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Statistical Power of Volunteer Monitoring Protocols

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Abstract

Citizens are concerned about the declining quality of water resources and are motivated as individuals and groups to participate in monitoring activities. Unfortunately, citizen volunteers often lack specific, scientific knowledge and training that would make their efforts more relevant and effective. In contrast, managers and policymakers are often reluctant to use volunteer data because they are unsure of its quality. We trained volunteers to collect benthic macroinvertebrates from seven streams using the same protocol as the biologists working for the local jurisdiction. Components of variance derived from ANOVA detected no significant differences between volunteer and professional field crews.

We combined metrics into a multimetric index and calculated its statistical power to detect differences in stream condition. The statistical power of the index improved by only 13% when we used professional data instead of volunteer data. We conclude that volunteer monitoring can extend our knowledge and understanding of the condition of local streams. In addition, the multimetric index has the statistical precision and reliability necessary to manage and protect rivers and streams.

Introduction

Citizen interest in issues related to water resources has increased dramatically in the last decade and many government programs now include volunteer data in their official reports (Kerr, et al., 1994; Mattson, et al., 1994; Firehock & West, 1995; Lathrop & Markowitz, 1995; Beauchene, 1997; Carlson, 1997; Karr, Allan & Benke, 1999). In the state of Washington, most of the approximately 11,000 volunteers are involved in surface water monitoring and protection. As of 1996, the Washington State Department of Ecology was able to develop reliable information for only four percent of Washington's surface waters (www.wa.gov/ecology/wq/wow/wdw/survey.html). Additional monitoring might be accomplished by training volunteers to collect the type of data needed by the state to monitor streams; however, many managers and scientists question the quality and reliability of volunteer data. Our goal was to provide the scientific


photo courtesy of the Bellevue Stream Team

tools of biological assessment to citizen volunteers and then compare their efforts with those of professional biologists using a formal statistical framework. Using statistical power analysis, we compared volunteer and professional protocols so that resource managers would have an objective measure of the reliability of volunteer assessments.

This project builds on other studies and uses the biological attributes, or metrics, that have proven to be reliable indicators of human disturbance for Pacific Northwest streams (Kleindl, 1995; Fore, Karr & Wisseman, 1996; May et al., 1997; Karr, 1998). Biological metrics such as mayfly taxa richness, percentage of predators, and percentage of tolerant organisms are combined into an index by transforming the metric values to a score of 5 (indicating a value similar to, or deviating slightly from, that observed in a minimally disturbed site), 3 (moderate deviation), or 1 (strong deviation; Karr et al., 1986; Davis and Simon, 1995; Barbour et al., 1998). The sum of metric scores provides an overall index value for each site that is then used to monitor and manage surface waters under the Clean Water Act (Ransel, 1995; Southerland & Stribling, 1995). For this study, we used multimetric indexes derived from volunteer and professional protocols to evaluate volunteer efforts in the field and the lab.

Table 1. Biological metrics for invertebrates and their response to human disturbance. Metric used in the volunteer index (VV) and the family-level index (VP.family) are marked by an asterisk.

Biological metric	Response
Taxa richness and composition	
Total number of taxa *	Decrease
Number of Ephemeroptera taxa *	Decrease
Number of Plecoptera taxa *	Decrease
Number of Trichoptera taxa *	Decrease
Number of long-lived taxa	Decrease
Tolerance	
Number of intolerant taxa	Decrease
% of individuals in tolerant taxa	Increase
Feeding ecology	
% of predator individuals	Decrease
Number of clinger taxa	Decrease
Population attributes	
% dominance (3 taxa) *	Increase

Materials and Methods

Study site descriptions

Streams sites were located in the Seattle area (King County) of the Puget Sound basin. Seven stream sites were selected to represent a gradient from minimally disturbed to extremely degraded. All seven watersheds had been logged extensively; land use ranged from scattered dwellings and farms (minimal disturbance) to highly developed urban landscapes. Three of the watersheds were completely developed (Pipers, Thornton and Kelsey) with the only green space located in city parks. Two watersheds (Soos and Evans) had very little native vegetation left and were mostly developed as suburbs. Two watersheds (Rock and Holder) had a high forest cover, though not the original vegetation. Population density and development were relatively low in the Rock and Holder watersheds but were rapidly increasing.

Field protocol

Volunteers and professional biologists used exactly the same sampling protocol and equipment to sample macroinvertebrates. Six sites were sampled by both crews, Pipers was only sampled by volunteers. Two crews, volunteer and professional, collected samples within approximately one month of each other. The second sample site was located upstream of the first to avoid any disturbance caused by the first crew's sampling. One site was an exception: both crews sampled the same location on Evans Creek.

Lab protocols

In the lab, volunteers first sorted and counted invertebrates based on physical features such as gill shape and placement in mayflies. From their data, we calculated five metrics (Table 1). Next, volunteer and professional samples were sent to a professional taxonomic lab for more complete identification. The professional lab identified most insects to species, genus for chironomids, and order or higher for non-insects. Knowing the taxonomic identity made it possible to calculate five more metrics (Table 1).

Data analysis

Four sets of data were used to evaluate the volunteers' work: (1) volunteers collected field samples and volunteers processed the data in the lab (VV); (2) professional biologists collected field samples and a professional taxonomist identified them (PP); (3) volunteer field samples were identified by a professional taxonomist (VP); and (4) the VP data set was modified so that taxa were identified exactly to the taxonomic level of family (VP.family). We compared volunteer and professional results in order to answer three questions: (1) How did volunteer lab methods compare with taxonomic identification by a professional lab? (2) For the same professional lab protocol, did field methods differ for volunteers and professionals? (3) What is the relative statistical precision of the four different protocols?

