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Assessing Overwater Structure-Related Predation Risk on Juvenile Salmon: Field Observations and Recommended Protocols

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Executive Summary

Overwater structures represent a source of potential impact to estuarine and marine nearshore habitats, and engender a variety of environmental concerns. For example, overwater structures may increase predation on juvenile salmonids by aggregating fish, avian, and marine mammal predators or heightening the predation rates of predator species normally associated with these structures, although conclusive evidence has not been demonstrated to date *in situ*. The purpose of this study was to evaluate whether conditions associated with overwater structures enhance predation pressure on juvenile salmon in Puget Sound. Washington State Ferry (WSF) terminals served as model overwater structures for exploring these issues.

This document reports bird and mammal survey results from six north-central Puget Sound WSF terminals and paired reference sites over both "pre-" and "peak" periods of outmigrating salmon fry abundance from April 1 to May 10, 2002. Intensive survey methods at one site (Mukilteo) also involved SCUBA transects (benthic predatory fishes), snorkel transects (pelagic fishes), bird and marine mammal predator surveys, salmon fry abundance surveys, documentation of nearshore fish assemblages during all diel phases using boat-deployed beach seines, collection of live potential fish predators and the use of lavage techniques to pump stomach contents, documentation of light measurements, and the use of dual-frequency identification sonar (DIDSON) to document potential predators associated with the water column and structurally complex terminal elements at night.

Pink and chum salmon fry were present in shallow, nearshore habitats of most study sites throughout the duration of the project. Salmon fry moved freely under the relatively narrow, shaded portion of the Mukilteo ferry terminal, where mean light levels during the day were reduced by over 97% in water. Juvenile pink and chum salmon dominated seine catches at the Mukilteo location, and two Pacific staghorn sculpin (*Leptocottus armatus*) at the reference site were the only potential salmon predators collected with this method. SCUBA surveys documented higher total fish species diversity and average abundance at the Mukilteo ferry terminal than at the reference site. Observations were made of four potential salmon predator species: quillback rockfish, copper rockfish, lingcod, and staghorn sculpin. Most of the potential fish-predator observations occurred in deeper habitats associated with the outer portion of the terminal. Transect surveys in shallower habitats recorded few predators at either the terminal or reference sites. DIDSON surveys at night also documented few instances in which large, water-column fish (potential salmon predators) were associated with ferry terminal structures. Stomach content analysis of potential fish predators revealed two salmon fry in the diet of one individual, a staghorn sculpin captured in a beach seine at the reference site. Potential bird and mammal predator species comprised about 30% of the individuals observed per survey count; however, actual observations of bird or mammal predation on fish were rare, and on only one occasion was a predator (tern sp.) observed capturing juvenile salmon.

We conclude that potential salmon predators were slightly more abundant at WSF terminals as compared with unmodified shorelines, although large aggregations were not observed on any occasion. The spatial distribution patterns of both bird and fish predators rarely overlapped with juvenile salmon oriented in surface waters close to shore. We were unable to verify whether potential predators were more abundant during peak salmon outmigration, because salmon were available in these habitats throughout the duration of our study. We found no evidence that avian, marine mammal, or fish predators consumed more juvenile salmon near WSF terminals than along shorelines without overwater structures. Few species appeared to be targeting abundant fry in nearshore habitats, and we observed only two occasions in which predators (one tern sp., one staghorn sculpin) had consumed juvenile salmon.

Several hypotheses are offered as to why we did not observe elevated rates of predation on juvenile salmon in the face of their greater relative availability to predators in nearshore habitats. We recommend applying a standardized field protocol to provide consistent procedures for evaluating predation risk to juvenile salmonids at existing overwater structures, especially as they are being expanded or modified. Use of these protocols over additional locations and situations will allow the scientific community to develop a stronger case for better evaluating this issue in the future.

Acknowledgements

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We would also like to thank the scientists, policy makers, and agency personnel who participated in the 2002 UW workshop on impacts of overwater structures to the marine environment. In particular, we would like to acknowledge the contributions of Si Simenstad (UW), who provided guidance throughout the workshop and this study, Brian Williams (WDFW), who provided contacts for information on salmon fry outmigration timing, and Kurt Fresh (NOAA Fisheries), for focusing discussion on the predation issue.

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Acronyms

BACI	before-after/control-impact
CPUE	catch per unit effort
DIDSON	dual-frequency identification sonar
DGPS	differential global positioning system
DPS	distinct population segment
ESA	Endangered Species Act
ESU	evolutionarily significant unit
FL	fork length
IRI	index of relative importance
MLLW	mean lower low water
MS-222	tricaine methanesulfonate
NOAA	National Oceanic and Atmospheric Administration
PAR	photosynthetically active radiation
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
RA	rapid assessment
SCUBA	self-contained underwater breathing apparatus
UW	University of Washington
WDFW	Washington Department of Fish and Wildlife
WSDOT	Washington State Department of Transportation
WSF	Washington State Ferries

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1.0 Introduction

Overwater structures represent a source of potential impact to estuarine and marine nearshore habitats and resources, and engender a variety of environmental concerns. These concerns have generally centered around three issues relevant to salmon, but are also important to general ecosystem processes and functions: 1) To what degree do overwater structures alter habitat conditions (e.g., light affecting primary production)? 2) Do overwater structures block or otherwise inhibit natural juvenile salmon migration? 3) Do overwater structures or the conditions they create result in increased predation pressure on juvenile salmon? Recent research has identified numerous information gaps regarding all three of these issues (Nightingale and Simenstad 2001). The purpose of this study is to evaluate whether conditions associated with overwater structures enhance predation pressure on juvenile salmon in Puget Sound. In this study, Washington State Ferries (WSF) terminals serve as model overwater structures for exploring likely predation issues in the region.

Eight species of salmonids are known to use nearshore habitats early in their outmigration and rearing period in Puget Sound (Simenstad et al. 1982). A number of populations in the region are currently listed as "threatened" under the Endangered Species Act (ESA), including chinook salmon (*Oncorhynchus tshawytscha*) within the Puget Sound evolutionarily significant unit (ESU), summer-run chum salmon (*O. keta*) within the Hood Canal ESU, and bull trout (*Salvelinus confluentus*) within the Coastal-Puget Sound distinct population segment (DPS). Coho salmon (*O. kisutch*) within the Puget Sound/Strait of Georgia ESU is a candidate species for listing.

Most juvenile salmon enter estuaries and nearshore marine habitats between early March and late June, feeding and rearing in the protective cover of shallow, productive habitats for extended periods. However, recent studies in King County, Hood Canal, and Sinclair Inlet have shown juvenile chinook are common in nearshore habitats from late January through September (Fresh et al. 2003) (King County Department of Natural Resources, unpublished data). The juvenile outmigration period is considered particularly critical to juvenile chum and chinook salmon, which spend more time in estuarine and nearshore habitats and may enter marine waters at only 30 mm to 80 mm length. These habitats include structurally complex, vegetated areas (e.g., *Zostera marina* beds, marshes, tidal channels) that are considered critical foraging, refuge, and migration corridors. Degradation, disruption, or loss of these habitats is hypothesized to limit growth and survival of salmonids and other dependent species.

WSF terminals represent one of many forms of overwater structure present in Puget Sound, and cover a relatively small percentage (0.4 miles; <0.02 %) of linear shoreline relative to the inland coastal waters of Puget Sound and the Strait of Juan de Fuca (2246 miles) (Hagen 1958). A previous state-of-the-knowledge synthesis of WSF-terminal impacts on juvenile salmon identified two potential types of effects: direct and indirect (Simenstad et al. 1999). Direct effects represent a disruption of migratory behavior, including delays due to disorientation, dispersal of schools, and a change in migratory routes into deeper waters. Much of this migratory disruption is attributed to conflicts in preferences among alternative light conditions. Indirect effects are represented by a reduction in habitat carrying capacity (lower primary production) as a result of shading, and the potential for increased predation, either via the aggregation of predators or by an increase in vulnerability of juvenile salmon through being forced from shallow refuges into deeper water habitats. The University of Washington is currently engaged in studies of habitat carrying capacity and prey production relative to shoreline structures. However, Simenstad et al. (1999) noted that studies have not addressed whether overwater structures concentrate "potential predators" or actual fish, bird, and marine mammal predators, nor have they examined likely predation situations in which high numbers of juvenile salmon pass under and/or around docks.

Overwater structures may also increase predation on juvenile salmonids by aggregating fish, avian, and marine mammal predators, or increase the predation rates of predator species normally associated with these structures, although conclusive evidence has not been demonstrated to date *in situ*. Several review papers have summarized studies documenting predators on salmonids in estuarine habitats (Thorpe 1994; Weitkamp 2003) (Table 1). However, few of these studies have specifically addressed overwater structure-related predation on juvenile salmon. In a review of the literature, Simenstad et al. (1999) found only 13 sources that specifically addressed the associated effects of overwater structures on predation on juvenile salmon or influences on potential predators. Six studies provided adequate information to differentiate between validated (by unambiguous observation or stomach contents), potential, and questionable predator species; additional references were added to expand the list of validated predators in unaltered habitats and associated with overwater structures (Table 1).

Regulatory agencies and permittees, such as the Washington State Department of Transportation (WSDOT) and WSF, have recognized that directed research is needed to develop the objective means to clarify the impact a particular overwater structure may have on juvenile salmon predation, to identify what design features can be incorporated into overwater structures to minimize and mitigate potential impacts, and to propose standardized methods for assessing impacts of overwater structures.

1.1 Problem Statement

In a workshop held January 9, 2002, to exchange information and provide feedback on WSDOT's comprehensive research strategy to determine whether ferry terminals affect migrating juvenile salmon, representatives from regulatory agencies noted a growing need to address the predation issue. The original proposal put forth at this meeting focused on juvenile salmon behavior relative to overwater structures; however, the general consensus of workshop attendees was that tagging technologies needed to improve before this research would produce definitive results.

Subsequent discussions with representatives from WSF have confirmed the need to establish whether WSF terminals do or do not affect predation on juvenile salmon. This information is needed by WSF to make decisions on designs for terminal improvements and modifications, to determine permit and mitigation requirements in construction projects, and to maintain uninterrupted service. Furthermore, this research directly responds to regulatory agency concerns about perceived ecological issues relevant to a wide variety of shoreline modification projects by WSDOT. Studies on WSF terminals will broaden the existing knowledge base while serving as a model to address more general questions concerning the effects of overwater structures on aquatic species.

1.2 Objectives

Our study attempted to establish conclusive evidence whether particular WSF terminals aggregate predators or affect predation on juvenile salmon, to develop standardized methods for surveying other WSF terminals or other overwater structures, and to recommend potential solutions (e.g., siting and design criteria) for reducing any observed impacts. As part of our evaluation, we also attempted to establish spatial/temporal patterns (e.g., habitat associations, time of day) of potential predator abundance near WSF terminals. The primary objective was to evaluate the following null hypotheses about potential fish, avian, and marine mammal predation on salmon fry near WSF terminals:

1) Potential salmon predators (fish, birds, and marine mammals) are no more abundant near or under terminals than along shorelines without overwater structures (paired reference sites)
2) Potential salmon predators are no more abundant in nearshore habitats when juvenile salmon outmigration is occurring than when juvenile salmon are absent
3) Potential salmon predators consume no more juvenile salmon near WSF terminals than along shorelines without overwater structures.

Previous research has shown that the following factors may affect predation pressure:

Predators	Prey (Juvenile Salmon)
Species occurrence	Availability (presence/absence)
Abundance	Predator avoidance behavior
Size	Size
Location (habitat associations: light levels, depth)	Location
Temporal variables (time of day, tidal stage)	Temporal variables
Feeding rate	
Ferry terminal design (height, width, length, orientation, number and type of pilings)	

Our evaluation incorporated these factors in the study design, which involved a variety of standardized surveys as well as innovative fish detection and tracking methods. We also used the data and knowledge gained from previous studies at WSF terminals (Shreffler and Moursund 1999; Simenstad et al. 1999) to support our conclusions as to whether WSF terminals aggregate predators of juvenile salmon, whether WSF terminal operations (e.g., night lighting, ferry activity levels, dock shading) and structural attributes influence predation, and what attributes of WSF terminals might affect predation rate.

1.3 Overview of Survey Methods and Study Areas

Six north-central Puget Sound WSF terminals and paired reference sites were used to address potential fish, bird, and mammal predation: 1) Mukilteo, 2) Clinton, 3) Edmonds, 4) Kingston, 5) downtown Seattle, and 6) Bainbridge Island (Figure 1). Each reference site contained no overwater structures and was located at least 100 m from its paired terminal study site. Where possible, the physical characteristics (substrate, beach slope) of each reference site were chosen to resemble its paired ferry terminal site.

The most comprehensive effort was concentrated at the Mukilteo ferry terminal, which was selected as a representative terminal to serve as an intensive study location for developing standardized sampling methods at other terminals (Figure 2). This site is of high priority for WSF terminal expansion. An existing Washington Department of Fish and Wildlife (WDFW) index of salmon fry abundance allowed timing of field efforts to coincide with peak fry outmigration. Additionally, the site allowed access to "unaltered" reference sites, an overwater structure without ferry activity, and to seawater facilities of the National Oceanic and Atmospheric Administration (NOAA) Fisheries laboratory. The ferry terminal is located in downtown Mukilteo. The south side of the terminal is characterized by a steeply sloped small embayment with gravel substrate. Riprap extends from under the ferry dock southward approximately 10 m. Behind the riprap is a concrete seawall that supports the terminal structure and buildings both north and south of the terminal. To the north of the terminal is a restaurant; to the south is a multistory residential complex. The ferry dock is supported by wood pilings and is 7 m to 10 m wide. An L-shaped fishing pier, owned by the Port of Everett, extends from the north side of the ferry dock. The beach on the north side of the terminal is predominantly sand with a gradual slope. Mukilteo State Park was used as a reference to the Mukilteo WSF terminal site (Figure 2). The State park is south of the terminal and Elliot Point. The beach has a moderate slope and is comprised of a gradation of sand to pebble to cobble, intermixed with some large boulders. Upland habitats are characterized by large woody debris (driftwood) and picnic sites bordering a field.

Study timing was guided by analysis of salmon marine fry abundance indices that are collected by above-water observations at various locations within Puget Sound by WDFW (personal communication, Don Hendrick, WDFW, 2001). These spring surveys have been conducted since 1966 by WDFW biologists, who walk sections of the marine shoreline at favorable tides and estimate the numbers of salmon fry observed migrating along shallow nearshore waters. Biologists use polarized glasses to better observe these surface-oriented fry, and species identity is confirmed by periodic dipnet samples. Results of these periodic surveys along a 0.4-mile stretch of shoreline encompassing the Mukilteo ferry terminal (WDFW Area 3, Subarea 2) indicate that pink salmon fry abundance peaks in late April, whereas chum salmon abundance peaks in early May (Figure 3).

Based on this information, we designed predator surveys to encompass both “pre-“ and “peak” periods of outmigrating salmon fry abundance during April and May 2002. A variety of standardized survey methods were used to assess predation by fishes on salmon fry at the Mukilteo ferry terminal during a preemigration survey in early April and a peak emigration survey in late April to early May (Table 2). Bird and mammal surveys were conducted at Mukilteo and at five other WSF terminals at weekly intervals from April 1 through May 10. Subsequent sections provide details of each study method.

Initial observation surveys at the Mukilteo ferry terminal were conducted from April 1 through April 5, 2002, before the peak abundance of most juvenile salmon fry in nearshore habitats. Efforts during this phase of the study focused on delineating reference sites, establishing permanent survey transects, refining survey methods in coordination with WSF activity, and clarifying diel patterns of fish abundance (day versus night versus crepuscular). Survey methods involved self-contained underwater breathing apparatus (SCUBA) transects (benthic predatory fishes), snorkel transects (pelagic fishes), bird and marine mammal predator surveys, and salmon fry abundance surveys (Table 2).

Intensive surveys of potential fish, bird, and marine mammal predator abundance continued from April 29 through May 8, during the peak abundance of outmigrating salmon fry in nearshore habitats at Mukilteo.

2.0 Methods

2.1 Salmon Fry Abundance and Behavior

2.1.1 Abundance and General Observations

Though not the primary focus of this field effort, qualitative visual surveys of salmon fry abundance were conducted from shore coinciding with all field efforts. These observations were used as an indicator of presence or absence of juvenile salmon at each site, which assisted in verification of potential predation events. Fry behavior was also noted relative to Mukilteo terminal structures, operations, and measured light levels. Shoreline survey methods mirrored ongoing WDFW protocols outlined above (i.e., shore-based, above-water observations using polarized glasses). Independent of our studies, WDFW conducted shoreline fry surveys weekly from March 5 to June 4, 2002, at the Mukilteo ferry terminal. In addition, observations of fry were made along the perimeter of the ferry terminal by divers using SCUBA (Section 3.2.3) and snorkel equipment on April 5, 2002.

2.1.2 Light Measurements

Light measurements were recorded using LI-COR LI-193SA spherical quantum sensors and an LI-250 light meter. The sensors measure photosynthetically active radiation, or PAR, which is the spectrum of light between 400 and 700 nm that supports photosynthetic production and growth. Units are μmol $m^{-2}s^{-1}$. The spherical quantum sensor is waterproof for use in aquatic environments, and collects light from all directions. Individual PAR readings were averages of instantaneous readings over a 15-sec interval.

On May 3, 2002, and May 6, 2002, ambient light was measured just above the water's surface and at a depth of approximately 0.1 m, where most juvenile salmon were observed. Light was measured along a transect parallel to shore that began 60 m south of the terminal and continued to a distance 60 m north of the terminal. PAR in air and in water was recorded at 10-m intervals to either side of the terminal, as well as directly under the center of the terminal. Light along the transect was measured during the day and at night. The presence or absence of juvenile salmonids was noted when light measurements were recorded. Additional point measurements in air and in water were made at night from a research boat, approximately 50 m offshore from the reference site.

2.2 Predation

2.2.1 Bird and Mammal Surveys

Quantitative, fixed-point count surveys of birds and marine mammals were conducted to document both the presence and feeding behavior of potential salmon predators at six ferry terminals (overwater structures) relative to paired, "unaltered" reference sites without overwater structures. Each fixed-point count survey consisted of four 20-min observation periods: two at each WSF terminal site (treatment) and two at each paired reference site (four 20-min observation periods). For each study site, observation stations encompassed 50 m of shoreline. For ferry terminals, the 50-m observation stations were located to either side of the terminal, whereas for reference sites, the observation stations extended 50 m to either side of a fixed point. During each 20-min observation period, all taxa and numbers of birds and marine mammals observed within the station boundaries (from shore to maximum viewing distance seaward) were counted and recorded over two to five successive scans. Initial surveys included only two scans, but were adjusted after the second week to three successive scans at 10-min intervals (0 min, 10 min, and 20 min), and later to five successive scans at 5-min intervals (0 min, 5 min, 10 min,15 min, and 20 min). To account for possible redundant counts of the same subjects, the mean number of individuals recorded per count was calculated for each 20-min observation period. General behavior (e.g., diving, foraging, perching) was also recorded, as were qualitative observations of unusual or noteworthy marine mammal and/or piscivorous bird activity. All successful predation events on fishes were noted, although verification of fish prey species was often difficult.

Observation times were spread across daylight hours (0700 to 1900 hrs) to maximize potential differences in diel activity. Tide status (ebb/flood) and height, general weather and water characteristics, and ferry activity (i.e., docked, departing, approaching, and absent) were also noted during each observation event. Potential fish predators were distinguished from nonpredator species based on a literature review of known feeding habits, which were generally confirmed by field observations. Large gulls (e.g., Western, glaucous-winged, and hybrid spp.) were particularly abundant around ferry terminals, but were never observed feeding on fish and were excluded from the analysis to minimize the confounding effect of their increased presence around areas of human activity. A chi-square analysis was used both across and within areas to test the null hypothesis that potential predators and nonpredators of juvenile salmon were equally distributed at the ferry terminal and reference sites averaged over the observation period. A chi-square analysis was also used to test the null hypothesis that potential predators and nonpredators of juvenile salmon were equally distributed across time between the ferry terminals and reference sites.

