundary than during full daylight. This feasibility study showed that acoustic tagging and tracking technology appears to be a useful tool for investigating the movement and behavior of juvenile salmon around ferry terminals and other OWS.

The following recommendations were made concerning the design and operation of WSF terminals with regard to minimizing the undesirable impacts of OWS on juvenile salmonid movement as well as additional research:

1. To minimize the shade-related impacts to migrating juvenile salmonids created by ferry terminals, OWS should be designed and constructed to allow incidental light to penetrate as far under as possible, while still providing the necessary capacity and safety considerations necessary to support their intended function. The physical design (e.g., dock height and width, dock orientation, construction design materials, piling type and number) will influence whether the shadow cast on the nearshore covers a sufficient area and level of darkness to constitute an impediment. Construction of closely spaced terminal structures should be avoided to minimize the potential cumulative impacts of multiple OWS on juvenile salmonid migration (Nightingale and Simenstad 2001).
2. Experiment with technologies and designs that can soften the light-dark edge to minimize potential temporary inhibition of movement.
3. Based on earlier research (Blanton et al. 2002), the incorporation of light-enhancing technologies in OWS design is likely to maintain light levels under OWS above that required by juvenile salmonids for feeding and schooling (i.e., estimated at between 0.0001 and 1 ft candles, depending on age and species [Ali 1959]). To encourage daytime movement under terminals and other OWS, it would be beneficial to decrease the dark-edge effect as much as possible. Providing even a small amount of light in a regular pattern under a dock may encourage fish to swim underneath. Natural lighting for fish could also be enhanced if the underside of the dock was reflective.
4. Continued research is needed to improve our understanding of the relationship between OWS and the behavior of migrating juvenile salmonids. The use of acoustic tagging-tracking technology demonstrated during this study should be further used to address the data gaps in our level of knowledge.
5. Fish feeding behavior during temporary delays of movement should be investigated. If prey resources and refuge habitat are adequate, fish may benefit from holding in an area adjacent to a terminal.

Acknowledgements

This study would not have been possible without the assistance of many individuals. First of all, we would like to gratefully acknowledge the continued support of this work by Washington State Department of Transportation personnel and contractors, including Rhonda Brooks, Paul Wagner, Marion Carey, Kojo Fordjour, Russ East, Sasha Visconti, and Joel Colby, as well as the terminal operators and ferry captains who accommodated us on many occasions. Their commitment to funding this type of research provides one of the few avenues whereby we continue to advance the state of the science.

We would also like to thank the scientists, policy makers, and agency personnel who participated in the 2002 University of Washington workshop on impacts of overwater structures to the marine environment. Thanks also to Dr. Martin Miller of the Pacific Northwest National Laboratory (PNNL) for his peer-review.

Members of the Wetland Ecosystem Team at the University of Washington School of Aquatic and Fishery Sciences assisted with fieldwork, especially Lia Stamatiou, Sarah Heerhartz, and Janet Miller. During tagging studies, field assistance was also provided by Kathryn Sobocinski (PNNL), by Samantha Whitcraft and Natasha Davis (National Oceanic and Atmospheric Administration), and by Dave Duvall (Grant County Public Utility District). The Port Townsend Marine Science Center allowed use of their flow-through tanks for holding fish prior to release.

Glossary

CPUE	catch-per-unit effort
DPS	distinct population segment
ESA	Endangered Species Act
ESU	evolutionary significant unit
LWD	large woody debris
NMFS	National Marine Fisheries Service
OWS	over-water structures
PAR	photosynthetically active radiation
PNNL	Pacific Northwest National Laboratory
ppt	parts per thousand
SAV	submerged aquatic vegetation
USACE	U.S. Army Corps of Engineers
UW-SAFS	University of Washington School of Aquatic and Fishery Sciences
WDFW	Washington Department of Fish and Wildlife
WSDOT	Washington State Department of Transportation
WSF	Washington State Ferries

Noted Marine Species

Common Name	Scientific Name
bull trout	*Salvelinus confluentus*
chinook	*Oncorhynchus tshawytscha*
chum	*Oncorhynchus keta*
coho salmon	*Oncorhynchus kisutch*
herring	*Clupea harengus pallasi*
sand lance	*Ammodytes hexapterus*
surf smelt	*Hypomesus pretiosus*
eelgrass	*Zostera marina*
green algae/ "sea lettuce"	*Ulva* spp.

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1.0 Introduction

Over-water structures (OWS), such as ferry terminals, bridges, and temporary work trestles, may affect juvenile salmon, especially chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*), directly, by disrupting migratory behavior along the shallow-water nearshore zone. Although individual shoreline structures may not impose significant impacts on salmon species, populations, or stocks, the cumulative effect of dense, contiguous shoreline modifications is likely a contributor to the present decline of several Puget Sound salmon species and may inhibit the success of recovery actions (Williams and Thom 2001).

Increasing demand for fast, safe, and efficient ferry service will likely require WSF to expand its ferry terminal infrastructure. In addition, many ferry terminals are reaching the end of their effective service life and will require structural renovation. Consequently, there is a practical need to gather data that can contribute to scientific assessments of ferry terminal effects on nearshore resources, such as juvenile salmon and the ecological processes that sustain them.

Residence times for salmonids in the Puget Sound region vary with species, location, time of year, and other factors. As the juvenile salmon move along the nearshore on their way to the ocean, they inevitably encounter OWS. However, few studies have actually assessed the influence of OWS on juvenile salmon aggregation or movement during peak out-migration periods. Although WSF terminals constitute a very small fraction of the overall extent of docks, piers, and other shoreline structures (currently, ferry terminals are located along only 0.4 linear miles of Puget Sound's more than 2000 miles of shoreline), WSDOT has an opportunity to use WSF terminals as models to address questions concerning the effects of OWS on aquatic species. Because of the increased concern for Puget Sound salmon stocks listed under the Endangered Species Act (ESA), WSDOT and WSF are specifically interested in resolving these issues and finding approaches to minimize damaging impacts.

In 1998, WSDOT initiated a comprehensive research program to evaluate the nearshore effects of its ferry terminals on migrating juvenile salmon. A research team composed of scientists from the University of Washington School of Fisheries, School of Marine Affairs, and the Battelle Marine Sciences Laboratory was reassembled to assess three topics of concern, the first of which is addressed in this paper:

1. The degree to which ferry terminals act as impediments to estuarine-nearshore migration of juvenile salmon
2. The degree to which ferry terminals affect estuarine secondary productivity that supports juvenile salmon foraging
3. The influence of ferry terminals in attracting or concentrating predators for migrating juvenile salmon.

Specific objectives of the research presented in this paper are:

1. Determine whether there are differences in the abundance of juvenile salmon under, adjacent to, or far from WSF ferry terminals;
2. If there are differences, determine whether WSF terminals alter the behavior (residence time, activity patterns, movement rates) of migrating salmon fry;
3. In addition, establish light level and dock characteristic thresholds that mediate any observed behavioral changes or abundance patterns.

This study utilized conventional methods for observing salmon movement and behavior (i.e., visual observations from shore, snorkeling, and seining) along with new experimental technologies that allow tagging and tracking of small individual fish. The tracking technology was tested for its ability to track juvenile salmon movement near OWS in a marine environment. The effort was divided into three tasks, which are broken out separately in the methods (Section 3) and results (Section 4). The three tasks are:

1. **Visual Surveys:** use land-based observations to characterize the distribution and abundance of chum salmon fry relative to 6-8 WSF terminals and paired reference sites without overwater structures over four weeks in April and May.
2. **Snorkel Surveys and Enclosure Nets:** use enclosure nets and snorkel surveys to characterize the distribution and abundance of juvenile chinook and coho salmon relative to 3-4 WSF terminal and paired reference sites without overwater structures over four weeks in June and July.
3. **Acoustic Tag and Telemetry:** evaluate the feasibility of applying new acoustic telemetry technology[1] to provide information on juvenile salmon movement around overwater structures in a marine environment. This task involved tagging and intensive tracking of up to 20 juvenile chinook and/or coho salmon at one WSF terminal site over a week period in June.

Together, the results from these studies will help to develop a comprehensive set of data and observations regarding the influence of overwater structures on juvenile salmon movement. This information is used by WSF to make decisions on terminal designs and modifications and to negotiate projects, permit conditions, and mitigation requirements to construct or modify ferry terminal projects.

[1] The subject acoustic telemetry technology is being developed jointly by NOAA Fisheries and Pacific Northwest National Laboratory with funding from the U.S. Army Corps of Engineers and Battelle Memorial Institute. Inquiries about the technology may be made to the Corps of Engineers, Portland District, Environmental Resources Branch.

2.0 Background

A brief summary of the existing knowledge related to juvenile salmon migration patterns and movement under overwater structures is presented in this section.

2.1 Nearshore Salmon Ecology

All species of salmonids use the nearshore corridor to some extent during their out-migration and rearing periods (Simenstad et al. 1982). Juvenile salmon may be found in these habitats throughout the year, with timing and location depending on species, stock, and life-history stage. The Puget Sound nearshore habitats are structurally complex, highly productive, and dynamic areas that are considered vital habitat for juvenile salmon, because they provide food and refuge from predators (Groot and Margolis 1991, Stouder et al. 1997, Quinn 2005). Three salmonid species are currently listed as threatened under the ESA (Table 1).

Most juvenile salmon enter nearshore marine habitats between early March and late June; however, recent Puget Sound studies have shown juvenile chinook are also common in nearshore habitats from late January through September (Fresh et al. 2003 and Brennen et al. 2004). Of all the salmon species, juvenile chum and chinook salmon are considered the most dependent on nearshore habitats, where they feed and develop before migrating to pelagic marine habitats (Levy and Northcote 1982, Simenstad et al. 1982, Groot and Margolis 1991, Levings 1994, Cordell et al. 1997, Quinn 2005). In general, juvenile salmon restrict their movements to habitats between 0.1 m and 2.0 m depth until they reach a size that allows them to exploit deeper channel and open-water habitats and associated prey resources. Many salmonids enter marine waters when they are only 30 mm to 80 mm in length (Simenstad et al. 1982).

Table 1. Salmonid Use of Nearshore-Estuarine Habitat (Williams and Thom 2001)

			Nearshore Marine and Estuary Use[a]		
Common Name	Scientific Name	Federal Stock Status	Adult Residence	Adult and Juvenile Migration	Juvenile Rearing
Chinook Salmon	*Oncorhynchus tshawytscha*	Threatened - Puget Sound ESU	●	●	●
Chum Salmon	*Oncorhynchus keta*	Threatened - Hood Canal ESU	○	●	●
Coho Salmon	*Oncorhynchus kisutch*	Species of Concern - Puget Sound/Georgia Strait ESU	⊗	●	⊗
Sockeye Salmon	*Oncorhynchus nerka*		○	●	○
Pink Salmon	*Oncorhynchus gorbuscha*		○	●	●
Cutthroat Trout	*Oncorhynchus clarki*		●	●	●
Steelhead	*Oncorhynchus mykiss*		○	●	⊗
Bull Trout	*Salvelinus confluentus*	Threatened - Coastal-Puget Sound DPS	●	●	●

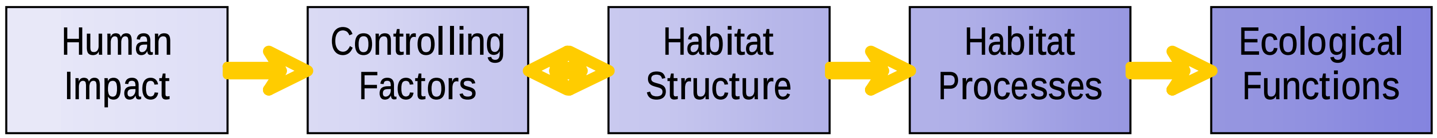
[a] Filled circles represent extensive use, cross-filled circles represent some use, and open circles indicate little or unknown use in these areas.

2.2 Over-Water Structures

Current research supports evidence that OWS influence key ecological *controlling factors*, such as light, that, in turn, determine the habitat characteristics that support critical ecological functions, such as fish migration. Figure 1 illustrates a conceptual model of the linkages between human impacts, habitat characteristics, and ecological function with regard to OWS. Such models are useful for organizing the potentially important variables and ordering relationships among them. Development of the conceptual model is usually an early step in understanding the structures and functions of the ecological system.

Using this conceptual model, an *impact* is defined as any anthropogenic disturbance that can affect a controlling factor. Thus, a dock, pier, or ferry terminal (e.g., OWS) that affects one or more of the controlling factors will be reflected in changes to habitat structure and will influence those ecological functions supported by the affected habitat features.

Light reduction by OWS is well-documented in the Pacific Northwest (Pentilla and Doty 1990, Fresh et al. 1995, Thom and Shreffler 1996, Thom et al. 1996, Thom et al. 1997, Fresh et al. 2001) and in other coastal regions (Backman and Barilotti 1976, Orth and Moore 1983, Thayer et al. 1984, Walker et al. 1989, Loflin 1993, Burdick and Short 1995, Olson 1996, Short and Wyllie-Echeverria 1996, Ludwig et al. 1997, Olson et al. 1997, Able et al. 1998, Burdick and Short 1999, Duffy-Anderson 1999). Research indicates that fish communities under OWS and around adjacent pilings differ from those in undisturbed adjacent areas because of differences in substrate, light availability, and degree of physical disturbance from propeller wash or other operations. In addition, the effects of OWS on migrating juvenile salmon may vary depending on the design and orientation of the structure relative to the shoreline, the extent of alteration of the underwater light field, the presence of artificial light, and cumulative or synergistic effects of multiple OWS or other shoreline modifications (Williams and Thom 2001). The resultant disruption of behavior includes migratory delays due to disorientation, dispersal, and reduced schooling behavior, as well as changes in swimming routes into deeper waters (Simenstad et al. 1999). Much of this migratory disruption is attributed to conflicts in preferences among alternative light conditions (Nightingale and Simenstad 2001).



CONTROLLING FACTORS	HABITAT STRUCTURE	HABITAT PROCESSES	ECOLOGICAL FUNCTIONS
• Tides & Currents • Wave Energy • Sediment Supply • Shoreline Geomorphology • Light Regime • Water Quality	• Vegetation Density • Vegetation Biomass • Vegetation Diversity • Habitat Patch Size & Shape • Substrate Composition • Large Woody Debris (LWD) • Landscape Position	• Primary Productivity • Shading & Cover • Temperature Regime • Sediment Transport (Drift Cell) • Nutrient Flux • Organic Carbon Cycling • Secondary Productivity • Habitat Connectivity	• Prey Production • Spawning • Rearing • Predation • Refugia • Migration • Biodiversity

Figure 1. Conceptual Model of the Impacts of Overwater Structures on Nearshore Ecosystems (adapted from Williams and Thom 2001 and Nightingale and Simenstad 2001)

2.2.1 Fish Response to Changes in the Light Regime

Based on the current level of scientific understanding, changes in nearshore ecological structure and function can influence juvenile salmon behavior and movement patterns. Studies in the Puget Sound region have suggested that under-pier light limitations could result in migration delays due to disorientation (Williams and Thom 2001). Most of the impacts on juvenile salmon migration and behavior can be traced to the influence of OWS on the natural light regime (e.g., under-dock shading and shadow lines). As discussed, OWS can create sharp underwater light contrasts by casting shade in ambient daylight conditions. They can also produce sharp underwater light contrasts by casting artificial light in ambient nighttime conditions.

The impacts of altered underwater light environments upon some aspects of juvenile salmonid physiology and behavior are reasonably well-documented (Fields and Finger 1954, Ali 1959, Dera and Gordon 1968, Puckett and Anderson 1987, Nemeth 1989, Browman et al. 1993, Coughlin and Hawryshyn 1993, Hawryshyn and Harosi 1993, Novales-Flamique and Hawryshyn 1996). Fishes rely on visual cues for spatial orientation, prey capture, schooling, predator avoidance, movement, and migration, and research has shown that many behavioral changes (e.g., minimum prey capture, feeding, and school dispersion) correspond to distinct light-intensity thresholds (Simenstad et al. 1999, Nightingale and Simenstad 2001). Thus, the reduced-light conditions found under an overwater structure may limit the ability of fishes, especially juveniles and larvae, to perform essential activities (NMFS 2005). Figure 2 depicts light conditions found to affect juvenile salmon feeding and schooling behavior. It is presumed that light intensity, or the level of contrast between adjacent shaded and unshaded environments, affect fish movement patterns in a similar manner.

The results from the literature are mixed. In general, research findings have shown that the response of fish to piers is complex, with some individuals passing under the dock, some pausing and going around the dock, schools breaking up upon encountering docks, and some pausing and eventually going under the dock (Nightingale and Simenstad 2001).

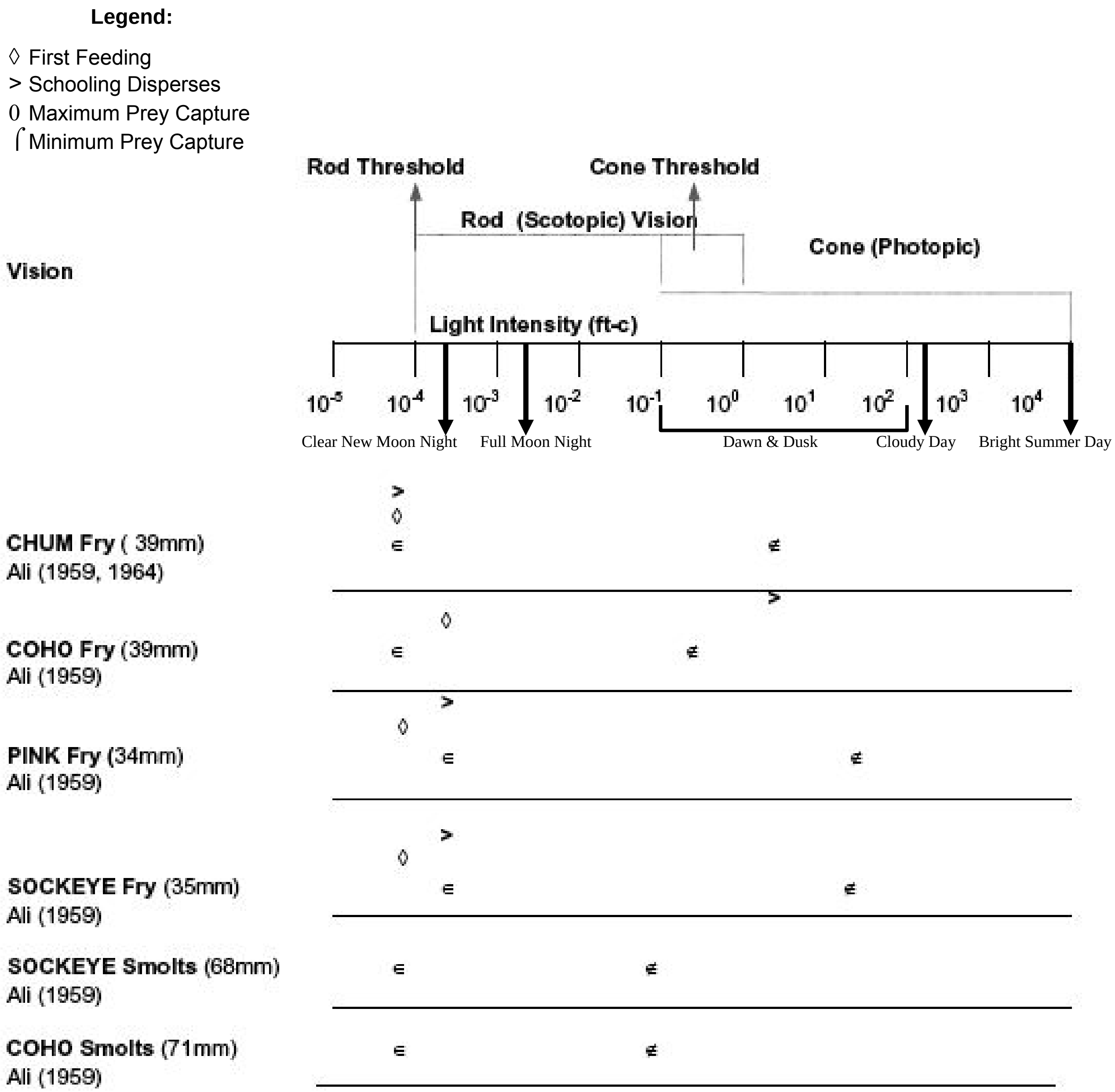


Figure 2. Measured Juvenile Salmon Behavior Patterns Related to Light Intensities (from Williams and Thom 2001, based on data from Ali 1959). (See upper left for symbol legend).

Specific examples of documented fish behavior around OWS from the literature illustrate the variety of responses juvenile salmon may have on encountering a structure. Some studies indicate juvenile salmon are reluctant to swim under docks, while others indicate that fish do swim under docks:

- Heiser and Finn (1970), Weitkamp (1982), and Pentec (1997) reported fish were reluctant to enter shadow zones under docks and areas of sharp contrast.

- Pentec (1997), Taylor and Willey (1997), Simenstad et al. (1999), Williams et al. (2003), and Toft et al. (2004) reported observing fish movement along the shadow zone boundary without penetration into the shadow.
- Shreffler and Moursund (1999) released juvenile chinook at the Port Townsend Ferry Terminal and found that the fish ceased their directional movement at the ferry terminal shadow line rather than immediately continuing under the terminal. Continued video monitoring and surface observations verified that the juvenile salmon consistently swam from the dock shadow line into the light followed by their immediately darting down and back into the light-dark transition area again. As the sun dropped along the horizon and the shadow line moved in under the terminal dock, the chinook school appeared to follow the shadow line, staying within the light-dark transition area.
- Williams and Thom (2001) also found, in some cases, that shoreline structures (including OWS) caused migrating juvenile salmon to move from their preferred shallow-water migration paths into deeper water to avoid the structures.
- Salo et al. (1980) reported that fish shifted from nearshore migration routes to deeper water migration routes to avoid passing under a structure.
- Bax et al. (1980) found that juvenile salmon often shifted their movement routes away from the shoreline (shallow water areas) into deeper water to swim around pier structures.
- Feist (1991) documented juvenile salmon congregating adjacent to piers and other OWS.
- Taylor (1997) and Weitkamp (1981) studied fish at marinas in Elliott Bay and Shilshole Bay. Both studies indicated there was a distribution of juvenile salmon along the outer bulkhead areas of the marinas without significant distribution under or around the floating piers.
- Roni and Weitkamp (1996) monitored juvenile salmon (primarily chum) during the replacement of the US Navy Manchester Fuel Depot pier between 1991 and 1994. The old pier was approximately 12.19 m (40 ft) in width and the replacement pier was less than 6.1 m (20 ft) in width. There was no clear indication from observations or data analysis that either pier was a complete barrier to juvenile salmon movement; however, during (before replacement) monitoring of the older, wider pier and during the replacement period (both piers in place), there was an indication that the piers were an impediment to juvenile salmon movement. After replacement of the old pier was complete and it was removed, monitoring of the new, narrower pier indicated that the new pier had less influence on juvenile salmon movement.
- Weitkamp (1982) found that under-pier distribution of fish appeared to be affected by light levels during a study of Port of Seattle Piers 90 and 91.
- Prinslow et al. (1980) observed some juvenile salmon in lighted areas under piers.
- Ratte and Salo (1985) found that juvenile salmon will swim under piers and docks.
- Williams et al. (2003) found pink and chum fry were abundant and concentrated in shallow nearshore habitats surrounding the Mukilteo Ferry Terminal, although no conclusive evidence was found that juvenile salmon were more abundant either under or near the terminal or along areas of unmodified shoreline.

Despite differences in these studies, current research findings indicate that OWS, except for very narrow ones, represent at some kind of behavioral obstacle to juvenile salmon movement and likely will result in behavioral changes in these fish upon encountering the OWS. The cumulative impact of very wide or multiple OWS is not well-understood, although the presence of such OWS is likely to represent a temporary impediment to juvenile salmon movement.

Change in light regime due to the presence of the OWS is likely one of the most influential local controlling factors in the nearshore environment. Light levels are controlled both by ambient factors, such as incident solar irradiance, time of day, and attenuation, and by characteristics of the OWS, such as orientation, width, and height above the water (Simenstad et al. 1999, Nightingale and Simenstad 2001). OWS can present sharp underwater light contrasts by casting shade under ambient daylight conditions. Previous studies found evidence that juvenile salmon react to shadows and other artifacts in the shoreline environment imposed by OWS, but generally found no quantitative information on the significance of these behavioral responses to juvenile salmon survival. OWS can also present sharp nighttime underwater light contrasts from artificial light sources.

Dock height, width, construction materials, and the dock's orientation to the arc of the sun are primary factors in determining the shade footprint that a given dock casts over the submerged substrates (Burdick and Short 1995; Fresh et al. 1995, 2000; Olson 1996, 1997). Burdick and Short (1999) found underwater light availability under docks to be primarily dependent upon dock height, followed in importance by dock width and dock orientation relative to the arc of the sun. In studies of ferry docks at Clinton, Bainbridge, and Southworth, Blanton et al. (2001) found docks in the east-west orientation precluded light under the structure at levels that led to seagrass mortality. Orientation in the north-south direction allows more penetration of light under a structure, decreasing the shade footprint (Burdick and Short 1995, Fresh et al. 1995, Olson et al. 1997).

Increased numbers of pilings used for structural support also increase the shade cast on the underwater environment. The piling material (i.e., concrete, wood, or steel) also determines underwater light, as concrete and steel pilings refract more light to the underwater environment than do light-absorbing wood pilings. An open-pile structure offers many benefits to fish and shellfish over a more densely packed structure by providing greater opportunity for light penetration. Adequate spacing between piles is important to reduce light limitations to the underwater environment. Minimizing the number of pilings, using construction materials that reflect light, and increasing the space between pilings can minimize habitat, and presumably fish behavior, impacts (Nightingale and Simenstad 2001).

Just as docks can create sharp underwater light contrasts by casting shade under ambient daylight conditions, they can also produce sharp underwater light contrasts by casting light under ambient nighttime conditions. Artificial lighting on dock structures, by changing the nighttime ambient light regime, may change nighttime movement patterns (Williams and Thom 2001). These light-induced behavioral changes are consistent with behavioral observations documented around OWS in the Puget Sound region (Fields 1966, Prinslow et al. 1979, Weitkamp 1982, Ratte and Salo 1985, Pentec 1997, Taylor and Willey 1997, Johnson et al. 1998).

3.0 Methods

This study utilized conventional methods for observing salmon movement and behavior (i.e., visual observations from shore, snorkeling, and seining) along with new experimental technologies that allow tagging and tracking of small individual fish. The tracking technology was tested for its ability to track juvenile salmon movement near OWS in a marine environment. The effort was divided into three tasks, which are broken out separately into 1) visual surveys, 2) snorkel surveys and enclosure nets, and 3) acoustic tag and telemetry. A total of 10 ferry terminals were surveyed during some portion of the overall study, but some tasks utilized only one or two of the sites, as shown in Table 2.