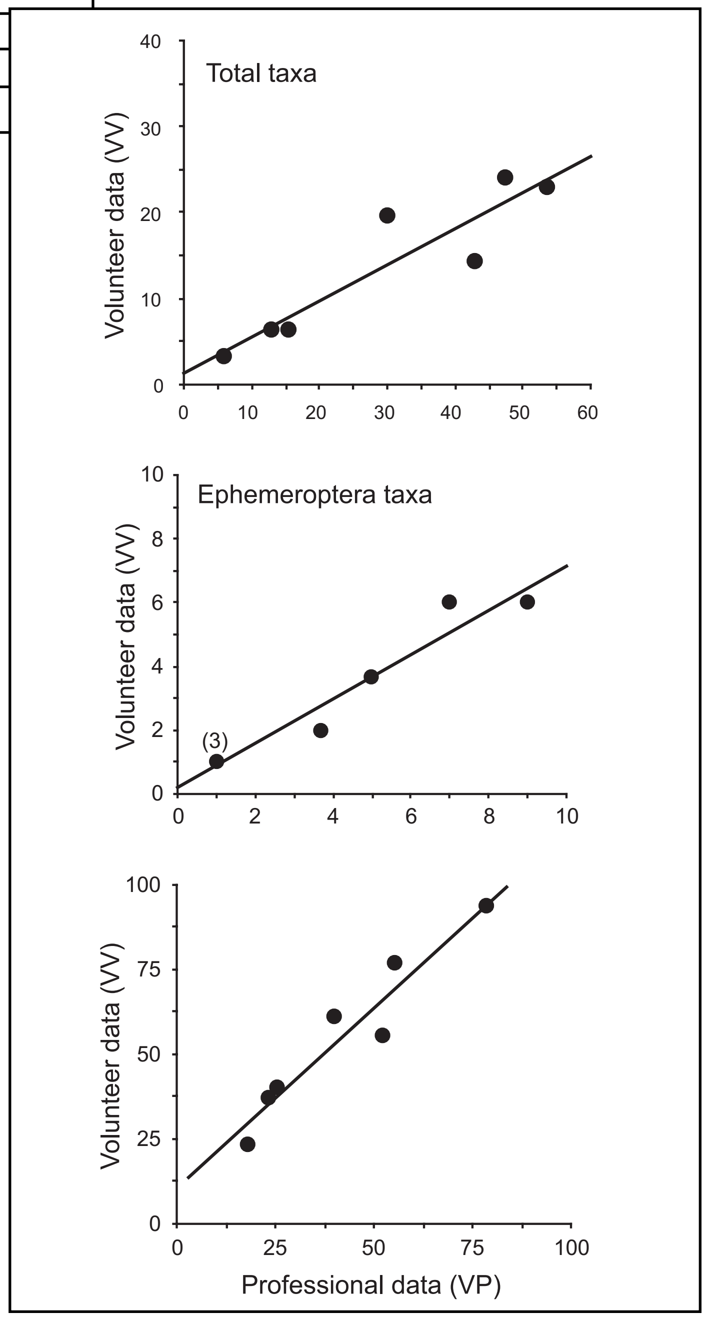

Figure 1. Volunteer metrics based on morphological sorting (VV) of similar taxa were highly correlated

(p << 0.01) with professional metrics based on species-level taxonomic analysis (VP).

First, we compared metric values derived from volunteer and professional lab identification. Although the professional taxonomist was expected to identify more taxa, a strong correlation between volunteer and professional metrics indicates that either method would rank sites similarly. Second, we compared field methods using variance estimates derived from ANOVA. We estimated the relative contributions of site differences, crew differences, and measurement error to the total variability of index scores. Third, we calculated the minimum detectable difference (MDD) for index scores based on a two-sample t-test (Zar, 1984) with aα0.05 and ß=0.20 (Peterman 1990) for a 2-sided test. Thus, we were asking, what size difference between index scores do we have an 80% chance of detecting for a specified a α0.05? We divided the possible range of the index (20 for the volunteer and 40 for the professional index) by the MDD to obtain the number of distinct categories of biotic integrity each index could detect.

Results

Metrics calculated by volunteers (VV) were strongly correlated with metrics calculated from professional taxonomic analysis (VP) (Figure 1) even though volunteers identified many fewer taxa. Volunteers missed many of the Diptera, including all the Chironomidae, and some smaller Trichoptera; they also had difficulty distinguishing between Diptera. Nonetheless, when metrics were scored and combined into an index, the indexes were strongly correlated even though the volunteer index had fewer metrics and, thus, a smaller range.

For the comparison of field methods, we held lab method constant by using professional lab analysis for both volunteer (VP) and professional (PP) field protocols. The variability due to crew differences (professional vs. volunteer) contributed 0% to the overall variability; thus, we conclude that there was no difference in field collection methods. In contrast, most of the variability in index scores (80% and 90%) was due to differences across sites, i.e., human disturbance. Only 10% of the variability was due to measurement error which included differences in sampling location within a reach or differences related to time of day or weather.

Index scores calculated from professional lab analysis of volunteer (VP) and professional field data (PP) were also strongly correlated (Figure 2). The volunteer index score (VP) was much higher for Evans. Evans was the only site where the identical location was sampled by both volunteer and professional crews. Volunteers sampled first and removed over 6,500 individuals and disturbed the stream and banks around the sample site. The PP index was lower because all of the taxa richness metrics were lower. Lower taxa richness metrics supported the idea that the professional sample was biased by the previous volunteer sampling.

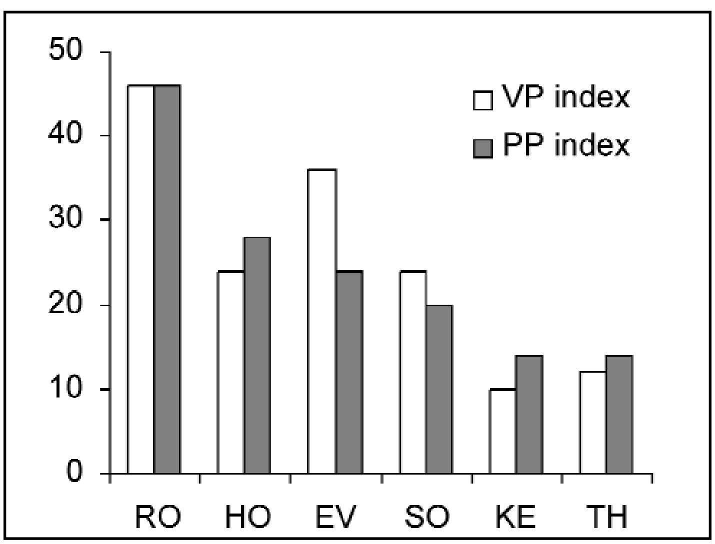

Figure 2. Index scores based on volunteer field methods (VP) and professional field methods (PP) were highly correlated with each other (Pearsons r=0.90, $p < 0.01$; n=6) and with disturbance (Spearmans r=0.84, $p < 0.05$; r=0.99, $p << 0.01$).

When we compared statistical precision of the various protocols, we found that a multimetric index based on volunteer data only (VV) could distinguish 4 categories of biotic integrity, exactly the same number as for the professional analysis at the family level (VP.family). For these protocols, the index ranged from 5 to 25; thus a change in index score of 5 or more points probably represents a real biological change. The protocol based on full taxonomic identification (VP) could detect 4.5 categories of biotic integrity. The gain in precision from a professional taxonomic analysis was thus quite small: precision increased only 13%.

The actual protocol used by King County averages the metric values for the three replicates collected at each site and calculates a single B-IBI score. Although the volunteers used the professional protocol for sampling, that protocol only yields one sample of three replicates for each site. For most of our analyses, we kept the three replicates separate because replicates are required to calculate statistical power. After we determined that there were no differences in field methods due to field crew differences, we felt confident using the samples made by professional and volunteer crews as field replicates of the full protocol. In this case, rather than using the replicates to calculate MDD, we assumed no difference due to crews and used the repeat visits as replicates to estimate MDD. Because it represented a greater sampling effort, the full protocol was more precise. The index could detect 5.8 categories based on a two-sample t-test design.