2.2.2 Beach Seines

Beach seining was conducted to gather data on the species composition and relative abundance of fish associated with the Mukilteo ferry terminal and one reference site. These data included information on the relative abundance of juvenile salmonids and potential predators in these habitats. The stomach contents of potential predators collected in the seine were examined to confirm food habits and predatory behavior (Section 2.2.5).

Seines were carried out on either side of the terminal, designated as Terminal North (Transect E) and Terminal South (Transect A), and at the reference site (Reference) (Figure 2). A standard 37-m Puget Sound beach seine set from a boat was used (Simenstad et al. 1991). This net, designed for capturing motile fish, was composed of 3-cm mesh with two 18-m-long wings that were 0.9 meters high at the ends and 2 m high where the wings attached to the central bag; the bag was 2 m high by 2.4 m wide by 2.3 m deep and made of 6-mm mesh.

A boat was used to facilitate setting the seine, which was deployed parallel to the shore then pulled shoreward onto the beach (Figure 4). The distance from shore ranged from approximately 10 m to 35 m, depending on site-specific variables (i.e., slope, tidal stage, terminal structures). After each seine haul, species identity, number, and size of fish and macroinvertebrate species were quantified. Fork length (FL) was measured of subsamples of highly abundant species.

2.2.3 SCUBA Surveys

SCUBA surveys were used to visually document demersal (bottom-associated) fish species and subsurface habitats at the Mukilteo ferry terminal and the paired reference site at Mukilteo State Park. Divers conducted a series of reconnaissance dives on April 2, 2002, to evaluate the ferry terminal and reference areas prior to beginning the survey. During the initial site assessments, divers collected information on depth profiles, compass bearings, substrates, species lists, obstructions, impediments, and other hazards potentially dangerous to divers (e.g., ferry traffic frequency). They also assessed the viability of different observation techniques and methods that could be best employed to capture the desired data for this study. SCUBA-based visual surveys using preestablished, semipermanent strip transects were selected, because divers could swim along a fixed, premarked line that allowed rapid, unencumbered observations at known distances. This technique allowed quantitative, repeatable, nondisruptive observations at the ferry terminal and reference site, was adaptable to a variety of environmental conditions (e.g., day versus night), and could be accomplished within short time windows between ferry departures.

Semipermanent strip transects were established along the length of the terminal by anchoring lead lines marked at 5-m increments to the bottom. Transects were located perpendicular to shore at both the terminal and reference areas (Figure 2). Each "strip" or line transect was standardized to a length of 35 m based on the length of the terminal structure. At the ferry terminal, the location and spacing of transects was designed to estimate fish utilization directly under the overwater structure (center line), at its edges, and on its periphery (10 m from either edge). Each lead line was assigned a letter designator, and observational data were then recorded based on the transect survey (indicated by an assigned letter designator) at 5-m intervals (i.e., 0-5 m, 5-10 m, etc.).

Once the semipermanent transects were established, they were systematically surveyed to produce a data "set" comprised of a single survey of each transect. On selected transects, video was also used to document the observations and the surrounding artificial structures of the terminal. Reference site transects were deployed using slightly different techniques in April and May. During April, a single, perpendicular transect to shore was randomly deployed for each survey in the reference site from a boat. After the transect line was deployed, divers descended to the start point of the transect and proceeded to survey the transect as described above. Divers recorded all fishes observed at a visual distance of 1 m to either side of the 35-m long transect, enabling quantitative estimates of fish density (70 m^2 per transect). During May, a set of three, semipermanent transects was established in the reference site for the duration of the study (Figure 2). As with transects at the ferry terminal, each data "set" was comprised of a single survey of each of the semipermanent established transects.

The primary means of recording data was via a wireless communications system from which the diver would relay observations to a surface recorder. The divers also carried an underwater slate as a backup or redundant recording system in case of malfunctioning of the communications system or temporary interference in diver-to-surface communications. These interferences typically occurred when a ferry departed, which created a bubble curtain that would interfere with underwater transmissions for the first several minutes.

Several other supplemental SCUBA dives were conducted over the course of the study to collect additional observational data on the existing structures of the ferry terminal and reference site. These dives collected data on demersal fishes, habitat types, and fry movement in areas (e.g., outer wing walls, dolphins) that were not systematically surveyed with the transect method. As with the systematic surveys, observations were recorded via diver-to-surface recorder using wireless communications.

Snorkel surveys were also conducted on several dates in early April to document the presence of potential water-column fish predators and salmon fry. Surveys were conducted in a manner similar to those described for SCUBA methods, and tracked the same transects beneath and near the Mukilteo ferry terminal. Snorkel efforts were discontinued after it was concluded that their results provided no additional information beyond what was already being collected by SCUBA.

2.2.4 Dual-frequency Identification Sonar (DIDSON) Surveys

The dual-frequency identification sonar (DIDSON) camera was deployed from a research boat as an experimental tool to document pelagic fish around various ferry terminal structures at night (Figure 5). Researchers used these images to ascertain the identity, abundance, and behavior of potential fish predators associated with these overwater structures under low light conditions. The DIDSON, developed by engineers at the University of Washington Applied Physics Laboratory (http://www.apl.washington.edu/ programs/DIDSON/DIDSON.html), uses multichannel acoustic reflections rather than light to create images of juvenile salmon and their potential predators. The DIDSON can capture near-video-quality images, regardless of visibility and without the use of electronic fish tags. In high-frequency mode, all but the smallest targets (<63 mm at 12-m range; <16 mm at 3-m range) intercept multiple beams (Figure 6). The software can record and display images in real time, and for a 12-m range will do so at 7 frames per second (Belcher et al. 2001). The result is something akin to an acoustic video camera.

A useful feature of this sonar design is that both structural details and fish can be observed at the same time on the same transmitted pulse. Previous experience has illustrated that it is desirable to have some structure in view at the same time that fish were present simply for spatial reference (Moursund et al. 2002). This is a marked contrast to traditional single- or split-beam sonar for which use around structures is limited because of reverberation and range saturation of the signal.

The DIDSON was deployed from a mount that could be swiveled and tilted by an operator aboard the vessel. Surveys involved the slow circumnavigation of overwater structures at a distance of 2 m to 10 m, panning and tilting the camera to encompass most of the submerged structural dock elements. Survey locations were collected simultaneously using a Trimble differential global positioning system (DGPS), and stored with the DIDSON records during the survey. The DIDSON was used in the high-frequency mode with a frame rate of 7 frames per second, and data were displayed in real time on a monitor aboard the vessel. Data files were saved to a notebook computer, with separate files generated sequentially.

2.2.5 Stomach Content Analysis

Fish predators were captured for stomach content analysis to investigate possible predation on salmonids in the ferry terminal area relative to the reference site. Methods employed for fish capture included beach seines (previously described), hook and line from the beach (including those from recreational fishermen), hook and line from a boat, speargun, and minnow traps. Hook-and-line sampling was conducted in the vicinity of the ferry terminal, using live bait (generally gunnels) or artificial lures that imitated small forage fish. Fish captured alive were anesthetized in a solution of tricaine methanesulfonate (MS-222) and pumped with seawater to flush stomach contents from the fish (Giles 1980). After pumping, fish were placed in an oxygenated bath of fresh seawater and then released upon recovery. Guts from fish that were speared or collected by recreational fishermen were excised and retained. In all cases, stomach contents were preserved in 70% ethanol and examined in the laboratory. Prey items were identified, sorted by taxa, and wet weights quantified.

3.0 Results

3.1 Salmon Fry Abundance and Behavior

3.1.1 Abundance and General Observations

Small schools of juvenile pink salmon were present in early April during initial, preemigration surveys at the Mukilteo ferry terminal (Figure 7). Single fish and/or small schools (<100 fish) were observed in surface waters ≤1 m deep near the shoreline during the latter stages of this effort. Weekly bird and marine mammal surveys detected a steady increase in nearshore salmon fry abundance through April. By the time of our intensive, peak-abundance surveys in early May, large mixed schools of chum and pink salmon (>1000 fish) were seen during both day and night surveys in nearshore habitats. No coho salmon were observed and only one juvenile chinook was noted at night (see next paragraph). Temporal trends in pink and chum salmon fry abundance were confirmed by WDFW surveys, which showed an initial pulse of pinks during the second week in April, followed by gradual increase in both pink and chum abundance that peaked in the first week of May (unpublished data, Don Hendrick, WDFW, 2002).

In general, no unidirectional movement was detected, and fry were observed feeding and milling over a variety of habitats, including sand, mixed gravel, cobble, pilings, and riprap. During the day, fry moved freely under the relatively narrow, shaded portion of the ferry terminal and did not appear to be inhibited by the differences in light levels detected here (Figure 7) (Section 3.1.2). During the night, chum and pink salmon fry (and an individual juvenile chinook salmon) were especially apparent under the floodlights from the restaurant directly to the north of the WSF terminal. In most cases, fry remained in shallow waters within 3 m of the shoreline, although severe currents generated by ferry prop-wash on arrival and departure did alter their movements.

3.1.2 Light Measurements

Two series of light measurements were recorded along the under-terminal transect during daylight hours, and one series was recorded at night. During the day, light at the water's surface was reduced by approximately 97% under the center of the dock compared with light outside the terminal footprint (Figure 8). Light decreased up to 89% (mean 38%) as it traveled from the air to the water. Mean readings in water outside the terminal were 954 µmol m^{-2} s^{-1}, and mean readings in water directly under the center of the terminal were 27.4 µmol m^{-2} s^{-1}. Low light readings at the 50-m north position corresponded to shading associated with the Port of Everett fishing pier adjacent to the terminal.

At night, light at the water's surface was reduced by approximately 99% under the center of the dock, compared with light outside the terminal footprint (Figure 9). Light levels decreased by up to 100% (mean 14%) between air and water. Mean readings in water outside the terminal were 0.32 µmol m^{-2} s^{-1}, and mean readings in water directly under the center of the terminal were 0.0 µmol m^{-2} s^{-1}. In some cases, light measured under the water at night was greater than that measured in air because of the proximity of lighting fixtures at the sampling location. Spotlights operated by Ivar's restaurant resulted in the elevated light readings on the north side of the terminal. Light levels were generally lower at the reference site than near the WSF terminal, with average PAR values of 0.0 µmol m^{-2} s^{-1} in water and 0.15 µmol m^{-2} s^{-1} in air.

Salmon fry were observed in all nearshore habitats during each transect sampling period (day and night). The fry were observed under a wide range of PAR values (0.0 µmol m^{-2} s^{-1} to 2370 µmol m^{-2} s^{-1}). Fry were observed both outside the terminal and underneath the terminal at all times, and shadows produced by the 10-m-wide terminal structure did not appear to act as barriers to fry movement at this location.

3.2 Predation

3.2.1 Bird and Mammal Surveys

A total of 31 standardized surveys were conducted at six WSF study locations over a 6-week monitoring period that spanned from April 1 through May 10, 2002 (Table 3). These surveys comprised 124 separate 20-min observation periods (62 at terminals, 62 at paired reference sites), involving 478 counts (i.e., 2 to 5 counts per observation period) of bird and mammal presence.

A total of 19 bird and mammal taxa (not counting gulls) were observed across all study locations during the course of quantitative surveys (Table 4). Of these taxa, three were mammals and 16 were birds. There were 2391 individual bird and mammal sightings noted, although this also includes redundant tallies of some subjects over subsequent counts (Section 2.2.1). The most frequently observed taxa included black brant, western grebe, surf scoter, Barrow's goldeneye, and pigeon guillemot. All of these wintering nearshore waterbirds are considered common or abundant in Puget Sound, although their populations (with the exception of goldeneyes) have demonstrated significant declining trends in the region since 1978-1979 (Puget Sound Water Quality Action Team 2002). Seals, river otters, loon spp., and terns were the least frequently observed taxa, with fewer than three individual sightings noted over the course of the study.

Typical diets and primary trophic categories of bird and mammal taxa observed during the surveys are summarized in Table 5 based on widely available diet descriptions (Terres 1956; Ehrlich et al. 1988) and a regional food-web study (Simenstad et al. 1979). Of the 16 avian taxa observed, the following 10 taxa were classified as piscivores that could be considered potential salmon predators: Pacific loon, common loon, western grebe, red-necked grebe, horned grebe, double-crested cormorant, common merganser, tern spp., pigeon guillemot, and belted kingfisher. Piscivorous birds employ various foraging methods, such as underwater pursuit diving, plunge diving, surface feeding, and aerial feeding in pursuit of their fish prey. All three mammal taxa (sea lion spp., Pacific harbor seal, river otter) observed during the survey are considered piscivores. The remaining six bird species, brant, Canada goose, mallard, bufflehead, Barrow's goldeneye, and surf scoter, are herbivores or benthivores that feed predominantly on molluscs and crustaceans. This categorization was further supported by our field observations. For example, bufflehead and surf scoters were often observed foraging on the attached invertebrate fauna on dock pilings.

Fairly low numbers of birds (excluding gulls) and mammals were observed during most point-count surveys (Table 6). At all locations over the course of the entire study, an average of 5.7 (±13.7 SD) individuals were seen per count (median = 1.4, minimum = 0.0, maximum = 102.5). At ferry terminals, counts averaged 4.1 (±6.2 SD) individuals versus 7.3 (±18.3 SD) at reference sites. More bird and mammal species were observed at reference sites (16 spp.) than at terminal sites (11 spp.), although the number of "predator" (piscivorous) taxa was similar at reference sites (10 spp.) and terminal sites (9 spp.) (Table 4). Potential salmon predators made up about 30% of the individuals observed per survey.

For analysis of predator association with terminal structures, the average count of each species per survey was calculated by site (Table 6). These averages were totaled by predator classification and site treatment (e.g., predator/nonpredator, terminal/reference). Averaged over areas, potential predators and nonpredators were not found to be equally distributed between the terminal and reference areas (statistically significant at $p < 0.025$; chi-square). In general, potential predators were observed at the ferry terminal sites significantly more often than expected (Table 7). Individual chi-square analyses were also conducted for all areas, except for Kingston and Seattle because of the lack of nonpredators at the Kingston reference and the Seattle Terminal sites. The remaining areas did not have an equal distribution of potential predators and nonpredators ($p < 0.001$). At Bainbridge Island and Edmonds, potential predators were observed at the ferry terminal sites more often than expected. At Clinton and Mukilteo, potential predators were observed at the reference sites significantly less often than expected.

Actual observations of bird or mammal predation on fish were rare, and on only one occasion was a predator observed capturing juvenile salmon. On April 22, 2002, a single, unidentified tern was seen diving on schooling salmon 1 m from shore at the Clinton ferry terminal; three juvenile salmon were captured during this event. Red-necked grebes were observed hunting among schooling salmon 5 m to 10 m from shore at the Edmonds ferry terminal on May 4, 2002, although no confirmed catches were reported. While conducting sampling at Mukilteo, we also observed a great blue heron hunting at night in shallow waters illuminated by lights from adjacent buildings. Although we could not substantiate the identity of the fish prey captured, these observations suggest that herons may use ambient lighting to hunt for juvenile salmon in illuminated nearshore areas at night. Future surveys should attempt to include some analysis of this effect.

Double-crested cormorants, pigeon guillemots, and kingfishers were seen preying on nonsalmonids, both during fixed-point count surveys and opportunistic observations. On four separate occasions, cormorants were observed capturing and eating starry flounder and sculpins at the Mukilteo, Clinton, and Kingston ferry terminals, as well as at the Mukilteo reference site. Pigeon guillemots were observed eating what appeared to be small sculpins 50 m offshore at the Mukilteo terminal. A kingfisher was also observed diving for prey near riprap at the south side of the terminal. Foraging by seals or sea lions was not observed. However, since smaller prey can be consumed underwater (National Marine Fisheries Service 1997), quantifying pinniped predation based solely on observations of surface feeding is unreliable.

Potential salmon predators were not equally distributed over time ($p < 0.001$), with more potential predators than expected observed in the reference areas during week 5 (Figure 10), which was attributed to a large flock of western grebes at the Seattle reference site. Potential predators were observed at the ferry terminals similar to the expected rate throughout the entire observation period. Because juvenile salmon fry were present in nearshore waters throughout the entire study period, we were unable to detect variations in predator abundance relative to salmon outmigration timing.

The highest diversity of bird and mammal taxa was observed at Edmonds (10 taxa), whereas the lowest diversity was observed at Seattle and Bainbridge (6 taxa each) (Table 8). Survey effort was equal at Edmonds and Seattle, suggesting a relationship between local habitat conditions and species richness. Some of the more commonly observed species, such as Western grebe, surf scoter, Barrow's goldeneye, and pigeon guillemot (Table 4), were widely distributed across study locations. Other taxa, such as black brant, mallard, belted kingfisher, and sea lion sp., were more often associated with a specific study location.

3.2.2 Beach Seines

A total of 16 beach seine sets were conducted at three Mukilteo sites during the day and night (Table 9). Four sets were conducted in habitat directly adjacent to the north of the terminal (Terminal North; Transect E) and five sets to the south (Terminal South; Transect A); seven sets were conducted at the Mukilteo State Park reference site.

A total of 25,018 fish comprising 13 species were captured during the study period (Table 10). Catches were numerically dominated (>99%) by juvenile salmon, the majority of which were identified as pink salmon (*O. gorbuscha*), with a mean FL of 33.8 mm, and chum salmon (*O. keta*), with a mean FL 50.0 mm. The ratio of pink to chum salmon, based on subsamples from each seine catch, was approximately 13 to 1. A total of three juvenile chinook salmon (*O. tshawytscha*), ranging in length from 125 mm to 138 mm FL, were also collected at the Terminal South (n = 2) and reference site (n = 1).

Only six species were collected at terminal sites, whereas 12 species were captured at the reference site. Fewer salmon appeared in night samples, though this was not examined quantitatively (Table 10). Juvenile salmon were collected at all sites, although catch per unit effort (CPUE) was highest at the terminal (Table 10, Table 11). Most other groups of species captured in beach seines had the highest CPUE at the reference site. These included shiner surfperch (*Cymatogaster aggregata*), threespine stickleback (*Gasterosteus aculeatus*), surfsmelt (*Hypomesus pretiosus*), and starry flounder (*Platichthys stellatus*).

Only two individuals of one potential predator species, the Pacific staghorn sculpin (*Leptocottus armatus*), were collected in all of the beach seine sets (Table 10). Staghorn sculpins are demersal ambush predators that feed on crustaceans and small fish (Emmett et al. 1991). The two sculpins collected at the reference site were subjected to gastric lavage for diet analysis (Section 3.2.5).

3.2.3 SCUBA Surveys

SCUBA observations involved quantitative transect surveys conducted at the ferry terminal and reference areas, as well as qualitative rapid assessments (RAs) made during initial planning dives and within areas not systematically surveyed with the transect method. A total of 48 quantitative surveys were conducted during the course of the study during both day and night diel phases (Table 12). Each survey encompassed a 35-m long transect (70 m^2) that extended from the ferry wingwalls to the shore, where most juvenile salmon were found. Thirty-four transects covering 2380 m^2 were conducted at the ferry terminal, whereas 14 surveys covering 910 m^2 were conducted at the reference site. Six other RA dives, 4 at the terminal and 2 at the reference site (Table 12), also assessed potential fish-predator abundance over a wider area not covered by transects. Each RA involved a pair of divers and lasted approximately 30 to 40 min. At the terminal, divers focused on the outer wingwalls, dolphins (groups of pilings), and ferry docking basin.

Divers recorded the depth and substrate associated with each of the letter-coded, 35-m transects at the Mukilteo ferry terminal (Figure 2, Figure 11). In general, a distinct scour halo could be observed under the dock, characterized by a central depression filled with uniform coarse substrates (cobble and gravel) that graded predictably to fine (mixed sand and shell hash) sediment on the shallow edges. Transect A (south periphery) was predominantly sandy substrate, ranging in depth from -12 ft to 0 ft mean lower low water (MLLW). Transect B (south edge) encompassed deeper habitats, from -35 ft to -6 ft MLLW, composed of gravel and cobble substrates that transitioned to sand at 30 m. Transects C (center line) and D (north edge) were similar to transect B in terms of depth and substrate, although these also encompassed numerous pilings and associated debris, such as spools of fishing line, cables, and concrete blocks. Transect E (north periphery) was the most shallow transect, ranging in depth from -11 ft to +1 ft MLLW. This transect was positioned under the adjacent public fishing pier and had numerous derelict crab traps and pilings with entangled fishing line; substrates were generally coarse with shell hash. Reference transects at Mukilteo State Park were laid out in areas that reflected the same depth distribution as the Mukilteo ferry terminal, and encompassed a variety of mixed sand, coarse gravel, boulder, and eelgrass habitats.