Table 2. Ferry Terminals and Fish Observation and Sampling Methods

	Tasks			
		Snorkel & Enclosure Nets / Seining		
Ferry Terminal	Visual Surveys	Snorkeling	Netting	Acoustic Telemetry
Anacortes	●			
Bainbridge	●			
Clinton	●			
Edmonds	●	●		
Fauntleroy	●	●		
Kingston	●			
Mukilteo	●			
Port Townsend	●		●	●
Southworth	●			
Vashon	●			

3.1 Study Sites

The following map shows the 10 ferry terminals used for the study (Figure 3). The photos and descriptions are from the WSF web site (http://www.wsdot.wa.gov/ferries/info_desk/terminals/). These terminals were chosen because they are representative of WSF structures, are relatively easy to access from the shore, and are in areas that have potential to affect fish movement or migration.

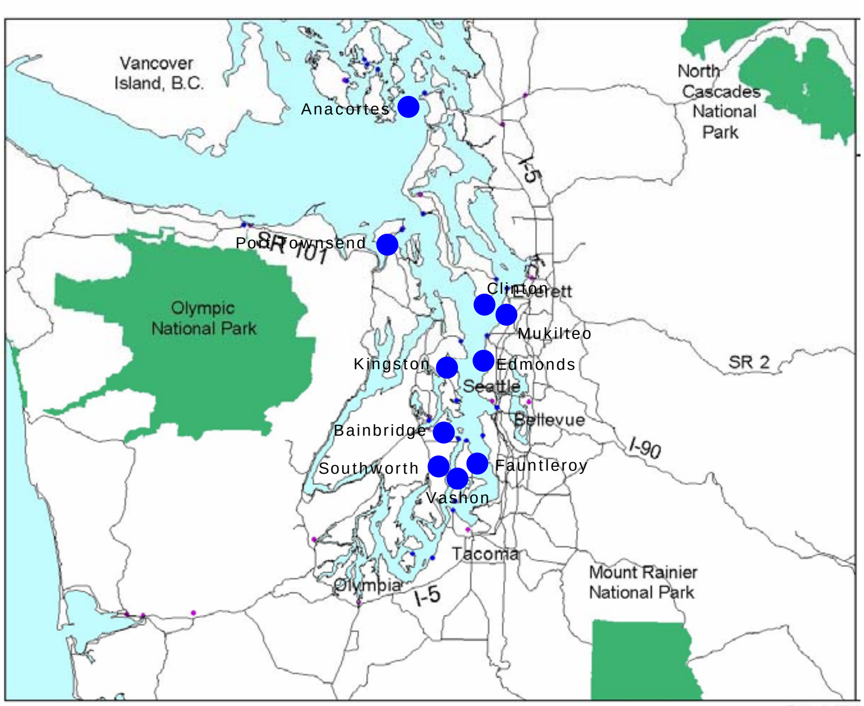


Figure 3. Washington State Ferry Terminals Surveyed for Chum Salmon (adapted from WSDOT).

Anacortes
The Anacortes ferry terminal is 26 m wide and points in a roughly north-south direction. Shoreline here is composed mostly of rocks with sand in deeper water. Ferries leaving this dock go to the San Juan Islands.

Bainbridge
The Bainbridge Island ferry connects the city of Winslow to Seattle. The terminal points in a northwest-to-southeast direction and is approximately 51 m wide. The shoreline is composed of sand, turning to mixed fines at lower elevations.

Clinton
The Clinton terminal on Whidbey Island is approximately 51 m wide. The dock points in a west-to-east direction. The entire shoreline is composed of sand and gravel and gently slopes into the water. This terminal was recently redesigned to include glass blocks along the passenger walkway to allow light through to beneath the terminal.

Edmonds
The terminal dock at Edmonds points in an east-to-west direction, with boats departing for the Kingston terminal on the west side of Puget Sound. The terminal is 24 m wide. Accessibility under the terminal is limited during low tides. Both the north and south sides of the terminal are bordered by riprap; both beaches are sandy. Due to the orientation of the dock, the distance from the shore to the bulkhead is longer on the north side than on the south.

Fauntleroy
The Fauntleroy ferry connects West Seattle to Vashon Island and Southworth. The shoreline is composed entirely of sand and small rocks, and gradually slopes into the water. The east-west oriented terminal is 21 m wide and is accessible at all tidal stages.

Kingston
The Kingston terminal docks ferries arriving from the Edmonds Terminal. The orientation of the dock is north to south. In addition to the main dock for boarding cars onto the ferries, there is also a passenger walkway that parallels the main dock to the west. To the west of this, there is another dock for the foot passenger ferry. The combined width of all docks (considered to be under the terminal) is approximately 40 m. The shoreline is composed of riprap to both the east and west of the terminal; below the terminal is sand. The area below the terminal is accessible only during low tides.

Mukilteo
The Mukilteo ferry connects Mukilteo to Clinton on Whidbey Island. The dock is 14 m wide and is orientated southeast to northwest at an angle to the shoreline, which runs east-west. The nearshore beneath the dock and 10 m to the west is riprap. Between 10 m and 50 m west of the dock and also east of the dock, the substrate is sand and gravel. A deep pool on the west side (estimated 3 to 5 m deep) is scoured by ferry propellers. To the east, the slope is gradual and the water shallow.

Port Townsend
The Port Townsend ferry connects to Keystone on Whidbey Island. The terminal points in a north-south direction and is approximately 36 m wide. Riprap extends along the east side and to 20 m west of the terminal. Further west, the substrate is sand. The shoreline drops more steeply on the east side than on the west side.

Southworth
The Southworth ferry terminal runs from west to east, connecting to Vashon Island and Fauntleroy. The beach is sandy throughout the transect. The terminal is approximately 16 m wide.

Vashon
The Vashon ferry terminal is at the northern tip of Vashon Island. It connects to both the Fauntleroy ferry terminal in west Seattle and the Southworth ferry terminal. The dock runs from south to north and is approximately 20 m wide. The shoreline is composed of gravel and cobbles onshore and sand further offshore.

3.2 Visual Surveys

The initial research task that was undertaken as part of this overall study was focused on the early spring out-migration period of juvenile salmon in Puget Sound. The objective of this task was to determine whether juvenile salmon congregate near WSF terminal structures during peak out-migration periods. The monitoring was conducted between April 20 and June 3, 2005. The task also characterized light levels around a number of WSF terminal OWS.

3.2.1 Observations

Qualitative surveys of migrating juvenile chum salmon were conducted along the shore on either side and beneath the terminals. Replicate observations were correlated with OWS features and light-level measurements to provide evidence of possible inhibition of natural movement. To separate the confounding effects of salmon behavior attributed to ferry activity, observations were made only when ferry docking and departure were not immediately impacting the nearshore physical environment.

A total of 30 surveys were conducted during low tide during daylight hours over a 7-week period between April 20 and June 3, 2005. Chum salmon were identified using unwritten Washington Department of Fish and Wildlife (WDFW) protocols, previously demonstrated to researchers. The method involved walking the nearshore and looking for juvenile salmon, aided by wearing polarized sunglasses. The location of salmon relative to the terminal (under, adjacent (within 10 m), or away (10-50 m)), school size, approximate depth, and behavior (including feeding, active movement, predator avoidance, or avoidance of shadows) were recorded.

3.2.2 Light Measurements

In-air and underwater light levels were recorded as photosynthetically active radiation (PAR) using a LI-COR LI-193SA spherical quantum sensor. PAR is the spectrum of light between 400 nm and 700 nm that supports photosynthetic production and growth. A spherical quantum sensor, which collects light from all directions, was used for the measurements, recorded in units of $\mu mol\ m^{-2}s^{-1}$. Underwater measurements were taken where the fish were observed, as soon as practicable, without disturbing the fish. Each PAR reading was an average of instantaneous readings over a 15-sec interval.

In-air light readings were also recorded along transects that ran parallel to shore. In-air readings, rather than in-water readings, were recorded because some areas under and around the terminals could not safely be accessed when wading. In-air samples provided consistency between samples and in-water light levels could be estimated using light attenuation coefficients and calculations. Beneath the terminal and within 10 m of either edge, light measurements were taken in air at ground level at 2-m intervals. Between 10 m and 50 m from the edge of the terminal, light measurements were taken every 10 m to provide a general profile of light levels to either side of the ferry terminal. Substrate composition along each transect was also recorded.

3.3 Snorkel Surveys and Enclosure Nets

This task focused on the late spring and early summer out-migration period of juvenile salmon in Puget Sound. The objective of this task was to determine whether juvenile chinook and yearling coho salmon (larger individuals usually found in deeper water than chum salmon) concentrate near WSF terminal structures during peak out-migration periods. This monitoring task was conducted in June and July of 2005.

Enclosure nets and snorkel surveys were used to characterize the distribution and abundance of juvenile chinook and coho and other nearshore fishes relative to terminals and unstructured reference sites. The standard protocols and field techniques used during this task have been developed along similar modified shorelines in the City of Seattle during previous studies conducted by scientists at the University of Washington School of Aquatic and Fishery Sciences (UW-SAFS; Toft et al. 2004). Monitoring and sampling was conducted beneath and adjacent to each terminal, as well as along natural shorelines away from OWS.

Initially, reconnaissance visits were made to several ferry terminals. After consulting with WSF and WDFW personnel, sampling was focused at the Edmonds, Fauntleroy, and Port Townsend terminals. Edmonds and Fauntleroy were sampled using snorkel surveys during both spring and neap tides from June 8 to July 27, 2005. Enclosure nets and beach seines were used at Port Townsend during June 20 to June 22, 2005. Snorkel surveys were also attempted at Port Townsend but were not successful because of low water visibility.

3.3.1 Snorkel Surveys

Snorkel surveys were conducted along transects parallel to shore. Snorkeling was done at both high and low tides during each day of sampling, with one diver surveying the site away from the terminal and one surveying underneath and adjacent to the terminal (Figure 4). Successful transects depended on suitable water visibility, as measured by horizontal secchi-disk measurements typically greater than 2.5 m (Toft et al. 2004). There were three main transect locations at each ferry terminal, detailed in Figure 5 and Figure 6:

1) underneath the ferry terminal,
2) adjacent to the ferry terminal (from the edge of the terminal to half of the width of the terminal on each side), and
3) away from the ferry terminal in an area with no OWS or shoreline modifications (starting at least 30 m away from the adjacent transect and continuing another 75 m).

Data collected during snorkeling transects were:

- fish identification and abundance
- approximate fish length (2.5-cm increments)
- water-column position of fish (surface, mid-water, bottom)
- fish behavior (unaffected, swimming away, fleeing, feeding, injured, schooling, hiding; plus mating and claw display for crabs)
- specific location if next to an OWS
- distance between waters surface and bottom of ferry terminal.

Figure 4. Border of the “Ferry” and “Adjacent” Snorkel Transects at the Fauntleroy Ferry Terminal

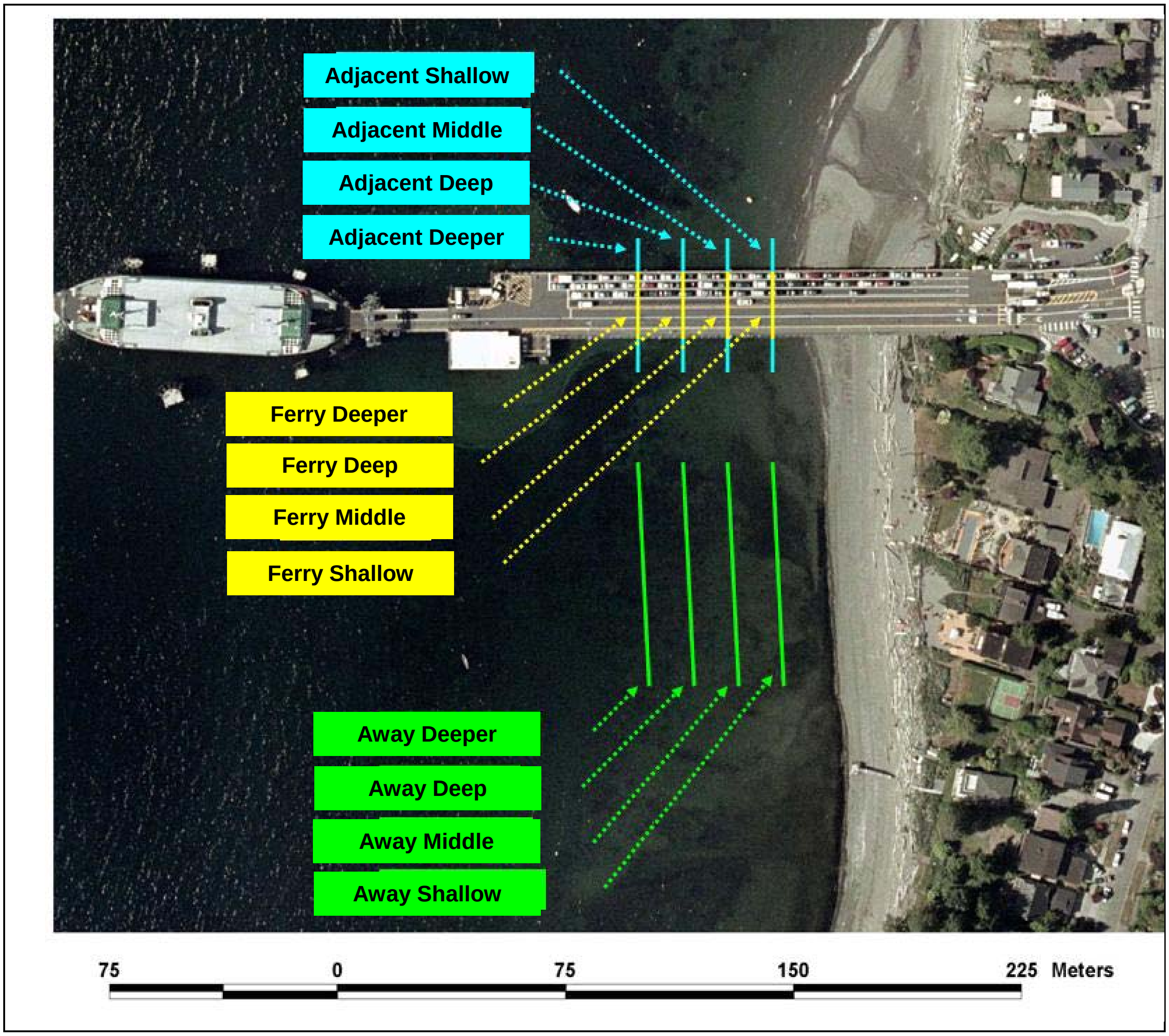


Figure 5. Map of Snorkel Transect Locations at Fauntleroy Ferry Terminal

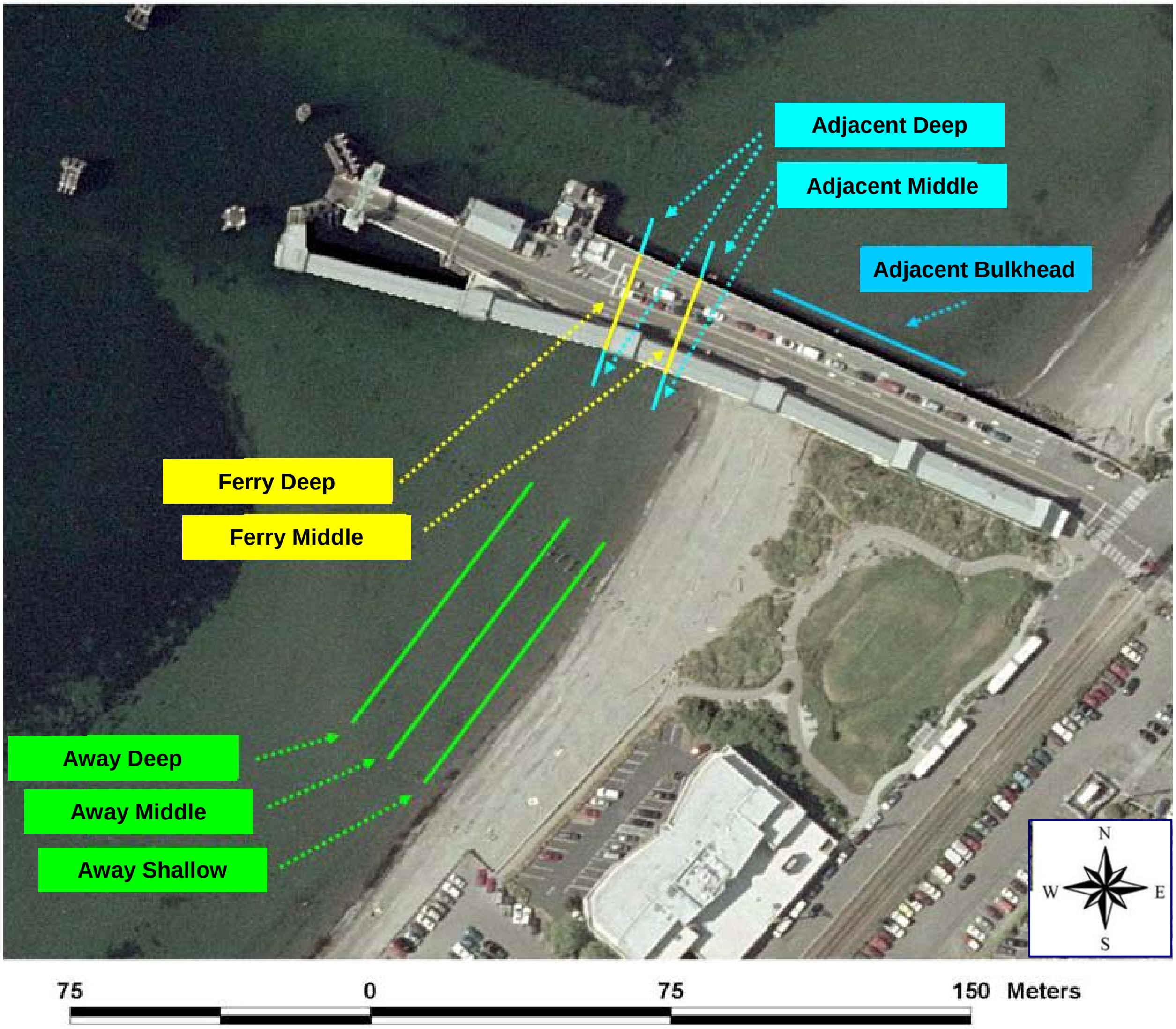


Figure 6. Map of Snorkel Transect Locations at Edmonds Ferry Terminal

The transects were based on water depth at the time of the survey (either low or high tide), and were not tied to a specific location or tidal elevation. Because of differences in nearshore morphology and terminal design, water depths at each transect were slightly different at each individual terminal. Fauntleroy had a gradual sloping sand beach at all transect locations (Figure 7). Therefore, four different water depths were able to be surveyed at Fauntleroy (0.5, 1.0, 1.5, and 2.0 m). Edmonds had a shoreline retained with a bulkhead (riprap) underneath the ferry terminal, causing deeper water depths at the edge of the shoreline (Figure 8). Therefore, only two water depths were surveyed underneath and adjacent to the terminal at Edmonds. A shallower area was surveyed at the gradual sloping beach away from the ferry terminal for a total of three water depths. Finally, an additional transect was conducted along the north adjacent edge of the Edmonds ferry terminal, which had a long retaining-wall bulkhead. Measured water depths at Edmonds varied with tidal height.

Fish abundance estimates were standardized by length and visibility (number of fish divided by transect length multiplied by horizontal secchi depth). Data were analyzed with univariate ANOVA tests (alpha = 0.05) using the statistical program S-Plus. For significant results, the Tukey test for multiple comparisons was used to identify specific differences between all possible pairs of means.

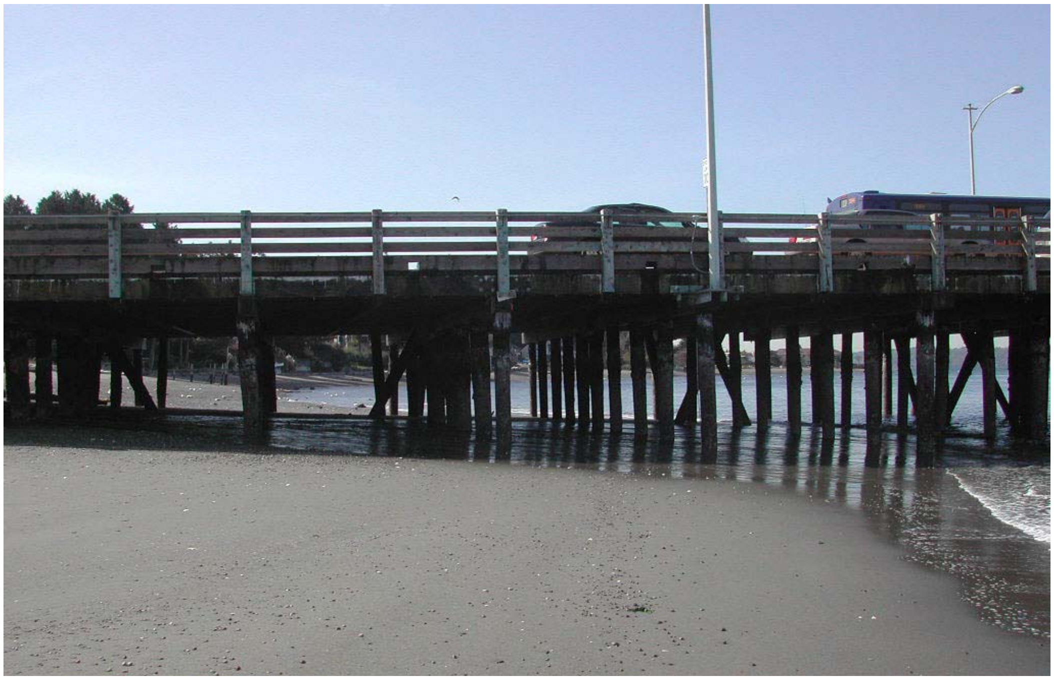


Figure 7. The Fauntleroy Ferry Terminal at a Low Tide

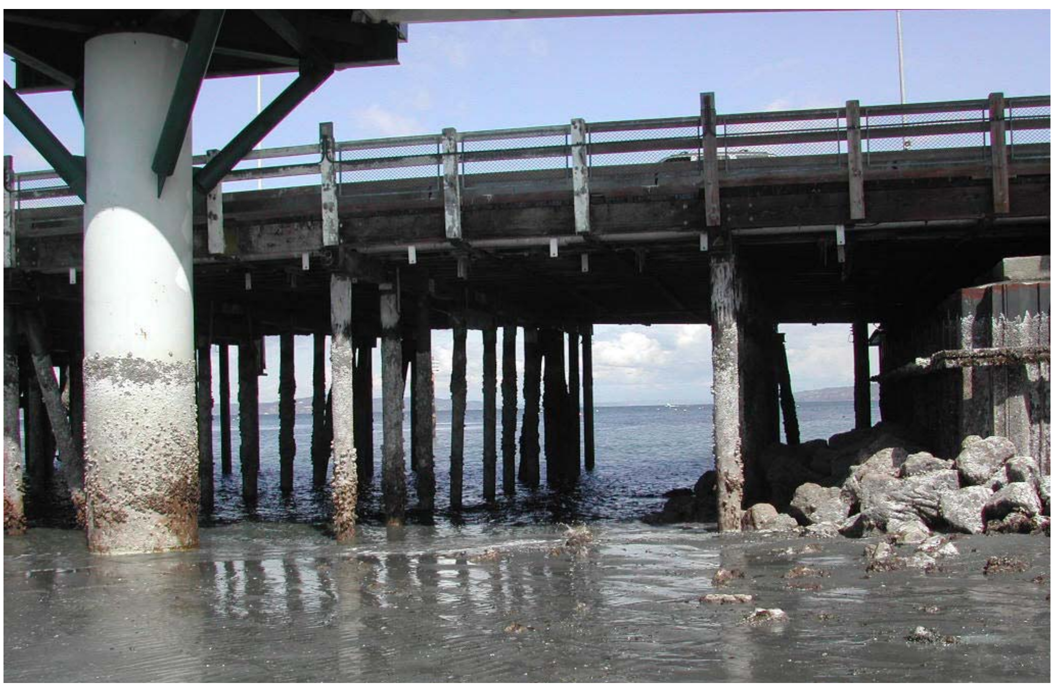


Figure 8. Edmonds Ferry Terminal at a Low Tide

3.3.2 Enclosure Netting and Beach Seining

Netting at Port Townsend was conducted with enclosure nets and beach seines (Figure 9). Enclosure nets consisted of a 60-m long, 4-m deep, 0.64-cm mesh net installed at high tide to enclose and sample a rectangular section of the shoreline (Figure 10). Nets were set to sample most of the width of the Port Townsend ferry terminal, 30-m parallel to shore with 15-m on each side (Figure 9). An enclosure net was set both underneath and adjacent to the north side of the ferry terminal, along a shoreline retained by a bulkhead. Fish were removed with either a small pole seine (4 ft by 30 ft) or dip nets as the tide receded, starting at mid-tide a few hours after net deployment (Figure 11).

All fish were removed at low tide, identified and counted, and returned back to their environment. Hatchery and wild status of salmonids were determined to the extent possible by recording clipped adipose fins. Fork lengths of salmonids were recorded up to n = 5 for 1) species, 2) hatchery or wild status, and 3) size class. Standard lengths of all other fish were recorded up to the first 20 individuals. Volume of water sampled was estimated by measuring the lengths of each side of the net and the water depth at each corner when the net was set, assuming a steady slope from shore to the poles (Toft et al. 2004).

Beach seines were conducted to sample a sand beach on the south side away from the Port Townsend ferry terminal (Figure 9). A standard 37-m Puget Sound beach seine was utilized. Beach seines were pulled at three different locations away from the terminal: near, middle and far.