Discussion

The purpose of this study was to determine if volunteers could collect high quality data relevant to the management of urban watersheds. We compared the volunteer results with assessments based on professional data at two points in the analysis. We compared (1) volunteer and professional lab methods based on the same field collection (VV to VP), and (2) volunteer vs. professional field collection methods for the same (professional) lab analysis (VP to PP). We found no differences between the field methods of professional and volunteer crews. For lab methods, professional taxonomic analysis yielded more precise identification of taxa, but precision of the assessment increased only slightly, by 13%.

The role of statistical power

Statistical power is defined as the probability of detecting a difference, or change, when a difference truly exists (Peterman, 1990). When monitoring programs collect measurements that have a large amount of error associated with them or when they base comparisons on an inefficient experimental design (Steidl, Hayes, & Schauber, 1997; Thomas, 1997), the resulting low statistical power means that changes in resource condition will be very difficult to detect. A monitoring program that can only detect extreme changes in a resource may not sound an alarm until after a resource is irreparably damaged (Peterman & M'Gonigle, 1992; Dayton, 1998). Such a program is unlikely to provide adequate protection. For these reasons, the success of any monitoring program relies on the statistical precision of the measurement tools used to assess resource condition. This study showed that the statistical precision of volunteer assessments was comparable to assessments based on professional methods.

The role of volunteers

Biological monitoring involves more than just collecting samples; there are several steps involved in putting a robust biological monitoring program in place (Yoder & Rankin, 1995; Maher, Cullen & Norris, 1994). The role that volunteers play depends on the purpose of the project and the questions being asked (Mattson et al., 1994; Carlson, 1997). This study showed that volunteers can provide meaningful field and laboratory support for monitoring of invertebrates as indicators of the condition of wadable rivers and streams.

Volunteer groups may be unable to pay for professional taxonomic analysis (~$250 per site for this protocol) but are often willing to spend their time to learn about local streams and understand their biology. For a local stream of concern, volunteers can monitor the stream and watch for changes. Each year after they have evaluated their samples and made an assessment, volunteers could archive their samples. If they observe a change and their assessment is contested, they can send their archived samples to a professional taxonomist for a more complete analysis.

Conclusions

In order to protect our remaining resources, we need to assess their condition reliably and regularly. The cost of sample collection can limit the number of sites monitored each year. Volunteer data collection can extend our knowledge and understanding of resource condition and supplement the information available to managers. This project demonstrated that citizen volunteers are capable of collecting meaningful data, and their assessments are comparable to those based on professional data.

Editor s Notes

A longer version of this article will appear in an upcoming issue of the *Journal of Freshwater Biology*.

Acknowledgments

Though they do not appear as co-authors, the many volunteers involved in this project made this study possible. Special recognition goes to J. Hobbs and C. Schulze. We would also like to recognize the work of J. Fairchild, D. Frostholm, J. Jackman, A. Kimpo, N. and L. Malmgren, K.C., J. and K. Miedema, S. Morley, B. D. and E. Nelson, J. and K. Nelson, E. O'Connor, R. Oslin, B. Rockenbeck, S. Still, P. Szewczykowski, L. and J. Theriault, J. Wall, and M. Windus. Special thanks to J. Anderson, C. Anderson, and J. White for project support. Funding was provided by a King County Water Quality Block Grant (#421347).

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Tracking Gray Whales in Puget Sound

by John Calambokidis, Cascadia Research

For more than a decade Cascadia Research has studied the gray whales that come into Washington waters to feed in the spring, summer, and fall. The research was initially motivated by concerns about the role of pollutants in gray whale deaths in the 1980s. Each year Cascadia:

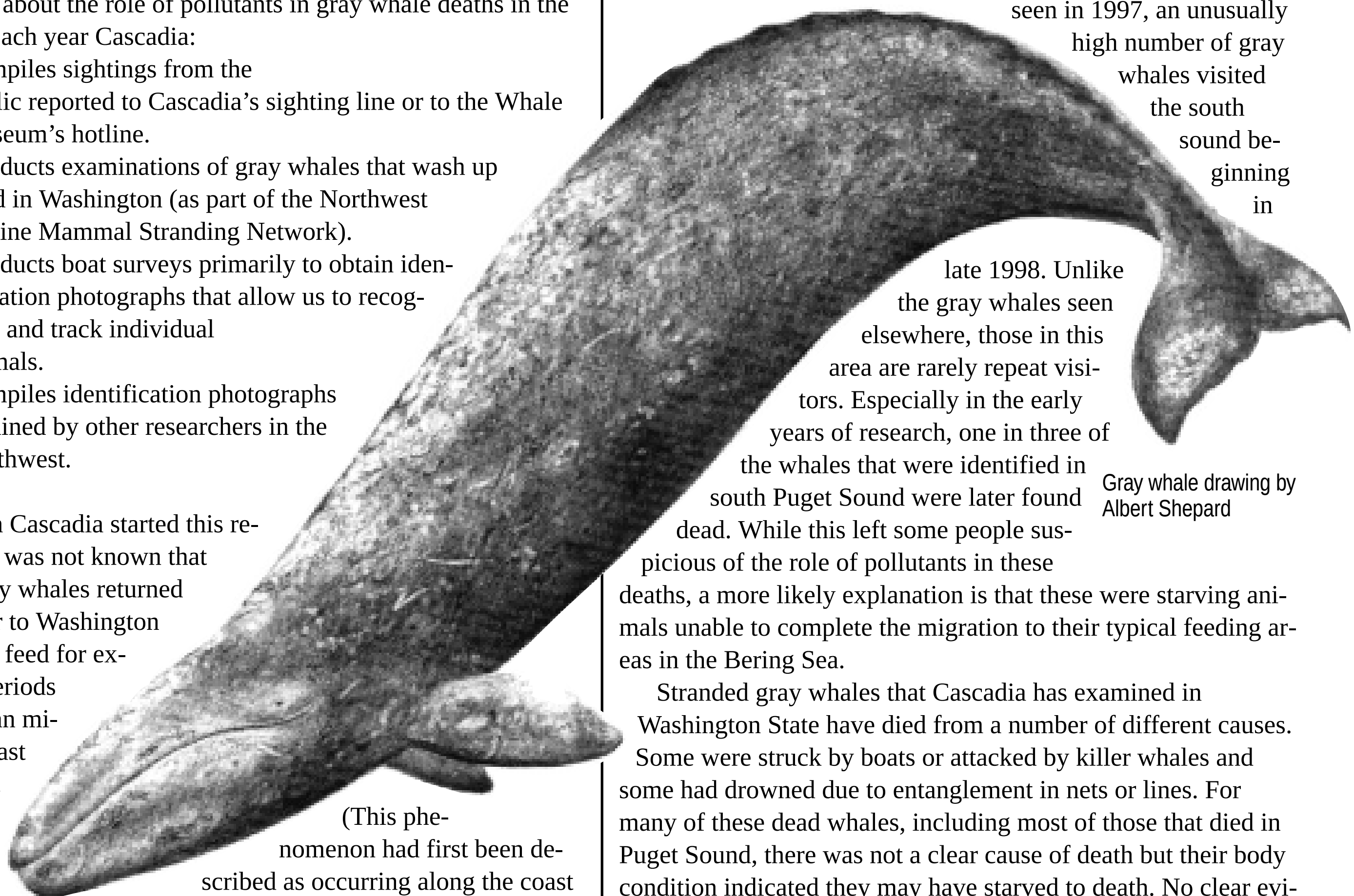
- Compiles sightings from the public reported to Cascadia's sighting line or to the Whale Museum's hotline.
- Conducts examinations of gray whales that wash up dead in Washington (as part of the Northwest Marine Mammal Stranding Network).
- Conducts boat surveys primarily to obtain identification photographs that allow us to recognize and track individual animals.
- Compiles identification photographs obtained by other researchers in the Northwest.