During all SCUBA surveys, a total of 124 observations comprising 24 fish taxa were recorded at both the terminal and reference site (Table 13, Figure 12). Groups of schooling species, such as surfperch and sandlance, were noted as a single observation; juvenile salmon (not quantified) were usually observed on all dives schooling at the water's surface near the shoreward end of each transect. Total fish species diversity and average abundance was higher at the Mukilteo ferry terminal (22 taxa, 5.8 observations/transect) than at the reference site (12 taxa, 4.4 observations/transect). Time of day also affected survey results, with much higher numbers of fish observations made at night (8.8 observations/transect) than during the day (1.4 observations/transect) at either site (Table 14).

Throughout the course of all dive surveys, 11 observations were made of four species previously documented as potential salmon predators: quillback rockfish, copper rockfish, lingcod, and staghorn sculpin (Table 13). Rapid assessment dives at outer structures of the ferry terminal made up most (five) of these observations (1.25 predators/RA survey). Both rockfish species were observed in the mid-water column associated with the vertical structure of the dolphins, whereas three lingcod were found at the base of wingwall and piling structures in 30 ft to 40 ft of water. Three observations of predators were recorded during quantitative transect surveys at both the terminal (0.09 predators/survey) and the reference sites (0.21 predators/survey). At the terminal, predators included two staghorn sculpins observed in shallow sandy habitats on transects A and D during the night of April 4, 2002, and one lingcod at 5 m (32 ft MLLW) on transect B during the day of April 29, 2002. At the reference site, three staghorn sculpins were observed in shallow sand and eelgrass at depths of 12 ft to 15 ft during the night of April 4, 2002. Too few potential predators were observed at the terminal to conduct a systematic analysis of abundance relative to transect position.

Snorkel surveys documented the presence of salmon fry along shorelines, and some schools of sandlance and shiner surfperch. No potential predators were observed with this method, and it was discontinued in favor of expending additional effort on SCUBA surveys.

3.2.4 DIDSON surveys

The DIDSON was used during 3-hour surveys on the nights of May 6 and May 7, 2002, when an evaluation with conventional underwater cameras was limited by low ambient light and the use of camera lighting would have been intrusive. The use of visible wavelength light at a high enough intensity for underwater video recording would alter fish behavior, e.g., elicit an escape response, and render the transects unrepeatable. Over the course of both nights (approximately 6 hours total), researchers twice surveyed all aspects of the Mukilteo ferry terminal (dolphins, pilings, wingwalls), as well as the abandoned U.S. Air Force fuel pier located to the north of the terminal. These survey data represent the first time DIDSON technology has specifically been used to locate and identify fish in complex marine nearshore habitats.

Images of fish taken underwater with the DIDSON acoustic camera are shown in Figure 13. Associated data on location, time, and fish descriptions are presented in Table 15. The DIDSON produced clear underwater images of structural details (e.g., entangled rope, cables; see Figure 13, image 4) and fish associated with these structures. In many cases, individual details of fish fins could be seen that assisted in identification to family, though species identification could not be independently confirmed. In most cases, the images also provide a downward-angled view of piling structures in the background; the acoustic shadow of fish in the foreground can be clearly seen on the pilings in image 6 (Figure 13). Demersal species generally could not be clearly differentiated from bottom substrates.

In general, we observed few instances in which large water-column fish (potential salmon predators) were associated with ferry terminal structures (Figure 13, Table 15). Most observations were tentatively identified as adult surfperch spp. (family Embiotocidae), based on their schooling behavior, size (240 mm to 280 mm total length), fin morphology, and similarly located diver observations (images 3, 5, 6). In all cases, these individuals were concentrated in high-current areas around the dolphins.

Other observations included a 280-mm fish resembling a ratfish (*Hydrolagus colliei*), swimming near pilings at the abandoned fuel pier on May 6, 2002 (Figure 13, image 1); small schooling fish that resembled forage fish moving through the same area (Figure 13, image 2); and a solitary fish (260 mm) that may have been a rockfish (*Sebastes* sp.) or surfperch in the mid-water column near the south terminal dolphins (Figure 13, image 4). None of the observations recorded during 6 hours of surveys suggested that large aggregations of potential salmon predators were associated with either of the overwater structures surveyed.

Juvenile pink and chum salmon were detected with the DIDSON in typical shallow, nearshore habitats north of the ferry terminal (Figure 14). However, these images were often unclear because of the reflection of surface water at the outer range of the camera, which is indicative of some of the inherent limitations of the technology. All sonar systems suffer in performance in extremely shallow waters due to the close proximity of multiple reflective surfaces (e.g., the water-air interface at the surface, waves, substrate type, and irregularities, such as rocks or boulders). For the DIDSON, at 12-m range, the beam along the vertical axis is nominally 2.5 m wide. Therefore, at depths less that 2.5 m, the sonar reflects off both the bottom and the surface simultaneously

3.2.5 Stomach Content Analysis

Stomach contents of 17 piscivorous fish comprising five species were examined (Table 16; Figure 15). With the exception of padded sculpin (*Artedius fenestralis*), all of the fish species analyzed have previously been classified as validated or potential predators of juvenile salmon (Table 1).

Laboratory analysis of the contents confirmed that a 170-mm Pacific staghorn sculpin (*L. armatus*) captured in a beach seine at the reference site had consumed two juvenile salmon (50 mm and 55 mm). It is unknown whether the salmon were consumed by the sculpin while in the net or prior to capture. Other fish species identified as prey of large piscivores include a gunnel (*Pholis* spp.), Pacific sand lance (*Ammodytes hexapterus*), and a staghorn sculpin. The gunnel was retrieved from the stomach of a quillback rockfish (*Sebastes maliger*), and the sandlance and sculpin from two lingcod (*Ophiodon elongatus*) (Figure 15). These predators were hooked near the south side of the ferry terminal. Four other lingcod captured in the vicinity of the terminal contained fish prey digested beyond recognition, although the bone structure from some of these prey suggested they were large forage fish or sculpins, but probably not juvenile salmon.

4.0 Summary of Results

Salmon Fry Abundance and Behavior:

- Salmon fry were present in shallow, nearshore habitats of study sites throughout the duration of the project. At the Mukilteo ferry terminal, pink salmon were first seen in early April, although the abundance of mixed schools of pink and chum salmon fry peaked in early May, coinciding with most of our intensive field efforts.

- Juvenile pink and chum salmon were generally found in surface waters within a short distance (<3 m) of the shoreline.

- During the day, salmon fry moved freely under the relatively narrow, shaded portion of the Mukilteo ferry terminal, where mean light levels in water were reduced by over 97% (mean light levels in water of 27.4 μmol m^{-2} s^{-1}).

- At night, salmon fry were also observed both under the terminal structure (mean light levels in water of 0.0 μmol m^{-2} s^{-1}) and outside of its footprint. Spotlights and other ambient lighting from adjacent buildings and businesses resulted in especially high light readings on the north side of the terminal.

Bird and Mammal Surveys:

- A total of 19 bird and mammal taxa (not counting gulls) were observed across all study locations during the course of quantitative surveys; 10 of the 16 observed bird taxa and all 3 mammal taxa were classified as piscivores (potential salmon predators). More bird and mammal species were observed at reference (16 spp.) than at terminal sites (11 spp.), although the number of "predator" (piscivorous) taxa was similar at reference (10 spp.) and terminal sites (9 spp.).

- An average of 5.7 (±13.7 SD) birds and mammals were seen per survey count; potential predators made up about 30% of the individuals observed per count.

- Potential predators were observed more often than expected at the ferry terminal sites. On average, 1.8 predators per survey count were observed at WSF terminal sites as compared with 1.27 predators at reference sites.

- Actual observations of bird or mammal predation on fish were rare, and on only one occasion was a predator (tern sp.) observed capturing juvenile salmon. Red-necked grebes (day), kingfishers (day), and a great blue heron (night) were also suspected of preying on salmon fry, although no confirmed catches were reported.

Beach Seines:

- Juvenile pink and chum salmon dominated (>99%) seine catches at all sites, although CPUE was highest at the terminal.

- Species richness of fishes was higher at the reference site (12 spp.) as compared with the Mukilteo ferry terminal (6 spp.). The relative abundance of most species, besides salmon, was highest at the reference site.

- Two Pacific staghorn sculpin (*L. armatus*) collected at the reference site were the only potential salmon predators collected by beach seine.

SCUBA Surveys:

- Total fish species diversity and average abundance was higher at the Mukilteo ferry terminal than at the reference site. Higher numbers of fish were observed at night (8.8 observations/transect) than during the day (1.4 observations/transect) at either site.

- During all SCUBA surveys, a total of 124 observations comprising 24 fish taxa were recorded at both terminal and reference areas. Only 11 observations (4 species: quillback rockfish, copper rockfish, lingcod, and staghorn sculpin) were made of species previously documented as salmon predators.

- Most of the potential fish-predator observations occurred in deeper habitats associated with the outer portion of the terminal (1.25 predators/survey). Transect surveys in shallower habitats <30 ft MLLW recorded few predators at either the terminal (0.09 predators/survey) or reference sites (0.21 predators/survey).

- The deep-water, benthic orientation of potential fish predators generally did not overlap with surface-oriented salmon observed near shorelines.

- No predators were observed during snorkel surveys conducted in early April.

DIDSON Surveys

- DIDSON surveys documented few instances in which large, water-column fish (potential salmon predators) were associated with ferry terminal structures. Most observations were tentatively identified as adult surfperch spp. (family Embiotocidae) concentrated in high-current areas around the dolphins (piling structures used for guiding ferries into the terminal).

Stomach Content Analysis:

- Seventeen fish comprising five species were subjected to quantitative analyses of stomach contents.

- Salmon (two fry, 50 mm and 55 mm FL) were observed in the diet of only one individual, a 170-mm Pacific staghorn sculpin (*L. armatus*) captured in a beach seine at the reference site.

- Quillback rockfish and lingcod had the remains of other fish species in their stomachs, including a gunnel, Pacific sandlance, and staghorn sculpin. Most lingcod captured in the vicinity of the ferry terminal contained fish prey digested beyond recognition, although the bone structure from some of these prey suggested they were large forage fish or sculpins, rather than juvenile salmon.

5.0 Discussion and Conclusions

Besides evaluating predation pressure on juvenile salmonids, our study provided information of a broader nature that contributes to the understanding of salmonid use of nearshore areas in Puget Sound. In this section we discuss this information and draw conclusions on the results from the predation study.

5.1 Salmon Fry Behavior around Overwater Structures

Although not the primary focus of our study, observations of pink and chum salmon fry provided a great deal of information on behavior in nearshore habitats under a variety of conditions. These species were present in most shallow habitats close to shore for the duration of the study, though concentrations were more readily visible in the shallow shoreline embayment associated with the Mukilteo ferry terminal. Schools of pink and chum salmon fry moved freely under the relatively narrow (10 m) portion of the ferry terminal, where light levels were reduced but not completely extinguished. At night, salmon fry were also observed in these habitats, and were especially visible under spotlights and other ambient lighting from adjacent businesses. It was not determined whether fry were attracted to these light sources, or whether they were simply more obvious to observers because of the ambient light levels. Salmon fry were also periodically flushed out of the protected embayment by extreme currents from ferry propeller wash during docking and departure, although no fry mortality was observed as a consequence of this disturbance, and schools of fry soon returned to the area. We suspect that this periodic disturbance suspends potential prey (e.g., small epibenthic crustaceans) and makes them more available to fry, though this hypothesis remains untested.

The foremost issue of concern is whether overwater structures may inhibit or alter migration pathways of juvenile salmonids. Most directed research in Washington State on salmon fry behavior in the vicinity of overwater structures has involved breakwaters in the context of marinas or highly developed ports (Williams and Thom 2001; Weitkamp 2003), erosion control structures in outer coast estuaries (Miller et al. 2002), reduced light associated with overwater structures (Nightingale and Simenstad 2001), and fry behavior around the Port Townsend ferry terminal (Shreffler and Moursund 1999). These and other studies (Weitkamp 2003) often confirm observations made at the Mukilteo ferry terminal, though responses may vary by species and age class, as well as by armoring or structure characteristics.

Salmon fry and forage fish schools may concentrate in higher densities behind breakwaters in marina basins as compared with unaltered nearshore areas (Heiser and Finn 1970; Penttila and Aguero 1978). Fish movement and schooling behavior documented in these studies suggested that concentration in these areas was volitional, with reluctance of juvenile salmonids to leave the shoreline and travel along bulkheads or connected breakwaters related to fish size. Heiser and Finn (1970) found that 35-mm to 45-mm pink and chum fry would not venture along bulkheads or connected breakwaters until reaching a larger size (50 mm to 70 mm). The design of the bulkheads, groins, or breakwaters may also affect fry behavior. Steep, vertical designs are thought to inhibit migration potential, whereas low-slope structures (<45° angle) of natural material (e.g., riprap) with irregular surface configuration provide more protective cover, shallow water shelter, and predation refuge (Williams and Thom 2001).

Miller et al. (2002) evaluated juvenile salmon behavior and migration around a groin and underwater dike in Willapa Bay, Washington. Juvenile chinook salmon were significantly more abundant adjacent to the groin, and divers observed juvenile salmon, individually and in small groups (3 to 5 individuals), feeding and moving on both sides and on top of the structure during all phases of the tide. Mark-recapture efforts showed that one chinook smolt successfully traveled from east of the groin to the west side of the groin over the course of one day. Low recapture rates of fish marked on either side of the groin perhaps provided the best indication that juvenile salmon were not remaining in these habitats for long periods of time, although groin habitats may have created conditions conducive to short-term feeding, resting, and transition to marine waters.

On the basis of a one-time experiment, Shreffler and Moursund (1999) found no evidence that the Port Townsend ferry terminal was a barrier to the migration of 1000 hatchery chinook that were released there. Surface observations, underwater video, and hydroacoustics confirmed that the chinook migrated from the release point (30 m from the southern edge of the terminal) underneath the terminal. However, the authors cautioned that this one-time finding did not allow any definitive conclusions about whether ferry terminals have an effect (i.e., serve as a barrier) to juvenile salmon migration.

In a review of the literature on juvenile salmon use of estuarine and nearshore habitats, Weitkamp (2003) concluded the following relative to effects of light on salmon behavior: 1) in general, all species of juvenile salmon prefer to migrate at night, typically along shorelines, and within 2 m to 3 m of the water surface; 2) chinook, chum, and pink fry tend to be found in schools; 3) great changes in light intensity appear to be resisted by all species of juvenile salmon; 4) overwater structures supported by more widely spaced concrete pilings are acceptable to migrating young chinook, whereas structures supported by densely spaced wood pilings are sufficiently dark to discourage use by chinook; 5) chum fry do not appear to avoid piers that may cause them to either move over deep water or into shaded conditions underneath the pier; 6) coho responses to light varied from study to study; and 7) no studies were identified on the behavior of pink fry or sockeye fry in relation to light.

Regardless, the ambiguity of results to date points to the continued need for directed, repeatable studies of this subject in the near future, as outlined under the WSDOT comprehensive research strategy. Suggested approaches should involve methods that differentiate between behavioral responses that are mediated by salmon species and age class, as well as by structural design. Likely methods include mark-recapture efforts, use of tags and telemetry, and various video technologies during peak timing of salmon abundance in nearshore habitats. Ongoing work by Oregon Department of Fish and Wildlife (Friesen et al. 2003) in the lower Willamette River has involved standardized sampling and radiotelemetry (both fixed sites and mobile tracking) to better clarify residence patterns, movement rates, and habitat relationships of juvenile salmonids and predator fish in lower river habitats. Preliminary results suggest that juvenile salmonids do exhibit preferences for some lower river shoreline habitats (e.g., alcoves, rock outcrops, and natural habitats) (Friesen et al. 2003). Similar research in the nearshore marine waters of Sinclair Inlet, Washington, by WDFW (Fresh et al. 2003) is using coded wire and fluorescent pigment tags to investigate the spatial and temporal use of littoral habitats by juvenile chinook salmon. Current findings show that chinook salmon are found in littoral habitats from April through September, with local populations residing for an average of 6 to 8 days in Sinclair Inlet. However, juvenile chinook originated from a vast number of sources outside the study area, including as far away as the Fraser River.

Recent work by Toft et al. (2003) further suggests the use of enclosure nets and snorkel surveys as the most effective methods in statistically based studies comparing abundance and behavior of juvenile salmon along marine shorelines. Enclosure nets allowed capture of fish and reliable measures of density, fish size, and species identification, though they could not be used under overwater structures and were very time consuming and labor intensive to deploy (one site per day using a 4-person crew) (Toft et al. 2003). Snorkel surveys allowed observation of schools of juvenile salmon congregated around the edges of piers, although water clarity (turbidity) was the major constraint, limiting observations to situations when secchi depth readings were below 3.5 m to 4.0 m.

Finally, it should be noted that pink and chum salmon fry were the focus of our study because of their apparent abundance in nearshore habitats. Juvenile chinook salmon were rare, with only three yearlings collected during beach seine sampling efforts. Much of this difference might be attributed to the typical timing of outmigration runs by species. Chum and pink salmon generally move into outer estuary habitats in March through April, peaking in early April to late May; chinook fry generally enter upper estuary marsh habitats in late March to May (Weitkamp 2003). Rice et al. (2001) generally found chinook fry abundance peaked in Skagit Bay beach-seine collections from April through July, and in offshore tow-net samples from June to October; Fresh et al. (2003) found juvenile chinook catches in Sinclair Inlet peaked in June.

5.2 Predation around Overwater Structures

As outlined in the introduction, our study was designed to conclusively establish whether particular WSF terminals aggregated predators and/or affected predation on juvenile salmon, to develop standardized methods for surveying other WSF terminals, and to recommend potential solutions (e.g., siting and design criteria) for reducing any observed impacts. We opportunistically focused much of our sampling effort at the Mukilteo terminal, although bird and mammal predator surveys were also conducted at five other north-central Puget Sound WSF terminals over a 6-week time frame. The varied scale of this effort is reflected in a discussion of our findings, as it centers on the study goals outlined at the outset (Section 1.2). Though our findings may not enable us to extrapolate impacts to all ferry terminals or overwater structures, or cumulative impacts to the viability of nearshore resources, the study does provide insight about general trends at various spatial and temporal scales, and provides recommendations for standardized survey protocols.

In Section 1.2, we stated the following null hypotheses of this research:

1) Potential salmon predators (fish, birds, and marine mammals) are no more abundant near or under terminals than along shorelines without overwater structures (paired reference sites)

2) Potential salmon predators are no more abundant in nearshore habitats when juvenile salmon outmigration is occurring than when juvenile salmon are absent

3) Potential salmon predators consume no more juvenile salmon near WSF terminals than along shorelines without overwater structures.

Below, we address our findings relative to each of these hypotheses (Table 17).

Hypothesis 1: Potential salmon predators (fish, birds, marine mammals) are no more abundant near or under terminals than along shorelines without overwater cover (reference sites).

Observational surveys at six locations suggest that potential salmon predators were statistically more abundant at WSF terminals as compared with unmodified shorelines (Table 17). Piscivorous birds were observed more often than expected at ferry terminal sites (1.77 per count) as compared with reference sites (1.27 per count). However, large aggregations of piscivorous birds were not observed at WSF terminals during any survey. Marine mammals were not abundant and did not appear to be targeting outmigrating salmon near WSF terminals during the 6-week spring study period.

Predatory fish surveys, which were conducted only at the Mukilteo ferry terminal and paired reference sites, produced similar findings (Table 17). SCUBA transects suggested that fish species diversity and abundance were higher at the terminal than at the reference site, especially at night, although potential predators comprised less than 10% of all observations. Most potential salmon predators were demersal species observed during rapid dive assessments in deeper habitats associated with the outer structures of the terminal. Snorkel surveys during the day detected no water-column species other than salmon fry and forage fishes, whereas DIDSON surveys at night documented large schools of surfperch, but few instances in which large water-column fish (potential salmon predators) were associated with ferry terminal structures. Most species of surfperch found in Puget Sound and the Straits are epibenthic planktivores that consume small crustaceans, and would not be considered predators of juvenile salmonids (Simenstad et al. 1979). In shallow nearshore habitats, Pacific staghorn sculpin were the only salmon predators observed during SCUBA surveys and collected by beach seine.