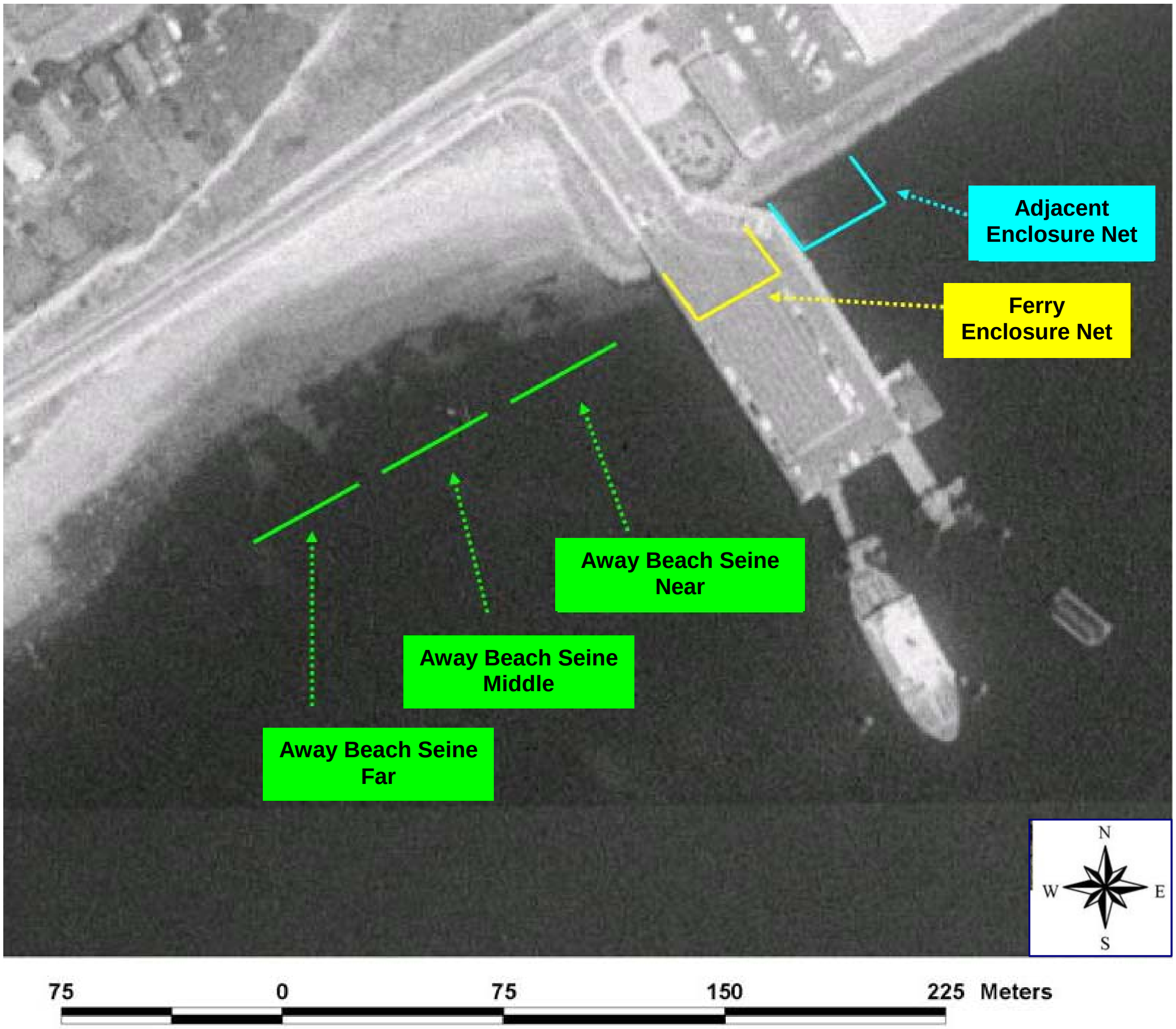


Figure 9. Map of Net Locations at Port Townsend Ferry Terminal

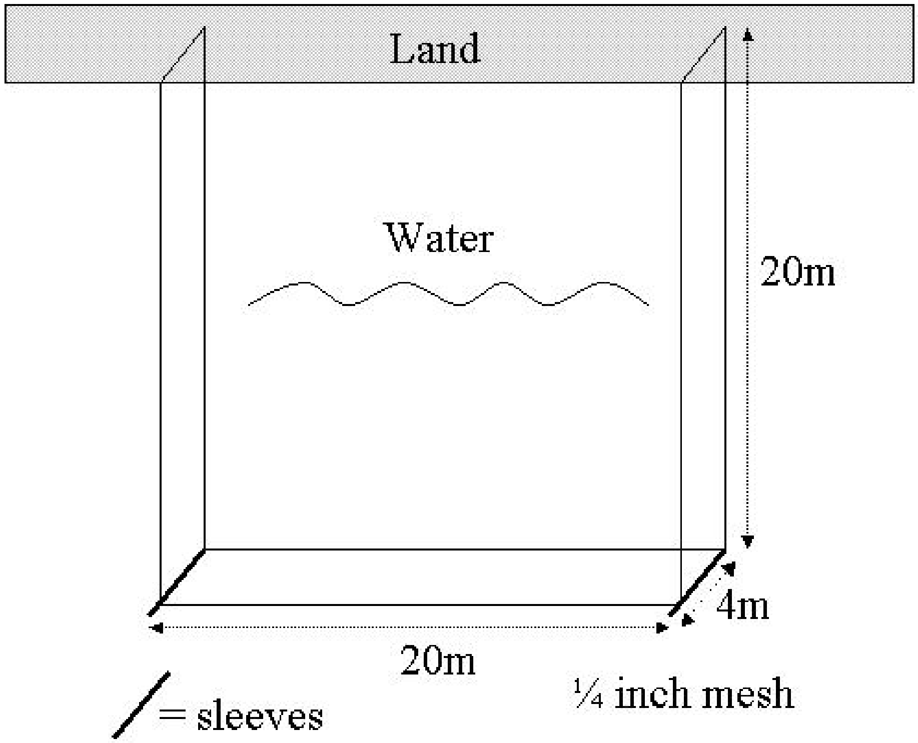


Figure 10. Enclosure Net Typical Deployment. Total net is 60 m long by 4 m high. Sleeves (approximately 10-cm [4-in.] diameter) are sewn in net 20 m in from each side.

Figure 11. Hauling a Pole Seine within the Enclosure Net at the Port Townsend Ferry Terminal

3.4 Acoustic Tagging and Telemetry

The objective of this task was to evaluate the feasibility of applying acoustic telemetry technology to provide information on juvenile salmon behavior relative to movement around OWS. Acoustic tags were used to track the movement of field-collected juvenile chinook salmon near the Port Townsend terminal. The acoustic telemetry technology used during this task was developed jointly by the National Marine Fisheries Service (NMFS) and Pacific Northwest National Laboratory (PNNL) with funding from the U.S. Army Corps of Engineers (USACE) and Battelle Memorial Institute.

A total of seven acoustic receivers (nodes) were deployed on and around the Port Townsend Ferry Terminal on June 20 and 21, 2005, in such a pattern as to achieve full coverage near the terminal. Two nodes were also placed at locations “far” from the terminal on each side. The maximum range was determined to be approximately 138 m (Figure 12). Tracking focused on using acoustic telemetry to monitor juvenile salmon movement in the vicinity of the acoustic nodes placed around the OWS. Tracks of individually tagged fish were analyzed to determine fish rates of movement, residence time, activity patterns, and swimming routes relative to the OWS and the nearshore area.

Figure 12. Acoustic Receiver (node) Placement and Estimated Ranges (shaded circles) at the Port Townsend Ferry Terminal.

Juvenile salmon were captured by beach seine and enclosure netting immediately to the south and under the WSDOT Port Townsend Ferry Terminal between June 20 and 22, 2005 as part of the enclosure netting task. After capture, the juvenile salmon were transported in large, aerated coolers to the Port Townsend Marine Center at Fort Worden and were held for 24 to 48 hours prior to tag implantation to ensure that they were not injured or sick. Transport times were between 20 and 30 minutes.

The surgical procedure used to implant the acoustic tags involved anesthetizing fish, making a small (~1 cm) incision, inserting the acoustic micro-transmitter (0.65 g in air, 0.39 residual mass in water, 417 kHz), and closing the incision with sutures (Figure 13). Each acoustic tag transmits a unique coded signal once every 4.2 to 4.9 seconds.

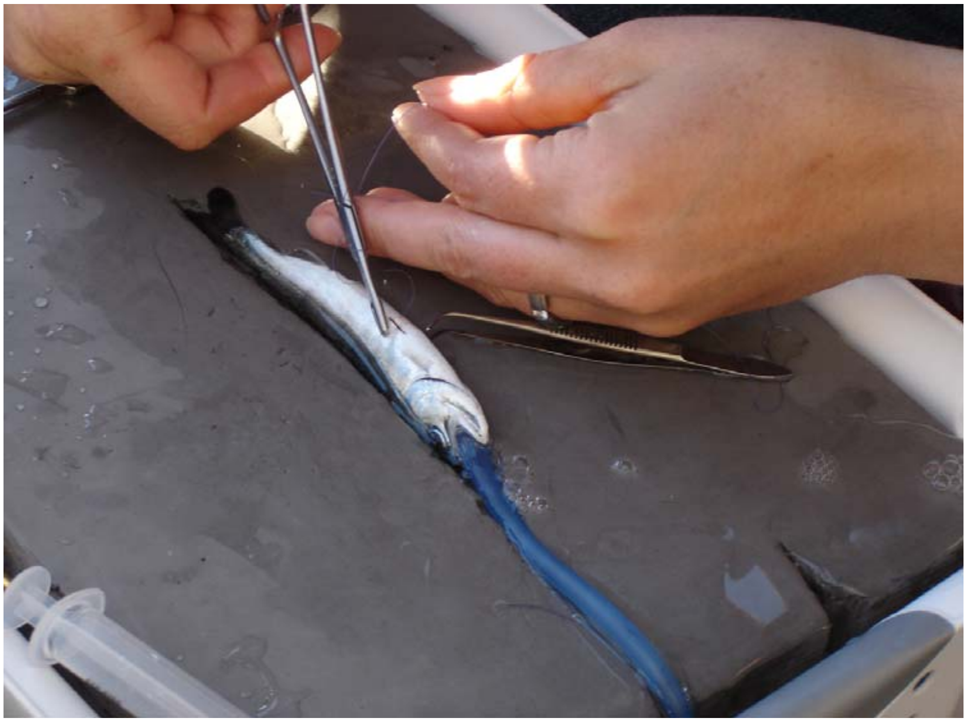


Figure 13. Surgical procedure on juvenile salmon in the Port Townsend Ferry Terminal acoustic telemetry study. The blue tube provides water to flush gills during surgery.

4.0 Results

4.1 Visual Surveys

4.1.1 Observations

As part of the first task, an estimated 5420 juvenile chum salmon in 39 separate schools were observed near ten ferry terminals in April and May, 2005. Peak numbers were counted during the first week of May (Figure 14). The salmon were assumed to be chum since the predominant pink salmon migration occurs every other year and pinks were not expected to be present in large numbers during these surveys. Most juvenile chum salmon were observed between 2 m and 10 m offshore, swimming in relatively dispersed schools of 20 to 700 fish. Average school size was approximately 150 fish. The range of water depths surveyed ranged from 0.4 m to 9 m, with most fish observed swimming in the upper 0.2 m of the water column (Figure 15). Fish swam actively in measured light levels as low as 138 µmol $m^{-2}s^{-1}$.

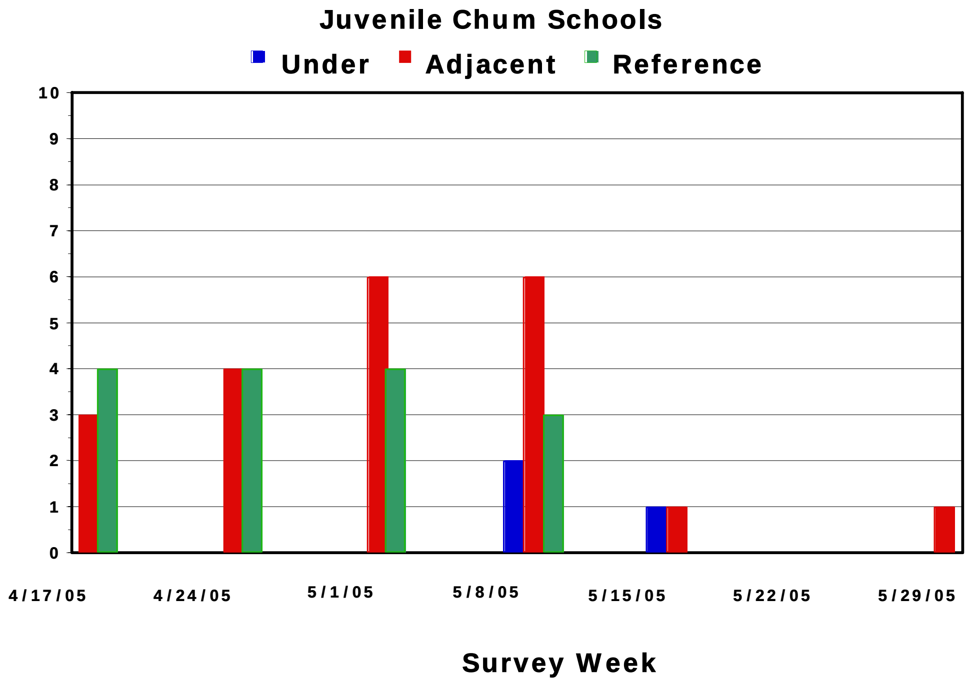


Figure 16 and Figure 17 show the results of surveys of chum salmon at ferry terminals during this task. Only 3 of the schools were observed partially underneath two ferry terminals, 21 were observed within 10 m outside the edge of a terminal, and 17 were observed between 10 m and 50 m outside the edge of a terminal (Table 3). During the study period, the only ferry terminals where juvenile chum salmon were not observed were at Southworth and Anacortes (two site visits and one site visit, respectively). The only occurrences of juvenile chum salmon observed partially under terminals or overhead walkways were at Kingston and Clinton. No juvenile chum salmon were observed to swim from one side of the terminal to the other.

At Kingston, on one occasion (May 20, 2005) a school of approximately 75 juvenile chum salmon were observed swimming and possibly feeding underneath the narrower foot-ferry dock and the ferry terminal overhead walkway. Fish were not observed swimming under the main terminal, however. Total water depth at their position was estimated at 5 m, but fish were observed swimming in the upper 0.5 m and were between 5 m and 15 m offshore. The tide was low and incoming. The sky conditions were sunny to partly cloudy (Figure 18).

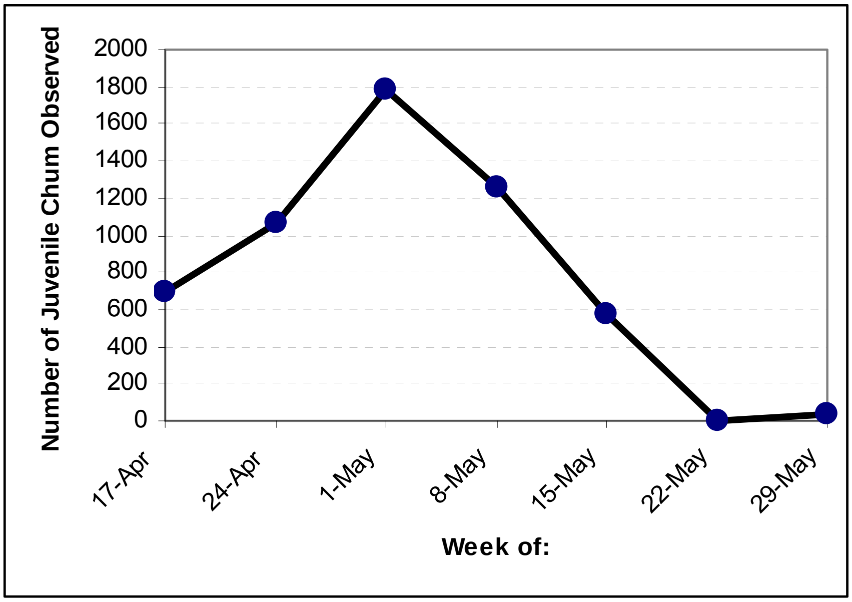


Figure 14. Weekly Numbers of Juvenile Chum Salmon Observed Over the Course of the Study Period

Figure 15. A Typical School of Juvenile Salmon Observed during the Study Period

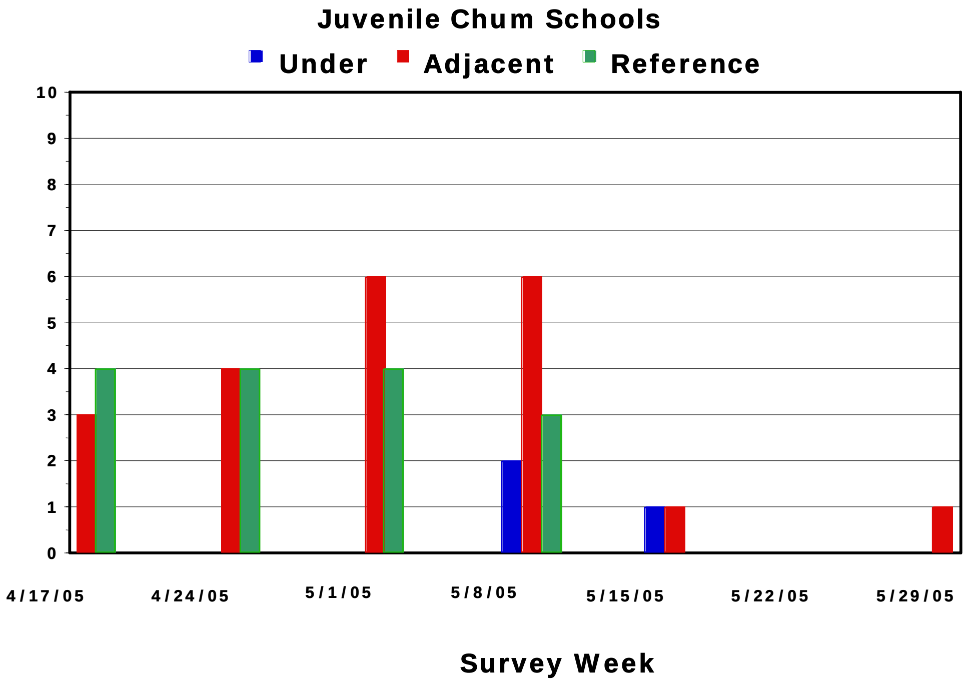


Figure 16. Number of Juvenile Chum Salmon Schools Observed at all Locations, by Date

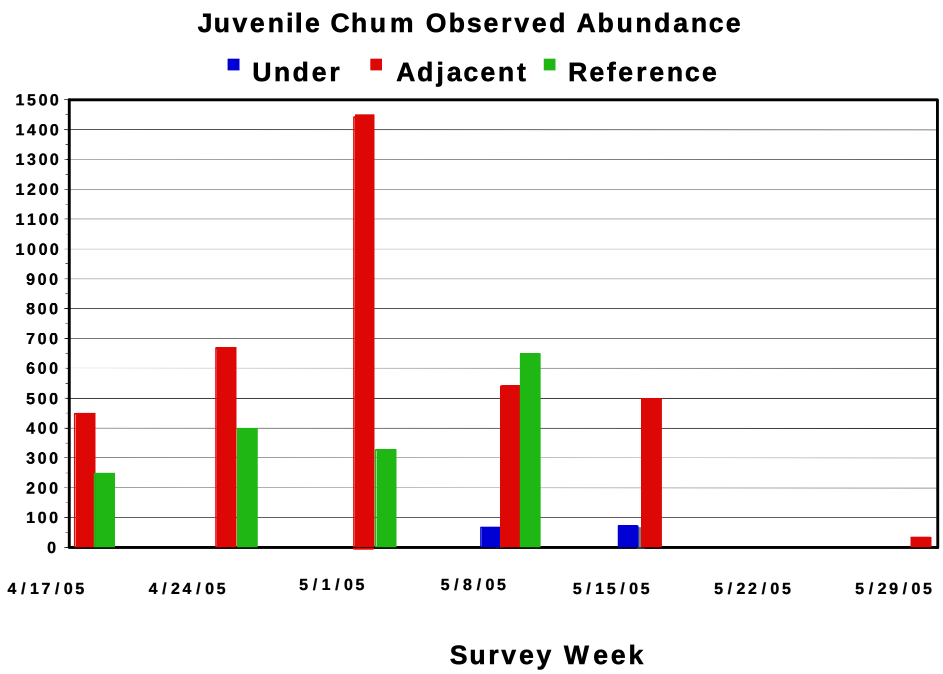


Figure 17. Juvenile Chum Salmon Individuals Observed at all Locations on Date Indicated

Table 3. Washington State Ferry Terminals and Observations of Juvenile Chum Salmon Schools at Ferry Terminals, Spring 2005

WSF Terminal	Approximate Dock Width* (m)	Number of Site Visits	Number of Schools Underneath Terminal	Number of Schools Adjacent to Terminal (0 to 10m)	Number of Schools Away from Terminal (10 to 50m)
Mukilteo	14	4	0	6	5
Southworth	16	2	0	0	0
Vashon	20	1	0	1	0
Fauntleroy	22	2	0	5	1
Anacortes	26	1	0	0	0
Edmonds	26	5	0	0	1
Port Townsend	36	3	0	2	0
Kingston	40[(a)], main terminal only 26	4	1	1	3
Bainbridge	51	4	0	0	1
Clinton	51	4	2	6	4

(a) Entire dock width spans outer distances between separate overwater structures, such as passenger walkways, even though there is open space between the structure and the main terminal.

Figure 18. A School of Juvenile Salmon Observed Swimming under the Kingston Ferry Terminal during the Study Period

At Clinton, on one site visit (May 13, 2005), a school of about 20 fish was observed on the north edge of the dock, holding between 2 m under the dock and 2 m outside the dock (possibly feeding, but showing no directional movement). Water depth was between 0.6 m and 0.8 m, with fish swimming near the surface. The day was overcast and in-air light levels decreased from 344 µmol $m^{-2}s^{-1}$ to 122 µmol $m^{-2}s^{-1}$ across the 4-m distance at the edge of the terminal structure (Figure 20). In-water light levels dropped 97% (from 127 to 4 µmol $m^{-2}s^{-1}$) over a 10-m distance outside the terminal to underneath the terminal (Figure 20). Although juvenile chum salmon were observed swimming near the edge of the terminal, no fish were observed to swim through the shadow line and into the shaded area under the terminal where the in-air light level was 51 µmol $m^{-2}s^{-1}$ (an 85% drop in light level over a 5-m lateral distance).

On the same day at Clinton, a school of approximately 50 fish was observed on the south edge of the dock. These fish were repeatedly swimming slowly in a circle near the surface with the outer edges stretching approximately 2 m under the dock and 2 m outside the dock. Each revolution took approximately 3 minutes. Water depth was approximately 1.5 m. Light level decreased from 359 µmol $m^{-2}s^{-1}$ to 208 µmol $m^{-2}s^{-1}$ across a 4-m distance (a 42% drop in light level). No fish were observed to swim through the shadow line and into the shaded area under the dock where the in-air light level was 56 µmol $m^{-2}s^{-1}$ (an 84% drop in light level over a 6-m distance). At this location, the in-water light levels dropped 89% (from 114 to 13 µmol $m^{-2}s^{-1}$) over a 10-m distance from outside the terminal to underneath the terminal (Figure 19).

A school of juvenile chum salmon along the edge of the Clinton terminal on April 20, 2005, were also observed not to swim under the ferry terminal, but instead appeared to be milling about near the edge of the terminal. The day was partly cloudy. Fish were observed near the north edge of the dock, but were not observed to swim under the dock. The in-air light level was 2377 µmol $m^{-2}s^{-1}$ outside the terminal shadow-line and dropped to 307 µmol $m^{-2}s^{-1}$ in the shaded area under the terminal (an 87% drop in light level over a 2-m distance).

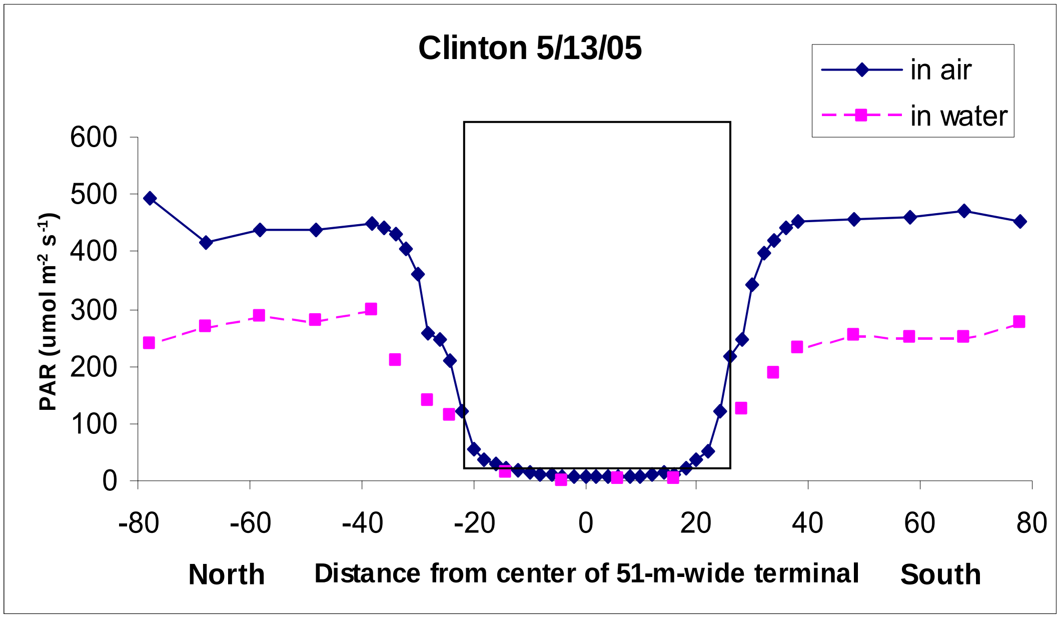


Figure 19. In-Air and In-Water Light Levels Measured at the Clinton Ferry Terminal on May 13, 2005, when Schools of Juvenile Chum Were Observed at the North and South Edges of the Terminal

4.1.2 Light Measurements

The in-air and in-water (at approximately 0.25 to 0.5 m water depth) PAR values were averaged for sunny, partly cloudy, and overcast days when juvenile chum were observed (Table 4). These measurements were recorded outside the influence of shading by the terminal, where the majority of juvenile chum salmon were observed. Plots of measured PAR values for all ferry terminals monitored during this task are presented in Appendix A.

Underneath the ferry terminals, minimum daytime light levels varied, with the darkest values measured underneath the widest terminals, other factors being equal. Under the Mukilteo terminal, the narrowest surveyed at just 14 m wide, light levels did not fall below 25 µmol $m^{-2}s^{-1}$ in water, even on overcast days. Terminals such as Edmonds, Anacortes, and Kingston that are approximately 26 m wide had minimum in-water light levels between 5 and 50 µmol $m^{-2}s^{-1}$, with lower values on overcast days and higher values on sunny days. Underneath Clinton and Bainbridge, the two widest terminals at 51 m each, minimum in-water light levels were consistently between 0 and 7 µmol $m^{-2}s^{-1}$.

Table 4. Mean In-Air and In-Water PAR Values (µmol $m^{-2}s^{-1}$) Measured at the Time and Place Juvenile Chum Were Observed, Spring 2005

Condition	Mean in-air PAR (µmol $m^{-2}s^{-1}$)	Mean in-water PAR (µmol $m^{-2}s^{-1}$)	Mean decrease in light level from air to water (%)
Sunny	1957	1586	19
Partly cloudy	1894	1446	24
Overcast	833	540	35

4.2 Snorkel Surveys and Enclosure Nets

4.2.1 Snorkel Surveys

General Observations

A total of 82 snorkel surveys were conducted at the Edmonds Ferry Terminal, and 78 snorkel surveys were conducted at Fauntleroy. During these surveys, water temperatures and salinity were very similar between the two sites. Average surface and bottom salinities were 27.8 parts per thousand (ppt) and 28.1 ppt at Edmonds, and 27.8 ppt and 27.9 ppt at Fauntleroy. Average surface and bottom temperatures were 13.2°C and 13.0°C at Edmonds, and 13.3°C and 12.9°C at Fauntleroy. Edmonds had only sparse amounts of eelgrass and the algae *Ulva* in shallow water, and beds of kelp were encountered only during deep transects on a very low tide. At Fauntleroy, there was an abundance of *Ulva* in shallow water and washed up on shore, especially in July.