When Cascadia started this research, it was not known that some gray whales returned each year to Washington waters to feed for extended periods rather than migrating past the coast. (This phenomenon had first been described as occurring along the coast of British Columbia). Close to 200 of these "seasonal resident" whales have been identified in Washington State. The use of the term "resident" for these whales is somewhat of a misnomer because they still migrate south each winter.

Most of the "seasonal resident" gray whales have been identified feeding off the northern Washington outer coast and in the Strait of Juan de Fuca. These animals are typically seen from spring through fall. In 1998, for the first time, a network of researchers collaborated with Cascadia in obtaining identification photographs of gray whales from northern California to Southeast Alaska. Analysis of these photographs is currently underway. However, initial analysis indicates that these whales utilize this entire region, showing some local site fidelity but switching locations in response to prey availability. One gray whale seen typically off the Washington coast for many years but not in 1998, was found feeding near Sitka in Southeast Alaska in 1998.

Another group of gray whales returns each spring to the Whidbey Island area. They are often seen feeding on dense ghost shrimp beds in Saratoga Passage and Port Susan between March and May. Five of these whales have been seen most years since 1990 (when Cascadia began surveying this area). One surprising fact is that they leave after only a few months and move on to unknown locations. They have not been sighted off the Washington or British Columbian outer coast. In the first five years of study, the group tended to leave earlier in the season each successive year. One possible explanation is that ghost shrimp are longer lived than most gray whale prey and thus, the whales moved on after depleting the ghost shrimp.

The number of gray whales coming into southern Puget Sound has been variable from year to year. Although few were seen in 1997, an unusually high number of gray whales visited the south sound beginning in late 1998. Unlike the gray whales seen elsewhere, those in this area are rarely repeat visitors. Especially in the early years of research, one in three of the whales that were identified in south Puget Sound were later found dead. While this left some people suspicious of the role of pollutants in these deaths, a more likely explanation is that these were starving animals unable to complete the migration to their typical feeding areas in the Bering Sea.



Gray whale drawing by Albert Shepard

Stranded gray whales that Cascadia has examined in Washington State have died from a number of different causes. Some were struck by boats or attacked by killer whales and some had drowned due to entanglement in nets or lines. For many of these dead whales, including most of those that died in Puget Sound, there was not a clear cause of death but their body condition indicated they may have starved to death. No clear evidence indicates that any of the whales died from pollutants, even though some accounts in the 1980s suggested this. The Environmental Conservation Division of the National Marine Fisheries Service has been testing gray whale tissue for contaminant levels. Levels of most contaminants have been much lower than are found in many other species of marine mammals.

There is more concern about potential mortality of gray whales this year due to reports of high numbers of gray whales that died when the population was at its breeding grounds in Baja, Mexico. This is an area where a proposed salt factory near the lagoons has heightened concern about threats to gray whales. Also, although the Makah Tribe did not kill a whale in 1998, attempts to hunt are poised to resume and this is certain to also raise concerns about impacts to gray whales. Given the current gray whale population of more than 26,000 however, the number of whales that have died or the number to be hunted do not appear to pose a threat to the population.

1999 promises to be an interesting year for gray whale research. There have already been five strandings, and initial surveys in April found more than 20 gray whales in Puget Sound. There are a number of ways people can help or participate in the research:

- If you see a gray whale in Puget Sound or inside waters, call Cascadia to report the sighting (1-800-747-7329)
- If you are in a boat, avoid disturbing the whale by maintaining a slow steady speed, stay behind and to the side of the whale (do not get ahead), and keep at least 100 yards away
- If you want to read more about Cascadia's gray whale research, contribute to their research effort, or adopt a gray whale, visit their web site (www.CascadiaResearch.org).

Editor s Note:

John Calambokidis and Cascadia Research spent the months of April and May dealing with the unprecendented number of gray whales in Puget Sound this spring, including 6 dead whales in the second half of April. The recent sightings and mortalities have resulted in heightened concern and interest on the part of natural resource agencies, the public and the media. Calambokidis has been conducting surveys, necropsies of dead whales, answering questions from the public and the media, coordinating with agencies, and dealing with the logistics of disposing and moving gray whales as part of the effort to try to determine the cause for the unusually high number of sightings and mortalities.

Cascadia Research is a non-profit research organization founded in 1979 and based in Olympia, Washington, that focuses on research of endangered marine mammals and human impacts on marine mammals. Access to their reports (including a full text version of the primary report on which this article is based) is available through the website. Their gray whale research is largely a volunteer effort although they receive some important support from the National Marine Mammal Laboratory and the Washington Department of Fish and Wildlife.

Non-indigenous Species in Puget Sound: Preliminary Results of the First Systematic Survey by the Puget Sound Expedition

By Betty Bookheim and Helen Berry, Nearshore Habitat Program, Washington State Department of Natural Resources

Awareness of the threat of non-indigenous species is becoming widespread. These species have been introduced to Washington's marine waters through shipping, aquaculture, and other human activities. In Puget Sound, current research into non-indigenous species has focused on tracking and controlling several species of concern, including the cordgrass *Spartina* species and the green crab *Carcinas maenas*. These species of concern and their undesirable effects on the ecosystem are comparatively well understood. In contrast, most non-indigenous species in Puget Sound are neither recognized nor known. Once recognized, the impacts of an introduced species are difficult to predict. While the impacts of many non-indigenous species can be unnoticed, others can be catastrophic. For example, an introduced Atlantic shipworm bored its way through the entire maritime infrastructure—wharves, piers and ferry slips—causing more than $2 billion in damage over a two-year period in northern San Francisco Bay. Although they are often more difficult to assess, the ecological effects of non-indigenous species can be more severe than the economic effects.

Sampling Techniques

To address the paucity of baseline information in Puget Sound, the Nearshore Habitat Program of the Washington Department of Natural Resources (WDNR) jointly organized the Puget Sound Expedition with the University of Washington (UW) and the San Francisco Estuary Institute. The cooperative project brought together 19 experts for the first systematic survey for marine non-indigenous species in the region. From September 8 - 16, 1998, scientists rapidly and inexpensively assessed the patterns of geographic distribution and relative abundance of non-indigenous species. The team sampled 25 sites that represent a range of environmental and anthropogenic conditions in the state's inland marine waters between Blaine and Shelton. (Figure 1) We adopted methods used by previous San Francisco Expeditions (Cohen and Carlton, 1995) that focused primarily on sampling floating docks and associated benthic habitats. These areas can be easily accessed, provide an obvious pathway for introduction, and provide a protected location for larval settlement and survival. In addition, nearby intertidal sites were opportunistically sampled.