As noted in Miller et al. (2002), part of the complexity in resolving whether predators aggregate at shoreline structures to feed on juvenile salmon is based on our inability to separate between basic habitat preferences of a particular species and volitional aggregation to specifically feed on outmigrating salmon. Increased animal abundance in structurally complex habitats has usually been attributed to the combined benefits of enhanced food supply and refuge from predators. In fact, habitat structure is often manipulated to enhance or aggregate specific faunal groups for human benefit (e.g., artificial reefs) (Seaman Jr. and Sprague 1991). WSF terminals and other similar overwater structures provide features, such as hard attachment substrate, structural complexity, and prey, that are similar to rocky sublittoral habitats in the region. Bottom-oriented carnivores, such as lingcod and rockfish, are typical predatory species found in these steep, structurally complex, and well-flushed habitats (Simenstad et al. 1979).

The higher relative abundance of fish species, small cottids, forage fish, and surfperch in particular, observed by divers near the ferry terminal supports the suggestion that fish abundance near the Mukilteo ferry terminal was driven by elements of structural complexity. Besides providing structural features that enhance refuge functions, WSF terminals have topographic features such as propeller scour basins and terminal pilings that may deflect currents and can be sites of strong horizontal and vertical changes in current velocity (Simenstad et al. 1999; Miller et al. 2002). These features may concentrate fish prey (e.g., epibenthic or planktonic organisms) in space and time through a variety of mechanisms, such as physically trapping in a downstream eddy or forcing a transition between stratified and well-mixed water, and often occur under predictable circumstances. Avian predators also predictably associate with physical marine features, in addition to large-scale currents and regimes, which are assumed to increase prey abundance or availability (Furness and Monaghan 1984; Ballance et al. 2001). Three of the bird species (loons, grebes, and cormorants) documented during our predator surveys sacrifice wide-area search capabilities in exchange for diving adaptations and, therefore, are limited to areas of high prey availability (Ballance et al. 2001).

Hypothesis 2: Potential salmon predators are no more abundant when juvenile salmon outmigration is occurring than when juvenile salmon are absent.

Observations of potential predators were made only when salmon were present; therefore, our findings relative to salmon fry abundance in the nearshore were inconclusive (Table 17). Our original aim was to determine whether potential salmon predators aggregate near WSF terminals in direct response to the juvenile salmon spring outmigration by making paired observations before the outmigration began and during the peak. Though we attempted to conduct initial surveys just before peak salmon fry outmigration, our study timing coincided with the first appearance of schools in the nearshore, and all subsequent observations of predator abundance and diet occurred while salmon were present.

From our observations during peak outmigration, it is apparent that juvenile salmon concentrate in schools close to shore and near the water surface, although the behavioral mechanisms for this are still unclear. The embayment near the Mukilteo ferry terminal may be an important concentrating mechanism; however, we cannot definitively conclude this based on the existing data. Other researchers have similarly noted that pink and chum salmon appear to concentrate in protected harbors and breakwater areas (Heiser and Finn 1970).

Hypothesis 3: Potential salmon predators consume no more juvenile salmon near WSF terminals than along shorelines without overwater structures.

Birds and Mammals

We found no evidence that avian or marine mammal predators consumed more juvenile salmon near WSF terminals than along shorelines without overwater structures (Table 17). Few species appeared to be targeting fry in shallow nearshore habitats and no aggregations of suspected predators were observed in these habitats on any occasion. The single occasion of confirmed predation on a juvenile salmon involved a tern, a species rarely observed during our surveys in Puget Sound. Outside of this study, we have also observed a single Bonaparte's gull (*Larus philadelphia*) specifically targeting and feeding on juvenile chum salmon along shorelines north of the Clinton ferry terminal during the spring of 2003. As previously noted, marine mammals were neither abundant nor observed feeding at WSF terminals during the study period.

Chum and pink salmon fry may be too small to be likely prey of large predators. Wood (1987) notes that mergansers appear to select a disproportionate number of large fish compared with sizes typically available. Pinniped predation on juvenile salmonids is affected by their size during outmigration, with yearling chinook, coho, and steelhead considered the most vulnerable (National Marine Fisheries Service 1997). Although extensive analysis of harbor seal diets in Washington coastal estuaries have shown that they consume some adult salmonids, there is little evidence of smolt consumption (Schroder and Fresh 1992). It is believed, however, that smolt predation is either not represented or underrepresented in most studies, because their otoliths are fragile and quickly digested and, therefore, may not be identified in stomachs or scat (National Marine Fisheries Service 1997). It should also be noted that it is often difficult to ascertain the identity of bird and mammal prey only with visual surveys. The underwater feeding behavior of pinnipeds and some avian species, combined with the fragility and rapid digestion rate of salmon as prey, further exemplify the difficulty of estimating salmon consumption rates in any study (National Marine Fisheries Service 1997).

Fishes

Our analysis of fish diets at the Mukilteo ferry terminal provides one piece of conclusive evidence that juvenile salmon were not a major dietary component of predatory fish species during our study (Table 17). Only two juvenile salmon were observed in the diet of a single staghorn sculpin collected at the reference site; these salmon were undigested and likely consumed in the bag of the beach seine. Staghorn sculpins are one of the most ubiquitous species in shallow sublittoral habitats of Puget Sound and are distributed throughout most Pacific Coast estuaries (Emmett et al. 1991). Juveniles and adults are found primarily in sandy habitats, but are also common over substrates ranging from soft mud, eelgrass, and rock. Common dietary items for juveniles (to 120 mm total length) include primarily benthic and epibenthic organisms, such as amphipods, isopods, burrowing shrimp, decapod crustaceans (shrimp and Dungeness crab), bivalve siphons, and polychaetes (Simenstad et al. 1979; Emmett et al. 1991; Williams 1994; Armstrong et al. 1995). Large juveniles and adults also may consume fish (including juvenile salmon, herring, juvenile sculpin, surfperch) and larger crustaceans (*Crangon* shrimp, crab).

Fishes identified in stomach contents of other species (i.e., lingcod, rockfishes) collected near the Mukilteo ferry terminal included only forage fish (i.e., sandlance), staghorn sculpin, and gunnels. Diets of these species match information reported in a number of previous publications. Lingcod are bottom-oriented piscivores that feed on Pacific herring, sand lance, flounders, rockfishes, and large crustaceans (Simenstad et al. 1979; Emmett et al. 1991). Besides anecdotal reports of lingcod feeding on hatchery-raised salmon at the Seattle aquarium (personal communication, Jeff Christiansen, Seattle aquarium), we know of no previous studies that have documented juvenile salmon in the diets of this species. Copper and quillback rockfishes are considered facultative epibenthic feeders that primarily prey upon small crustaceans (gammarids, brachyuran crab, peracarida, mysidae); fishes (Scorpaenidae, Pacific sandlance) are a less-important dietary component (<20% total index of relative importance) (Simenstad et al. 1979). Ratfish are nocturnal predators that consume a diverse variety of prey, including crabs, isopods, amphipods, gastropods, bivalves, and fishes (Simenstad et al. 1979). Ratfish were not identified as a potential predator in a recent review of predators found to prey on young salmon in estuaries (Weitkamp 2003).

5.3 Alternative Explanations of the Findings

The evidence establishing whether significant numbers of potential predators were aggregated at the terminals needs further interpretation, especially relative to spatial and temporal distribution patterns of prey and predators. Pink and chum fry were an abundant and concentrated prey resource readily available to potential predators in all shallow nearshore habitats, although we found no conclusive evidence that juvenile salmon were more abundant near WSF terminals than along areas of unmodified shoreline. Most of the bird species that could be considered potential salmon predators (e.g., loons, grebes, double-crested cormorant, common merganser, tern sp., and pigeon guillemot) were observed at the outer portions of terminal structures near dolphins or wingwalls where few juvenile salmon were observed. Similarly, larger fish species that were considered potential predators were demersal species that consumed primarily benthic prey and were found in deeper terminal habitats at the Mukilteo ferry terminal, further suggesting that salmon oriented in the top 2 m of the water column would be unlikely prey items. The confirmed predators (staghorn sculpin and tern sp.) that co-occurred with salmon fry in shallow habitats were not observed in large numbers, suggesting they were not aggregating to preferentially feed on juvenile salmonids.

We offer four nonmutually exclusive hypotheses as to why we did not observe elevated rates of predation on juvenile salmon in the face of their greater relative availability to predators in nearshore habitats:

- The WSF terminals we studied did not inhibit or alter migration pathways of juvenile salmonids
- Juvenile salmon have evolved behaviors that minimize their predation risk in marine or estuarine systems, regardless of the presence of shoreline structures
- The greater availability of forage fish may serve to reduce the relative rate of predation on juvenile salmonids
- Our study design or methods were inadequate to capture effects over the proper temporal and spatial scales.

The first hypothesis is that the WSF terminals we studied did not inhibit or alter migration pathways of juvenile salmonids. In other words, these overwater structures may not have created exceptional conditions (e.g., like those below dams or hatcheries) to concentrate salmon and make them more susceptible to predation. Few studies to date have produced adequate empirical evidence to conclude that overwater structures increase or decrease predation on juvenile salmonids (Carrasquero 2001, Williams and Thom 2001, Weitkamp 2003). Because known juvenile salmon predators have a strong affinity to shoreline structures, management recommendations often take a conservative approach (i.e., mitigate potential cumulative effects and protect fishes) by regulating these elements in nearshore shallow-water habitats (Carrasquero 2001). More recent studies by Friesen et al. (2003) indicate a low incidence of salmonid mortality from suspected fish predators (pikeminnow, smallmouth bass, walleye, and largemouth bass) in the lower Willamette River, though low sample sizes (n = 71) precluded statistical determination of differences among habitat or bank treatment types.

A number of studies have shown that salmon predators aggregate in response to other unnatural or exceptional circumstances, such as spawning channels, hatcheries, or dams, where juvenile salmon are concentrated relative to natural conditions. Aggregative responses to uneven prey distributions have previously been quantified in terms of predator numbers, or time spent by a predator, per unit areas of different prey density (Hassell and May 1974). For example, large populations of northern pikeminnow (*Ptychocheilus oregonensis*) often aggregate below hydroelectric and irrigation diversion dams, where they prey upon small fish that are disoriented or injured. Sims et al. (1977 and 1978, in Brown and Moyle 1981) found 20% to 88% of the pikeminnows below dams on the Columbia River consumed outmigrating salmonids. Salmon consumption by pikeminnows has also often been correlated with periods of smolt release from hatcheries, although under natural conditions, salmonids are often not major prey items (Brown and Moyle 1981; Buchanan et al. 1981). Ruggerone (1986) documented aggregations (250 to 350) of gulls actively foraging for fish within 75 m of the Wanapum Dam tailrace on the Columbia River. During a 25-day peak outmigration period, gulls consumed an estimated 2% of the salmon population during spring outmigration. Wood (1987) also found that merganser abundance was orders of magnitude higher below the Big Qualicum hatchery than in tidal waters during spring releases of salmon fry.

The second hypothesis is that juvenile salmon have evolved behaviors that minimize their predation risk in marine or estuarine systems, regardless of the presence of shoreline structures. All animals must balance the conflicting needs of achieving high food intake and avoiding predators. Because predation risk alters prey behavior, predators often play an important indirect role in the habitat distribution of prey (Pulliam 1989). For fish in estuarine habitats, the risk of predation is thought to diminish with both decreasing water depth and increasing individual size (Ruiz et al. 1993). Thus, small (40 mm to 60 mm) juvenile salmon likely achieve refuge from deepwater predators by using shallow waters close to shore. Larger fishes that would potentially prey on salmon may be limited to deeper habitats where they themselves are less susceptible to predation by marine mammals and birds. Other researchers have similarly noted that marine fish that might prey on young salmon are located near the bottom or at mid-depths, where they are unlikely to encounter young salmon (Weitkamp 2003). For juvenile salmon, this strategy may engender trade-offs in access to more profitable feeding areas and increased susceptibility to some species of diving or wading birds, though these hypotheses remain untested.

The third hypothesis is that in marine habitats, the greater availability of forage fish may serve to reduce the relative rate of predation on juvenile salmonids. Collis et al. (2002) found significantly lower proportions of juvenile salmonids in the diets of birds nesting lower in the Columbia River estuary (km 8) compared with those nesting upriver (km 34 near Rice Island). Marine forage fishes such as herring (*Clupea* spp.), smelt (Osmeridae), shiner perch (*C. aggregata*), and Pacific sand lance (*A. hexapterus*), were more prevalent in the diets of double-crested cormorants, gulls, and Caspian terns in the estuary compared with the diets of those foraging in upriver locations. Wood (1987) found adult mergansers consumed young salmon in freshwater streams but primarily blennies and sculpins in tidal waters. Similarly, seabird predation on hatchery-raised pink salmon (*O. gorbuscha*) between April and June of 1995 in Prince William Sound, Alaska, indicated that salmon fry just entering the marine environment were not especially susceptible to avian predation (Scheel and Hough 1997). The authors attributed this decline in vulnerability to the presence of other attractive food patches and to a decline in the number of seabirds foraging along the shoreline later in the study.

The fourth hypothesis as to why we may have not observed elevated predation on juvenile salmon in nearshore habitats was that our study design or methods were inadequate to capture effects over the proper temporal and spatial scales. Potential study weaknesses included the limited duration of the study and our inability to compare predator aggregation before and during peak salmon abundance. Logistical realities limited much of our study to investigations at one WSF terminal and a paired reference site over a 3-week period. We attempted to remedy these limitations by expanding the scale of bird and mammal surveys to five other WSF terminals over a 6-week time frame. Furthermore, although our study design involved a comprehensive set of surveys at all hours during peak nearshore salmon fry abundance (Section 1.2), we did not conduct night surveys of potential bird and mammal predators. Anecdotal observations suggested that juvenile salmon were likely prey items of some birds (e.g., great blue herons) during the night, especially in areas with artificial lighting. Future studies should be prepared to better address this issue.

Though our findings may not enable us to extrapolate impacts to all ferry terminals or overwater structures, or about cumulative impacts of predators to juvenile salmon in the nearshore, the study does provide good insight into general trends at the sites we studied. It also provides the basis for recommending standardized survey protocols at other sites that may guide and strengthen more general conclusions about predation risk of juvenile salmonids near overwater structures. Drawing on the lessons learned in this study, we recommend use of a field protocol that is intended to provide a standardized procedure for evaluating predation risk to juvenile salmonids at ferry terminals and other overwater structures (Appendix A). The protocol is organized according to a tiered approach that allows the user to obtain useful information while retaining some flexibility in the face of likely constraints (e.g., cost, spatial and temporal variability) associated with a particular study situation. The protocol provides a basis for developing a larger data set using identical sampling procedures. Application of this protocol to more locations and situations will allow the scientific community to develop a much stronger case for evaluating predation pressure associated with nearshore anthropogenic structures.

5.4 Conclusions and Recommendations

- *Our interpretation of the abundance, distribution patterns, and diets of potential predators suggest that juvenile salmon did not experience biologically significant levels of predation near the ferry terminals studied during the spring of 2002.* Although potential predators of salmon were slightly more abundant near ferry terminals than at unaltered reference areas, large aggregations of predators were never observed in either nearshore setting. Furthermore, the spatial distribution patterns of both bird and fish predators rarely overlapped with juvenile salmon oriented in surface waters close to shore. Finally, we confirmed only two instances in which predators were preying on salmon fry; these included a tern which captured three salmon fry near the Clinton ferry terminal, and a staghorn sculpin which consumed two fry at the Mukilteo reference site.

- *Future studies involving planned construction of overwater structures or other nearshore modifications should use procedures that sample repeatedly and simultaneously at the potential impact site and at one or more reference sites during the periods before and after an impact has occurred.* This Before-After/Control-Impact (BACI) study design allows the researcher to eliminate the natural variability between sites by synoptic sampling over a relatively short period of time (Stewart-Oaten et al. 1992; Underwood 1992; Schroeter et al. 1993). Although we lacked the ability to assess conditions of WSF terminals before they were put in place, the inclusion of replicate terminal and unaltered reference sites strengthened our general conclusions regarding potential predation on juvenile salmon by birds and mammals.

- *We recommend applying a standardized field protocol (Appendix A) to provide consistent procedures for evaluating predation risk to juvenile salmonids at existing overwater structures, especially as they are being expanded or modified.* To date, we have found no definitive examples of predator aggregation in response to alterations of marine shoreline habitats, although this issue has been characterized by limited numbers of empirical studies. Use of these protocols over additional locations and situations will allow the scientific community to develop a stronger case for evaluating this issue in the future. Furthermore, behavioral research and observational studies must be undertaken to determine what factors (e.g., salmon species and size class, structural designs and size) may create exceptional conditions to concentrate salmon and make them more susceptible to predation near overwater structures.

- *We endorse sustainable development practices that minimize impacts to controlling factors (e.g., light levels, physical disturbance, sediment transport) that mediate habitat structure and ecological function in nearshore ecosystems.* As the weight of evidence accumulates regarding salmon predation risk near overwater structures, we should adopt management practices that sustain these controlling factors and maintain nearshore habitats in as close to their natural state as possible. This could include efforts to maximize natural light penetration through structures (Blanton et al. 2002), minimize artificial lighting around piers at night, increase piling spacing to allow sediment transport, and move activities offshore that cause unnatural turbidity or sediment disturbance (Carrasquero 2001; Thom et al. 2001; Williams and Thom 2001).

- *Washington State Ferry terminals cover a very small percentage (0.4 miles; <0.02%) of linear shoreline in the inland waters of Puget Sound and the Strait of Juan de Fuca.* Our data suggest that cumulative improvements to private and public structures that enhance habitat structure and function would likely have a net positive effect in improving conditions for juvenile salmon and other resources using these areas. For example, though we did not observe elevated rates of predation on juvenile salmon near WSF terminals, design elements of the Mukilteo ferry terminal that could improve nearshore habitat structure and function include minimizing artificial lighting levels of adjacent properties near the terminal at night, moving the ferry dock further offshore to reduce propeller wash disturbance, and restoring natural shoreline configuration and sediment composition using innovative bulkhead protection measures.

- *The design and direction of our research was the direct result of input from a large group of peers gathered at a WSDOT-sponsored workshop on this topic in 2002.* We strongly recommend continued research conducted in an open and collaborative manner to refine science-based recommendations on how to improve nearshore ecosystem conditions in Puget Sound.

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Figures

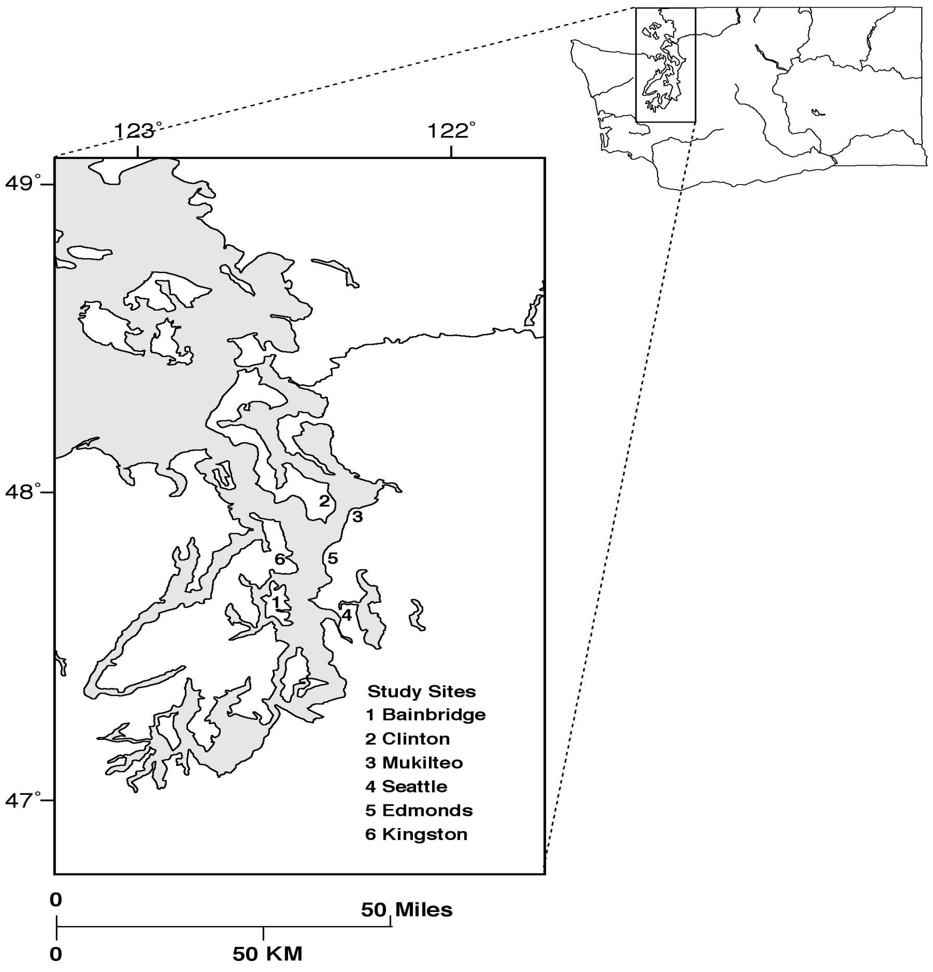

Figure 1. Washington State Ferry terminals used in study for evaluating marine mammal and bird predation on juvenile salmon.