Fish community composition differed between the two sites, with sand lance, pile perch, shiner perch, juvenile smelt, and other larval fish being the most abundant at Edmonds, and shiner perch, striped sea perch, and sole the most abundant at Fauntleroy (Figure 20). Juvenile salmonids generally accounted for only a small percentage of the overall fish abundance. Observed species and length estimates are summarized in Table 5.

In general, greater numbers of juvenile salmonids tended to be observed adjacent to ferry terminals than under or away from the terminal, although no differences in densities specific to each site were statistically significant (Figure 21). However, when the two sites were combined, juvenile chinook and coho densities were statistically more abundant at Adjacent than at Away, perhaps indicating that the fish pause in their directional movement or congregate at the edges of OWS.

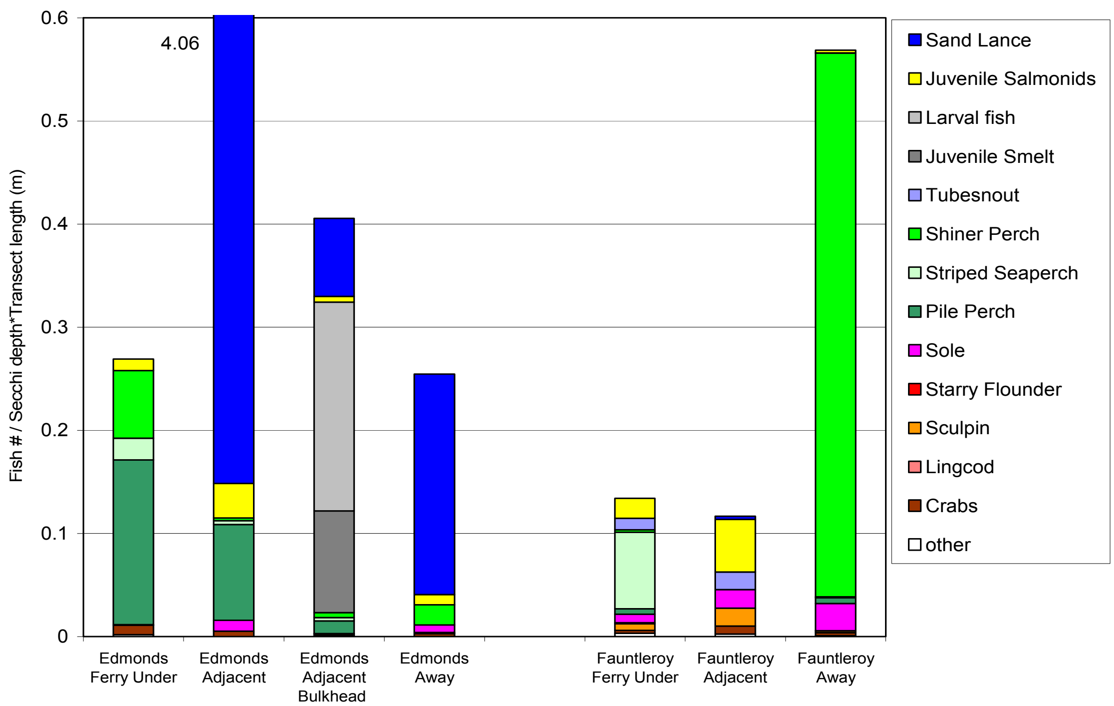


Figure 20. Total Average Densities of Fish and Crabs from Snorkel Surveys

Table 5. Average Length Estimates of Fish and Crabs from Snorkel Surveys

Common Name	Scientific Name	Average Length (cm)	Min	Max
Adult Salmon	*Oncorhynchus* spp.	57.5	55.0	60.0
Chinook	***Oncorhynchus tshawytscha***	**12.8**	**10.0**	**15.0**
Chinook/Coho	***Oncorhynchus tshawytscha/kisutch***	**12.7**	**7.5**	**20.0**
Coho	***Oncorhynchus kisutch***	**13.8**	**10.0**	**17.5**
Chum	***Oncorhynchus keta***	**6.3**	**5.0**	**7.5**
Dungeness Crab	*Cancer magister*	13.8	5.0	20.0
Gunnel	Pholidae	15.0	12.5	17.5
Herring/Smelt	*Clupea harengus pallasi*/Osmeridae	8.8	7.5	10.0
Juvenile Smelt	Osmeridae	6.3	5.0	7.5
Kelp Crab	*Pugettia* spp.	8.8	5.0	12.5
Larval fish	-	4.6	1.0	7.5
Lingcod	*Ophiodon elongatus*	86.3	70.0	102.5
Pile Perch	*Rhacochilus vacca*	13.8	5.0	22.5
Red Rock Crab	*Cancer productus*	12.5	5.0	17.5
Pacific Sand Lance	*Ammodytes hexapterus*	12.0	7.5	15.0
Sculpin	Cottidae	14.7	5.0	22.5
Shiner Perch	*Cymatogaster aggregata*	9.0	5.0	17.5
Sole	Pleuronectidae	13.5	5.0	32.5
Starry Flounder	*Platichthys stellatus*	25.4	7.5	62.5
Threespine Stickleback	*Gasterosteus aculeatus*	3.8	2.5	5.0
Striped Seaperch	*Embiotoca lateralis*	12.9	5.0	22.5
Trout	*Salmo* spp.	18.8	17.5	20.0
Tubesnout	*Aulorhynchus flavidus*	12.8	5.0	17.5

Note: Length estimates of fish are based on total length, and crab lengths are carapace width.

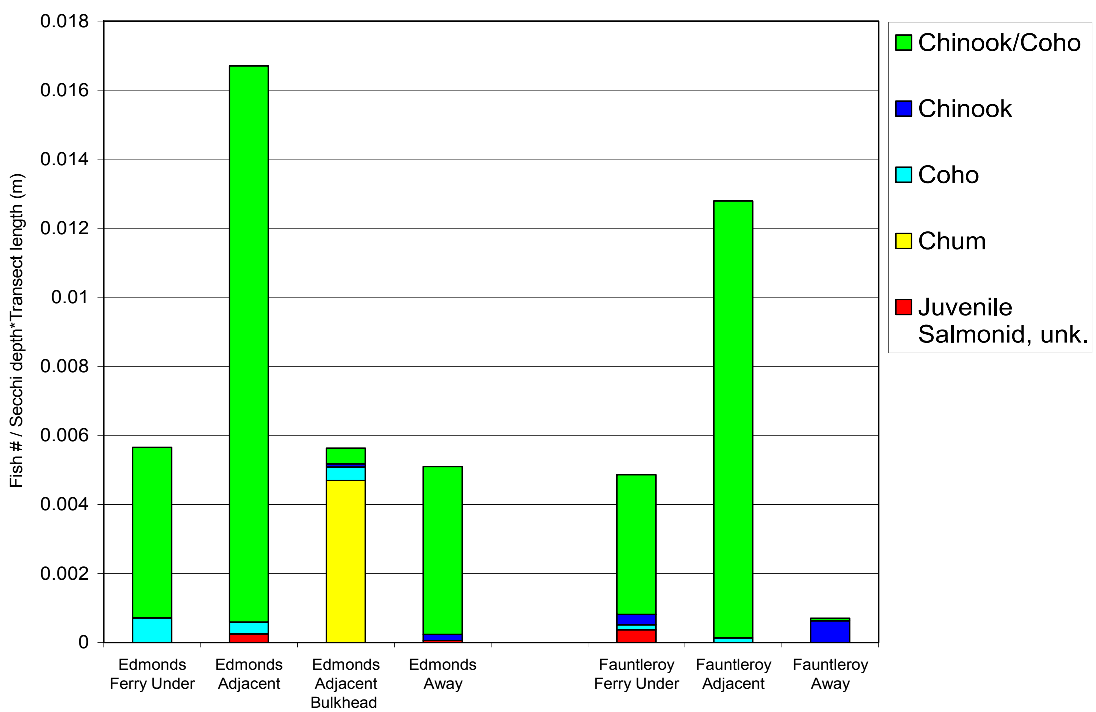


Figure 21. Total Average Densities of Juvenile Salmonids from Snorkel Surveys

Water-column position and behavior varied with the species of fish and crab observed (Table 6). Water-column position of juvenile salmonids was mostly in the middle, similar to other species of pelagic fishes, such as smelt and sand lance. In general, perch occurred in slightly deeper water than did salmon, followed by bottom fishes, such as sculpin and sole. The most common behavior categories observed were swimming and schooling. The only observations of feeding were by sand lance and shiner perch. The percentage of observations of juvenile salmonids in categories of water-column position and behavior varied with strata (Table 7). The majority of observations in the bottom of the water column occurred at the Adjacent sites, with only one occurrence underneath (Ferry) a ferry terminal. Conversely, the majority of observations in the surface of the water column occurred at Away sites, with one occurrence underneath (Ferry) a ferry terminal.

Table 6. Number of Observations of Fish and Crabs for Categories of Water-Column Position and Behavior

	Water-Column Position			Behavior								
Fish Species	**Bottom**	**Middle**	**Surface**	**Claw Display**	**Feeding**	**Flee[a]**	**Hiding**	**Injured**	**Schooling**	**Schooling/ Feeding**	**Swam Away[b]**	**Unaffected**
Adult Salmon		1				1						
Chinook		4	1						1		3	1
Chinook/Coho	5	34	4						13		29	1
Coho			2						1		1	
Chum	1	5									5	1
Dungeness Crab	28				2						2	24
Gunnel	2										1	1
Herring/Smelt		1									1	
Juvenile Salmonid, unk.	2		1			1					2	
Juvenile Smelt		1	1						2			
Kelp Crab	1	3										4
Larval fish		4	2						6			
Lingcod	2										1	1
Pile Perch	52	30							41		10	31
Red Rock Crab	37	3	1	1	2						4	34
Pacific Sand Lance	3	14	2			1			10	4	4	
Sculpin	30					4					17	9
Shiner Perch	31	58			3	1		1	45	3	21	15
Sole	97	1				4	1				56	37
Starry Flounder	9					2					2	5
Threespine Stickleback			1								1	
Striped Seaperch	34	6			1				6		10	23
Trout		1									1	
Tubesnout	8	3							2		2	7

[a] Flee – fish darted away quickly, as in a startle response
[b] Swam Away – fish gradually moved away, but did not dart away quickly

Table 7. Percentage of Observations of Juvenile Salmonids in Categories of Water-Column Position and Behavior

Site	Fish Species	Water-Column Position			Behavior				Total Number of Observations
		Bottom	Middle	Surface	Flee	Schooling	Swam Away	Unaffected	
Ferry	Chinook			100%			100%		1
	Chinook/Coho		100%			30%	60%	10%	10
	Coho		100%				100%		2
	Juvenile Salmonid, unk.	100%			100%				1
Adjacent	Chinook/Coho	23%	73%	5%		41%	59%		22
	Coho	50%	50%				100%		2
	Juvenile Salmonid, unk.	100%					100%		1
Away	Chinook		100%			33%	33%	33%	3
	Chinook/Coho		67%	33%		11%	89%		9
	Juvenile Salmonid, unk.			100%			100%		1

Edmonds

Juvenile salmonid observations spanned the sampled water depths at both Edmonds and Fauntleroy (Figure 22). The most observations at the Ferry and Adjacent sites at Edmonds were at the middle (average 1.2 m) water depth, whereas at the Away site, most were at the shallow-water (average 0.8 m) depth (Figure 23). These depths all corresponded to the transects closest to shore, as there was no shallow depth surveyed at the Ferry and Adjacent sites, because the shallow-water zone was truncated by shoreline bulkheads. At the Ferry site, all of the chinook observations were at the middle depth, whereas none were observed at the deep-water (average 1.7 m) depth. This was not the case at the Adjacent and Away sites, which had chinook observations at all depths surveyed. Water depths at the Adjacent Bulkhead site ranged from 0.4 m to 2.5 m.

Juvenile salmonid observations at Edmonds were separated between high and low tides, as there were enough observations to make a suitable comparison (Figure 24 and Figure 25). Juvenile salmon were only seen underneath the ferry terminal during transects conducted at a low tide, none were observed at high tides. The highest tide that a salmon was observed underneath the terminal was +1.8 m, the next highest was +1.6 m, both on neap tides during which there was only a 3-m clearance beneath the ferry terminal. On spring tides, the highest tide for a juvenile salmonid observation was at +0.8 m. All other strata had observations of juvenile salmonids at both high and low tides, at similar densities for chinook and coho salmon.

Figure 22. Location of Observations of Various Fish Species at Edmonds Ferry Terminal

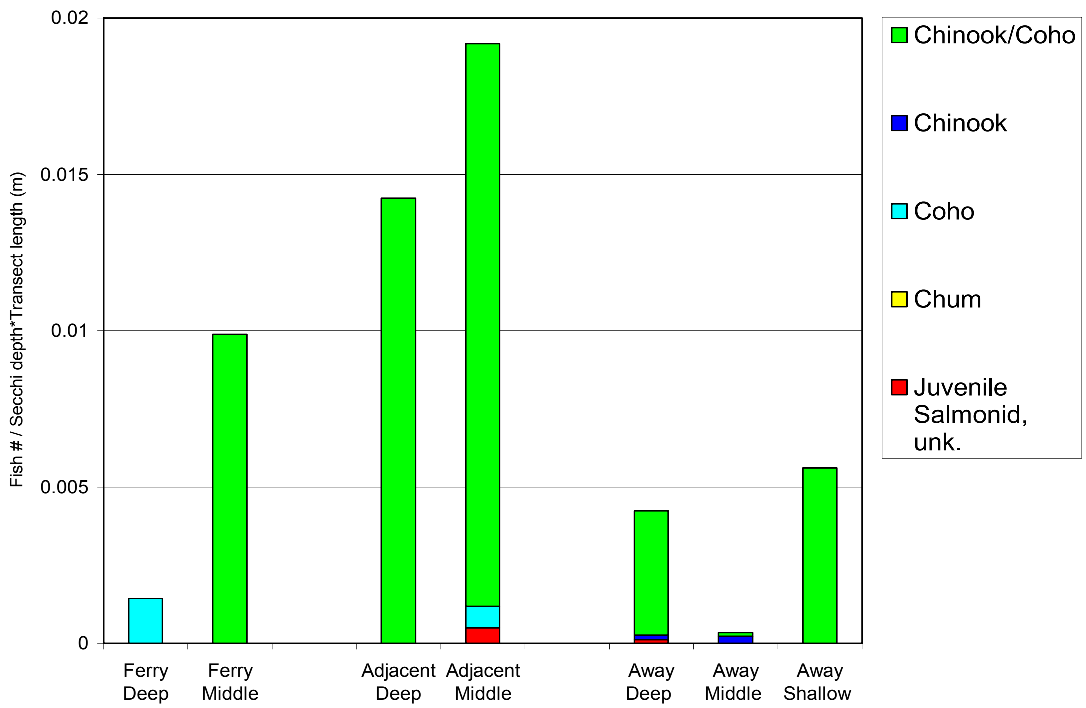


Figure 23. Total Average Densities of Juvenile Salmonids from Snorkel Surveys for all Depths at the Edmonds Ferry Terminal (average shallow depth 0.8 m, middle 1.2, deep 1.7)

Figure 24. Location of Juvenile Salmonid Observations at Edmonds Ferry Terminal During High and Low Tides

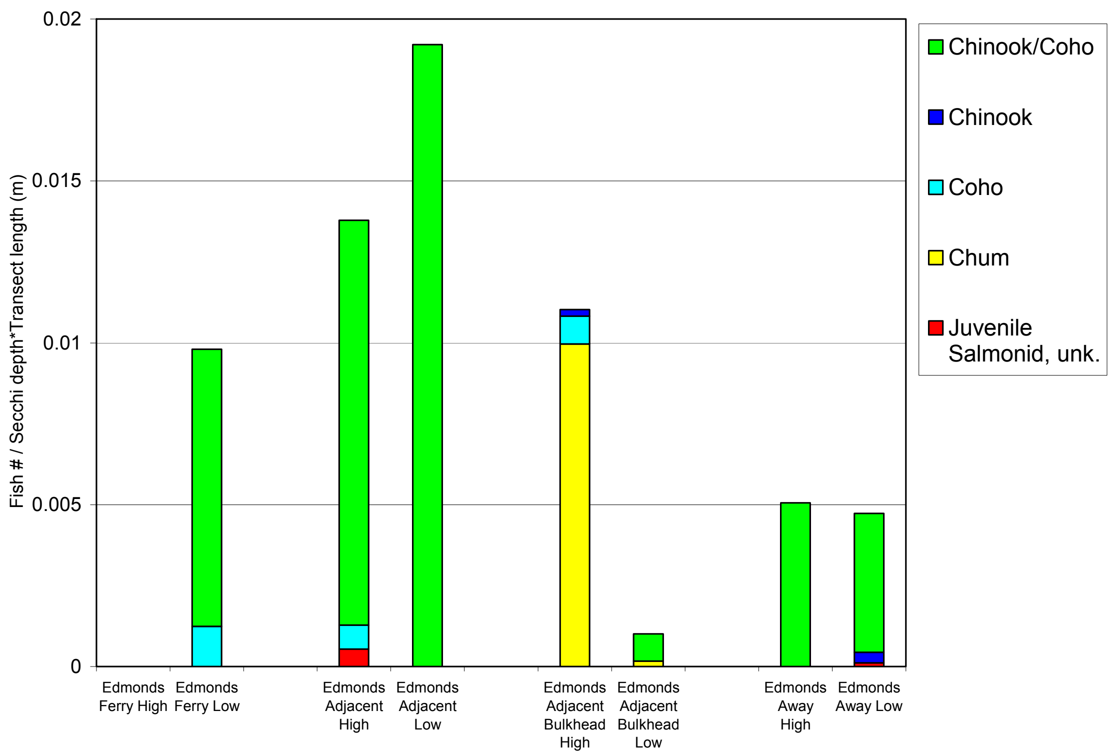


Figure 25. Total Average Densities of Juvenile Salmonids from Snorkel Surveys at High and Low Tides at the Edmonds Ferry Terminal

Significant statistical differences (grouped by strata) for total fish densities at the Edmonds Ferry Terminal were as follows:

- Crabs and pile perch were more abundant under the ferry terminal (Ferry) than at transects located at a distance (Away) from the terminal.
- Sand lance were more abundant adjacent to the ferry terminal (Adjacent) than at the other sites.
- Pile perch were more abundant at Adjacent than at Away sites.
- Sole were more abundant at Adjacent than under the terminal (Ferry).
- Larval fish and juvenile smelt were more abundant at the Adjacent-Bulkhead site than at the other sites.
- Total fish density was highest adjacent to the ferry terminal.

<u>Fauntleroy</u>

Juvenile salmonid observations spanned the sampled water depths at Fauntleroy. Most of the juvenile salmonid observations at the Ferry and Adjacent sites at Fauntleroy were at the deep-water (average 1.7 m) depth (Figure 26). At the Away site, the only juvenile salmonid observations were at the middle-water (average 1.0 m) depth. There were juvenile salmonid observations at the middle, deep, and deeper (average 2.0 m) transects at the Ferry site, and at the shallow (average 0.5 m), middle (average 1.0 m), and deep (average 1.7 m) transects located at the Adjacent sites.

There were only two significant statistical differences in total fish densities at the Fauntleroy Ferry Terminal:

- Sculpin were more abundant at Adjacent than Away sites.
- Shiner perch were more abundant at the Away site (high numbers of shiner perch at the Away site were likely due to large schools occurring over eelgrass beds at the deep and deeper transects).

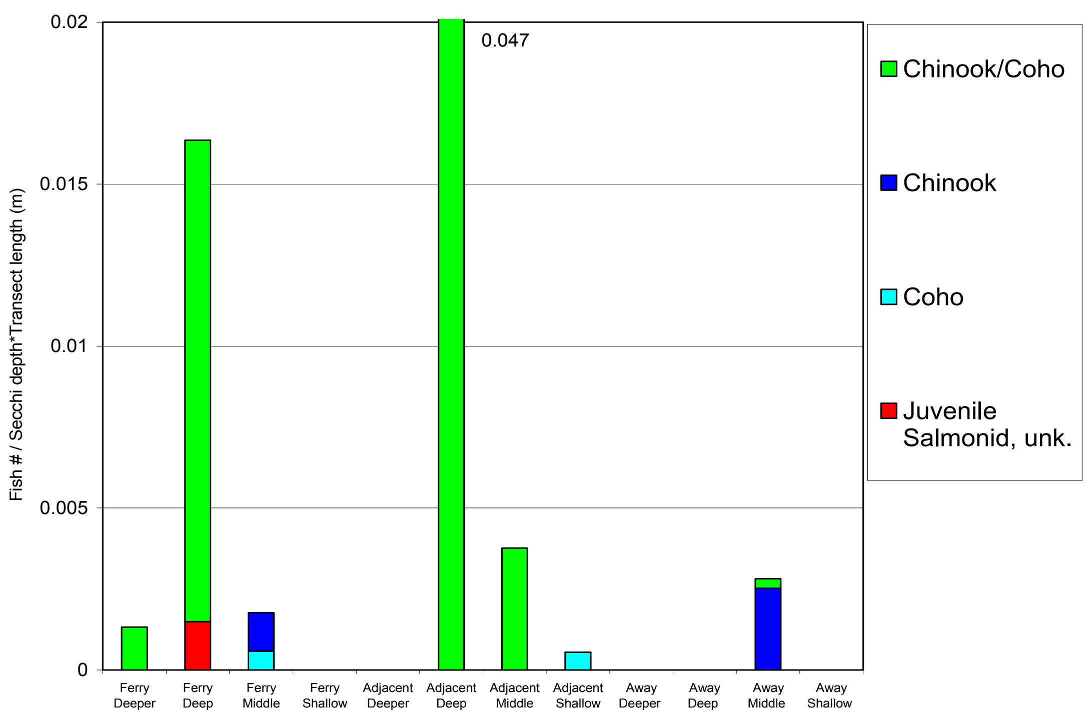


Figure 26. Total Average Densities of Juvenile Salmonids from Snorkel Surveys for all Depths at the Fauntleroy Ferry Terminal (shallow depth 0.5 m, middle 1.0, deep 1.5, deeper 2.0)

4.2.2 Enclosure Netting and Beach Seining

Enclosure nets were used only at the Port Townsend Ferry Terminal (Figure 11). During this netting effort, the average surface and bottom salinity was 29.8 ppt. The average surface and bottom temperatures during netting periods were 11.9°C and 11.7°C. Water-surface area sampled by enclosure nets was 450 m^2. Water volume sampled was 517.5 m^3 for the enclosure net located under the ferry terminal (Ferry) and 540 m^3 for the enclosure net located adjacent to the ferry terminal (Adjacent). Beach-seine surface area and volumes sampled were estimated to be around 520 m^2 and 790 m^3 respectively. Because enclosure nets were only set during a 1-week sampling period and not replicated, catches were represented by catch-per-unit effort (CPUE) rather than density.

Total fish catches (Figure 27) were processed for the two enclosure nets and for two beach seines (near and middle distances from the terminal). At the Away sites that were sampled by beach seines, the middle seine was composed mostly of sand lance and juvenile sole. The Near seine had the highest numbers of juvenile salmonids, and also had high numbers of juvenile sole, gunnels, and sculpin. The enclosure net beneath the ferry terminal (Ferry) had the highest numbers of juvenile sole, along with shrimp and crabs. The enclosure net located adjacent to the ferry terminal (Adjacent) had the highest numbers of padded sculpin and gunnels, and also had high numbers of shrimp and crabs.

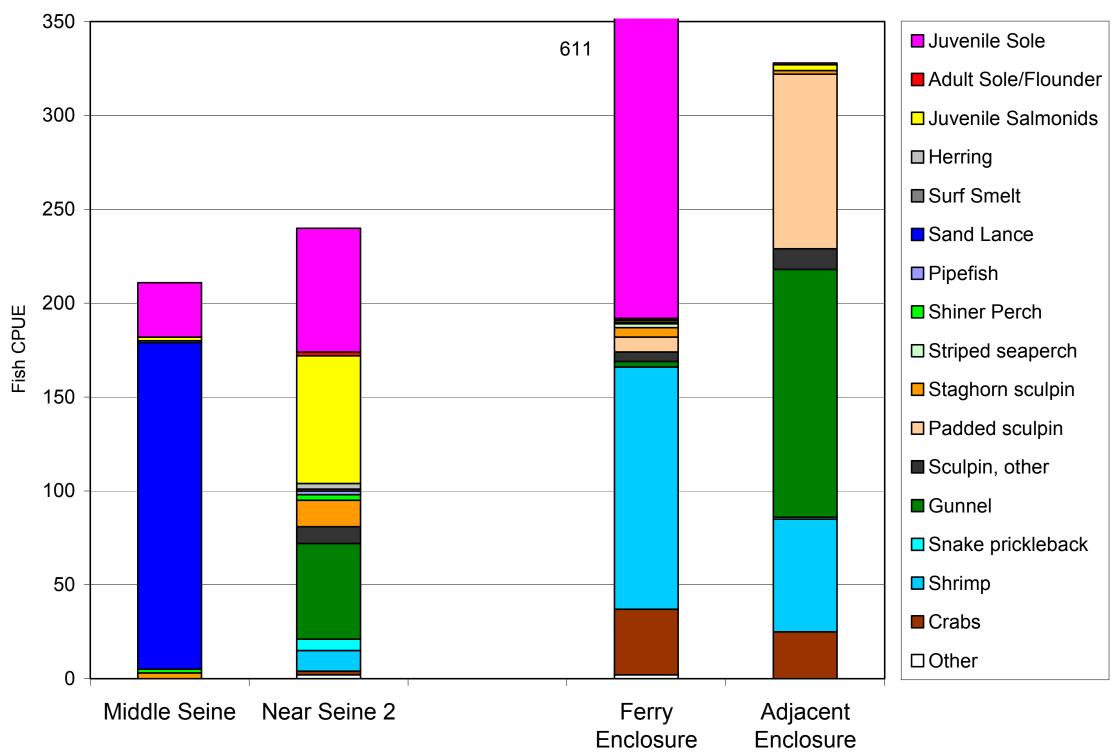


Figure 27. Total Numbers of Fish and Crabs from Enclosure Net Sampling

Total juvenile salmonid catches (Figure 28) were processed for the two enclosure nets and for four beach seines (one haul each at the Middle and Far from the terminal sites, and two hauls at the Near the terminal site). Overall, juvenile sockeye salmon were the most numerous species of juvenile salmon captured. All species of juvenile salmon were most abundant at the beach seine site located closest to the terminal

(Near). However, there were large differences in abundance between the two replicates at the Near site, reflecting the large degree of variability that is typical over multiple samples. There were fewer juvenile salmon at the Middle and Far beach seine sites, including fewer juvenile chinook salmon.