The survey focused on invertebrate and algae species which are common organisms in a fouling community. Dock-fouling organisms were sampled by a variety of simple manual techniques. Sampling tools included hand scrapers, sieves, a long-handled scraper with a fine steel mesh net, and a long-handled (2.4 meter pole) net with 1 mm mesh. From each dock site we obtained a one-liter representative voucher collection, and additional samples of material of interest. The samples were kept on ice, on days with laboratory time scheduled soon after the field work, and preserved in formalin or alcohol on other days. A sample of live bay mussels (*Mytilus* spp.) was collected from each site

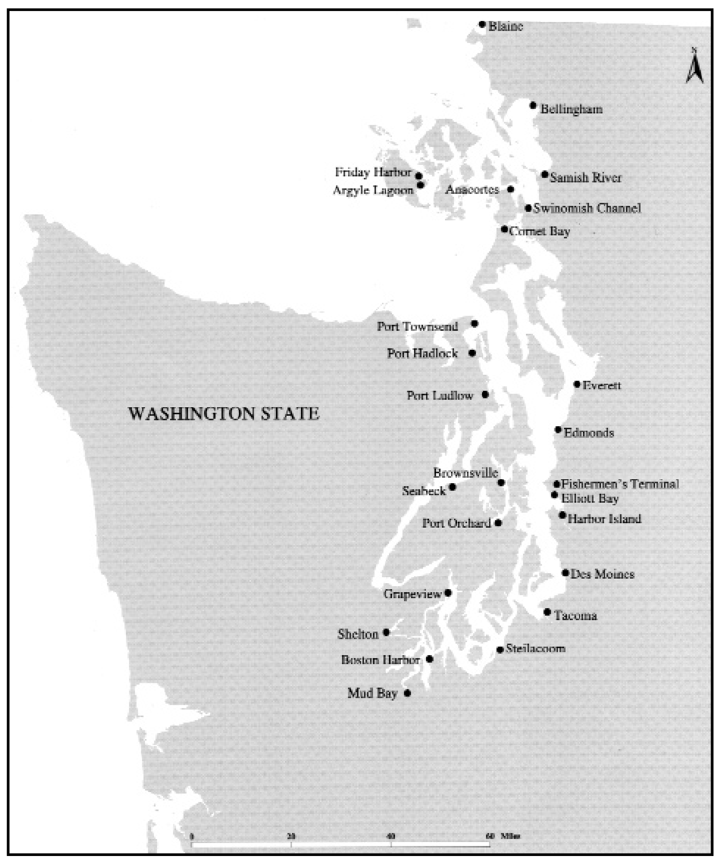


Figure 1. Map of Study sites

where they were present and frozen to preserve them for subsequent genetic analysis.

At most dock sites, benthic and plankton samples were taken. An Ekman grab was used to obtain non-quantitative bottom samples that were sieve-washed and sorted on site. A custom-made cylindrical benthic sampler, fitted with 1 mm stainless steel mesh walls, was thrown out on a line and retrieved by dragging along the bottom, working like a small benthic sled to collect larger infauna. Vertical plankton hauls and horizontal plankton tows were taken by pulling a plankton net alongside each dock, close to the dock fouling, in an effort to obtain demersal organisms such as harpacticoid copepods.

Taxonomic identification was conducted at the King County Environmental Lab during sampling and at the Friday Harbor Labs for six days following sampling. Taxonomists with a broad range of expertise were needed to identify the diverse biotic com-

Table 1. Origins, First Records and Mechanisms of Introduction of Non-indigenous Species Collected by the Puget Sound Expedition

This list of species is provisional pending further taxonomic work and review by expedition members and associates.

Native ranges, dates of first record (planting, collection, observation or report) in Puget Sound and on the Pacific Coast of North America, and possible initial mechanisms of introduction to the Pacific Coast are given. First records consisting of written accounts that do not state the date of planting, collection or observation are preceded by the symbol "<". Mechanisms given in parentheses indicate less likely mechanisms. Mechanisms are listed as:

- OA-with shipments of Atlantic oysters
- SF-in ship fouling or boring
- BW-in ship ballast water or seawater system
- OJ-with shipments of Japanese oysters
- SB-in solid ballast
- MR-planted for marsh restoration or erosion control

General Taxon	Species	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Seaweeds	*Sargassum muticum*	Japan	1944	?	OJ
Anthophyta	*Spartina anglica*	England	1961-62	1961-62	MR
	Zostera japonica	W Pacific	1957	?	OJ
Foraminifera	*Trochammina hadai*	Japan	1983	1997	BW,SF,OJ
Cnidaria	*Cordylophora caspia*	Black/Caspian Seas	ca. 1920	ca. 1920	BW,SF
	Diadumene lineata	Asia	1906	<1939	OA,SF
Annelida	*Hobsonia florida*	NW Atlantic	1940	1940	?
	Pseudopolydora sp.	?	?	?	?
Mollusca	*Batillaria attramentaria*	Japan	1924	1924	OJ
	Crepidula fornicata	NW Atlantic	1905	1905	OA
	Myosotella myosotis	Europe?	1871	1927	OA(SB,SF)
	Crassostrea gigas	Japan	1875	1875	OJ
	Mya arenaria	NW Atlantic	1874	1888-89	OA
	Nuttallia obscurata	Japan, Korea (China?)	1989	1991-96	BW
	Venerupis philippinarum	NW Pacific	1924	1924	OJ
Copepoda	*Choniostomatid copepod*	?	?	1998	?
Cumacea	*Nippoleucon hinumensis*	Japan	1979	1998	BW
Isopoda	*Limnoria tripunctata*	not known	1871 or 1875	?	SF
Amphipoda	*Ampithoe valida*	NW Atlantic	1941	?	BW,OA,SF
	Caprella mutica	Japan to Vladivostok	1973-77	1998	BW,OJ
	Corophium acherusicum	not known	1905	1974-75	OA,SF
	Corophium insidiosum	N Atlantic	1915	1930	OA,SF
	Eochelidium sp.	Japan or Korea	early 1990s?	1997	BW
	Grandidierella japonica	Japan	1966	?	BW,OJ,SF
	Jassa marmorata	NW Atlantic	1941	?	BW, SF
	Melita nitida	NW Atlantic	1938	1966	BW,OA,SB,SF
	Parapleustes derzhavini	W Pacific?	1904	1998	SF
Entoprocta	*Barentsia benedeni*	Europe	1929	<1998	OJ,SF
Bryozoa	*Bowerbankia gracilis*	NW Atlantic?	<1923	<1953	OA,SF
	Bugula sp. 1	?	?	1993	?
	Bugula sp. 2	?	?	1998	?
	Bugula stolonifera	NW Atlantic	<1978	1998	SF
	Cryptosula pallasiana	N Atlantic	1943-44	1998	OA,SF
	Schizoporella unicornis	NW Pacific	1927	1927	OJ,SF
Urochordata	*Botrylloides violaceus*	Japan	1973	1977	OJ,SF
	Botryllus schlosseri	NE Atlantic	1944-47	?	OA,SF
	Ciona savignyi	Japan?	1985	1998	BW,SF
	Molgula manhattensis	NW Atlantic	1949	1998	BW,OA,SF
	Styela clava	China to Okhotsk Sea	1932-33	1998	BW,OJ,SF