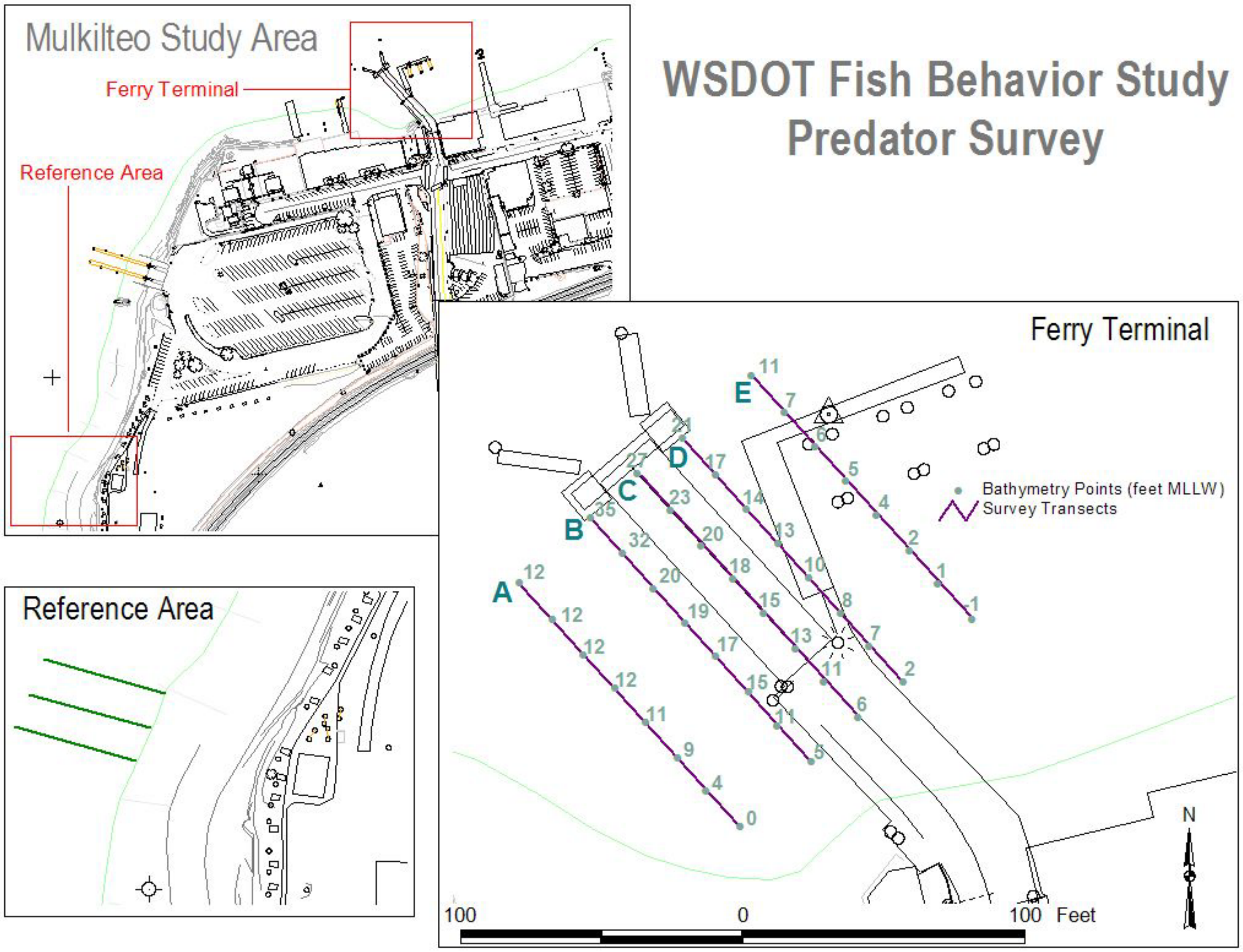

Figure 2. Study areas and dive survey transects at Mukilteo Ferry Terminal, spring 2002.

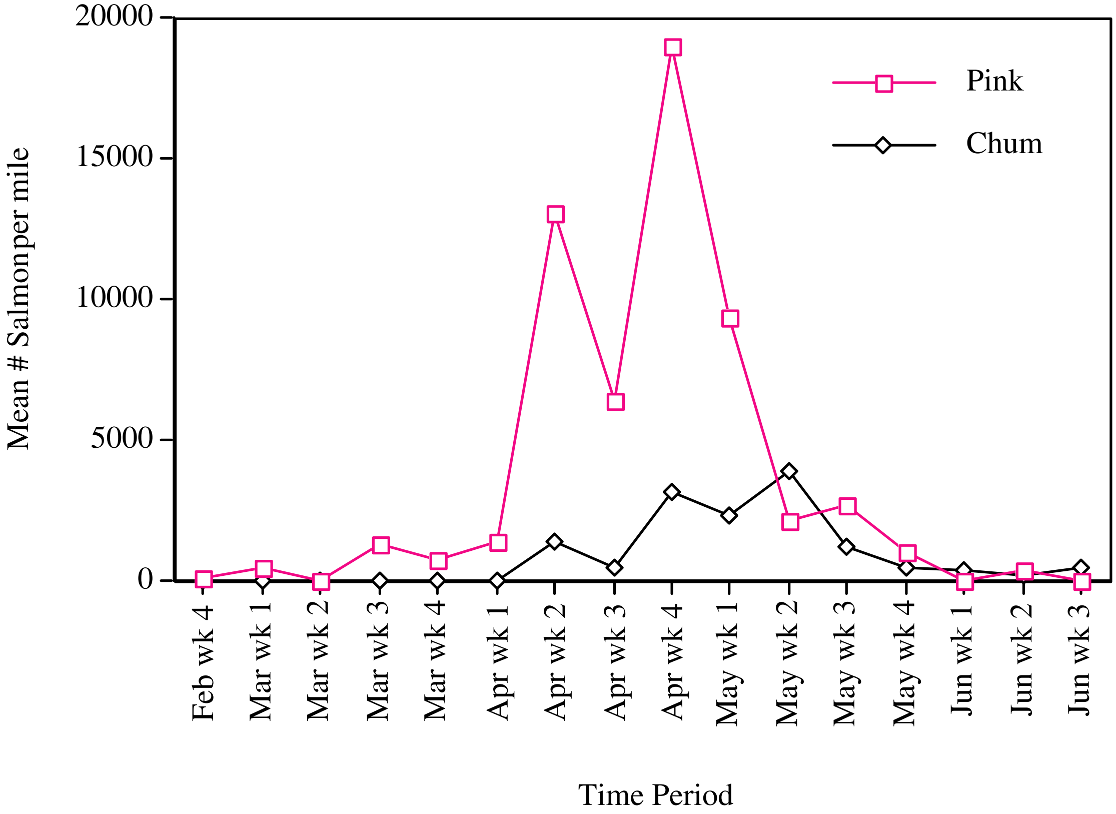

Figure 3. Abundance of pink and chum salmon fry observed in nearshore habitats near Mukilteo Ferry Terminal, 1966 – 2002 (WDFW unpublished data).

Figure 4. Setting and retrieving the beach seine, Mukilteo Ferry Terminal - spring, 2002.

Figure 5. DIDSON mounted on the Pacific Northwest National Laboratory Research Vessel (mount operator on far left of screen).

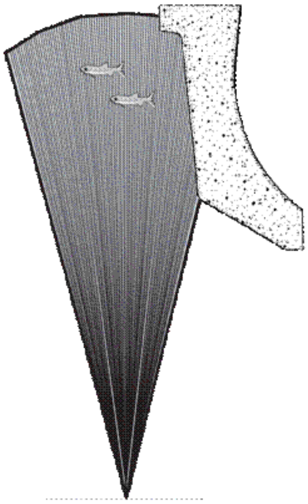

Figure 6. Diagram of the 96 beams along the horizontal plane of the sonar.

Figure 7. Salmon fry schooling in nearshore (left) and under pilings of Mukilteo Ferry Terminal (right)

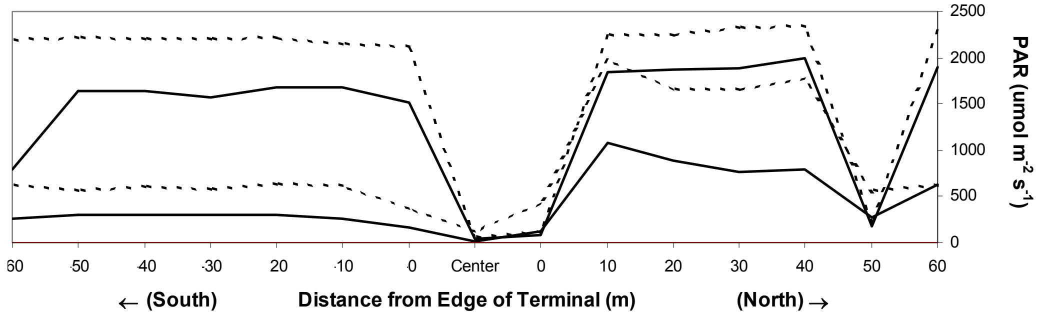

Figure 8. Four light transects recorded during daylight under the Mukilteo Ferry Terminal showing average PAR in air (two dotted lines) and just-under-the-water-surface (two solid lines).

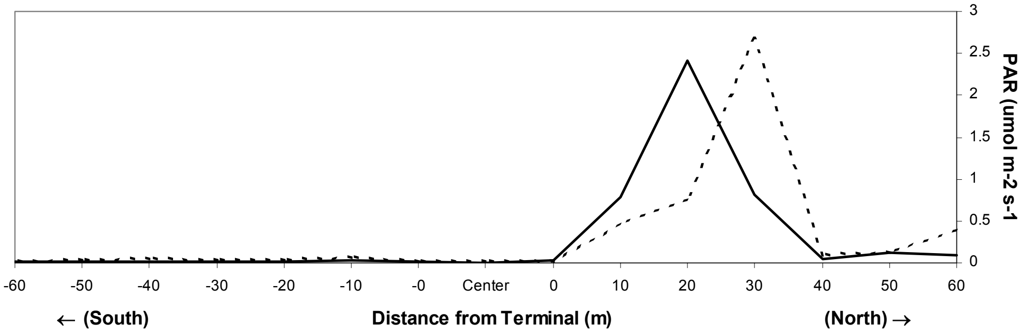

Figure 9. Two light transects recorded at night under the Mukilteo Ferry Terminal showing average PAR in air (dotted line) and just under the water surface (solid line).

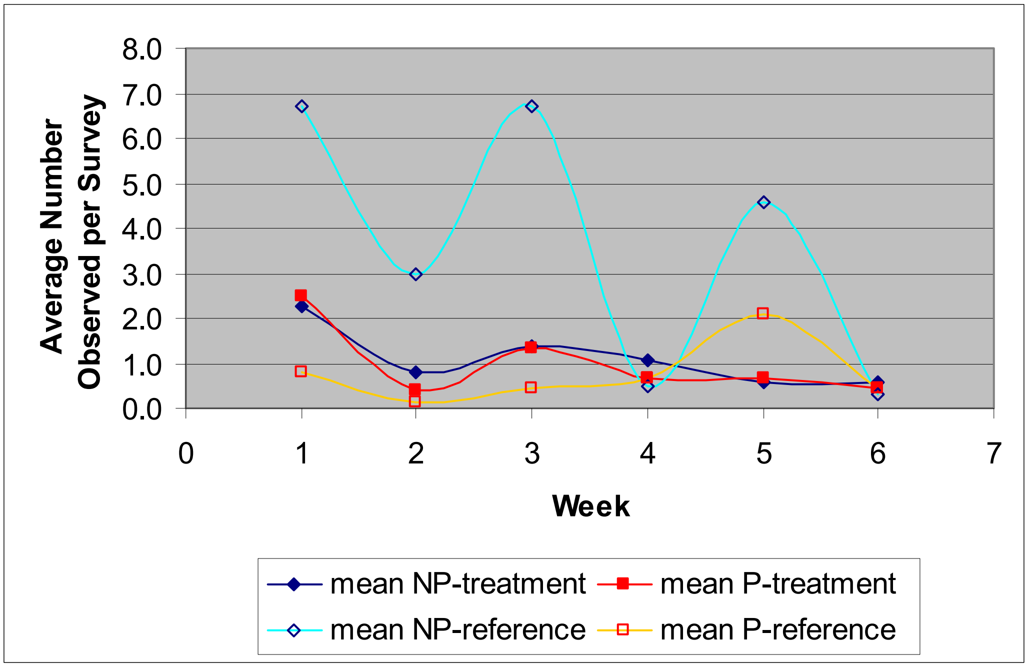

Figure 10. Distribution of potential bird and mammal predators (P) and nonpredators (NP) of juvenile salmon by week averaged over all sites for all point-count surveys combined.

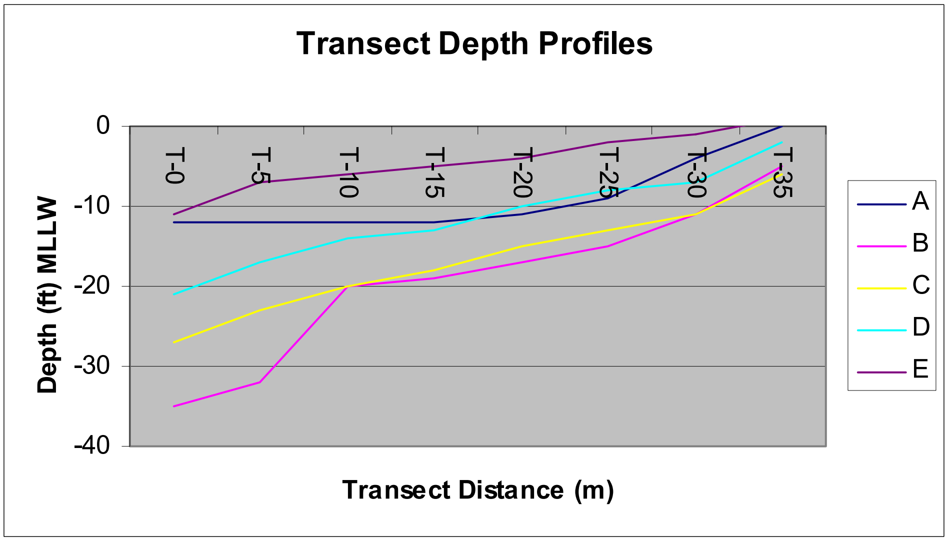

Figure 11. Depth profiles of SCUBA survey transects at Mukilteo Ferry Terminal.

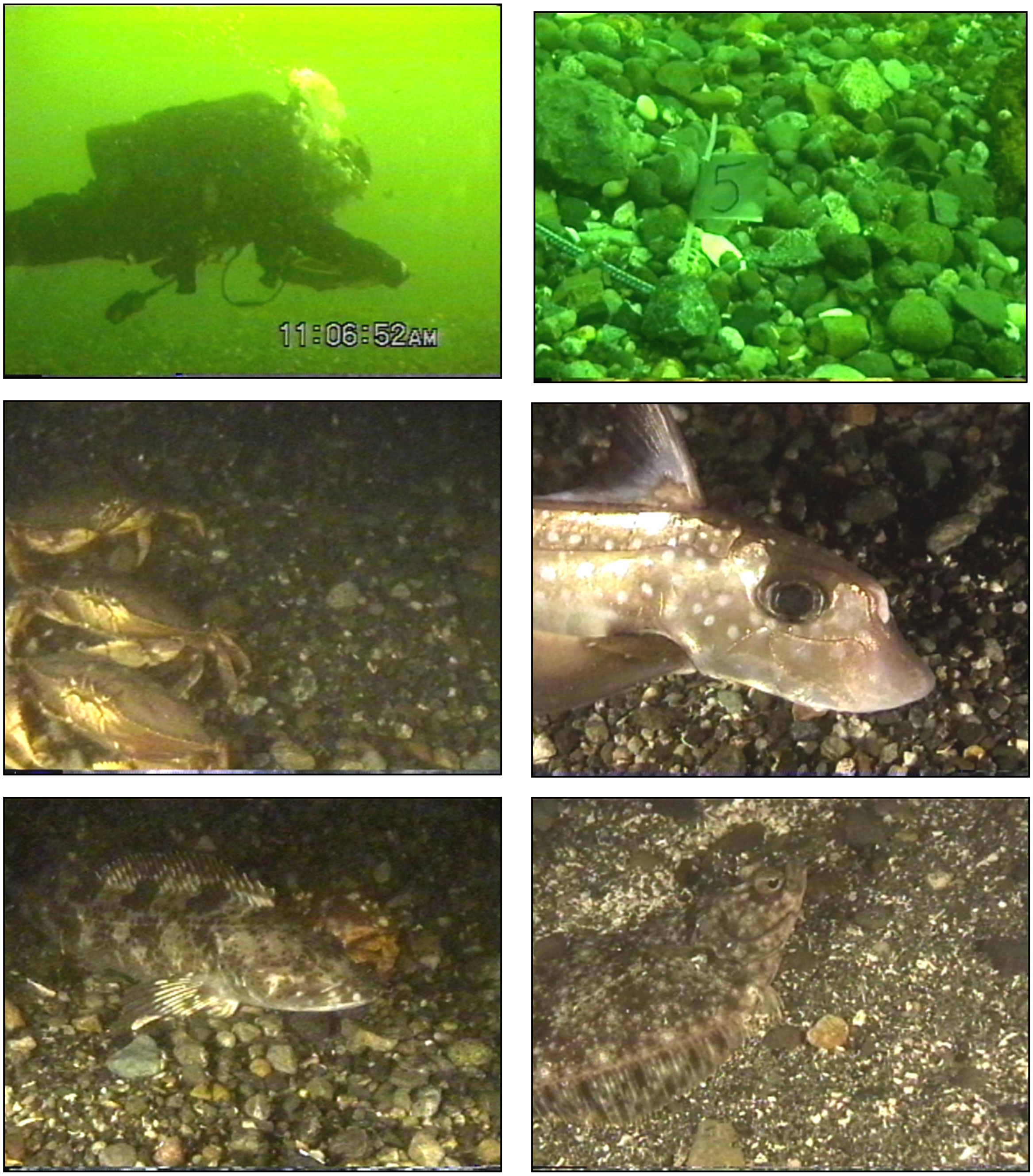

Figure 12. Photos Taken During SCUBA Surveys at Mukilteo Ferry Terminal. (Top) Diver and 5-m Marker on Strip Transect; (Middle) Dungeness Crabs and Ratfish, (Bottom) Lingcod and Flatfish.