At the enclosure net sites, only one coho was caught beneath the ferry terminal (Ferry), and at the Adjacent site, three juvenile chinook salmon were captured. A total list of all species captured (and average length measurements) during net sampling is provided in Table 8.

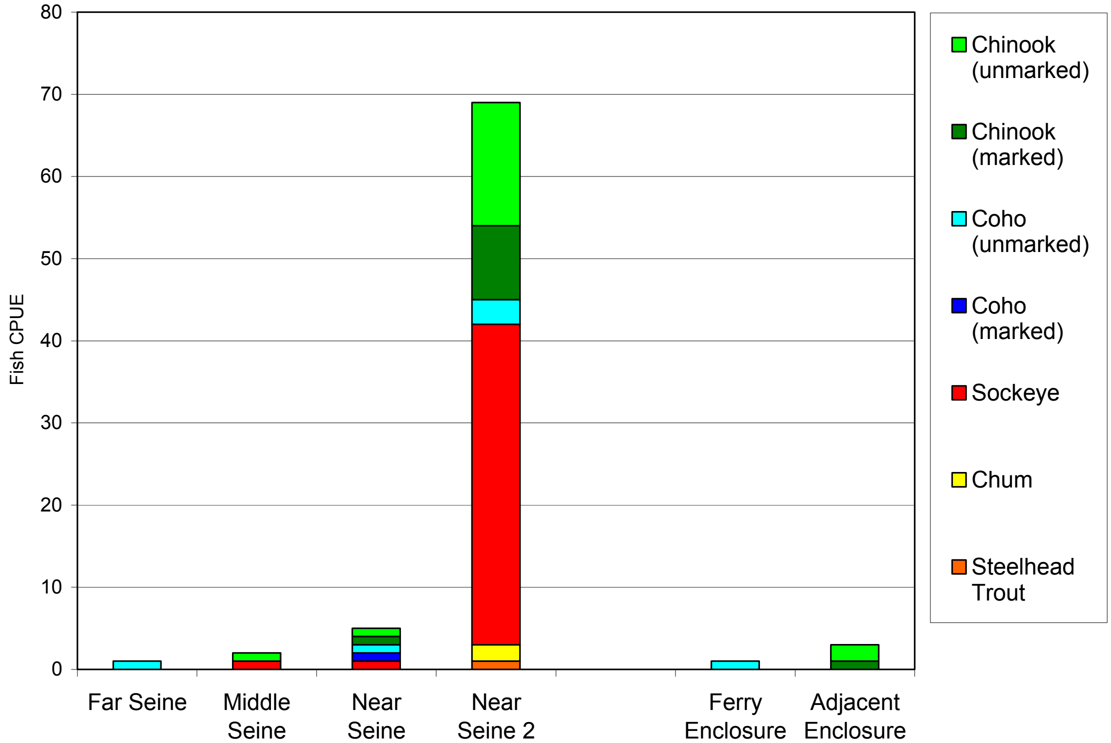


Figure 28. Total Numbers of Juvenile Salmonids from Net Sampling

Table 8. Average Lengths of Fish and Crabs from Net Sampling

Common Name	Scientific Name	Average Length (cm)[a]
Bay Pipefish	*Syngnathus griseolineatus*	11.5
Buffalo Sculpin	*Enophrys bison*	5.3
Cancer Crab, juv.	*Cancer* spp.	2.4
Chinook - Marked	***Oncorhynchus tshawytscha***	**10.6**
Chinook - Unmarked	***Oncorhynchus tshawytscha***	**11.4**
Chum	***Oncorhynchus keta***	**7.1**
Coho - Marked	***Oncorhynchus kisutch***	**14.4**
Coho - Unmarked	***Oncorhynchus kisutch***	**12.6**
Dungeness Crab	*Cancer magister*	15.7
Fluffy Sculpin	*Oligocottus snyderi*	5.6
Graceful Crab	*Cancer gracillis*	6.3
Great Sculpin	*Myoxocephalus polyacanthocephalus*	23.0
Gunnel	Pholidae	9.7
Helmet Crab	Cheiragonidae	6.0
Herring	*Clupea harengus pallasi*	9.2
Juvenile Sole	Pleuronectidae	4.8
Kelp Crab	*Pugettia* spp.	2.3
Pacific Sand Lance	*Ammodytes hexapterus*	9.1
Pacific Snake Prickleback	*Lumpenus sagitta*	16.3
Pacific Staghorn Sculpin	*Leptocottus armatus*	8.7
Padded Sculpin	*Artedius fenestralus*	7.9
Poacher	Agonidae	3.2
Red Rock Crab	*Cancer productus*	11.9
Rock Sole	*Pleuronectes (Lepidopsetta) bilineata*	16.5
Rosylip Sculpin	*Ascelichthys rhodorus*	8.2
Saddleback Sculpin	*Oligocottus rimensis*	7.5
Sculpin, juv.	Cottidae	3.5
Shiner Perch	*Cymatogaster aggregata*	7.4
Silverspotted Sculpin	*Blepsias cirrhosus*	4.5
Sockeye	***Oncorhynchus nerka***	**8.5**
Soft Sculpin	*Gilbertidia sigalutes*	2.5
Spotfin Sculpin	*Icelinus tenuis*	4.8
Starry Flounder	*Platichthys stellatus*	10.4
Steelhead Trout	*Salmo gairdneri*	22.5
Striped Seaperch	*Embiotoca lateralis*	12.1
Surf Smelt	*Hypomesus pretiosus pretiosus*	15.0
Threespine Stickleback	*Gasterosteus aculeatus*	3.0

(a) Length measurements of salmonids are fork-length, other fish are standard length, and crab lengths are carapace width.

4.3 Acoustic Tagging and Telemetry

4.3.1 Acoustic Tagging

Table 9 shows the tagging dates and information on the fish that were tagged. High mortality on the first tagging date was likely due to the sensitive physiological state of the test fish and effects of a high concentration (MS-222, 40 mg/L) of fish anesthetic during the surgical procedure. Anesthetic concentration was reduced (MS-222, 30 mg/L) in subsequent surgeries, resulting in higher post-surgery survival rates. Specific data for the fish released in this task are detailed in Table **10**.

Table 9. Tagging Data for Juvenile Salmon Used in the Acoustic Telemetry Study

Tagging Date	MS222 (mg/L)	Number Tagged	Post -Surgery Mortality	Number Released
June 20, 2005	40	5	5	0
June 21, 2005	30	27	8	19

Table 10. Data on Individual Acoustically Tagged Fish Released in 2005 in the Telemetry Study

Tag Date	Species	Length (mm)	Weight (g)	Tag ID	Release Date/Time
June 21	Chinook	112	14.6	G72609c48	6/22/05 16:50
June 21	Chinook	109	13.8	G7261c836	6/23/05 16:34
June 21	Chinook	114	17.0	G726044dd	6/22/05 16:50
June 21	Chinook	123	20.1	G72609d16	6/23/05 16:30
June 21	Coho	116	18.2	G7260b0c8	6/23/05 16:30
June 21	Coho	132	25.4	G7260b80a	6/23/05 16:34
June 21	Chinook	115	18.4	G7260bbe8	6/23/05 16:34
June 21	Chinook	113	15.8	G72607781	6/22/05 16:50
June 21	Chinook	111	14.0	G7261c629	6/22/05 16:50
June 21	Chinook	98	11.1	G7260435e	6/23/05 19:38
June 21	Chinook	114	16.5	G72605c82	6/23/05 19:38
June 21	Chinook	115	16.2	G72608cd5	6/23/05 21:27
June 21	Chinook	104	13.1	G726091b5	6/23/05 21:31
June 21	Chinook	133	25.3	G7260685d	6/23/05 19:38
June 21	Chinook	117	15.8	G7260671c	6/23/05 19:42
June 21	Chinook	95	9.5	G72608076	6/23/05 19:42
June 21	Chinook	111	15.5	G72606d62	6/23/05 19:42
June 21	Chinook	100	11.0	G726087f5	6/23/05 21:27
June 21	Chinook	103	13.1	G7261d069	6/23/05 21:31

4.3.2 Telemetry

A total of 19 tagged juvenile chinook and coho salmon were released immediately adjacent to the Port Townsend Ferry Terminal on June 22 and 23, 2005. The "South" release location was at the interface between the shoreline and the south edge of the Port Townsend Ferry Terminal (Figure 29). The "North" release location was on the north side of terminal at the shoreline (Figure 29). Table 11 shows the release times and locations for acoustically tagged fish released adjacent to the Port Townsend Ferry Terminal on June 22 and 23, 2005. Two of the fish that were released were noted to be in poor condition when they were released. Data from these two fish were not included in the analyses of movement under and around the ferry terminal.

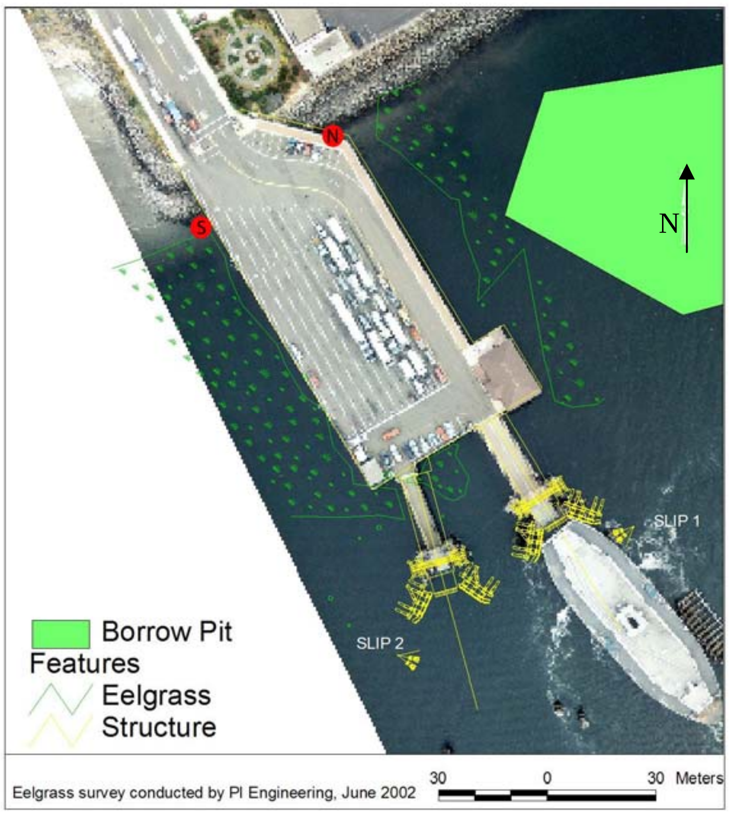


Figure 29. Release Locations (red circles) of Acoustically Tagged Juvenile Salmon at the Port Townsend Ferry Terminal

Table 11. Release Information for Acoustically Tagged Juvenile Salmon at the Port Townsend Ferry Terminal

Release Date	Release Time	Release Location	Number Released
June 22, 2005	16:50	South	4[a]
June 23, 2005	16:30	South	2
June 23, 2005	16:34	North	3[a]
June 23, 2005	19:38	South	3
June 23, 2005	19:42	North	3
June 23, 2005	21:27	South	2
June 23, 2005	21:31	North	2

(a) One fish from each of these releases was in poor condition at release.

For each tagged fish detected, the total time was calculated by subtracting the time and date of the first detection from the time and date of the last detection in the array. Whether each fish passed under the terminal was determined by examining the detection histories. For example, if a fish was released on the south side of the terminal and then subsequently detected on the north side, it was concluded that the fish had transited under the terminal. The net movement of individual fish was estimated by the timing of individual hits among the acoustic nodes within the array.

All of the tagged fish that were released were detected multiple times. A total of 11,904 transmissions were detected in the acoustic array during the tracking period. The total time that individual tagged fish were detected (excluding the fish that were released in poor condition) ranged from just under an hour (50 minutes and 32 seconds) to just under 15.5 hours (15 hours, 28 minutes, and 1 second). Table 12 presents detection history information on individual tagged fish that were released adjacent to the terminal.

Individual detection histories of acoustically tagged fish are presented in Appendix B. The detection histories of fish that were released in poor condition (G7261c836 and G72609c48) are also presented. The figures in Appendix B depict the movement of tagged fish by showing the nodes on which they were detected between the time of release and the time of last detection.

Of the 17 fish released in good condition, 9 (53%) did not appear to have passed under the terminal. The remaining 8 (47%) fish appeared to have passed under the terminal. Net movement of fish was also split relatively evenly, with 7 (41%) showing net movement in a northward direction and 10 (59%) showing a net movement to the south. Acoustically tagged juvenile salmon released during the daytime (before 17:00 PDT) appeared less likely to pass under the terminal than fish released later in the evening (after 19:30 PDT). Only two of the seven (29%) fish released during daylight were judged to have passed under the terminal, whereas 6 of 10 (60%) of the fish released later in the evening were found to have passed under the terminal. Based on this feasibility study, it appeared the presence of the Port Townsend ferry terminal does not prevent juvenile salmon from moving along the shoreline. However, based on this small data set, it appears daylight may affect these movement patterns.

Table 12. Detection History Information for Acoustically Tagged Juvenile Salmon Released Adjacent to the Port Townsend Ferry Terminal

TagMessage	ReleaseDate	Release Location	South	S. outside	S. inside	Center	N. inside	N. outside	North		Node SN	time	Node SN	time	Total time detected	Terminal Crossed?	Net Movement Direction
G72609c48	6/22/05 16:50	South					1			1	424	6/23/05 21:57	424	6/23/05 21:57	0:00:00	N	
G72607781	6/22/05 16:50	South	148				64	151	133	496	422	6/22/05 16:49	547 - N	6/22/05 18:02	1:12:54	Y	N
G726044dd	6/22/05 16:50	South	157	1			7	7		172	424	6/22/05 16:49	521 - S	6/22/05 18:12	1:22:39	N	S
G7261c629	6/22/05 16:50	South	141				240	149	181	711	422	6/22/05 16:50	547 - N	6/22/05 18:14	1:23:53	Y	N
G72609d16	6/23/05 16:30	South	92	103	75	1	92	51		414	424	6/23/05 16:38	521 - S	6/23/05 18:09	1:30:52	N	S
G7260b0c8	6/23/05 16:30	South	2196	374	407	417	426	393		4213	424	6/23/05 16:31	521 - S	6/24/05 7:59	15:28:00	N	S
G7261c836	6/23/05 16:34	North		1			4	3		8	424	6/23/05 16:34	422	6/23/05 16:39	0:04:55	N	
G7260b80a	6/23/05 16:34	North		67	20	24	249	228	161	749	423	6/23/05 16:30	547 - N	6/23/05 18:33	2:03:32	N	N
G7260bbe8	6/23/05 16:34	North		31	14	10	366	698	104	1223	421	6/23/05 16:31	547 - N	6/23/05 20:26	3:55:24	N	N
G7260685d	6/23/05 19:38	South				38	147	154	73	412	424	6/23/05 18:37	547 - N	6/23/05 20:25	1:48:02	Y	N
G7260435e	6/23/05 19:38	South	69			3	12	31		115	422	6/23/05 18:38	424	6/23/05 21:09	2:30:53	N	S
G72605c82	6/23/05 19:38	South	761			2	16	2		781	423	6/23/05 18:57	521 - S	6/24/05 10:25	15:28:01	N	S
G7260671c	6/23/05 19:42	North	28			4	7	6		45	422	6/23/05 18:40	521 - S	6/23/05 19:31	0:50:32	Y	S
G72608076	6/23/05 19:42	North	165			9	16	36		226	422	6/23/05 18:44	521 - S	6/23/05 20:20	1:36:35	Y	S
G72606d62	6/23/05 19:42	North	453	145	165	61	63	81		968	422	6/23/05 18:41	521 - S	6/24/05 8:00	13:18:23	Y	S
G72608cd5	6/23/05 21:27	South	98			4	2	1		105	423	6/23/05 21:26	521 - S	6/23/05 22:20	0:53:46	N	S
G726087f5	6/23/05 21:27	South	35	2	2	102	71	35	126	373	425	6/23/05 16:32	547 - N	6/23/05 23:46	7:13:35	Y	N
G726091b5	6/23/05 21:31	North				23	72	127	132	354	423	6/23/05 21:31	547 - N	6/23/05 23:16	1:45:17	N	N
G7261d069	6/23/05 21:31	North	73			74	185	166	40	538	423	6/23/05 21:30	521 - S	6/23/05 23:55	2:25:56	Y	S

Note: Fish that were released in poor condition are shaded gray. The number of hits on each node are shown for the south autonomous, south outside (on terminal), south inside (on terminal), center (under terminal), north inside (on terminal), north outside (on terminal), and north autonomous locations.

5.0 Conclusions

The major findings of the present study are:

- Juvenile salmon aggregate near the edge of the ferry terminal OWS.

  During the day, juvenile salmon (chum, chinook, and coho) were observed most frequently adjacent to ferry terminals (within 10 m of the edge of the OWS), but were also observed far from (10 to 50 m away) and underneath the terminals. Variations in habitat, as mediated by tidal stage (affecting current magnitude and direction, light under structures, water level) and time of day (light level, sun angle, cloud cover), likely affect these movements.

  - ♦ *21 schools of chum were observed in the region adjacent to terminals, 15 schools were observed away from terminals, and only 3 schools were observed partially under terminals (Table 3).*
  - ♦ *When snorkel survey data was combined for both terminals (Fauntleroy and Edmonds), juvenile salmon were much more abundant in areas adjacent to the ferry terminal OWS as compared with surveyed sites at a distance away from or under the ferry terminal (Figure 21).*
  - ♦ *Juvenile salmon captured in both enclosure nets and beach seines at the Port Townsend terminal were much more abundant in areas adjacent to terminal than in areas under or away from the terminal (Figure 28).*

- Juvenile salmon aggregated adjacent to the Fauntleroy Ferry Terminal were deeper in the water column than were the fish that were observed away from the terminal (Figure 26).

  This tendency may be in response to the overhead shading caused by the structure of the terminal. This response was not as pronounced at the Edmonds Ferry Terminal (Figure 23).

- Juvenile chum remained on the light side of a dark/light shadow line when the decrease in light level was approximately 85% over a short horizontal distance (e.g., five meters).

- Juvenile chinook and coho moved under and past the Port Townsend terminal more quickly and more often during the late evening, when there was a less distinct shadow boundary than there was during full daylight.

  Based on this acoustic tagging and tracking feasibility study, the technology appears to be a useful tool for investigating the movement and behavior of juvenile salmon around ferry terminals and other OWS. From the analysis of tracking data on the limited number of tagged fish, it appeared that the tagged juvenile salmon did exhibit movement patterns that indicate migration along the shoreline in shallow nearshore areas. In addition, about half of the tagged fish were able to transit under the ferry terminal and were not prevented from following normal shoreline movement patterns by the presence of the OWS. However, based on this small data set, it appears the level of daylight may have an effect on these movement patterns. Acoustically tagged juvenile salmon released during the daytime appeared less likely to pass under the terminal than did fish released later in the evening when shadow lines adjacent to the OWS were not as distinct. Only about a quarter of the tagged fish released during daylight were judged to have passed under the terminal, whereas over half of the tagged fish released later in the evening were found to have passed under the terminal.

- During the day, juvenile salmon may move more readily under OWS at low tide, when more incidental light penetrates under the OWS.

  *Juvenile salmon were only present under the 24-m wide Edmonds terminal during low tide (Figure 25, **Error! Reference source not found.**). All other regions sampled had observations at both high and low tides, at similar densities for chinook and coho salmon. These observations demonstrate that the shading caused by ferry terminals and other OWS characteristics can deter or delay juvenile salmonid migration, and that this effect may be decreased at low tides when ambient light can better filter beneath the terminal structure.*

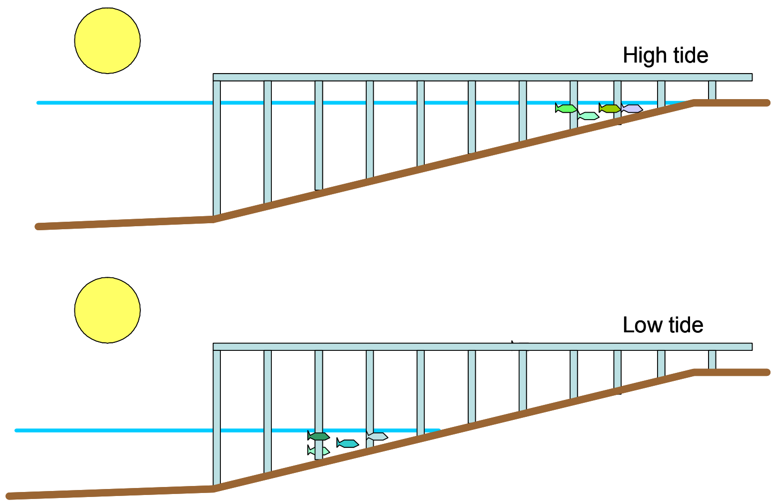


Figure 30. Depiction of juvenile salmonid movement near shore at high tide and at low tide. Fish tended to move under structures at low tide, but not at high tide.

- Juvenile chum did not swim from one side to the other under any of the ten terminals during daytime observations.

  Only 3 schools, observed at two terminals were observed entering the light/dark shadow region. These fish were observed on the edge of the 51-m wide Clinton terminal and under the foot-ferry dock and ferry terminal overhead walkway (not the main terminal) at Kingston.

  The small number of schools of juvenile chum salmon that were observed adjacent to the terminals does not provide enough data to support a conclusive statement about the influence of OWS and changes in natural light regime on fish migration behavior.

- We cannot conclude whether fish moved under the dock or around the dock consistently during periods when light-dark contrast was not inhibiting movement. Fish movement was not unidirectional (e.g., south to north), but varied considerably both near terminals and away from terminals.

It is probable that most OWS are temporary impediments to juvenile movement only during specific periods of time or under specific environmental conditions. Based on the observations of this study and previous research, it appears that OWS with a more pronounced dark under-dock condition tend to be more of an obstacle for juvenile salmon movement than structures which allow greater light penetration. It is also likely that the individual structural characteristics of each OWS, as well as the level of human activity present at the OWS, also affect how strong an impediment each OWS is to migrating juvenile salmon.

5.1 Recommendations

Based on previous research and the findings of this study, there is an indication that OWS, except for very narrow structures, represent at least a partial obstacle to juvenile salmon movement and likely will result in behavioral changes in these fish upon encountering the OWS during nearshore migration periods. The cumulative impact of very wide or multiple OWS is still not well-understood, although the presence of multiple, closely spaced, or large OWS is likely to represent a temporary impediment to juvenile salmon movement.

The following recommendations are made concerning the design and operation of WSF terminals with regard to mitigating the undesirable impacts of OWS on juvenile salmonid movement:

1. To minimize the shade-related impacts to migrating juvenile salmonids created by ferry terminals, OWS should be designed and constructed to allow incidental light to penetrate as far under as possible, while still providing the necessary capacity and safety considerations necessary to support their intended function. The physical design (e.g., dock height and width, dock orientation, construction design materials, piling type and number) will influence whether the shadow cast on the nearshore covers a sufficient area and level of darkness to constitute an impediment. Construction of closely spaced terminal structures should be avoided to minimize the potential cumulative impacts of multiple OWS on juvenile salmonid migration (Nightingale and Simenstad 2001).
2. Experiment with technologies and designs that can soften the light-dark edge to minimize potential temporary inhibition of movement.
3. Based on earlier research (Blanton et al. 2002), the incorporation of light-enhancing technologies in OWS design is likely to maintain light levels under OWS above that required by juvenile salmonids for feeding and schooling (i.e., estimated at between 0.0001 and 1 ft candles, depending on age and species [Ali 1959]). To encourage daytime movement under terminals and other OWS, it would be beneficial to decrease the dark-edge effect as much as possible. Providing even a small amount of light in a regular pattern under a dock may encourage fish to swim underneath. Natural lighting for fish could also be enhanced if the underside of the dock was reflective.
4. Continued research is needed to improve our understanding of the relationship between OWS and the behavior of migrating juvenile salmonids. The use of acoustic tagging-tracking technology demonstrated during this study should be further used to address the data gaps in our level of knowledge.
5. Fish feeding behavior during temporary delays of movement should be investigated. If prey resources and refuge habitat are adequate, fish may benefit from holding in an area adjacent to a terminal.