munities routinely found in Puget Sound. Additionally, familiarity with both local and non-local species was needed in order to identify non-indigenous species. Extensive specialized expertise was provided through 19 scientists from 10 institutions. Participants included: Helen Berry (DNR), Brian Bingham (Western Washington University), Betty Bookheim (DNR), James Carlton (Williams College), John Chapman (Oregon State University), Andrew Cohen (San Francisco Estuary Institute), Jeff Cordell (UW), Leslie Harris (Los Angeles County Museum of Natural History), Terrie Klinger (UW, Friday Harbor Labs), Alan Kohn (UW, Seattle), Eugene Kozloff (UW, Friday Harbor Labs), Charles and Gretchen Lambert (California State University), Kevin Li (King County Department of Natural Resources), Claudia Mills (UW, Friday Harbor Labs), Bruno Pernet (UW, Friday Harbor Labs), David Secord (UW, Tacoma), Jason Toft (UW), and Marjorie Wonham (UW).

Expedition Findings

The Expedition collected and identified 39 non-indigenous invertebrate, algae and vascular plant species in six days of sampling. Much analysis remains to be completed, including genetic analysis of mussels, and identification of plankton samples. Highlights of the preliminary findings include:

- We collected 10 non-indigenous species which had not been previously reported in Puget Sound. These discoveries increase the number of known non-indigenous species to 52 in Puget Sound salt and brackish waters. Previously unrecorded non-indigenous organisms that were found by the Expedition include: the copepod *Nippoleucon hinumensis*, a choniostomatid copepod, the amphipods *Caprella mutica* and *Parapleustes derzhavini*, the bryozoans *Bugula stolonifera*, *Bugula* species, and *Cryptosula pallasiana*, and the ascidians *Ciona savignyi*, *Molgula manhattensis*, and *Styela clava*.
- Puget Sound has far fewer non-indigenous species than San Francisco Bay, which is known to have over 150 species in similar habitats (A.Cohen, unpublished data, 1999). However, this comparison should not put us at ease. San Francisco Bay is known to be one of the most invaded estuaries in the world, where introduced species are the dominant flora and fauna.
- For the non-indigenous species collected by the Expedition whose native range is known, approximately half are from the North Atlantic and half are from the Western Pacific. However, the importance of the two source regions appears to have shifted over time. The majority of species discovered before 1950 are from the North Atlantic while the majority of species discovered after 1950 are from the Western Pacific (Table 1).
- Initial analysis of the distribution of non-indigenous species collected by the Expedition reveals no obvious trends with regard to salinity, temperature or region. The highest number of introductions was found at Shelton, Des Moines, Seabeck and Blaine, which represent the northern and southern endpoints and two midpoints in the study area.
- The Expedition scientists will continue research on the distribution and impacts of non-indigenous species. Results have already been made available in a range of forums, including the 1999 Marine Bioinvasions Conference at the Massachusetts Institute of Technology, the Washington Shellfish Growers Conference, and Sea Grant publications.

Next Steps

The Expedition took a first step toward providing baseline information on non-indigenous species present in Puget Sound. However, the ecology and potential impacts of most of the species found are not well understood. More research is needed to understand the ecological consequences of introduced species, including more comprehensive surveys to determine distribution and abundance, source areas, native habitats, and life histories.

In conjunction with research, management strategies are essential to address the threat of these species. Policies are needed to minimize the introduction and spread of non-indigenous species through such activities as shipping, aquaculture, and recreational boating. The ecological integrity of our marine ecosystem needs to be protected and restored in order to decrease its susceptibility to invasion. WDNR is working with the Washington Department of Fish and Wildlife (WDFW), the lead agency for controlling nuisance species and minimizing species introductions.

For more detailed information, copies of the Expedition report are available from the Nearshore Habitat Program at WDNR (360) 902-1100. Questions about non-indigenous species and their management can be addressed to Scott Smith, the WDFW aquatic nuisance species coordinator at (360)902-0306.

Acknowledgements

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Ferry Terminal Impacts on Juvenile Salmon Migrating through Puget Sound Nearshore Environments

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Abstract

The University of Washington's School of Fisheries and School of Marine Affairs and Battelle Marine Sciences Laboratory are jointly conducting a comprehensive research project supported by the Washington State Department of Transportation (WSDOT) to determine whether ferry terminals impact migrating juvenile salmon and, if so, how future design and modifications to both ferry terminals and operations can mitigate impacts. Shoreline structures such as ferry terminals may adversely affect juvenile salmon (especially ocean-type chinook and chum) by directly disrupting their migratory behavior along shallow water shoreline habitats, indirectly reducing carrying capacity by reducing the production of under-structure habitats, and promoting increased predation by other fish and birds. This project is in three phases: I. assessment of the state of technical knowledge and preliminary characterization of existing light environment and biological communities associated with ferry terminals of different sizes, ages, and construction materials; II. pilot studies on juvenile salmon response to over-water structures and effects on their under-structure prey resources; and III. full-scale implementation of field sampling and experiments. Phase I assessments of the technical literature are completed. Results from Phase I assessment of more than 60 direct sources of information provide evidence that juvenile salmon react to shadows and other artifacts in the shoreline environment imposed by shoreline structures, and can encounter limited prey resources under shoreline structures when disturbance of important habitats such as eelgrass (Zostera marina) occurs. Evidence for significant increases in predation associated with docks is generally lacking. However, effects vary depending on the design of the shoreline structure, its alteration of the underwater light field, the presence of artificial light, and significance of short-term delays in the salmons' migration or cumulative impacts. Early in Phase II, research is focused on developing techniques for documenting in situ behavior and quantifying effects on juvenile salmon encountering ferry terminal structures. Phase III, to be initiated later this year, will involve sampling and experiments at different WSDOT ferry terminals to test juvenile salmon and their prey resources' responses to differing ferry terminal structures, ferry activity and environmental conditions. Ultimately, results from this research will address new terminal design or retrofitting and ferry operations criteria for the WSDOT ferry system to mitigate any impacts on estuarine/nearshore migrating juvenile salmon.