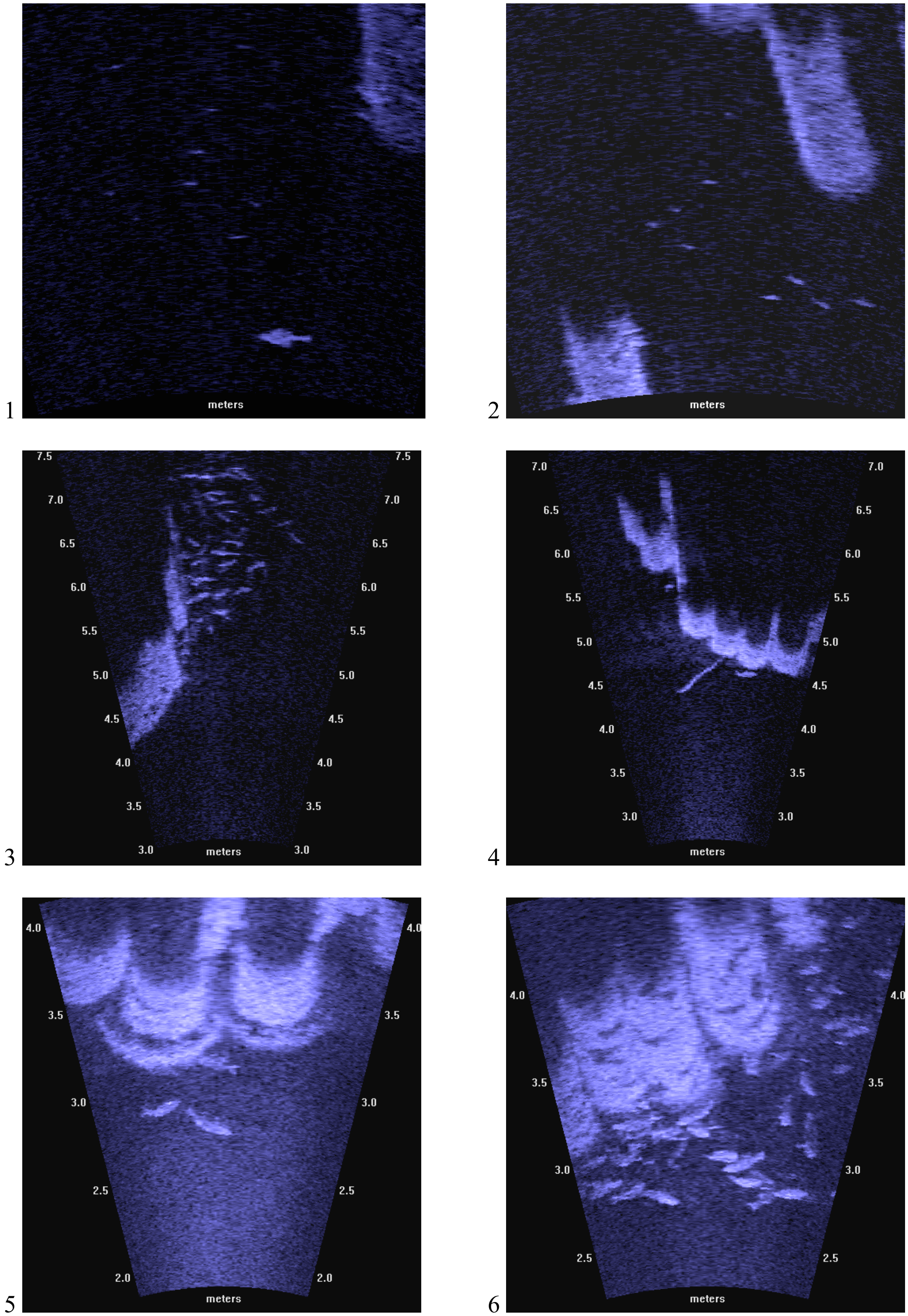

Figure 13. Actual DIDSON output of fishes associated with underwater structures. See Table 15 for location details; numbers on images provide range (meters) from DIDSON.

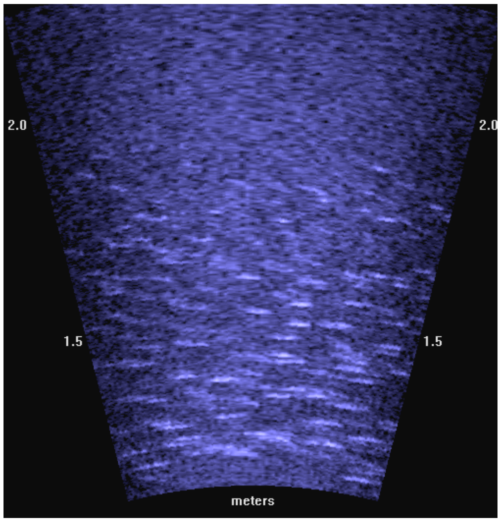

Figure 14. DIDSON Image of Juvenile Pink and Chum Salmon (Range 0 to 2.0 m).

Figure 15. Lingcod pumped for stomach contents (photo left) and sand lance retrieved from stomach (photo right).

Tables

Table 1. Validated, Potential, and Questionable Predators on Juvenile Salmon (adapted from Simenstad et al. 1999)

Study and Location	Validated Predators	Potential Predators	Questionable Predators
(Fresh et al. 1981) Nisqually Reach, southern Puget Sound	Pacific staghorn sculpin	Spiny Dogfish, Ratfish, Coho salmon, Chinook salmon, Cutthroat trout, Steelhead, Walleye pollock, Copper rockfish, Quillback rockfish, Great sculpin, Rock sole, Starry flounder	Cabezon
(Simenstad et al. 1979) Northern Puget Sound and Strait of Juan de Fuca	Caspian term, Common tern, Rhinoceros auklet, Bald eagle, Common merganser, Double-crested cormorant, Pacific harbor seal	Other obligate piscivores (both fish and bird species)	
(Cardwell et al. 1978)[1], Birch Bay Marina, north Puget Sound, WA		Pacific staghorn sculpin, Cutthroat trout, Chinook salmon, Coho salmon	Starry flounder, Striped seaperch, Pile perch
(Fresh et al. 1981) Marine waters of Puget Sound (south and central)	Coho salmon (juvenile and subadult), Chinook salmon (subadult), Steelhead trout, Cutthroat trout		
(Prinslow et al. 1980)[1] U.S. Naval Submarine Base, Bangor, WA	Cutthroat trout	Spiny dogfish, Chinook salmon, Coho salmon, Pacific hake, "cottids"	
(Ratte and Salo 1985)[1] Commencement Bay		Cutthroat trout, Steelhead, Dolly Varden, Coho salmon, Chinook salmon, Pacific cod, Walleye pollock, Pacific hake, Prickly sculpin, Pacific staghorn sculpin, Brown rockfish	Pacific tomcod
(Hargreaves et al. 1990) Barclay Sound, Vancouver Island	Hake, Walleye Pollock, Spiny dogfish, Black rockfish		
(Dames and Moore 1994)[1] Manchester Naval Fuel Pier		Cutthroat trout, Steelhead, Pacific hake, Great sculpin, Pacific staghorn Sculpin, Rock sole, Starry flounder	Pacific tomcod, Buffalo sculpin, Shiner perch, Striped perch, C-O sole, English sole
(Taylor and Willey. W.S. 1997)[1] Port of Seattle		Western grebe, Belted kingfisher, Red-breasted merganser, Common merganser	
(Pentec Environmental 1997)[1] Everett Harbor	Cormorant spp.		
(Yurk and Trites 2001)[1] Puntledge River Bridge, Vancouver Island, BC	Harbor seals		
Jeff Christianson, (pers. communication 2002) Seattle Aquarium	Lingcod, Black rockfish, Other rockfish spp., Spiny dogfish		
(Weitkamp 2003) Review of various studies in marine, estuarine, and freshwater habitats	Common murres, gull spp., Bonaparte gulls, mergansers, harbor seals, staghorn sculpins, hake, rockfish, lingcod, sculpins, subadult chinook salmon, cutthroat trout, spiny dogfish, large Pacific herring, Dolly Varden, buffalo sculpin, yearling coho salmon, Pacific cod, Aleutian sculpin, prickly sculpin, rainbow trout, river lamprey		

(1) Studies associated with overwater structures.

Table 2. Survey Methods and Study Objectives during Field Studies at Mukilteo Ferry Terminal, 2002

Survey Method	Salmon Fry Abundance and Size	Potential Bird and Marine Mammal predators; abundance and Location	Potential Fish Predators (Benthic spp.); Abundance, Size, Location	Potential Fish Predators (Pelagic spp.); Abundance, Size, Location	Diet; Predation on juvenile salmonids	Behavioral Observations (Predators and Salmon Fry)	Physical conditions
Fry Abundance Surveys	***a, b***					***a, b***	
Bird & mammal surveys		***a, b***			***a, b***	***a, b***	
Fish Predator SCUBA Surveys			***a, b***			***a, b***	
Fish Predator Snorkel Surveys				***a***		***a***	
Fish Predator Collection & Stomach Content Analysis					***a, b***		
DIDSON Surveys				***b***		***b***	
Beach Seine Sampling	***b***		***b***	***b***			
Light Level Measurement							***b***

a = Preemigration - early April
b = Peak emigration – late April / early May

Table 3. Marine Mammal and Bird Surveys by Location and Date, Puget Sound, Spring 2002.

Location	Week of 4/1	Week of 4/8	Week of 4/16	Week of 4/22	Week of 4/29	Week of 5/6	Total Surveys
Mukilteo	XX	X	X	X	XXX	X	9
Clinton	X	X		X		X	4
Edmonds	X	X	X	X	X	X	6
Kingston			X		X	X	3
Seattle	X	X	X	X	X	X	6
Bainbridge Is.		X		X		X	3

X = 1 survey (four 20-minute observation periods).

Table 4. Bird and Mammal Taxa Observed During Weekly Visual Surveys at ll WSF Study Sites, April to May 2002. Historic Abundance[1] and Recent Trends[2] Are Noted from Northern Puget Sound and Strait of Juan de Fuca studies.

Common Name	Scientific Name	Number of Sightings			Historic Abund[1]	Recent Trend[2]
		Total	Terminal	Reference		
Birds						
Common Loon[!]	*Gavia immer*	1	0	1	C	Decline
Pacific Loon[!]	*Gavia pacifica*	1	0	1	C	Decline
Horned Grebe[!]	*Podiceps auritus*	53	19	34	C*	Decline
Red Necked Grebe[!]	*Podiceps grisegena*	31	14	17	C*	Decline
Western Grebe[!]	*Aechmophorus occidentalis*	438	199	239	A	Decline
Double-crested Cormorant[!]	*Phalacrocorax auritus*	46	33	13	C	Decline
Black Brant	*Branta bernicla nigricans*	1055	0	1055	A*	Decline
Canada Goose	*Branta canadensis*	5	0	5	C*	ND
Mallard	*Anas platyrhynchos*	3	0	3	A*	ND
Barrows Goldeneye	*Bucephala islandica*	245	212	33	C*	Stable
Bufflehead	*Bucephala albeola*	6	0	6	C*	Stable
Surf Scoter	*Melanitta perspicillata*	315	240	75	A	Decline
Common Merganser[!]	*Mergus merganser*	65	22	43	C	Increase
Gull spp.	*Larus* spp.	n/a	n/a	n/a	A	Stable
Tern sp. [!]	*Sterna* sp.	2	2	0	C*	ND
Pigeon Guillemot[!]	*Cepphus columba*	105	101	4	C	Decline
Belted Kingfisher[!]	*Ceryle alcyon*	10	10	0	N/D	ND
Mammals						
Sea lion sp. [!]	Otariidae	7	0	7	ND	ND
Pacific Harbor Seal[!]	*Phoca vitulina*	1	0	1	ND	Increase
River Otter[!]	*Lutra canadensis*	2	2	0	ND	ND
Total Sightings		2391	854	1537		
Number Taxa		19	11	16		
Number Piscivorous Taxa (from Table 5)		13	9	10		

! Piscivorous taxa (Table 5).

n/a Present, but not quantified.

(1) Historic Abundance (A = Abundant, C = Common, NC = Not Common, R = Rare, ND = No Data; asterisk denotes seasonal occurrence) from Simenstad et al. (Simenstad et al. 1979).

(2) Recent Trends from Puget Sound Water Quality Action Team (Puget Sound Water Quality Action Team 2002).

Table 5. Common Diets of Avian Taxa Observed During Predator Surveys, Spring 2002

Common Name	Trophic Category[3]	Diet	Source
Common Loon[!]	Facultative piscivore	In saltwater, eats rockcod, flounder, seatrout, herring, etc. Some crustaceans, crab and amphipods.[1,2] Prey taxa include: gunnels, Pacific sandlance, staghorn sculpin, surf smelt, juvenile flatfish, shrimp, crabs.[3]	1, 2, 3
Pacific Loon[!]	Facultative piscivore	Mostly fish: shiner perch, small herring, also, crustaceans, molluscs.[1] In marine waters, assumed to eat fish, crustaceans, and molluscs.[3]	1, 3
Horned Grebe[!]	Facultative piscivore	Eats mostly small animals (99%).[1] Mostly small fishes: e.g. darters, anchovies, perch, shad, sculpin, stickleback, etc. Also crustaceans, molluscs and aquatic insects.[1,2] Fish (Pacific sandlance, Pacific herring, and staghorn sculpin) and small shrimp and crabs in marine waters.[3]	1, 2, 3
Red-necked Grebe[!]	Obligate piscivore	Small fishes: sticklebacks, herring, sculpins, etc.[1] Also eats aquatic insects and invertebrates and amphibians.[2] Spawning Pacific herring, Pacific sandlance, stickleback, blennies, and sculpin have been reported as food organisms.[3]	1, 2, 3
Western Grebe[!]	Obligate piscivore	More fish than any other grebe and more along coast than interior; carp, lake mullet, chubs, catfishes, perch, bluegills, smelt, herring. Also molluscs, crabs, marine worms, aquatic insects.[1] Prey include Pacific herring, staghorn and other sculpins, shiner perch, and smelt. Also shrimp.[3]	1, 3
Double-Crested Cormorant[!]	Obligate piscivore	Almost exclusively fish: gunnels, sculpins, sandlance, capelin, herring, flounders, smelt, surf fishes, sardines[1]. Primarily schooling fishes, but also crustaceans; shrimp, crab..[2] Gunnels, Pacific sandlance, shiner perch, snake prickleback, staghorn sculpin, Pacific herring, juvenile salmon, anchovy.[3]	1, 2, 3
Black Brant	Obligate herbivore	Eelgrass main component of diet, augmented by ulvoid algae.[3] Also crustaceans, molluscs, worms, marine insects.[1]	1, 3
Canada Goose	Facultative herbivore	Primarily grazes on shoots/roots/seeds of grasses and sedges. Along coasts, may eat molluscs and small crustaceans on tide flats.	1, 2
Mallard	Omnivore, Facultative herbivore	Seeds and shoots of aquatic vegetation. Also eats snails, molluscs, aquatic insects, tadpoles, fishes and fish eggs. Will even scavenge on dead salmon[1]. Seeds of saltmarsh plants and incidentally on polychaete annelid worms.[3]	1, 3
Barrow's Goldeneye	Facultative benthivore	In saltwater; eats molluscs, periwinkles and other gastropods-some sea urchins, starfish and marine worms.[1] Insects, and especially molluscs and crustaceans in marine habitats.[3]	1, 3
Bufflehead	Facultative benthivore	On saltwater, takes shrimp and other small crustaceans and shellfishes, largely snails.[1] In marine habitats, crustaceans, molluscs, and to a lesser extent small fish, appear to be the most important food items; herring eggs in shallow sublittoral waters may also be consumed when available.[3]	1, 3
Surf Scoter	Facultative benthivore	Primarily molluscs. Secondarily crabs, fishes urchins, sand dollars, marine worms, eelgrass and widgeon grass.[1] Primarily molluscs, crustaceans, and insects. [3]	1, 3
Common Merganser[!]	Obligate piscivore	Mostly small fishes: minnows, sticklebacks, killifishes.[1] Small demersal fishes (cottids, pholids, stichaeids, pleuronectids) and schooling neritic fishes (Pacific herring, Pacific sandlance), apparently including juvenile salmon[3]	1, 3
Tern spp. [!]	Piscivore	Dives for small fishes, e.g., minnows, squids, shrimp.[1] Prey taxa of Common, Arctic, and Caspian tern include Pacific herring, Pacific sandlance, smelt, juvenile salmon, shiner perch, etc.; also some crustaceans and molluscs. [3]	1, 3
Pigeon Guillemot[!]	Facultative piscivore	Small, bottom-dwelling fishes, molluscs, crustaceans and marine worms.[1] Chicks fed mostly fish.[2] Shallow, sublittoral fishes; blennies, flatfish, sculpins; also Pacific sandlance, surf smelt, pricklebacks.[3]	1, 2, 3
Belted Kingfisher[!]	Facultative piscivore	Mainly small fishes. Occasionally, aquatic invertebrates (along coast-clams & oysters)[1], amphibians, reptiles, insects, small birds, mice, rarely berries.[1,2]	1, 2
Sea Lion sp.[!]	Obligate piscivore	Primarily octopus, squid, and fishes; assumed that schooling epipelagic fishes (Pacific herring, anchovy, sandlance) and demersal forms (hake, Pacific cod, and walleye Pollock) are important prey in Washington/B.C. waters.[3]	3
Pacific Harbor Seal[!]	Obligate piscivore	Predominantly fishes (>90%), with small percentage of squid, crab, shrimp, and octopus. Primary fish prey include gadids, clupeids, hexagrammids, rockfish, and salmonids, although this varies on a seasonal basis.[3]	3
River Otter[!]	Facultative piscivore	Fish make up the greatest proportion of diet, although other foods include amphibians, insects, crustaceans, clams, mammals, and birds.	

! Denotes documented or potential predators of juvenile salmon.

[1] – (Terres 1956); [2] – (Ehrlich et al. 1988); [3] – (Simenstad et al. 1979).

Table 6. Average Number of Each Species Observed per Visual Survey by Site; Potential Predators of Juvenile Salmon Highlighted

Site:	Mukilteo Ferry Terminal	Clinton Ferry Terminal	Edmonds Ferry Terminal	Kingston Ferry Terminal	Seattle Ferry Terminal	Bain-bridge Terminal	Mukilteo Ref	Clinton Ref	Edmonds Ref	Kingston Ref	Seattle Ref	Bain-bridge Ref	Total Terminal	Total Ref	Grand Total
Black Brant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.2	0.0	0.0	0.6	0.0	27.8	27.8
Canada Goose	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.2
Mallard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1
Barrows Goldeneye	2.8	1.8	0.4	0.7	0.0	0.4	0.3	0.2	0.1	0.0	0.2	0.2	6.0	1.0	7.0
Bufflehead	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.2
Surf Scoter	1.0	3.1	1.8	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	5.9	1.9	7.8
Common Loon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pacific Loon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Horned Grebe	0.0	0.0	0.2	0.6	0.0	0.0	0.0	0.5	0.3	0.1	0.0	0.0	0.7	0.9	1.7
Red-Necked Grebe	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.1	0.0	0.3	0.3	0.6
Western Grebe	0.8	0.3	0.3	0.2	3.1	0.3	0.2	0.3	0.0	0.0	3.6	0.5	4.9	4.7	9.6
Cormorant	0.0	0.1	0.1	1.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	1.3	0.2	1.5
Merganser	0.0	0.0	0.6	0.1	0.0	0.0	0.3	0.0	0.1	0.8	0.0	0.0	0.6	1.2	1.8
Tern Sp.	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Pigeon Guillemot	0.3	0.6	0.3	0.3	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.0	2.2	0.1	2.3
King Fisher	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4
Sea lion	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Harbor Seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Otter	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Total NP	3.7	4.9	2.2	0.7	0.0	0.4	0.3	0.2	29.3	0.0	0.3	1.0	11.9	31.1	43.0
Total P	1.1	1.1	1.6	2.1	3.9	0.8	0.9	1.0	0.7	0.9	3.7	0.5	10.6	7.6	18.2
Grand Total	4.8	6.0	3.9	2.8	3.9	1.2	1.2	1.1	30.0	0.9	4.0	1.5	22.6	38.7	61.2

NP – Nonpredator; P – Predator

Table 7. Observed Average Number of Designated Species per Predator Survey Scan

	Nonpredators of Juvenile Salmon	Potential Predators of Juvenile Salmon	Total
Terminal Sites	1.99	1.77	3.76
Reference Sites	5.18	1.27	6.45
Total	7.17	3.04	10.21

Table 8. Spatial Distribution of Bird and Mammal Taxa Across WSF Study Locations By Weekly Survey, April - May 2002

Common Name	Mukilteo	Clinton	Edmonds	Kingston	Seattle	Bainbridge Island	% of Locations
Birds							
Common Loon	1						17%
Pacific Loon		4					17%
Horned Grebe		4	4,6	3			50%
Red Necked Grebe			3,4,5,6		2	2	50%
Western Grebe	1,2,3,4,5,6	1,4,6	1,5	5	1,2,3,4,5,6	6	100%
Double-crested Cormorant	2,5,6	2,6	3	3,5,6			67%
Black Brant			1,2,3,5			4	33%
Canada Goose						4	17%
Mallard					1,2		17%
Barrows Goldeneye	1,2,3	1,2	1,4,6	3,6	1	2,4,6	100%
Bufflehead			2				17%
Surf Scoter	1,2,3,5,6	1,2,4,6	1,6	3	3,4,6		83%
Common Merganser.	3		2,3,4	3,5			50%
Tern sp.		4					17%
Pigeon Guillemot	2,3,5,6	1,2,4,6	1,6	3	3,4,6		83%
Belted Kingfisher						2,4	17%
Mammals							
Sea lion sp.	1,2,4						17%
Pacific Harbor Seal	5						17%
River Otter				6			17%
Number of Surveys	9	4	6	3	6	3	
Spp. Richness	9	8	10	8	6	6	

1 = Week of 4/1
2 = Week of 4/8
3 = Week of 4/16
4 = Week of 4/22
5 = Week of 4/29
6 = Week of 5/6.