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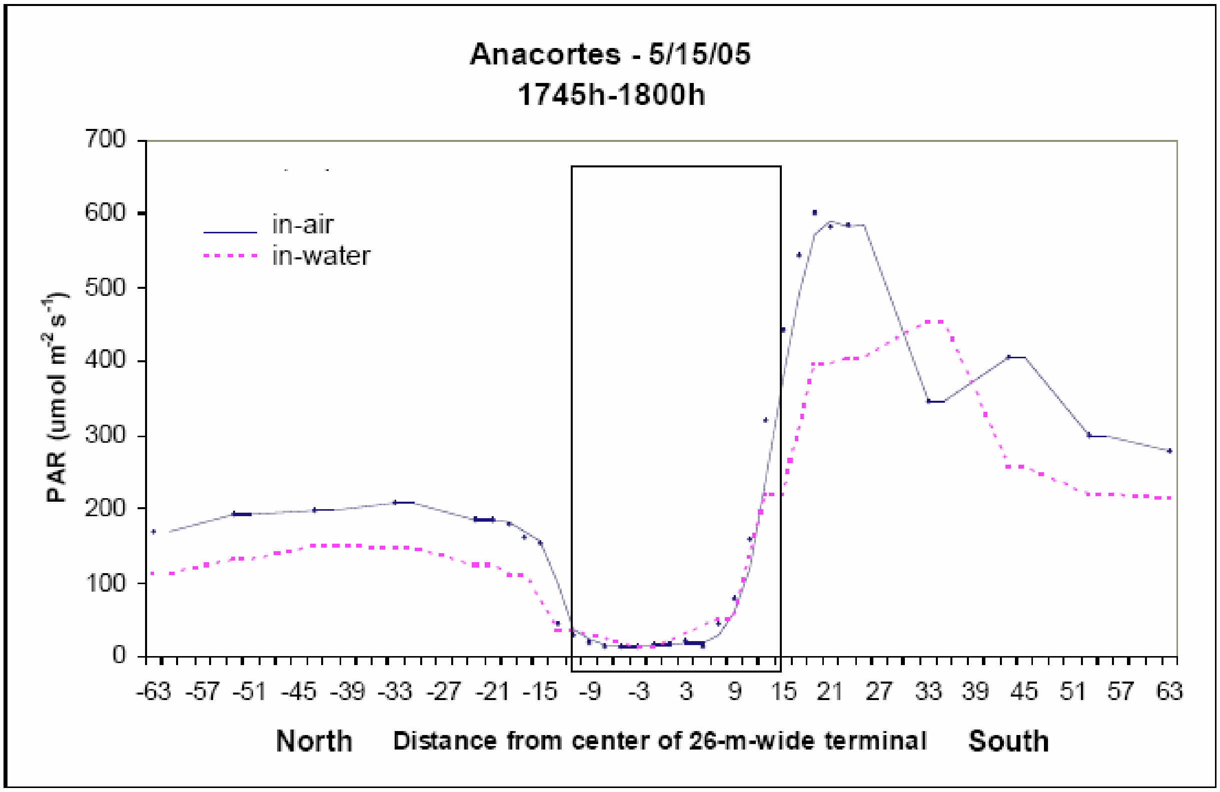
Appendix A

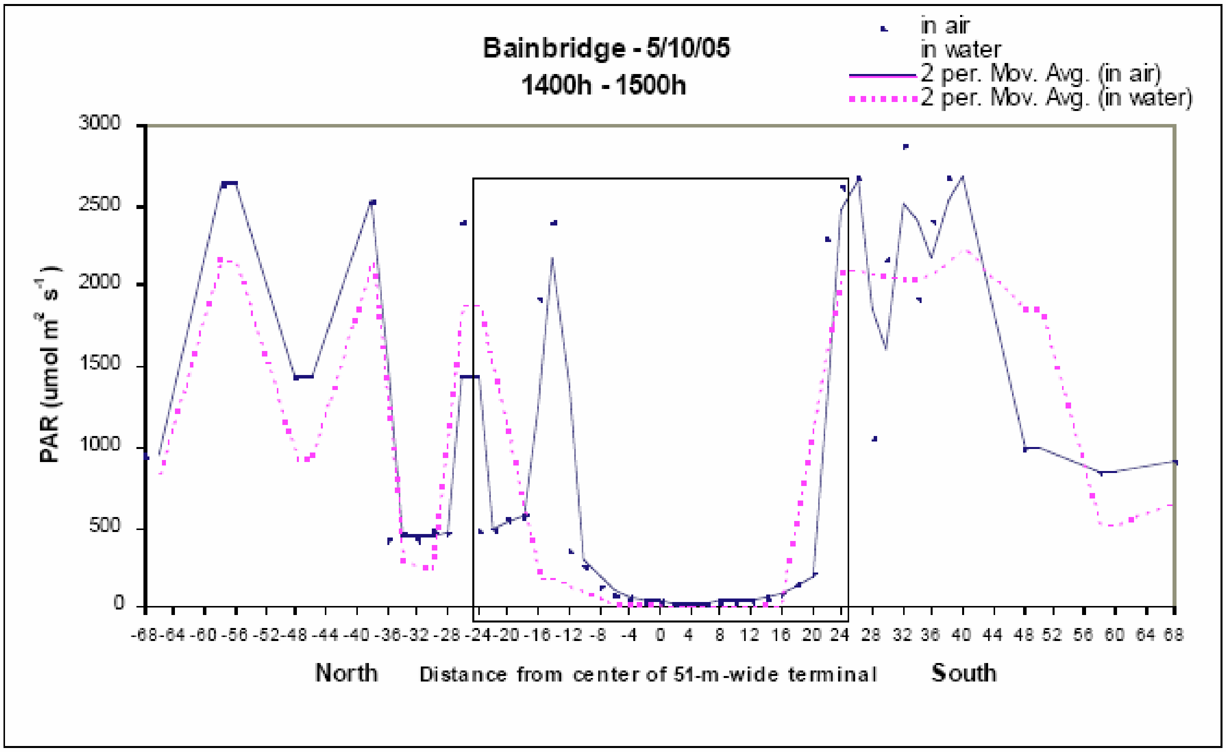
In-Air and In-Water Light Measurements at Eight Washington State Ferry Terminals

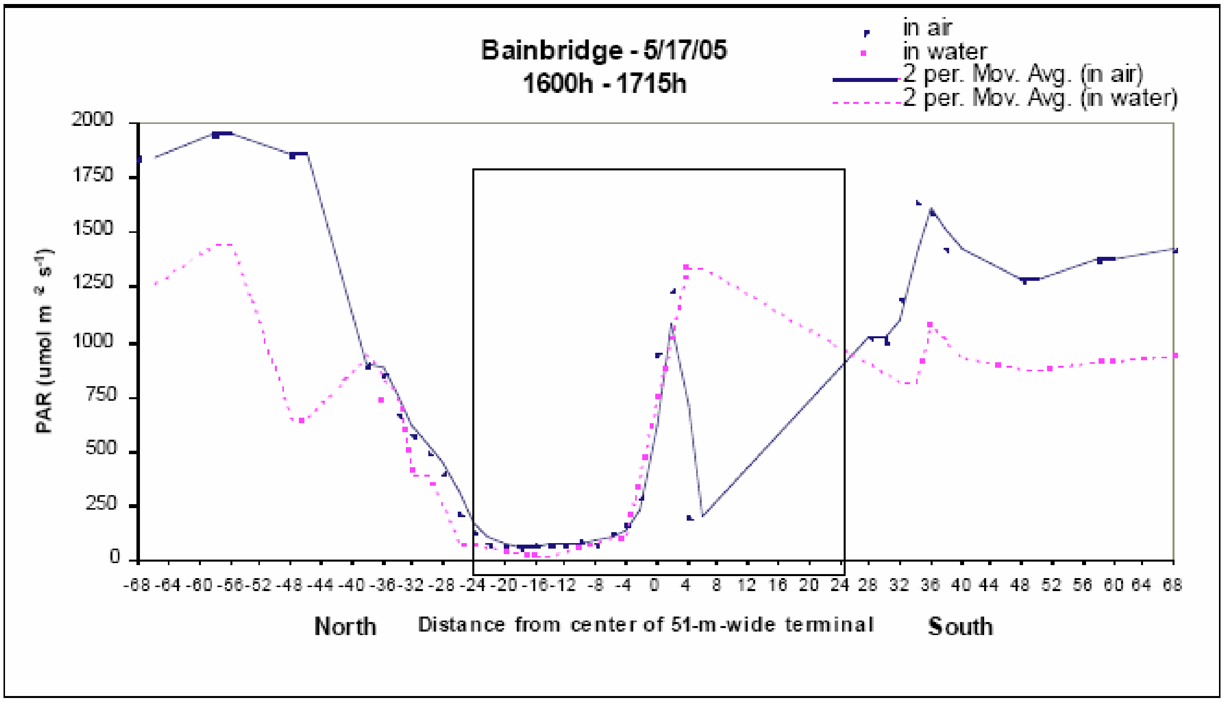
(Note: In the following figures, the Y-axis scales are variable. Lines represent moving averages; dots are actual data points. Solid rectangles represent the width of the ferry terminal; dotted rectangles indicate that additional structures, such as pedestrian walkways, also produced shade.)

Anacortes Ferry Terminal

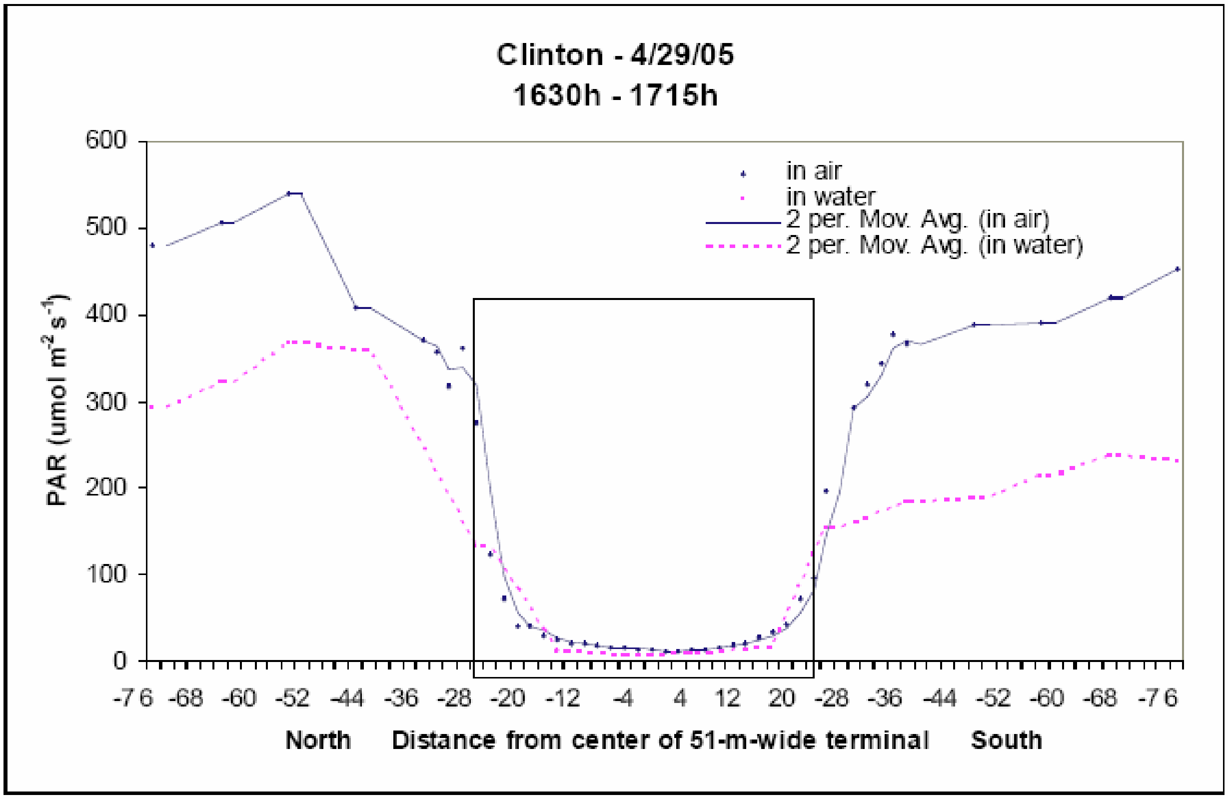


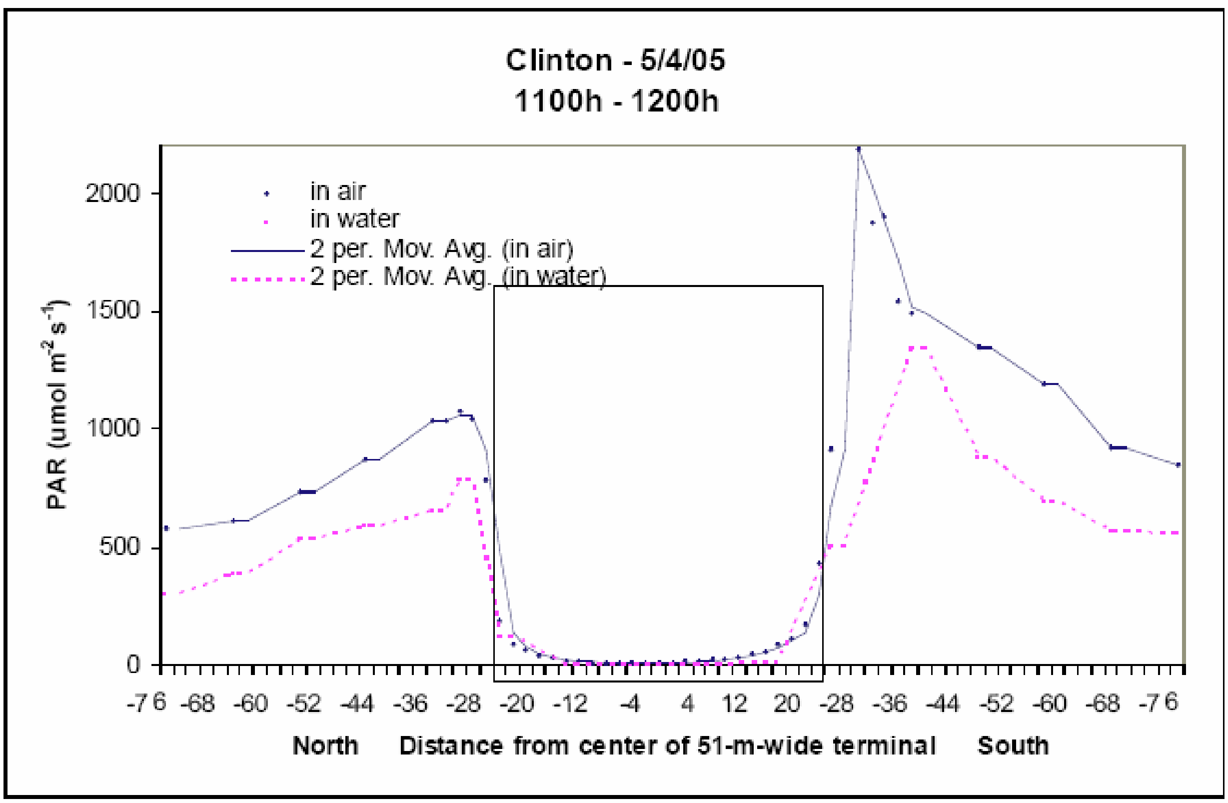
Bainbridge Ferry Terminal



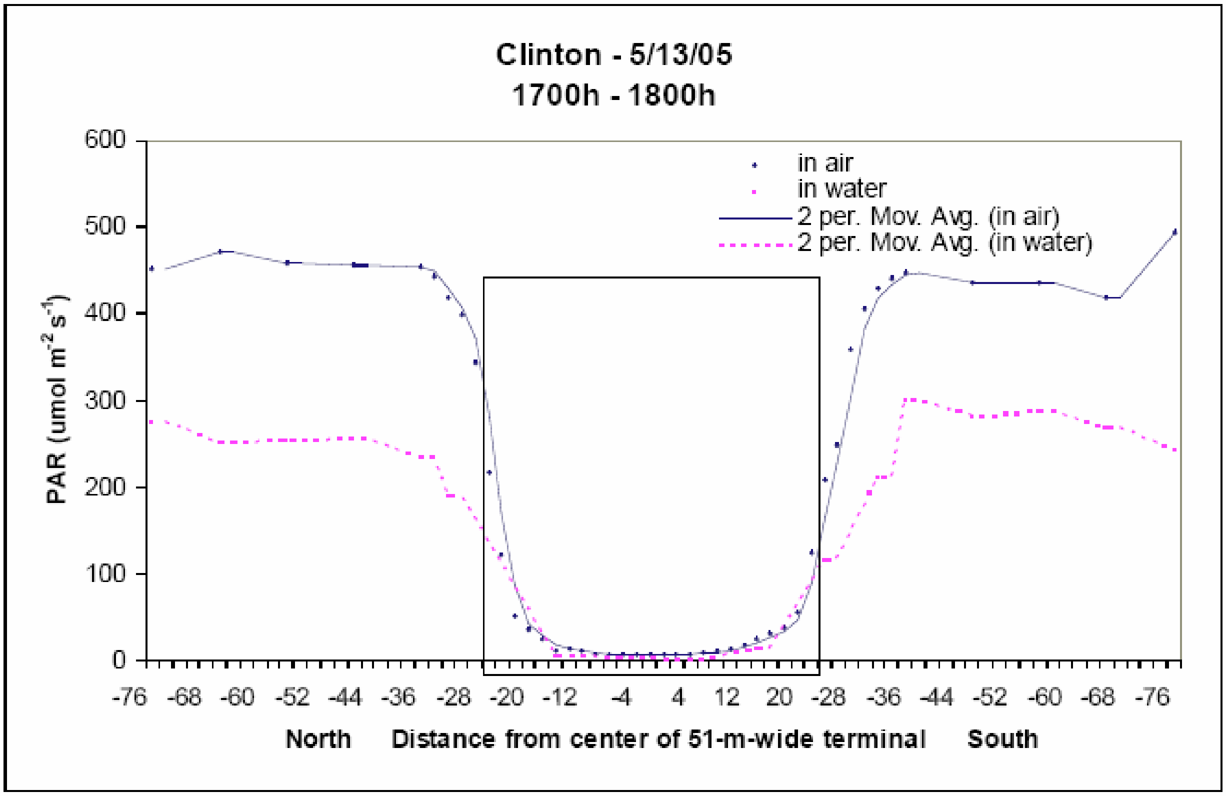


Clinton Ferry Terminal

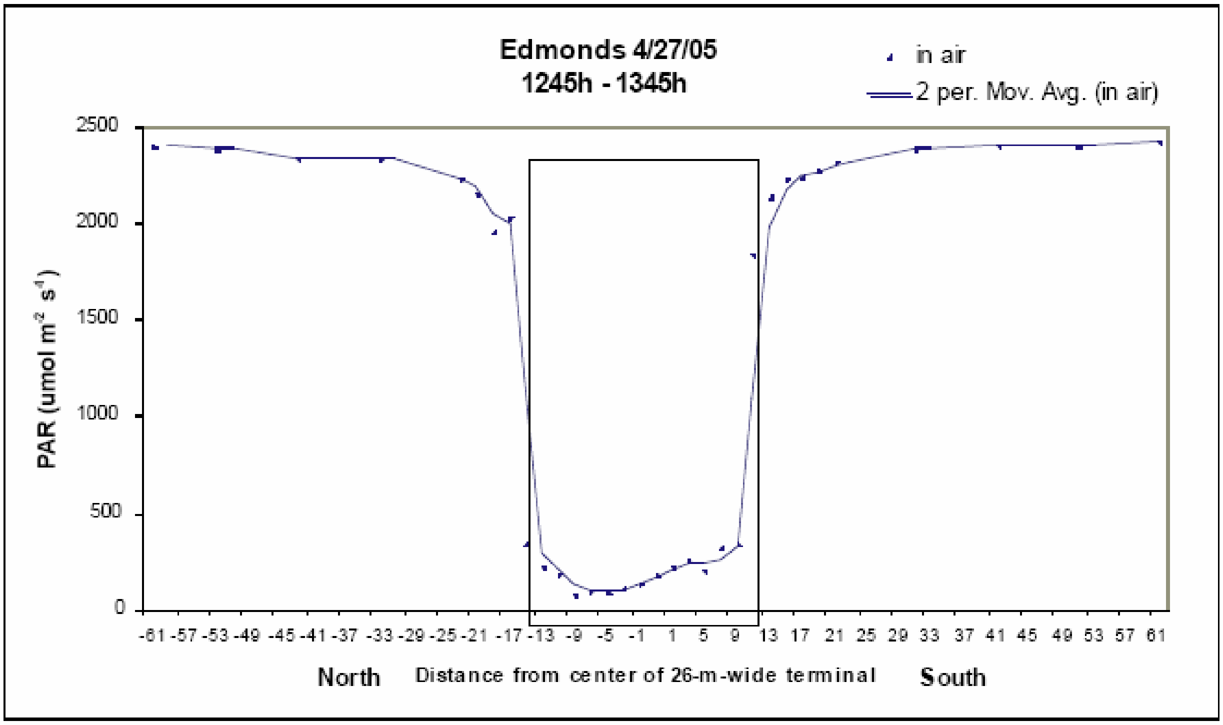


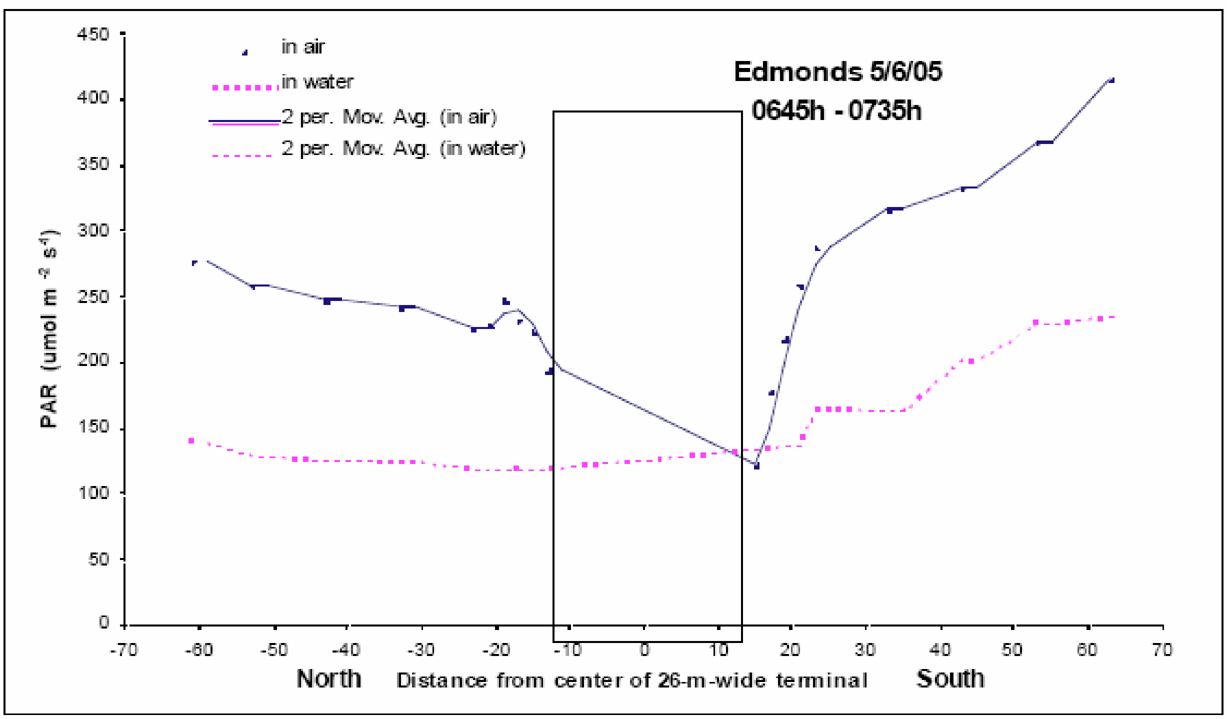


Clinton Ferry Terminal, continued.

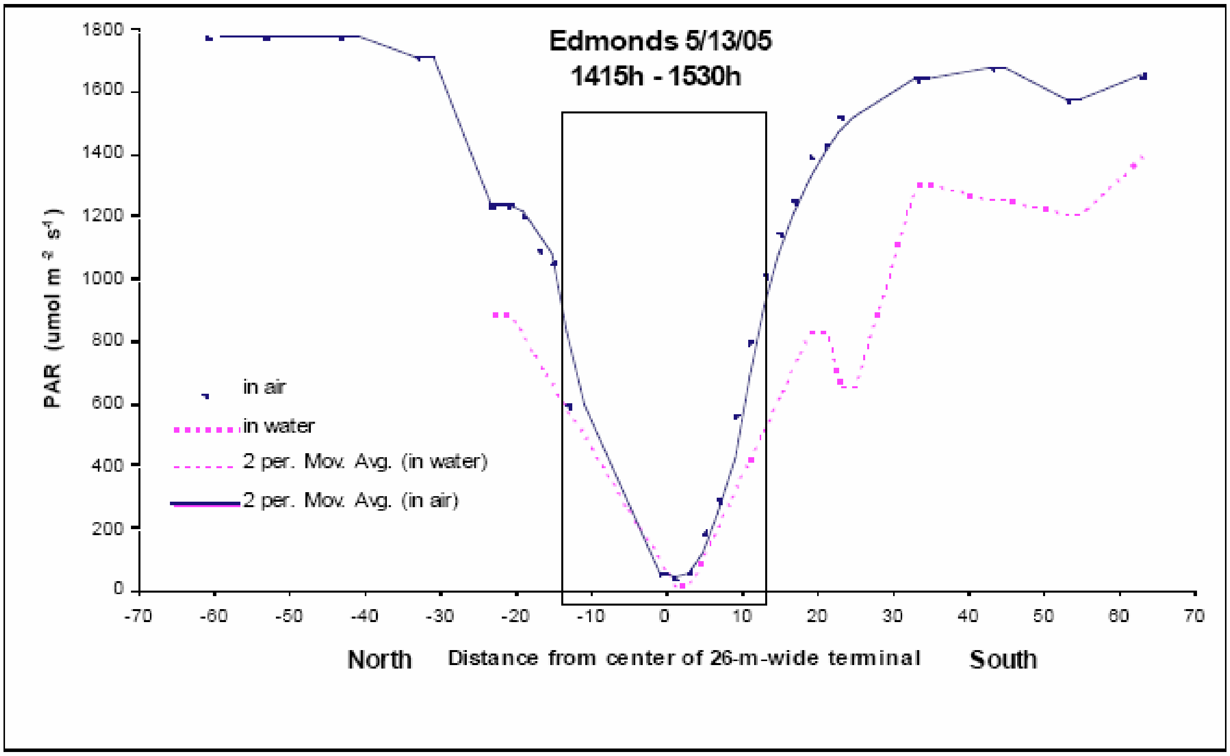


Edmonds Ferry Terminal

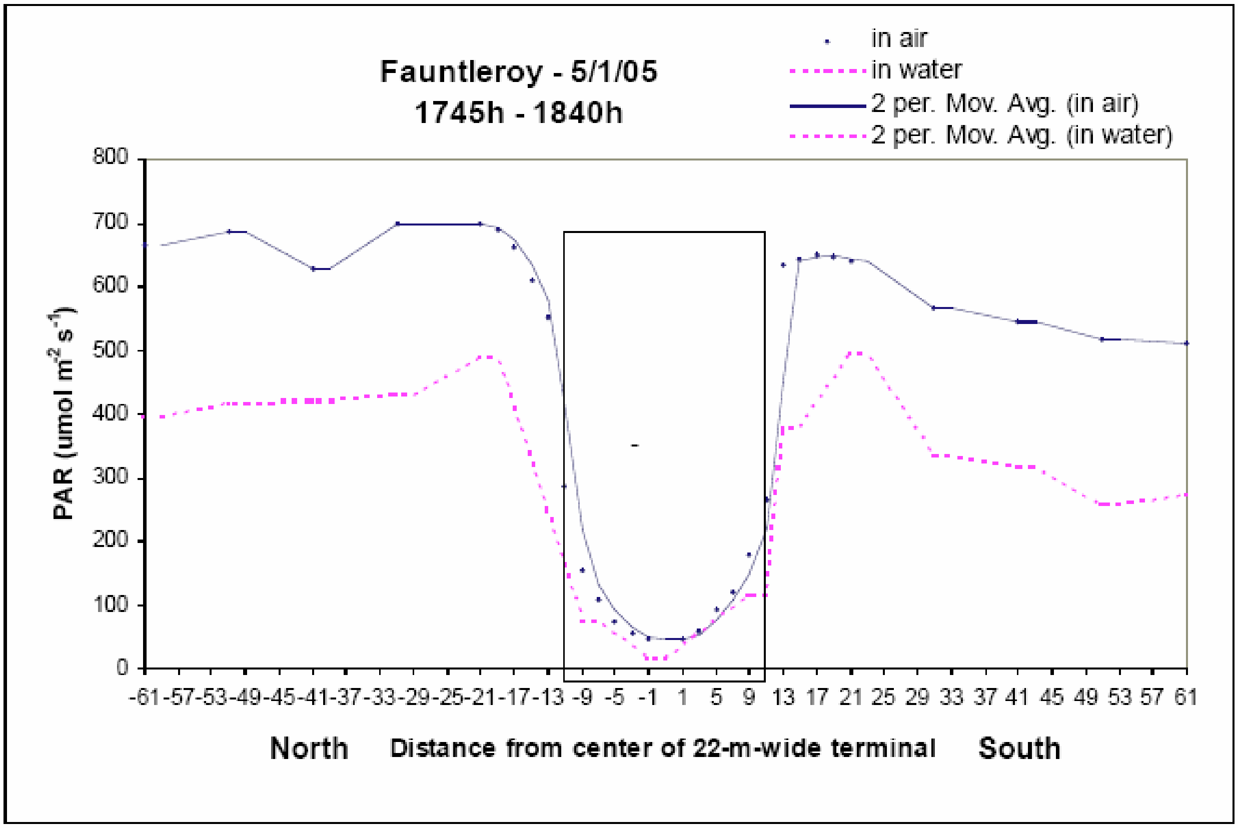


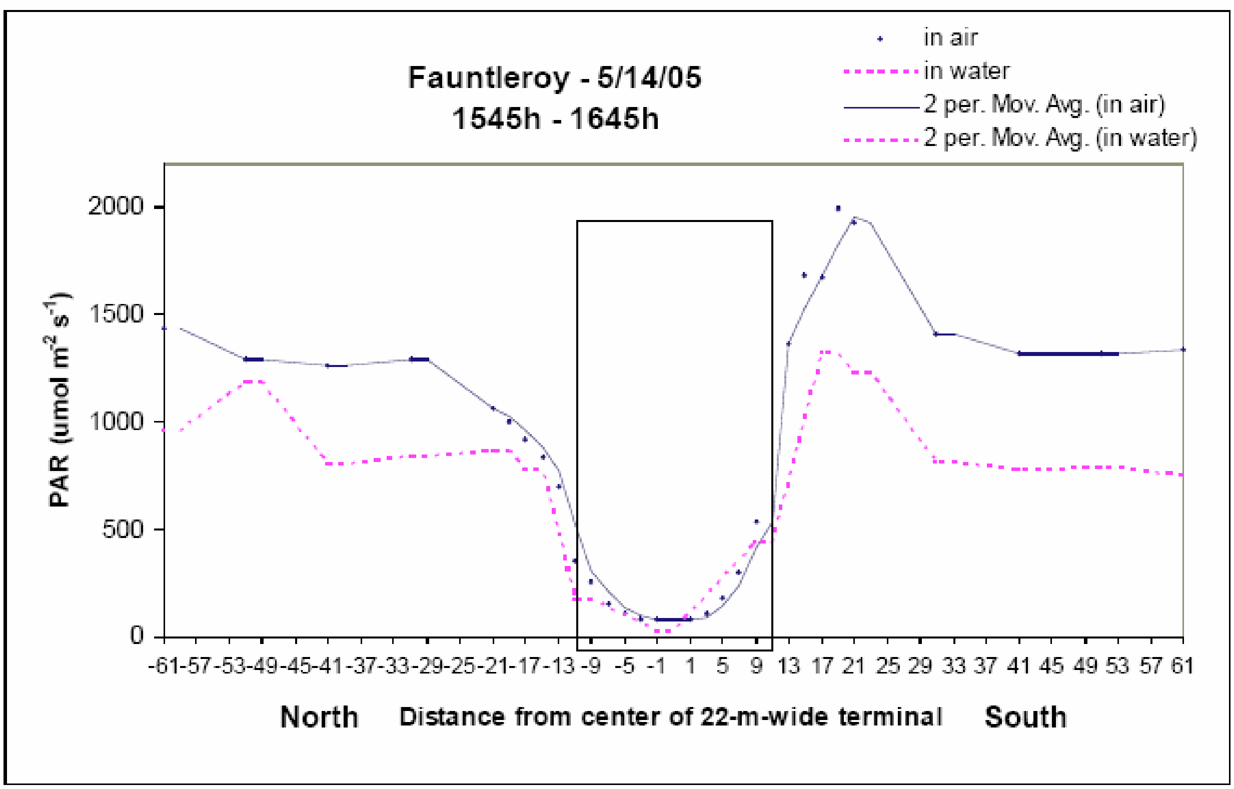


Edmonds Ferry Terminal, continued.