Introduction

Shoreline structures such as ferry terminals pose potential barriers or inhibitors to juvenile salmon migrating along shallow water habitats of Puget Sound during their emigration to the Pacific Ocean. Many of Puget Sound's salmon populations rely on estuarine and nearshore environments during their early life history. This period is tied to early entry to Puget Sound as fry and fingerlings 30-80 mm in length after no or minimal residence in their natal freshwater spawning sites. Accumulating evidence indicates that the estuarine/nearshore period is a critical life history stage in meeting juvenile energy, growth and survival requirements for these "ocean-type" populations. Juvenile ocean-type chinook, chum and pink salmon that migrate early as fry or fingerlings are believed to be particularly vulnerable because they volitionally migrate along the shallow water. Two Puget Sound salmon stocks of Endangered Species Act (ESA) concern (fall chinook, summer chum) fall into this estuarine/nearshore-reliant category. The mechanisms believed to account for this reliance are: (1) preference for shallow water habitat as a refuge from predation; (2) preference for small, non-evasive food organisms that are readily available in shallow water habitats; and (3) aversion to entering a contrasting light environment to which the juvenile salmon are not adapted or have no experience. The corollary is that when encountering certain types of over-water structures, juvenile salmon preferentially seeking shallow water will be forced into deep water, resulting in higher predation risk and lower feeding capacity. Many shoreline structures and modifications represent the potential conditions to alter juvenile salmon behavior and their migratory habitat, of which ferry terminals are but one type.

The Washington State Department of Transportation (WSDOT) Ferry System is increasingly concerned with the need to mitigate the impacts of its ferry terminals and operations on environmental resources in the estuarine/marine waters of Washington State. Increasing pressures from burgeoning ferry use will require WSDOT to expand its ferry terminals in the near future. Overall population pressures on the shoreline are also increasing concurrently. Consequently, there is an urgent need to gather scientific data that can contribute to cumulative impact assessments of ferry terminals and other shoreline structures that potentially affect nearshore resources such as juvenile salmon and the ecological processes that sustain them. Due to the increased concern and listing of Pacific salmon stocks under the Endangered Species Act (ESA), WSDOT is specifically interested in resolving issues and approaches for mitigating impacts to migrating juvenile salmon.

In response to this need, in early 1998, WSDOT initiated support of a comprehensive research project to evaluate the nearshore effects of its ferry terminals on migrating juvenile salmon. A research team (Simenstad et al. 1997) of the University of Washington's (UW) School of Fisheries and School of Marine Affairs and the Battelle Marine Sciences Laboratory

(BMSL) which had previously assessed ferry-related impacts on eelgrass habitat for WSDOT was reassembled to assess the influence of ferry terminals in:

- limiting or altering the estuarine nearshore migration of juvenile salmon;
- reducing estuarine primary and secondary productivity supporting juvenile salmon foraging;
- attracting or concentrating populations of predators on migrating juvenile salmon.

The objectives of the overall research project are to:

- identify documented and hypothesized impacts of ferry terminals on juvenile salmon (Phase I);
- synthesize all evidence around the identified mechanisms of impact, analyze the scientific basis for or against impacts, prepare a synopsis of the outstanding gaps in the state of the knowledge, and recommend research to resolve those gaps (Phase I);
- conduct research to identify the mechanisms and magnitude of ferry terminal impacts on migrating juvenile salmon and their requisite nearshore habitats (Phase II-III); and
- prepare a final interpretive document that summarizes the synthesis and research results about ferry terminal impacts on juvenile salmon and their nearshore habitat, and provide recommendations for best management practices and mitigation for future ferry terminal construction, retrofitting and operations (Phase III).

This research program is being conducted in three phases (Figure 1): I. assessment of the state of our technical knowledge about the effects of shoreline structures on migrating juvenile salmon, and preliminary characterization of existing light environment and biological communities associated with ferry terminals of different sizes, ages, and construction materials; II. pilot studies on juvenile salmon behavior and response to over-water structures and on their under-structure prey resources; and III. full-scale implementation of field trials testing the effects of different ferry terminals and ferry activity patterns on migrating juvenile salmon.

Phase I has recently been completed, the results of which will be available in a WSDOT technical research report and online at WSDOT's Web site in May. Phase II is presently underway. Phase III will be initiated by fall 1999, with extensive field investigations scheduled for 2000 and 2001, and results available in late 2001 to early 2002.

Phase I: Status of Knowledge

Phase I began with an informational workshop held in March 1998 to: (1) introduce resource agencies, tribes, the public, and other stakeholders to the objectives, hypotheses, and scope of the newly initiated research program; (2) seek information for incorporation into the synthesis document; and (3) to solicit input prior to beginning any laboratory or field studies. One of the primary results of the workshop was the realization that the scope of