Table 9. Beach Seine Sets Conducted at Mukilteo Ferry Terminal and Reference Sites, May 2002

Site	**Day**	**Night**
Terminal North	3	1
Terminal South	3	2
Reference	4	3

Table 10. Species of Fish Captured in Beach Seines at the Ferry Terminal and Reference Sites, Mukilteo, May 2002

				Salmonids			**Other Species**									
Date	**Time**	**Location**	**Tide**	**Chum salmon**	**Pink salmon**	**Chinook salmon**	**Bay pipefish**	**Starry flounder**	**Saddleback gunnel**	**Crescent gunnel**	**Shiner surfperch**	**Staghorn sculpin**	**Surf smelt**	**Pacific sandlance**	**Buffalo sculpin**	**Threespine stickleback**
5/1/02	1453	Terminal N	low	169	2140			1	1							
5/1/02	230	Terminal N	slack	89	2992											
4/30/02	1240	Terminal N	ebb	43	645											
4/30/02	1335	Terminal N	slack	85	1223											
			Subtotal	385	7001	0	0	1	1	0	0	0	0	0	0	0
5/1/02	1408	Terminal S	ebb	45	3258		1									
5/1/02	115	Terminal S	ebb	32	334				1							
5/1/02	147	Terminal S	ebb	78	1044	2										
4/30/02	1100	Terminal S	ebb	42	1721											
4/30/02	1305	Terminal S	slack	163	2732											
			Subtotal	360	9089	2	1	0	1	0	0	0	0	0	0	0
5/1/02	1600	Reference	low	31	79			1		2	23	1			2	
5/1/02	300	Reference	flood	15	32			1			7	1	2	1		3
5/1/02	350	Reference	flood	69	10			1			1					
5/1/02	415	Reference	flood	77	19	1	2				1		2			2
4/30/02	910	Reference	ebb	191	518											
4/30/02	940	Reference	ebb	238	3605											
4/30/02	1010	Reference	ebb	372	2866						1					
			Subtotal	993	7129	1	2	3	0	2	33	2	4	1	2	5
			Total	**1739**	**23218**	**3**	**3**	**4**	**2**	**2**	**33**	**2**	**4**	**1**	**2**	**5**

Table 11. Catch Per Unit Effort (CPUE) by Fish Category at Sampling Sites, Mukilteo, May 2002

Fish Category	Terminal North	Terminal South	Reference
Flatfish	0.3	0.0	**0.4**
Forage Fish	0.0	0.0	**0.7**
Gunnel	**0.3**	0.2	**0.3**
Salmon	**1,846.5**	1,575.2	1,160.4
Sculpin	0.0	0.0	**0.6**
Surfperch	0.0	0.0	**4.7**
Other Fish	0.0	**0.2**	1.0

Bold indicates highest CPUE for each fish category.

Table 12. Spatial and Temporal Distribution of SCUBA Dive Surveys at Mukilteo Ferry Terminal and Reference Area

Salmon Emigration Timing	Date	Diel Phase	Terminal						Reference	
			Transect Code					RA Dives	Number of Transects	RA Dives
			A	B	C	D	E			
Pre	4/2/02	day						1		
	4/3/02	day						1		
	4/4/02	day	●	●	●	●	●		6	1
	4/4/02	night	●	●	●	●	●		2	
	4/5/02	day	●	●	●	●	●			
Peak	4/29/02	day	●	●	●	●	●			
	5/2/02	day	●	●	●	●			3	
	5/3/02	night	●	●	●	●	●	1		
	5/7/02	day							3	1
	5/8/02	night	●	●	●	●	●	1		
Combined	Total		7	7	7	7	6	4	14	2

RA (rapid assessment) dives involved observations made by 2 divers over 30-40 minutes.

Table 13. Fish Taxa Observed During SCUBA Surveys at Mukilteo Ferry Terminal and Reference Site

		Terminal			Reference		
Common Name	**Scientific Name**	**Survey (n=34)**	**R.A. (n=4)**	**Total**	**Survey (n=14)**	**R.A. (n=2)**	**Total**
Solitary Spp. (Individual Counts)							
Spotted ratfish	*Hydrolagus colliei*		2	2		1	1
Quillback rockfish*	*Sebastes maliger*		**1**	**1**			
Copper rockfish*	*Sebastes caurinus*		**1**	**1**			
Kelp greenling	*Hexagrammos decagrammus*	1		1	1		1
Lingcod*	*Ophiodon elongatus*	**1**	**3**	**4**			
Unident. sculpin spp.	*Cottidae spp.*	26		26			
Cabezon	*Scorpaenichthys marmoratus*		1	1	1	1	2
Staghorn sculpin*	*Leptocottus armatus*	**2**		**2**	**3**		**3**
Buffalo sculpin	*Enophrys bison*	4		4			
Threadfin sculpin	*Icelinus filamentosus*	3		3			
Padded sculpin	*Artedius fenestralis*	3		3			
Sailfin sculpin	*Nautichthys oculofasciatus*	6		6			
Sturgeon poacher	*Agonus acipenserinus*					1	1
Prickleback spp.	*Stichaeidae*	1		1			
Gunnel spp.	*Pholididae*	7		7			
Unident. flatfish	*Bothidae or Pleuronectidae*	9		9	3	1	4
Rock sole / Turbot	*Pleuronichthys spp.*	2		2	4	1	5
English sole	*Pleuronectes vetulus*	7		7	2		2
Sanddab spp.	*Citharichthys spp.*	5	1	6	1		1
Starry flounder	*Platichthys stellatus*					1	1
Schooling spp. (1 Count per School)							
Tubesnout	*Aulorhynchus flavidus*	3		3			
Pacific sandlance	*Ammodytes hexapterus*	2		2		1	1
Striped surfperch	*Embiotoca lateralis*	6	1	7			
Shiner surfperch	*Cymatogaster aggregata*	2	1	3	1		1
Total Observations		90	11	101	16	7	23
Number Taxa		18	8	22	8	7	12
Validated Salmon Predators/Survey		**0.09**	**1.25**		**0.21**	**0.00**	

* Designates salmon predators validated from the literature (see Table 1); predator data noted in bold.

Table 14. Quantitative Survey Effort and Average Number of Fish Observations per Survey by Diel Phase and Site

Effort (Surveys)	Day	Night	Total
Terminal	20	15	35
Reference	12	2	14
Total	32	17	49
Observations/Survey			
Terminal	0.5	5.3	5.8
Reference	0.9	3.5	4.4
Total	1.4	8.8	10.2

Table 15. Location, Time, and Description of Fish Sightings During DIDSON Surveys

Image #	.avi file name	Description	Fish Size (mm)	Time	Date	Location	GPS Coordinates
Fig. 13	2002-05-06_#004	Ratfish/Sculpin?	270 mm	0035	5/6/2002	Fuel pier	NA
Fig. 13	2002-05-06_#005	UID small fish (forage fish?)	110 mm	0036	5/6/2002	Fuel pier	NA
Fig. 13	2002-05-06_#31	Schooling surfperch	240 mm	0136	5/6/2002	Ferry terminal, N. dolphin	NA
Fig. 13	2002-05-07_#14	Rope; surfperch	260 mm	0042	5/7/2002	Ferry terminal, S. dolphin	47 56.969 N 122 18.316 W
Fig. 13	2002-05-07_#17	Schooling surfperch	280 mm	0109	5/7/2002	Ferry terminal, N. dolphin	48 56.978 N 122 18.297 W
Fig. 13	2002-05-07_#18	Schooling surfperch	270 mm	0112	5/7/2002	Ferry terminal, N. dolphin	49 56.983 N 122 18.242 W
Fig. 14	2002-05-07_#28	salmon fry	40-60 mm	0138	5/7/2002	Ferry terminal	47 56.954 N 122 18.254 W

UID - Unidentified

Table 16. Stomach Contents of Potential Fish Predators Captured at Mukilteo, May, 2002

Predator Species							
Common Name	**Scientific Name**	**Length (mm)**	**Catch Method**	**Location**	**Date**	**Time**	**Stomach Contents / Size / Weight**
Padded sculpin (5)	*Artedius fenestralis*	103-133	minnow trap	Terminal S	5/6/02	2308	1 crab (*Hemigrapsus*) leg
Spotted ratfish	*Hydrolagus colliei*	430	hook and line	Wingwall S	5/2/02	130	barnacles and mussels
P. staghorn sculpin	*L. armatus*	215	seine	Reference	5/1/02	300	none
P. staghorn sculpin	*L. armatus*	n/d	hook and line	Terminal S	5/1/02	1430	1 gastropod
P. staghorn sculpin	*L. armatus*	170	seine	Reference	5/1/02	1600	2 juv salmon (50 & 55 mm FL) =2.06 g, 11 isopod (*Sphaeroma*) = 0.70 g. 3 gammarid amphipod
P. staghorn sculpin	*L. armatus*	250	hook and line	Terminal N	5/7/02	2300	UID fish parts
Quillback rockfish	*Sebastes maliger*	340	hook and line	Dolphin S	5/1/02	300	1 gunnel (*Pholis*), 75mm = 1.134g, 1 crab (*Hemigrapsus*) appendages = 0.098g
Lingcod	*O. elongatus*	585	hook and line	Terminal S	5/1/02	1435	1 sand lance (*Ammodytes*), 90 mm = 2.66 g
Lingcod	*O. elongatus*	n/d	hook and line	Terminal S	5/1/02	1435	1 staghorn sculpin (*L. armatus*)
Lingcod	*O. elongatus*	725	hook and line	Terminal N	5/7/02	800	UID fish bones/vertebrae/eye (likely sculpin based on bony plates,stout structure) = 7.93g
Lingcod	*O. elongatus*	660	hook and line	Terminal N	5/7/02	2030	UID fish bones- 2 partial spines (25mm &30 mm)
Lingcod	*O. elongatus*	740	hook and line	Terminal N	5/8/02	945	UID fish bones/vertebrae (likely forage fish based on fine structure = 0.75g
Lingcod	*O. elongatus*	710	speargun	Dolphin S	5/8/02	321	UID fish bones = 4.88g

UID - Unidentified

Table 17. Study Conclusions Regarding the Potential Effect of WSF Terminals on Juvenile Salmonid Predation.

Goal	**Conclusion (1) ***	**Conclusion (2) ***
Potential salmon predators are more abundant at WSF terminals than along shorelines without overwater structures.	Yes	Yes
Potential salmon predators are more abundant at WSF terminals when salmon outmigration is occurring.	Inconclusive	Inconclusive
Predators consume more juvenile salmon near WSF terminals than in paired natural reference sites.	No	No

* Conclusion (1) refers to *fish* predator findings at Mukilteo ferry terminal; conclusion (2) refers to *bird and mammal* findings at six WSF terminals.

Appendix A - Field Protocol for Assessment of Predation Risk to Juvenile Salmonids

Purpose

The Field Protocol is intended to provide a standard procedure for evaluating predation risk to juvenile salmonids at ferry terminals and overwater structures, and is based on the lessons learned during the Pacific Northwest National Laboratory (PNNL) study of ferry terminal-associated predation on juvenile salmon at the Mukilteo ferry terminal. Application of this protocol to additional locations and situations will allow the scientific community to develop a database, based on consistent methods, to evaluate predation pressure associated with nearshore anthropogenic structures.

Guidance Documents

In addition to the study above, we recommend consulting the following key document before implementing this Field Protocol:

Estuarine Habitat Assessment Protocol (EHAP; Simenstad et al. 1991) provides procedures that quantitatively assess the function of estuarine wetlands and associated nearshore habitats for fish and wildlife. The goal of EHAP is "*to initiate systematic, on-site measurement of estuarine wetland and nearshore habitat function for fish and wildlife utilization by assessing the attributes of the habitats identified as being functionally important to fish and wildlife.*" Though some aspects of the EHAP are due for revision, it continues to serve as an essential tool that provides consistency among the many biological sampling programs in the region.

Tiered Approach to the Field Protocol:

There are many constraints (e.g., cost, spatial and temporal variability in predator and juvenile salmon abundances, availability of field staff, permitting issues, existing overwater structures, frequency of ferry arrivals/departures, etc.) in attempting to assess predation risk to juvenile salmonids in the vicinity of ferry terminals or other overwater structures. Recognizing these constraints, we have organized potential assessment activities within the Protocol in hierarchical order:

1. **Minimum**: those assessment activities that should be conducted under all circumstances.
2. **Recommended**: those assessment activities that provide an adequate or appropriate measure of predation risk.
3. **Preferred**: those assessment activities that provide an optimum measure of predation risk. This may include some experimental technologies that offer promise in the future.

Matrix of Assessment Activities

Assessment activities that we have identified as being useful for evaluating predation risk to juvenile salmonids are summarized in Table 1. For each assessment activity, we have made a determination of whether that activity should be performed as part of a minimum, recommended, or preferred level of assessment. We made these determinations based on the likelihood of obtaining data for any given activity, and by weighing the various advantages and disadvantages of implementing that activity.

The following assessment activities are the **minimum** that should be performed:

- Bird Surveys
- Marine Mammal Surveys
- Salmon Fry/Potential Predator Abundances: Beach Seine
- WDFW Salmon Fry Index Area Surveys
- Gut Content Analysis (Fish): Beach Seine Collection/Gastric Lavage
- Gut Content Analysis (Fish): Hook and Line plus Gastric Lavage (Note: this can include opportunistic sampling of fishes collected by recreational fishers in locations where there is a fishing pier next to the ferry terminal)
- Gut Content Analysis (Fish): Hook and Line plus Excise Stomach (Note: this can include opportunistic sampling of fishes collected by recreational fishers where there is a fishing pier next to the ferry terminal).

In addition to the above minimum activities, the following additional activities are **recommended:**

- Fish Surveys: SCUBA Transects
- Salmon Fry/Potential Predator Abundances: Enclosure Sampling
- Salmon Fry/Potential Predator Behavioral Observations: SCUBA/Snorkel and Underwater Video
- Light Levels.

The **preferred** level of assessment includes minimum and recommend levels activities, as well as the following:

- DIDSON (“acoustic flashlight”)
- Tagging of Validated or Potential Predators
- Gut Content Analysis (Fish): Spear and Excise Stomach
- Salmon Prey Availability-Epibenthic Plankters
- Salmon Prey Availability-Pelagic Zooplankton
- Salmon Prey Availability-Neuston
- Feeding by Juvenile Salmon: Gut Contents Analysis.

We believe that the **minimum** level of assessment could be conducted by one funding entity with a few trained field staff and access to the requisite field equipment. The **recommended** level of assessment would require more resources in terms of dollars, field staff and effort, and equipment. The **preferred** level of assessment would likely require a collaborative effort on the part of several (or multiple) funding partners and access to equipment (e.g., DIDSON camera; PIT tags, scanners) that is either not readily available or expensive to rent or buy.

Table 1. Assessment Activities for Evaluating Predation Risk to Juvenile Salmonids Near Overwater Structures.

Assessment Activity	Specific Methods	Data Collected	Advantages	Disadvantages	Data Likelihood	Tiered Approach
Predation on Juvenile Salmonids						
Standardized Surveys of Potential predators						
Bird Surveys	Fixed-point Count Shore-based observer	Bird species & abundance; behavior, predation observations	Bird ID straightforward; low time	Predation events seldom observed; difficulty identifying prey (esp. salmon fry)	Good	**Minimum**
Marine Mammal Surveys	Fixed-point Count Shore-based observer	Marine mammal species & abundance, behavior, predation observations	Mammal ID straightforward; low time	Predation events seldom observed; difficulty identifying prey (esp. salmon fry)	Good	**Minimum**
Fish Surveys	SCUBA transects	Fish species & abundance; behavior, georeferenced locations	Accepted methods; conclusive results	Time & gear intensive; requires expertise in fish ID underwater; predator avoidance of divers?	Good	Recommended
Potential Fish Predator / Salmon Fry Abundance						
Potential Predator / Salmon Fry	Beach seine	Species, abundance, lengths	Accepted method for determining salmon abundance; can be used near structures	Ineffective under most structures; labor intensive (boat & field crew of 3 minimum); large predators may avoid net; permit issues	Good - fry Fair - predators	**Minimum**
Potential Predator / Salmon Fry	Enclosure net	Species, abundance, lengths	Accepted method for determining salmon abundance; can be used near structures	Ineffective under structures' labor intensive (boat & field crew of 3 minimum); permit issues	Good	Recommended
Salmon Fry	WDFW Salmon Fry Index Area Surveys; shore-based observer	Visual estimate of pink & chum fry abundances (by species)	Salmon run timing; little additional field effort besides coordination with WDFW for data; verifies presence/absence of salmon as prey	WDFW does not survey all shorelines; qualitative method with high variability; surface-oriented pink & chum are surveyed most effectively; coho or chinook underrepresented	Good	**Minimum**

Assessment Activity	Specific Methods	Data Collected	Advantages	Disadvantages	Data Likelihood	Tiered Approach
Behavioral Observations						
Potential Predator / Salmon Fry	SCUBA / snorkel + video	Underwater video footage	Conclusive results; no fish mortality	Hit or miss method; visibility dependent; predator avoidance of divers?	Fair to Good	Recommended
Potential Predator / Salmon Fry	DIDSON (dual-frequency identification sonar)	Underwater images of potential fish predators in water column	Visibility not an issue, even at night; predator avoidance not an issue	Species ID problematic - requires divers to "groundtruth"; expensive to purchase or rent & requires specialized expertise to operate; labor intensive (requires boat, field crew of 3)	Fair to Good	Preferred
Potential Predator / Salmon Fry	PIT tag or radio tracking of validated predators	Site fidelity, growth, survival, locations & movements of predators	Conclusive results; low fish mortality	Initial capture difficulties; cost of PIT tags & scanners or radio tags & tracking equipment	Fair to Good	Preferred
Stomach Content Analysis						
Fish Predators	Seine collection + gastric lavage	Species ID of prey in stomachs	Conclusive results; low fish mortality	Capture difficulties	Fair	**Minimum**
Fish Predators	Hook & line + gastric lavage	Species ID of prey in stomachs	Conclusive results; low fish mortality	Capture difficulties; public perception issues	Fair to Good	**Minimum**
Fish Predators	Hook & line + excise stomach	Species ID of prey in stomachs	Conclusive results; opportunistic use of recreational catches	Fish mortality; some capture difficulties; public perception issues?	Fair to Good	**Minimum**
Fish Predators	Spear + excise stomach	Species ID of prey in stomachs	Conclusive results	Fish mortality; some capture difficulties; public perception issues?	Fair to Good	Preferred
Juvenile Salmon	Seine collection + gastric lavage	Species ID of prey in stomachs	Conclusive results; low fish mortality	Permit issues; sample processing & analysis time + costs	Good	Preferred
Associated Environmental Variables						
Light Levels	Light sensor	Photosynthetically	Rapid, straightforward, conclusive information on light	Requires purchase/rental of light	Good	Recommended

Assessment Activity	Specific Methods	Data Collected	Advantages	Disadvantages	Data Likelihood	Tiered Approach
		active radiation	levels	sensor		
Salmon Prey Availability	Epibenthic cores	Species,abundances, densities	Conclusive results	Sample processing & analysis time + costs	Good	Preferred
Salmon Prey Availability	Plankton nets	Species, abundances, densities	Conclusive results	Sample processing & analysis time + costs	Good	Preferred
Salmon Prey Availability	Neuston net	Species, abundances, densities	Conclusive results	Sample processing & analysis time + costs	Good	Preferred

Descriptions of Assessment Activities and Specific Methods

Assessment activities and specific methods are listed and described below in the order in which they appear in Table 1. Additional details of some sampling methods may be obtained in the body of the report.