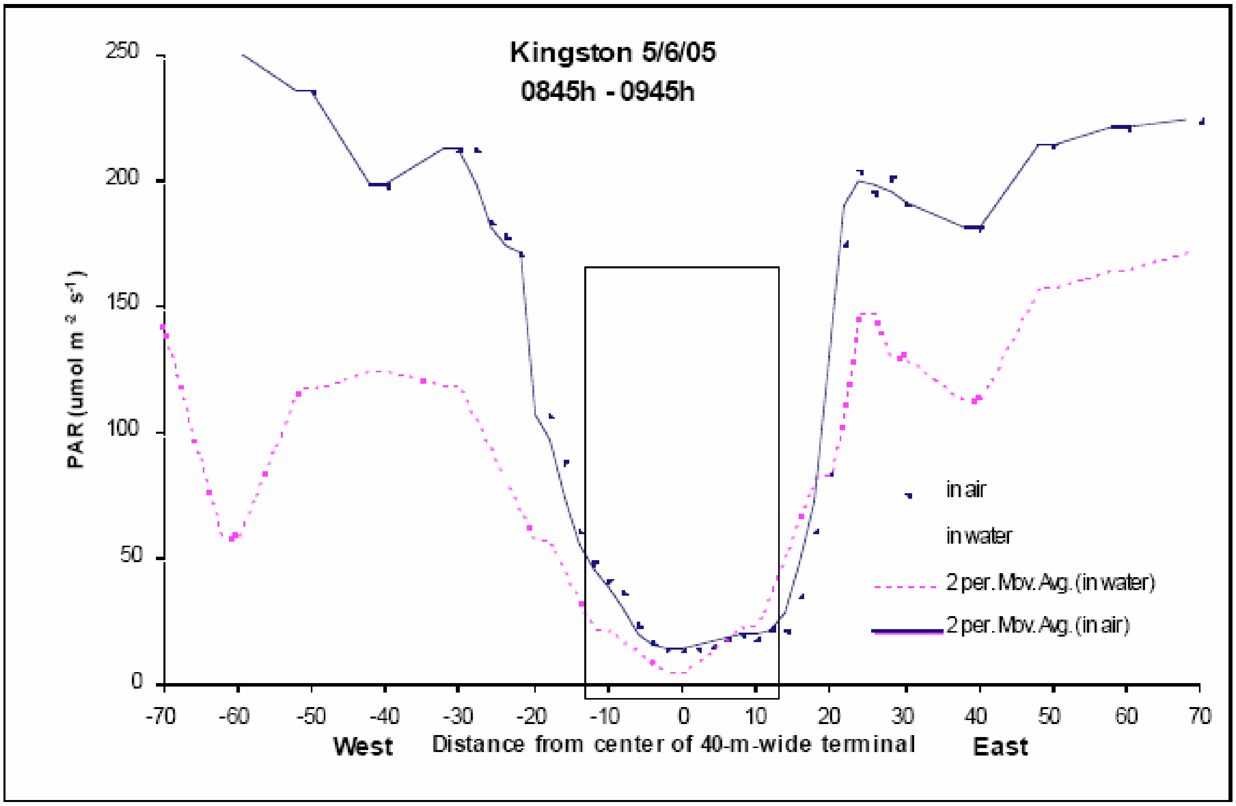


Fauntleroy Ferry Terminal

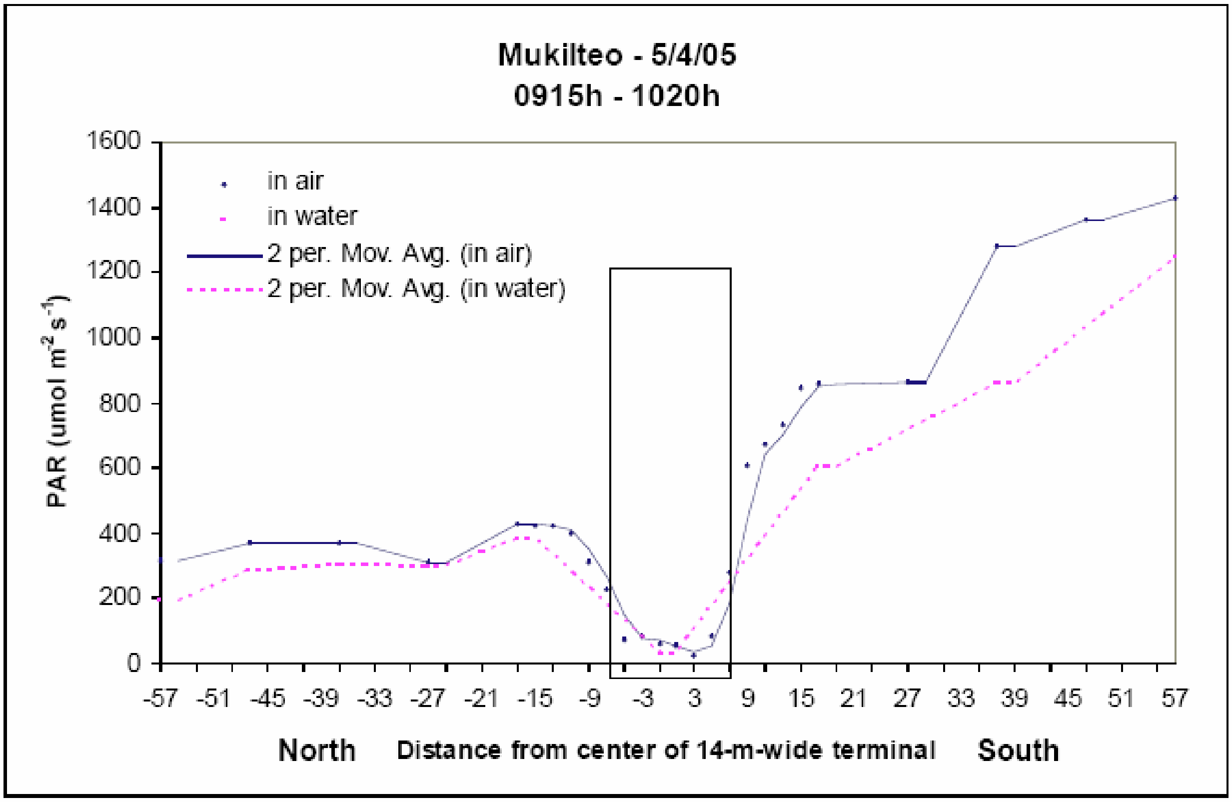




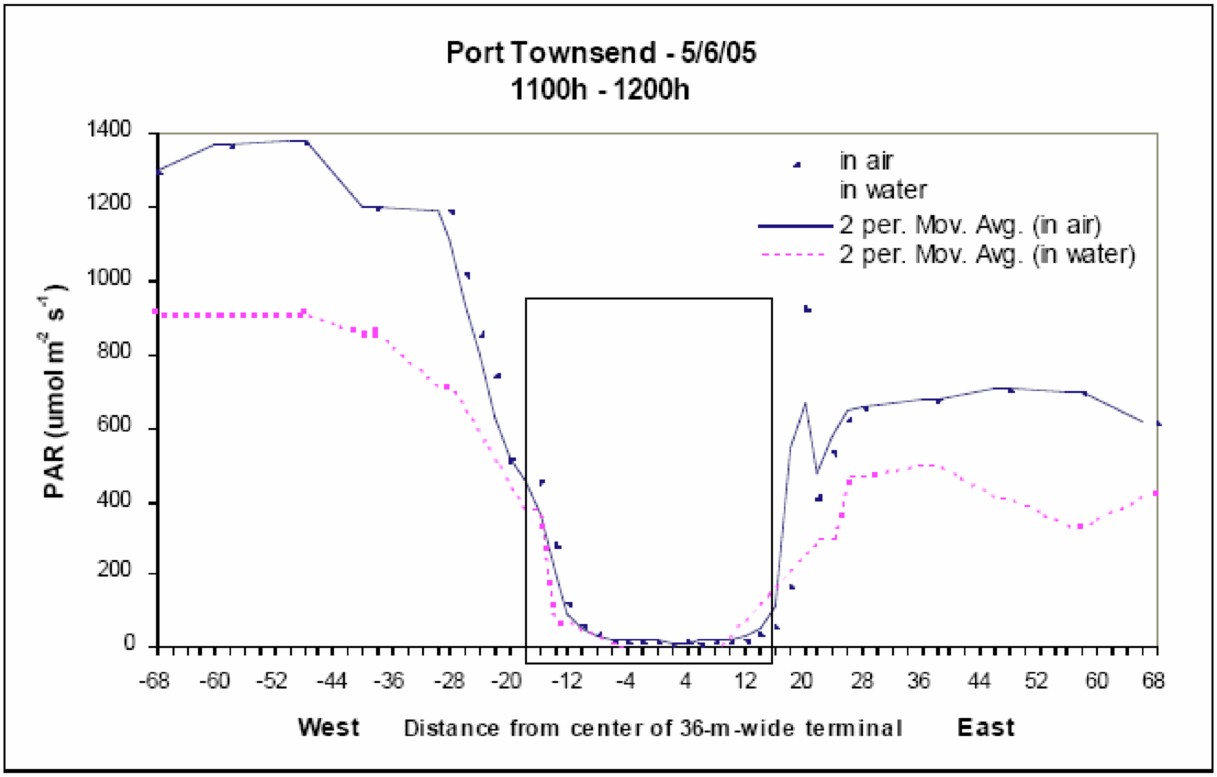
Kingston Ferry Terminal

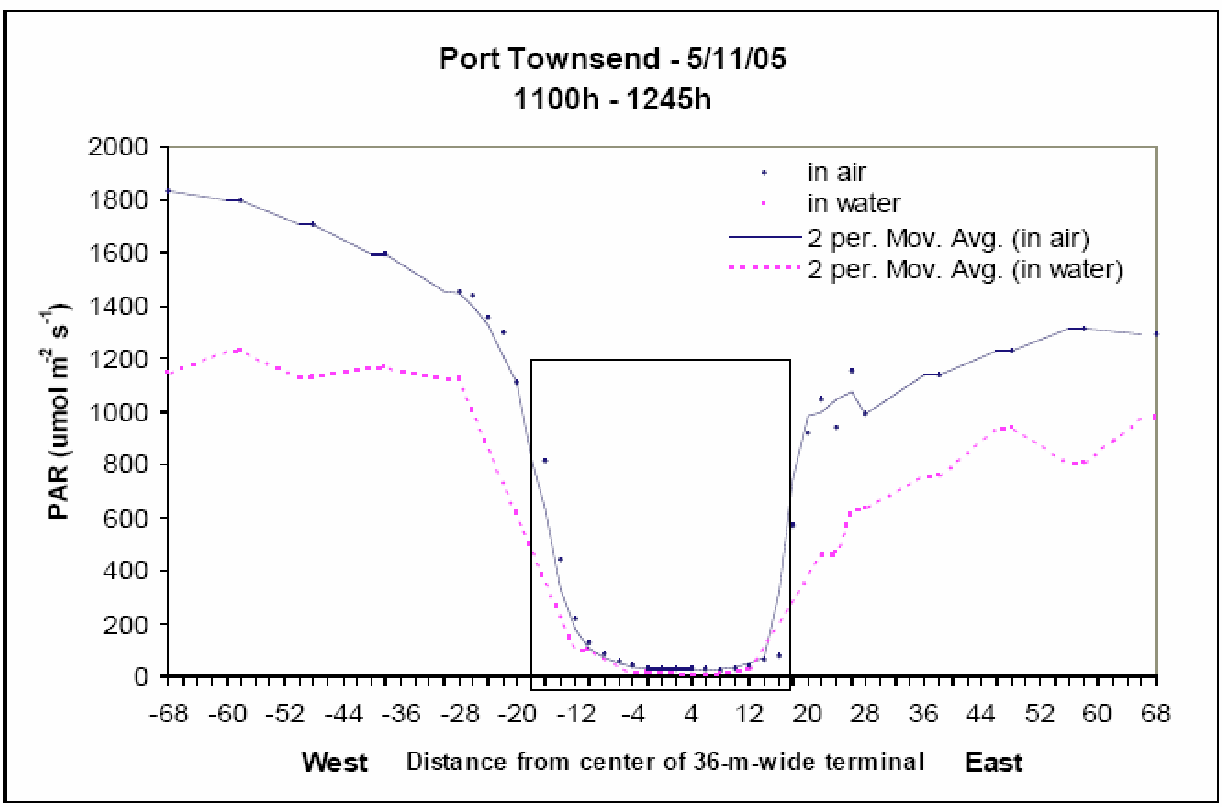


Mukilteo Ferry Terminal



Port Townsend Ferry Terminal





Appendix B

Acoustic Tagging-Tracking Experiment Data

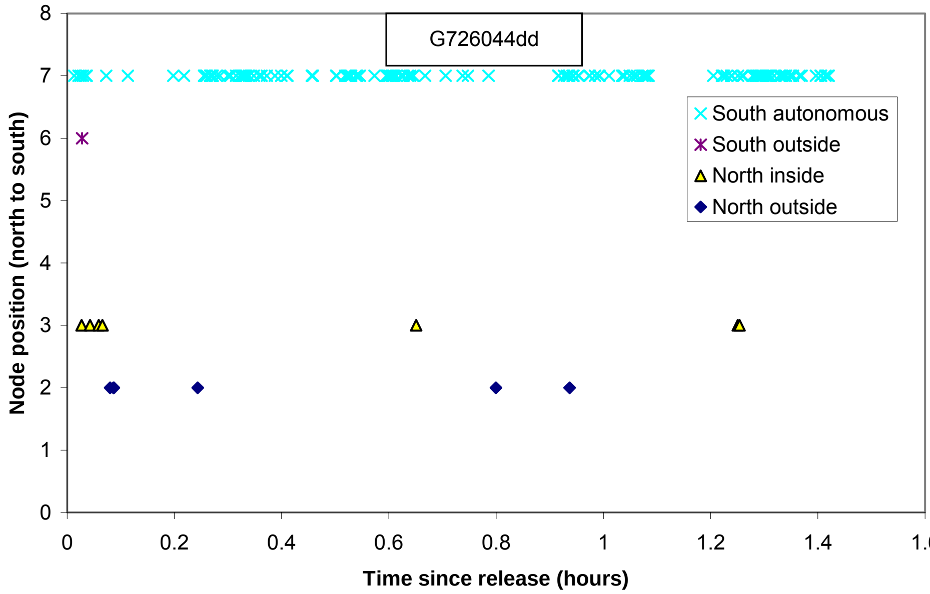


Figure B1. Detection history information for the 114 mm-long juvenile chinook salmon implanted with transmitter G726044dd that was released at the south location on June 22 at 16:50.

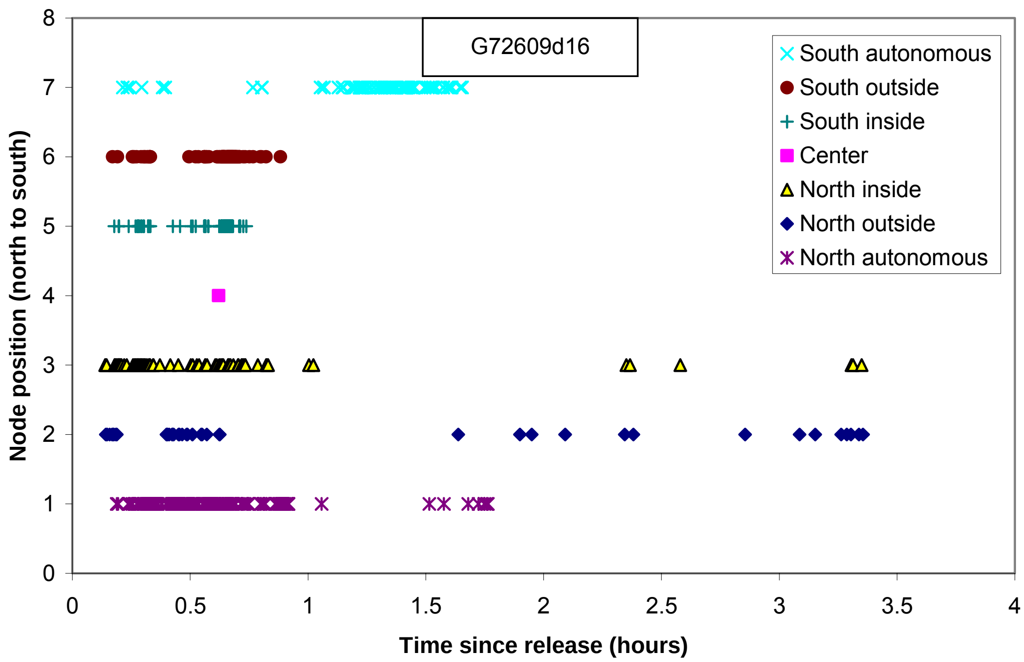


Figure B2. Detection history information for the 123 mm-long juvenile chinook salmon implanted with transmitter G72609d16 that was released at the south location on June 23 at 16:30.

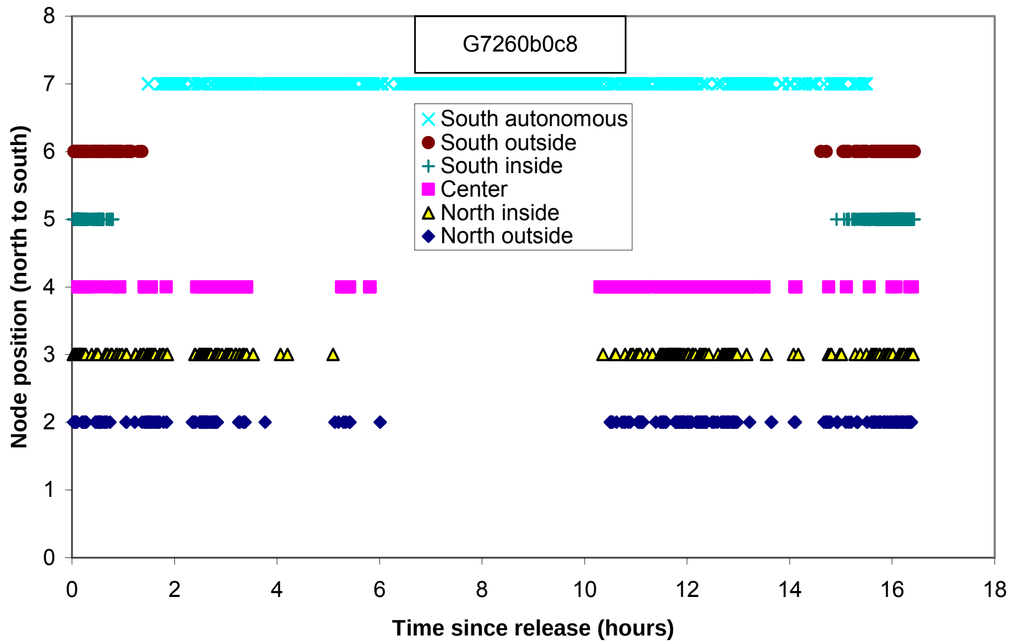


Figure B3. Detection history information for the 116 mm-long juvenile coho salmon implanted with transmitter G7260b0c8 that was released at the south location on June 23 at 16:30.

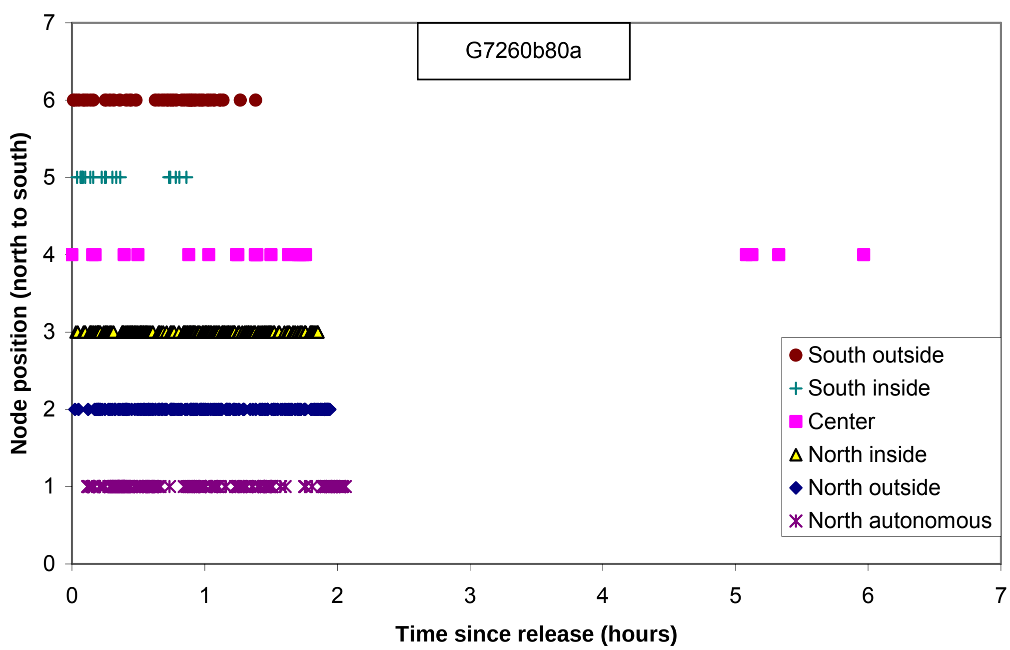


Figure B4. Detection history information for the 132 mm-long juvenile coho salmon implanted with transmitter G7260b80a that was released at the north location on June 23 at 16:34.

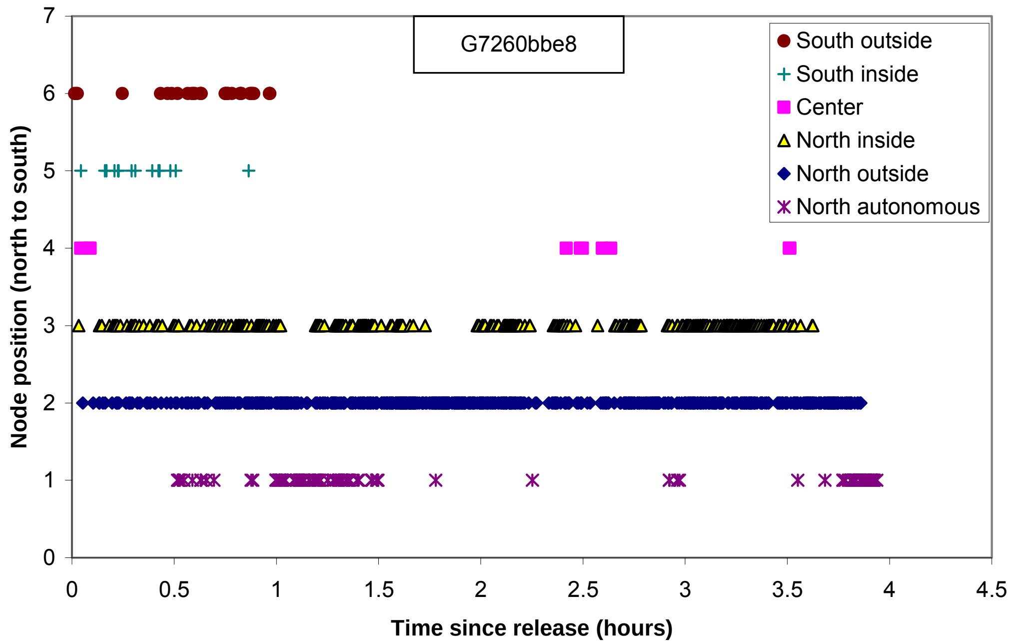


Figure B5. Detection history information for the 115 mm-long juvenile chinook salmon implanted with transmitter G7260bbe8 that was released at the north location on June 23 at 16:34.

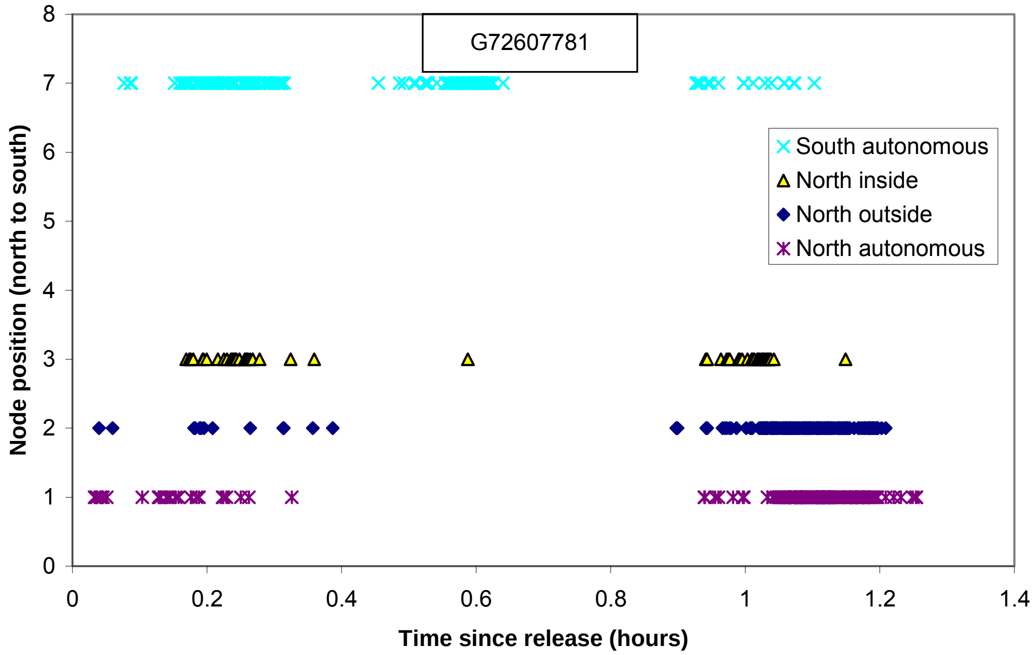


Figure B6. Detection history information for the 113 mm-long juvenile chinook salmon implanted with transmitter G72607781 that was released at the south location on June 22 at 16:50.

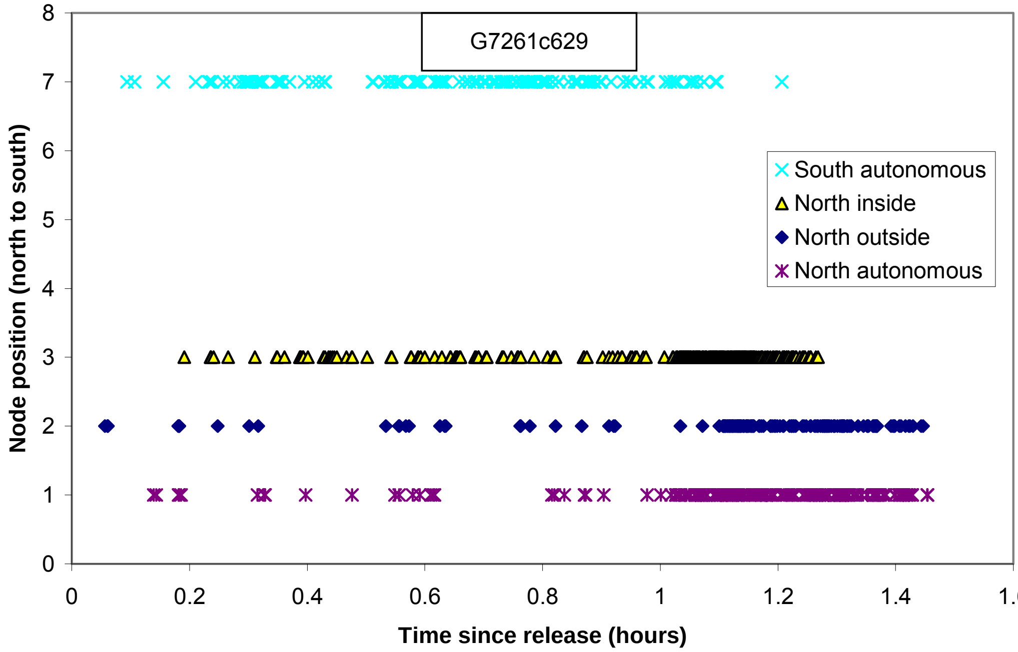


Figure B7. Detection history information for the 111 mm-long juvenile chinook salmon implanted with transmitter G7260c629 that was released at the south location on June 22 at 16:50.

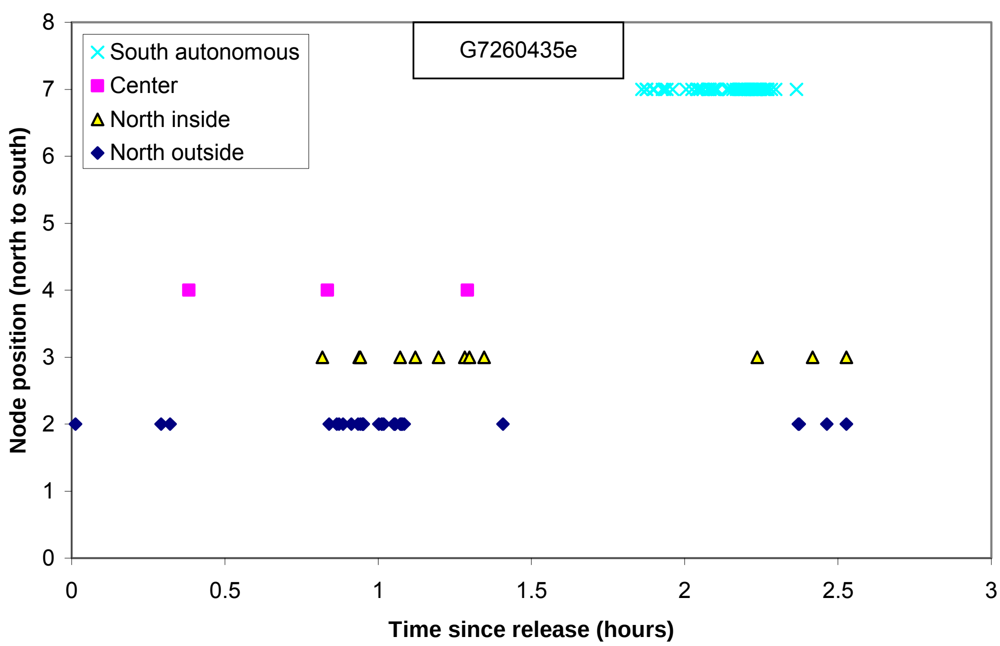


Figure B8. Detection history information for the 98 mm-long juvenile chinook salmon implanted with transmitter G7260435e that was released at the south location on June 23 at 19:38.

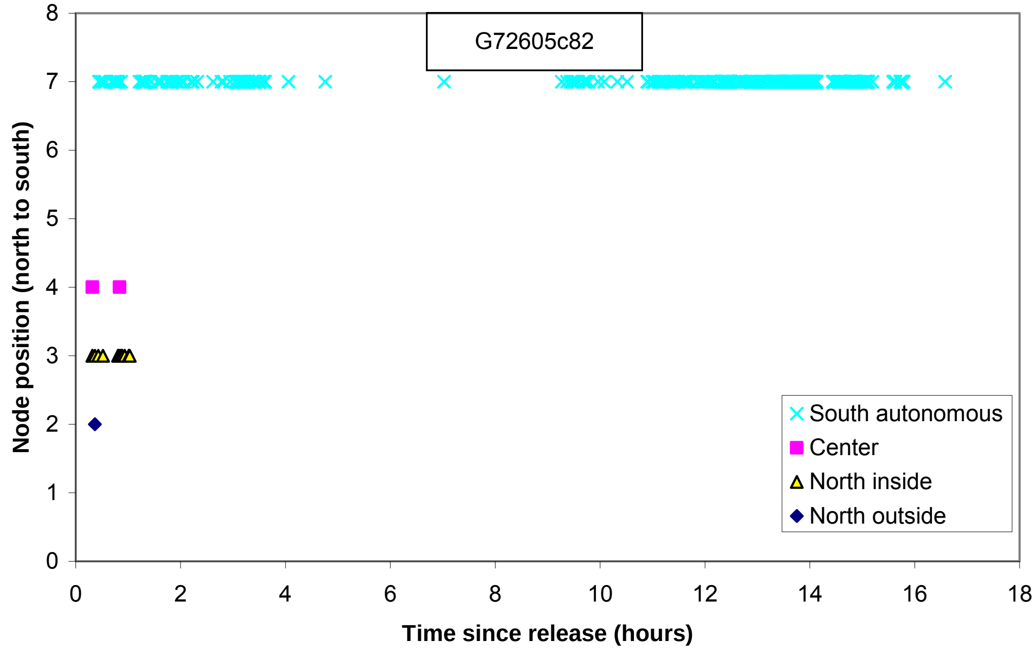


Figure B9. Detection history information for the 114 mm-long juvenile chinook salmon implanted with transmitter G72605c82 that was released at the south location on June 23 at 19:38.

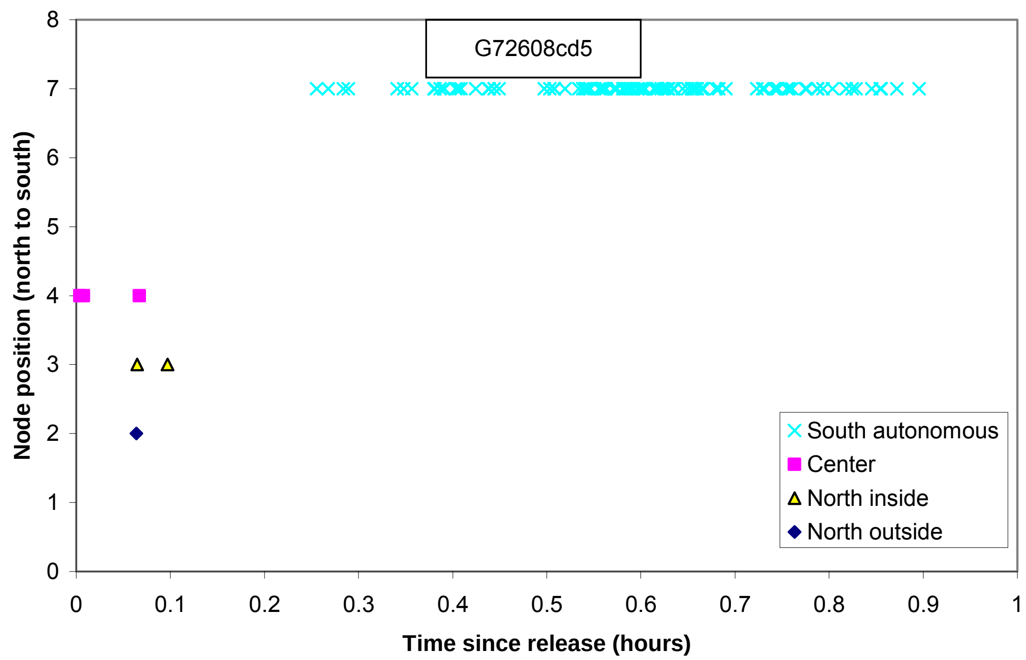


Figure B10. Detection history information for the 115 mm-long juvenile chinook salmon implanted with transmitter G72608cd5 that was released at the south location on June 23 at 21:27.

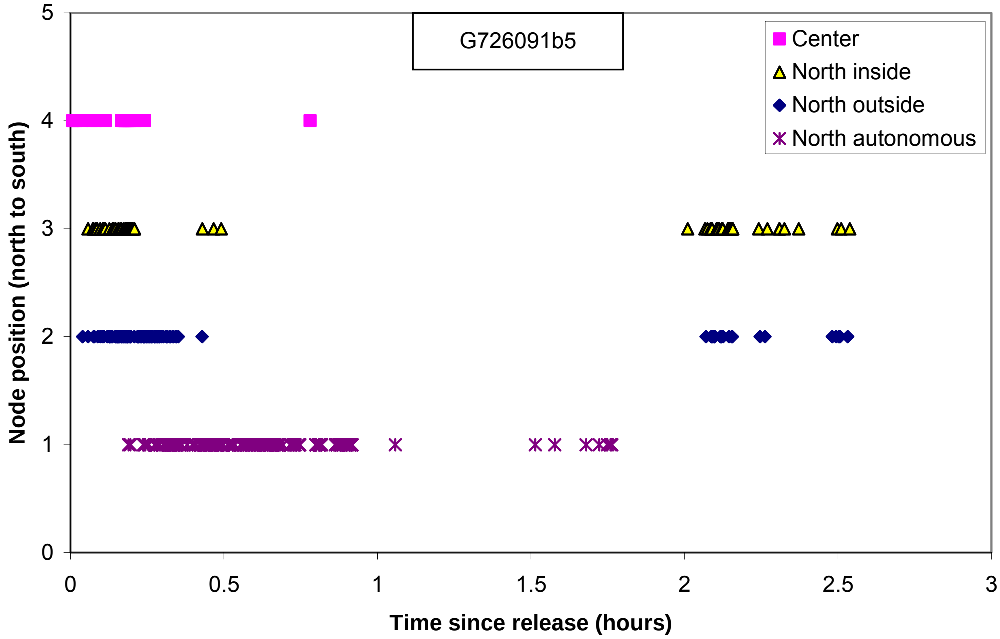


Figure B11. Detection history information for the 104 mm-long juvenile chinook salmon implanted with transmitter G726091b5 that was released at the north location on June 23 at 21:31.

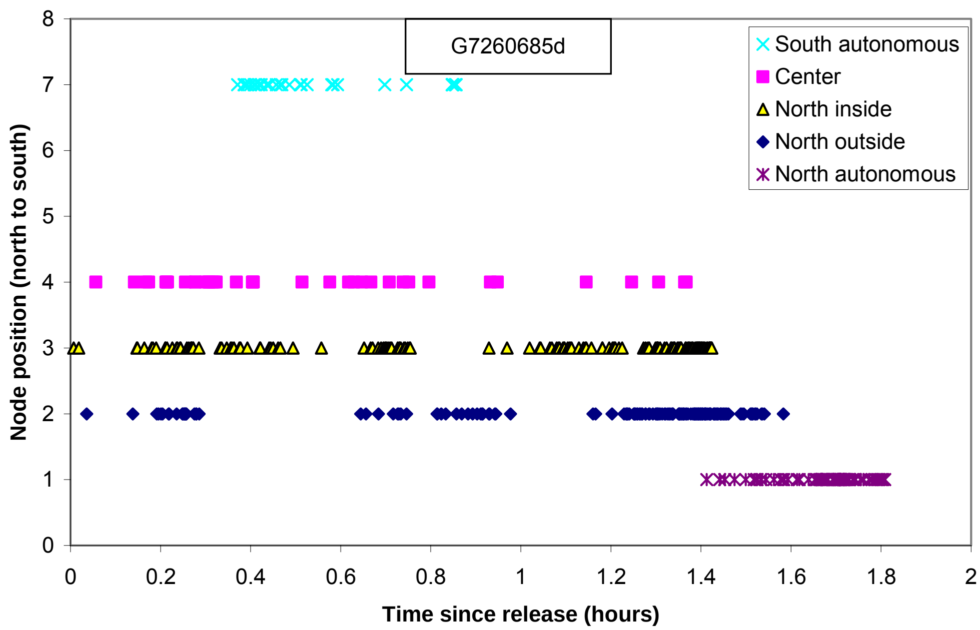


Figure B12. Detection history information for the 133 mm-long juvenile chinook salmon implanted with transmitter G7260685d that was released at the south location on June 23 at 19:38.

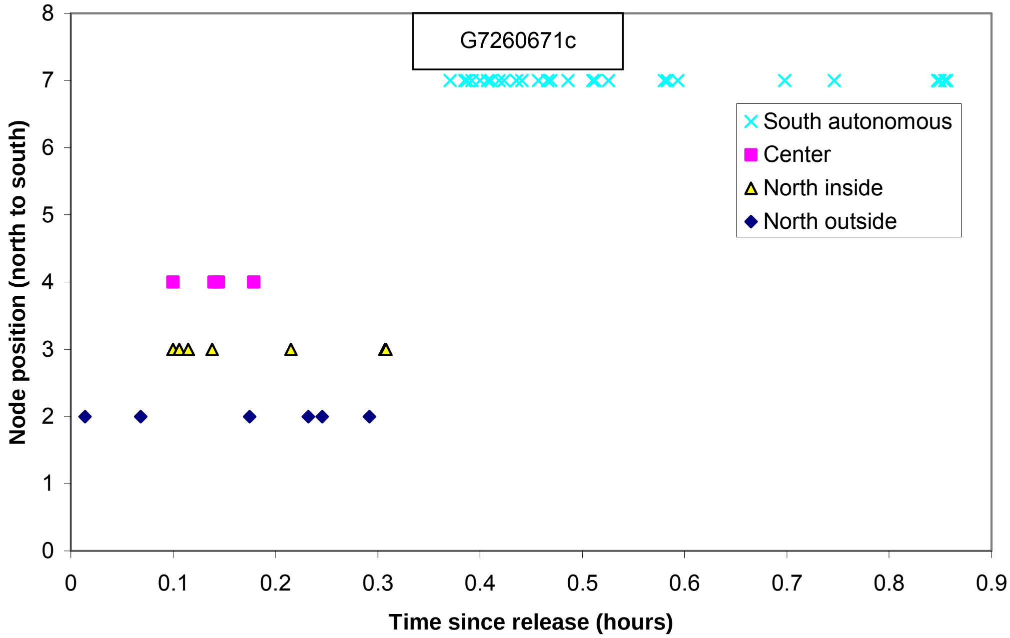


Figure B13. Detection history information for the 117 mm-long juvenile chinook salmon implanted with transmitter G7260671c that was released at the north location on June 23 at 19:42.

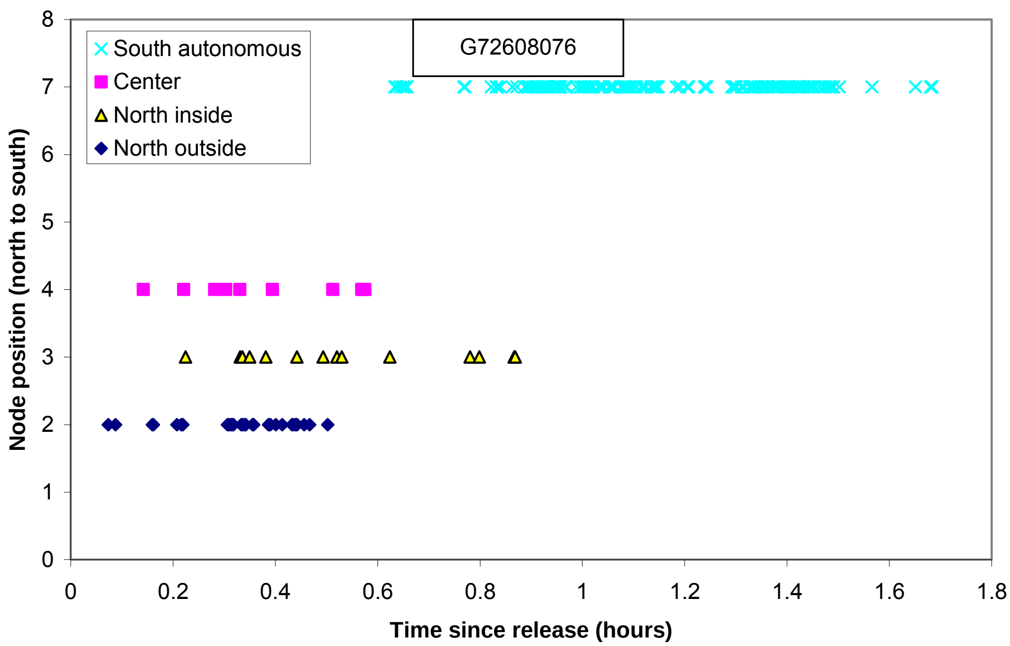


Figure B14. Detection history information for the 95 mm-long juvenile chinook salmon implanted with transmitter G72608076 that was released at the north location on June 23 at 19:42.

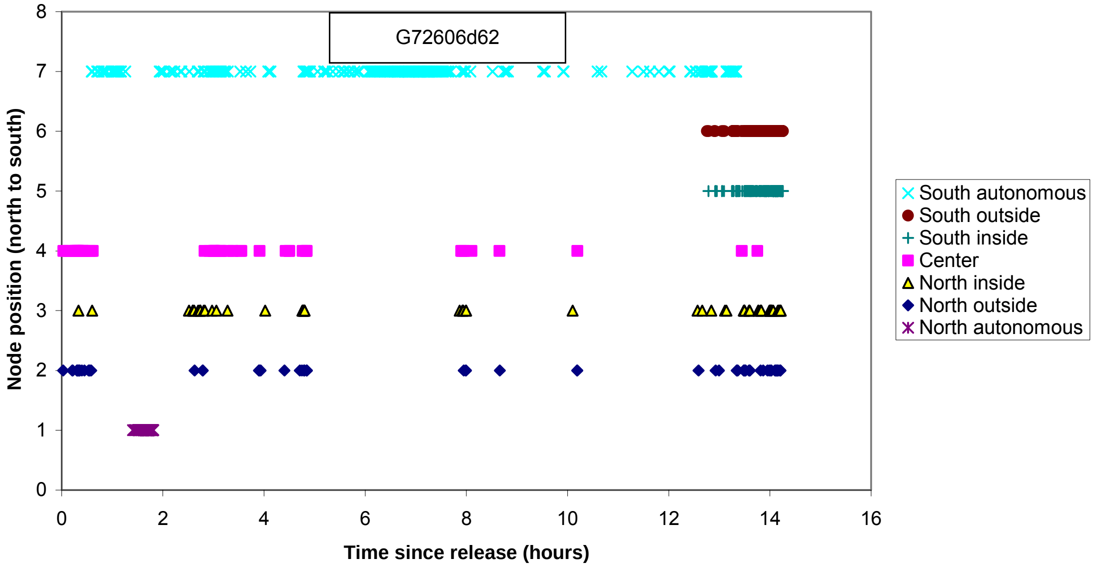


Figure B15. Detection history information for the 111 mm-long juvenile chinook salmon implanted with transmitter G72606d62 that was released at the north location on June 23 at 19:42.

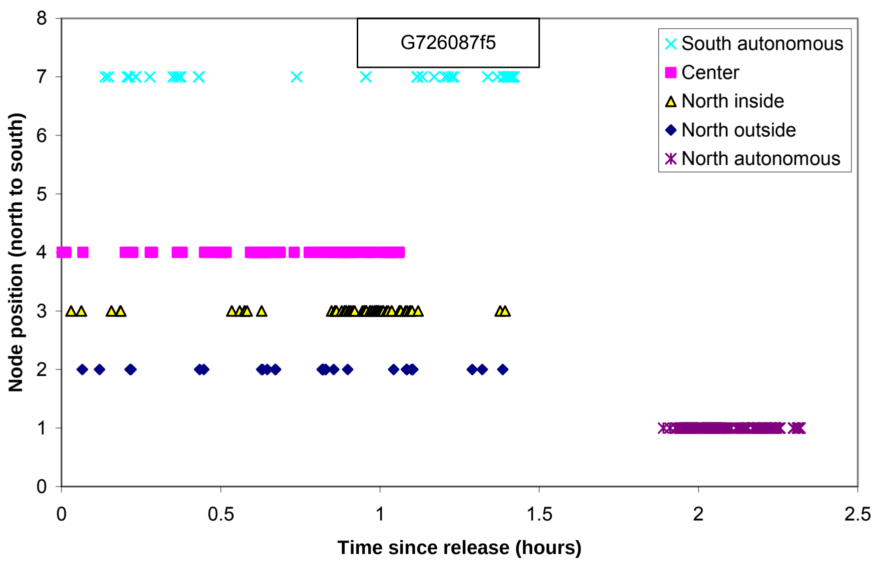


Figure B16. Detection history information for the 100 mm-long juvenile chinook salmon implanted with transmitter G726087f5 that was released at the south location on June 23 at 21:27.

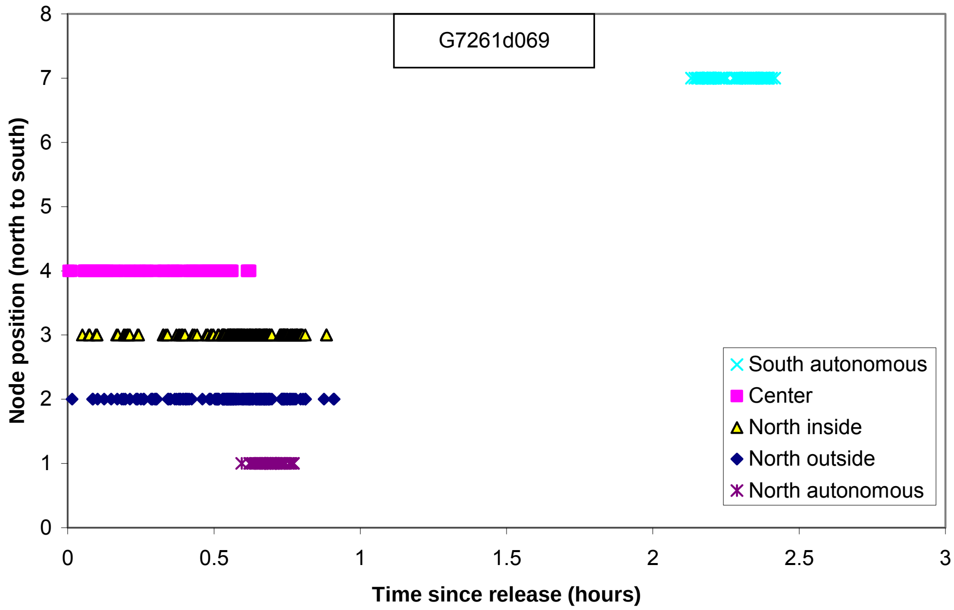


Figure B17. Detection history information for the 103 mm-long juvenile chinook salmon implanted with transmitter G7260d069 that was released at the north location on June 23 at 21:31.