Standardized Surveys of Potential Predators

Birds and Marine Mammals

Although there are variants in the general methods, quantitative fixed-point count surveys of birds and marine mammals can be conducted to document both the presence and feeding behavior of potential predators at overwater structures relative to paired reference sites without overwater structures. Each fixed-point count survey consists of four 20-min observation periods: two at each "treatment" site and two at each paired reference site. For each study site, observation stations encompass a stretch of shoreline (50 m in this study) located to either side of the overwater structure, as well as similar lengths of unaltered shoreline at the reference site.

During each 20-min observation period, all taxa and numbers of birds and marine mammals observed within the station boundaries (from shore to maximum viewing distance seaward) are counted with the aid of binoculars, and recorded over five successive scans at 5-min intervals (0 min, 5 min, 10 min,15 min, and 20 min). To account for possible redundant counts of the same subjects, the mean number of individuals recorded per count is calculated for each 20-min observation period. General behavior (e.g., diving, foraging, perching) should be recorded, as well as qualitative observations of unusual or noteworthy marine mammal and/or bird activity. All successful predation events on fishes are to be noted, with attempts made to verify fish prey species.

Observation times should be stratified over time of day to maximize the likelihood of differences in diel activity (day and crepuscular periods) by particular species. Based on the findings of our study, additional effort should be directed at examining bird and mammal predation near overwater structures at night, especially relative to artificial lighting. Tide status (ebb/flood) and height, general weather and water characteristics, and human activity should also be noted during each observation event. Chi-square analysis can be used to test hypotheses of distribution between location and over time.

Fishes

Quantitative and repeatable estimates of fish density and behavior can be obtained using standardized SCUBA and snorkel transects. SCUBA transects involve divers recording observations along measured, underwater "strip" transects on the species, size, activity, and other characteristics of demersal (bottom-associated) fishes. This technique is generally nondisruptive and is adaptable to a variety of environmental conditions, diel phases (e.g., day and night), and human activity windows (e.g., ferry departures and arrivals). In our experience, fish densities were higher during night SCUBA surveys at the Mukilteo ferry terminal (see report results).

Semipermanent strip transects are established along the length of the overwater structure by anchoring marked lead lines to the bottom. Transects are located perpendicular to shore at both the overwater structure and "unaltered" reference areas with similar depth contours. Each "strip" or line transect should be standardized in length based on the length of the terminal structure, and assigned a letter/number designator for subsequent survey identification. The location and spacing of transects should be designed to estimate fish utilization directly under the overwater structure, at its edges, and on its periphery (e.g., 10 m from either edge).

Once the transects are established, observational data are then systematically recorded at selected intervals (e.g., 5-m intervals: 0-5 m, 5-10 m, etc.). Divers record all fishes observed at a fixed distance (based on visibility; 1-m in this study) to either side of the transect, enabling quantitative estimates of fish density. Strip transect observations can either be made by two divers independently covering the entire transect width, or two divers each making simultaneous observations along each side of the transect line. True replicate sampling should involve repeated surveys of the transect. Video and still photography should also used if possible to verify fish observations and the structural attributes of the overwater structure. Rapid visual assessments using SCUBA should also be conducted to collect supplemental observational data in areas that are not systematically surveyed with the transect method.

Snorkel surveys may also be conducted in a manner similar to those described for SCUBA methods to document the presence of potential water-column fish predators. Relative abundance and behavioral observations of salmon fry, which are often associated with near-surface waters, may also be conducted with this method, although water clarity may impact effectiveness.

Potential Fish Predator / Salmon Fry Abundance

In addition to SCUBA and snorkel transects, a variety of capture methods may be used to estimate the abundance and species composition of fish assemblages.

Beach Seine

Beach seining can be used to gather data on the species composition and relative abundance of fish associated with the edges of overwater structures, although the structural complexity of these habitats may inhibit sampling underneath these structures. A standard 37-m by 2-m Puget Sound floating beach seine (Simenstad et al. 1991), designed for capturing both sedentary and motile fish, is composed of 3-cm mesh with two 18-m-long wings that taper from 0.9 meters high at the ends to 2 m high where the wings attach to the central bag; the bag is 2 m high by 2.4 m wide by 2.3 m deep and made of 6-mm mesh. In this design, the top 2 m of the water column is sampled, which may affect perceptions about fish species (including salmon) assemblage composition.

A boat is generally used to facilitate setting the seine, which is deployed 30-m from and parallel to the shore, then pulled shoreward onto the beach (see Simenstad et al. 1991 for more details). In this configuration, it samples 520 m^2, although site-specific variables (i.e., slope, tidal stage, structures) may affect the area sampled. After each seine haul, species identity and number of fish species are quantified. All individuals are measured (standard or fork length) and weighed, although subsamples (generally at least 25 randomly selected individuals) may be taken of abundant species.

Enclosure Net Sampling

Enclosure net sampling can be used to assess the presence and abundance of fish in shallow water habitats; we refer to the methods used by Toft et al. (2003) along City of Seattle marine shorelines. Enclosure nets consist of a 60-m long, 4-m deep, 0.64-cm mesh net placed around temporarily fixed poles to corral a rectangular section of the shoreline. The poles are installed at low tide the day before net deployment so as to minimize disturbance at the time of sampling. The net is installed at high tide, with fish removed by small pole seine or dip nets as the tide recedes.

Sampling data provides per-unit-area and volume densities of juvenile salmon and other fish on each unit of shoreline that is sampled. Nets typically sample a 20-m square section of shoreline; volume is determined by measuring water depth at the poles when the net is set, assuming a steady slope from shore to the poles. Sampling typically takes place during spring tides to take advantage of higher tides.

WDFW Salmon Fry Index Area Surveys

Marine salmon fry abundance indices are collected by above-water observations at various locations within Puget Sound by WDFW. These spring surveys have been conducted since 1966 in some locations by WDFW biologists, who walk sections of the marine shoreline at favorable tides and estimate the numbers of salmon fry observed migrating along shallow nearshore waters. Biologists use polarized glasses to better observe these surface-oriented fry, and species identity is confirmed by periodic dipnet samples.

In the absence of existing WDFW data, similar qualitative visual surveys of salmon fry abundance can be conducted from shore to provide an indicator of presence/absence of juvenile salmon at each site and assist in verification of potential predation events. Fry behavior should also be noted relative to ferry terminal structures, operations, and measured light levels. Relative abundance of salmon fry (number/km) can be compared over time and across locations.

Behavioral Observation

Though standardized surveys provide a good deal of information on the behavior and movements of potential salmon predators, other technologies may need to be enlisted to observe behavior during low light and high turbidity conditions, or to document individual fish movement and residency patterns.

DIDSON (acoustic camera)

In low-light (e.g., night) or low-visibility situations, novel technologies like the DIDSON (Dual-frequency IDentification SONar) can capture near-video-quality images to ascertain the identity, abundance, and behavior of potential fish predators associated with overwater structures. The DIDSON, developed by engineers at the University of Washington Applied Physics Laboratory (see http://www.apl.washington.edu/ programs/DIDSON/DIDSON.html), uses multi-channel acoustic reflections to create images of juvenile salmon and their potential predators. In high frequency mode, all but the smallest targets (<63 mm at 12-m range, <16 mm at 3-m range) intercept multiple beams. The software can record and display images in real time, and at a 12-m range will do so at 7 frames per second (Belcher et al. 2001). Both structural details and fish can be observed at the same time on the same transmitted pulse (Moursund et al. 2002).

The DIDSON is deployed from a mount that can be swiveled and tilted by an operator aboard a vessel. Surveys involve the slow circumnavigation of overwater structures at a distance of 2 to 10 m, panning and tilting the camera to encompass most of the submerged structural dock elements. Survey locations are collected simultaneously using a Trimble differential global positioning system (DGPS), and stored with the DIDSON records during the survey. Data are displayed in real time on a monitor aboard the vessel, with data files saved to a notebook computer.

Tagging of Validated or Potential Predators

Tagging and recapturing individual fish has been one of the fundamental challenges of fisheries research. One of the best available methods for long-term tagging of individual fish is to use Passive Integrated Transponder (PIT) tags. In contrast to radio tags, which have a battery that eventually will cease to function, PIT tags contain a small computer chip that transmits its code only when induced by an external energy source. PIT tags are tiny identification chips, about the size of a grain of rice, which are injected into fish specimens for permanent identification. Tags are inserted into the body cavity with nearly 100% tag retention and high fish survival. The tag ("chip") is detected by means of a hand-held scanner. The scanner reads the tag's electromagnetic code and displays the tag's number. The tag does not require any

AC current. The scanners can be either portable, working on batteries, or require AC current. Some have the capability to store codes from many fish before they are downloaded to a computer; others simply display the code of the current reading without storage. With the use of PIT tags, researchers are better able to study the individual growth, reproduction, and survival of fish. The main disadvantage of using PIT tags is the lack of submersible detection equipment. Using current technology, the PIT tag can only be detected at a distance of up to 18 cm in water. Thus, PIT-tagged fish have to be recaptured. This method would allow researchers to evaluate growth, survival, and the site fidelity of individual predators to a particular ferry terminal. It would not, however, enable researchers to evaluate real-time predator movement patterns.

An alternative, but shorter-term and more expensive, method would be to affix radio transmitters to predators. The radio transmitter emits a unique signal that is picked up by a hand-held antenna aboard a vessel. The signal becomes stronger as the researcher gets closer to the tagged fish. The advantages of this methodology are that it would allow for real-time tracking of predator movements, and it doesn't require the researchers to recapture the fish.

Fish Predator Capture

Besides the beach seine and enclosure net methods outlined above, other means may be used to capture large fish predators for stomach content analyses or for tagging and tracking. Hook-and-line fishing from a boat or from shore can be particularly effective for nonlethal capture of fishes, especially if one can enlist the efforts of local recreational fishermen. Hook-and-line sampling is generally conducted in the vicinity of the overwater structure of interest using live bait or artificial lures that imitate small forage fish. In addition, a speargun can be used by divers to lethally collect some individuals.

Stomach Content Analysis

Two approaches may be used for obtaining the stomach contents (prey) of selected fish species: gastric lavage and stomach dissection. Gastric lavage offers a nonlethal approach to stomach content collection, and is preferred in most cases. Live-captured fish are anesthetized in a solution of tricaine methanesulfonate (MS-222), and a tube, syringe, or nozzle is inserted into their stomach. Pumped seawater is then used to flush stomach contents into a collecting sieve or container (Giles 1980). After pumping, fish are placed in an oxygenated bath of fresh seawater and then released upon recovery. Stomach dissection is generally conducted on fish that are speared or collected (kept) by recreational fishermen. Contents from the foreguts are retained. In all cases, stomach contents are preserved in 70% ethanol and later examined in the laboratory.

The recommended method for fish diet composition is an Index of Relative Importance (IRI), which is calculated for each food item "i":

$$IRI_i = \%FO\ (\%NC_i + \%GC_i)$$

where %FO is the percentage of frequency of occurrence, %NC is the percentage of numerical composition, and %GC is the percentage of gravimetric/volumetric composition (Simenstad et al. 1991, pp. 91-92). Because the resulting numerical values for the IRI depend greatly upon sample size, the relative importance is often converted to the percentage of the total IRI (%IRI).

Associated Environmental Variables

Light Levels

Light measurements are recorded using LI-COR LI-193SA spherical quantum sensors and a LI-250 light meter. The sensors measure photosynthetically active radiation, or PAR, which is the spectrum of light between 400 and 700 nm that supports photosynthetic production and growth. Units are μmol m^{-2} s^{-1}. The spherical quantum sensor is waterproof for use in aquatic environments, and collects light from all directions. Individual PAR readings are averages of instantaneous readings over a 15-sec interval.

Ambient light should be measured just above the water's surface and at a depth of approximately 0.1 m, where most juvenile salmon are observed. Transects under the structure may be used to measure light levels at selected intervals (1 m to 10 m), and light attenuation may be measured by taking vertical readings at selected intervals in the water column. The presence or absence of juvenile salmonids should also be noted when light measurements are recorded.

Salmon Prey Availability-Epibenthic Plankters

The following section has been extracted and modified from the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991, pp. 69-74) and Cordell et al. (1994). Epibenthic plankters are very small macrofaunal or meiofaunal organisms, which live in the interface between the bottom substrate and the water column, either in the very surface layer or in the benthic boundary layer. Epibenthic plankters include predominantly harpacticoid copepods, gammarid amphipods, cumaceans, and isopods.

The historically recommended sampling method is to use a portable, hand-held epibenthic suction pump, in which a sampling cylinder with fine mesh (typically 0.130 mm) screened ports is very slowly lowered to enclose an area of the bottom (179 cm^2) and a segment of the adjoining benthic boundary layer (Simenstad et al. 1991). The pumped water and epibenthic plankters are captured and screened on a 0.130-mm mesh sieve. More recent comparisons (Cordell et al. 1994) have suggested cores that sample an area of 0.0024 m^2 to a depth of 10 cm are equally effective. Each sample is rinsed from the sieve into a labeled jar or plastic vial and preserved in 5% buffered formalin. The label contains the date, time, sample location, transect number and elevation, and replicate number. After 7 to 10 days in buffered formalin, the sample should be transferred to an alcohol solution, usually 45% isopropanol or 70% ethanol.

In the laboratory, epibenthic plankters should be sorted and identified under a stereo microscope to the lowest possible taxa, preferably to species. Density and standing stock of each taxa should be expressed, respectively, as the number and biomass per unit area (e.g., no. m^{-2}, g wet m^{-2}) or volume (e.g., no m^{-3}, g wet m^{-3}) of the habitat.

Epibenthic plankters should be sampled biweekly from March through June. In lieu of statistical predetermination using pilot studies or historical data, the sample size should be (n) = 15 in intertidal habitats distributed randomly within uniform microhabitats along tidal elevation strata (transects). Optimum tidal elevation is 0.0 ft (MLLW) with additional transects recommended at +2.0 ft, -2.0 ft, +4.0 ft, and -4.0 ft in that relative order of priority.

Salmon Prey Availability-Pelagic Zooplankton

The following section has been extracted and modified from the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991, pp. 75-79). Pelagic zooplankton are those organisms that occupy the water column and are passive or only weakly swimming. Except for larvaceans and fish larvae, these are exclusively crustaceans, including predominantly calanoid and cyclopoid copepods, as well as several decapods (larvae), euphausiids, hyperiid amphipods, and cladocerans.

The recommended sampling method is to use paired nets in a "bongo" configuration towed from an outboard boat. The most common bongo net configuration uses a 60-cm diameter mouth opening equipped with 0.333-mm or 0.500-mm mesh nets funneling into two separate cod-ends. Often, one net of each mesh size is used to maximize the efficiency of each mesh type for zooplankton (0.333-mm) versus ichthyoplankton (fish larvae) (0.500-mm). Two flow meters should be installed inside the net openings to provide precise sampling volumes. Sampling should be conducted in the surface layer, as many juvenile salmon prey taxa are found concentrated in this microhabitat.

In the field, each sample is rinsed from the cod-end into a labeled jar or plastic vial and preserved in 5% buffered formalin. The label contains the date, time, sample location, net mesh size, and replicate number. After 7 to 10 days in buffered formalin, the sample should be transferred to an alcohol solution, usually 45% isopropanol or 70% ethanol. In the laboratory, pelagic zooplankton should be sorted and identified under a stereo microscope to the lowest possible taxa, preferably to species. Density and standing stock of each taxa should be expressed, respectively, as the number and biomass per unit area (e.g., no. m^{-2}, g wet m^{-2}) or volume (e.g., no m^{-3}, g wet m^{-3}) of the habitat.

Pelagic zooplankton should be sampled monthly from March to August. In lieu of statistical predetermination using pilot study or historical data, the sample size (n) = 5 standardized tows at, or just below, the surface. Optimum sampling times are associated with dawn and dusk periods, when vertical migrators are nearest the surface layer.

Salmon Prey Availability-Neuston

The following section has been extracted and modified from the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991, pp. 80-82). Neustonic and drift invertebrates are a distinct assemblage of organisms comprised of adult and larval insects that are deposited onto or emerge into the surface layer, and certain other aquatic insects and crustaceans that spend most of their time in the surface layer of the water column. The recommended sampling method is to use a neuston net equipped with 0.253-mm mesh net and a cod-end for collecting the sample. A neuston net is essentially a modified plankton net that is designed to float on the surface of the water with its mouth opening (0.025 m^2) sampling just the water surface layer. Usually the neuston net is hand towed, held in an active current, or towed outboard of a small boat. Maintenance of a constant depth (position at which the net sits in the water) or simultaneous measurements of current velocity are required to determine the sampling volume.

In the field, each sample is rinsed from the cod-end into a labeled jar or plastic vial and preserved in 5% buffered formalin. The label contains the date, time, sample location, and replicate number. After 7 to 10 days in buffered formalin, the sample should be transferred to an alcohol solution, usually 45% isopropanol or 70% ethanol. In the laboratory, neustonic and drift invertebrates are sorted and identified under a stereo microscope to the lowest possible taxa, preferably to species. Density and standing stock of each taxa should be expressed, respectively, as the number and biomass per unit area (e.g., no. m^{-2}, g wet m^{-2}) or volume (e.g., no m^{-3}, g wet m^{-3}) of the habitat.

Neustonic and drift invertebrates should be sampled monthly, during discrete freshwater and tidal flow phases. In lieu of statistical predetermination using pilot study or historical data, the sample size should be (n) = 5.

Sampling Design

In all cases, we stress the importance of simultaneously sampling at a paired reference site (without overwater structures) to provide a local basis of comparison. Reference sites should be in fairly close proximity to the study site, with similar physical characteristics (e.g., substrate, beach slope, water properties).

The following discussion is modified from the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991). The distribution of physical, chemical, and biological attributes of the nearshore habitats where overwater structures are located are complex over space and time. Thus, sampling the habitats (and predators) around ferry terminals will be necessary, as most habitats are too complex to monitor in their entirety. Sampling design will necessarily vary from structure to structure, because habitats and the corresponding biological community at each area will vary.

An adequate sampling design always incorporates three principal components of scientific quality: 1) *repeatability* in terms of the potential to be exactly repeated, 2) *reliability* as the quality to sustain scientific confidence, and 3) *validity,* because it is based on precedence and evidence.

Proper sampling requires considerable time and effort. Thus the dilemma: how do you balance sampling rigor with the resources at hand? How do you distribute the sampling effort and intensity to minimize the damage that destructive methods (e.g., spear fishing to collect predators) will cause at the site?

The Estuarine Habitat Assessment Protocol (Simenstad et al. 1991) recommends considering five "rules" in developing a sampling design:

- Rule 1: Know the habitat you are proposing to sample
- Rule 2: Know the sampling response (attribute) you are monitoring
- Rule 3: Select samples using a consistent standardized technique
- Rule 4: Clearly specify your sampling strata
- Rule 5: Determine the optimum sampling size statistically, given the purposes and resources of the study and considering the potential damage to the site with excessive destructive sampling.

One cautionary note: Prior to initiating sampling at any ferry terminal, we cannot overemphasize the importance of coordinating with WSF Operations and the terminal agent on duty. Depending on the nature of the sampling and the proximity to where ferries are departing or arriving, WSF will issue the researchers a hand-held VHF radio. This allows frequent and direct communication between the terminal agent and the researchers to ensure the safety of everyone involved.

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