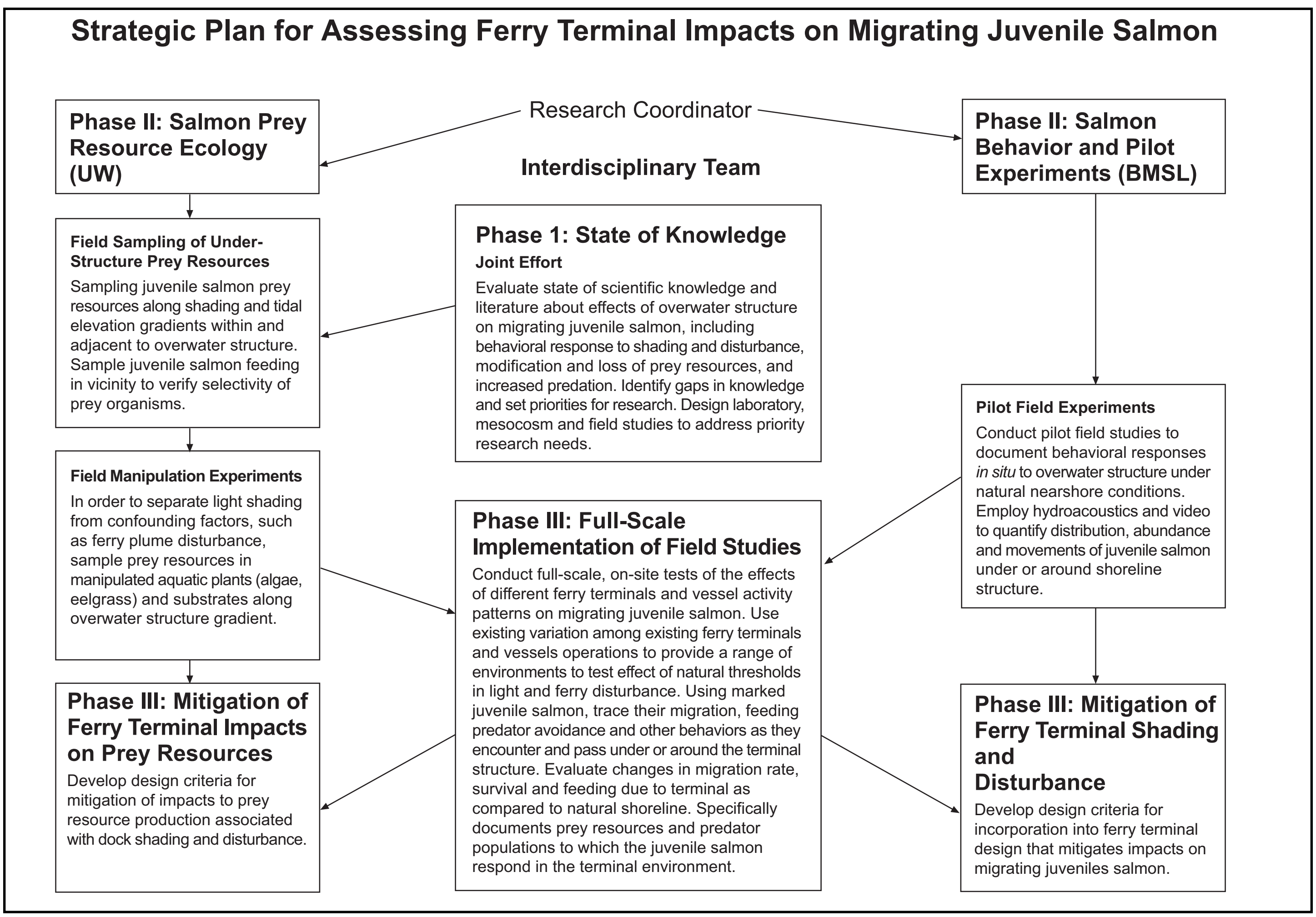

Figure 1. Strategic plan for assessing ferry terminal impacts on migrating juvenile salmon

literature review would have to include the broad spectrum of over-water structures because information is extremely limited for ferry terminals and comparable structures. Although it was acknowledged that much of the information would not apply to ferry terminals, the benefits of accumulating a broader review of over-water structure impacts would outweigh the need to categorize impacts by scale and type of structure.

Subsequently, an intensive literature survey was conducted of the scientific literature and other technical publications, and input solicited from experts in estuarine habitats and salmonid life histories. Over 60 direct (explicitly addressing fish, prey and aquatic habitat responses to over-water structures) sources were summarized by three topics: (1) migratory behavior, (2) primary-secondary production links to salmon prey resources, and (3) predation on salmon. These were integrated into a simple conceptual model that related both direct and indirect effects (Figure 2). A WorldWideWeb site[1] was established to provide the opportunity for review of information as it was gathered and incorporated into the database, and a mechanism for direct submission of comments, suggestions and contributions.

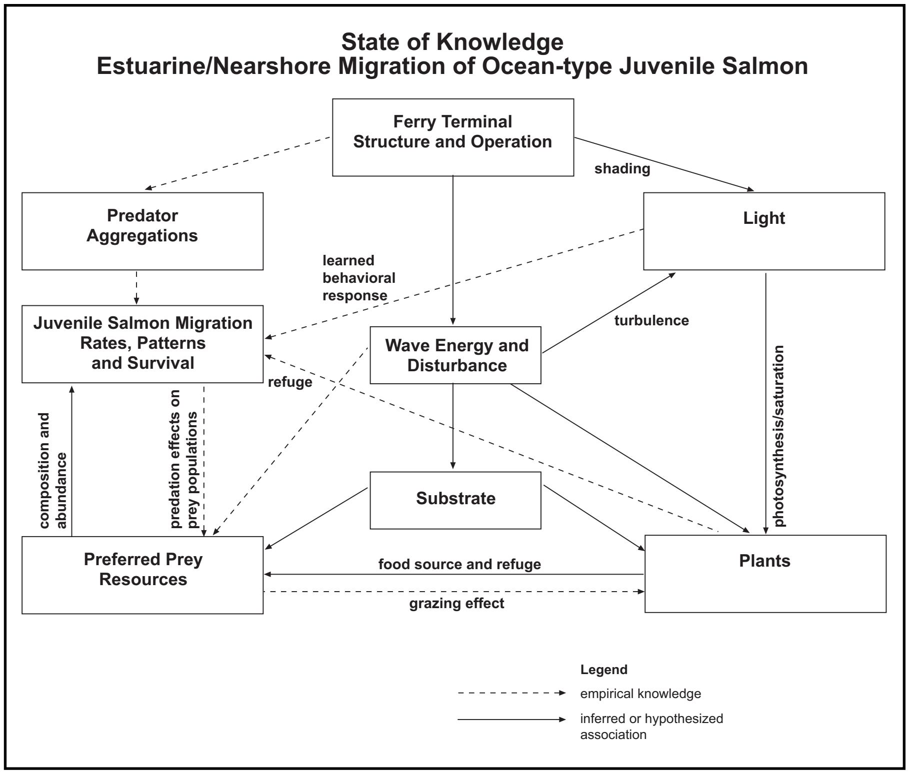

Figure 2. Conceptual model of direct and indirect effects on salmon habitat.

In preparation for a second workshop, scientists from BMSL also conducted diving and light surveys at five ferry terminals. The goal of these surveys was to gather preliminary data and underwater video to document the existing light environment and biological communities associated with ferry terminals of different sizes, ages, and construction materials.

The second workshop was held in August 1998 to present the results of the team's state of knowledge on the impacts of ferry terminals on migrating juvenile salmon. In coordination with the workshop participants, the UW-BMSL team developed a research program to address specific gaps in our understanding of identifiable impacts. Based on the Phase I analyses, the research team concluded that (1) ocean-type juvenile salmon prefer to migrate in shallow water along the edges of refugia, such as eelgrass, dock shadows, turbid zones, 2) schools of salmon fry and fingerlings disperse upon encountering docks but are attracted to under-dock lights at night and to prey resource areas, 3) delays in migration direction occur when juveniles are confronted with conflicts in preferences, and 4) there is little technical data to substantiate that shoreline structures aggregate predators, although there are some conditions (e.g., artificial lighting around docks at night) that need to be investigated further. The workshop participants identified the need for better conceptual models of both fish and aquatic plant responses to light relative to the variability in shoreline structure environments, and the need to recognize diel (day or night) effects on over-water structure impacts on juvenile salmon.

Phase II: Pilot Experiments

Participants at the second workshop identified a number of factors that might affect juvenile salmon migration, including light levels, "perceived" predators, ferry activity patterns, and dock characteristics. Phase II will focus primarily on the effects of light on juvenile salmon. In collaboration with the US Army Corps of Engineers-Seattle District (USACE-Seattle) the research team is conducting preliminary field experiments using hydroacoustic and video methods to track juvenile salmon responses to altered light environment in the nearshore region at the Port Townsend Ferry Terminal in Spring 1999. The results of this pilot field study will provide critical data to aid in the design of Phase III's large-scale, replicated, mark and recapture studies.

Phase III: Full-Scale Field Studies

Results of Phases I and II will be used to develop full-scale, on-site tests of the effects of different WSDOT ferry terminals and vessel activity patterns on migrating juvenile chum and chinook salmon (Figure 1). Existing variation among WSDOT ferry terminals and vessel operations will provide a range of environments to test the effect of ranges and variation in under-terminal light level and characteristics and ferry disturbance, as well as potential terminal-associated predators, on migratory behavior, feeding, and prey resource production and availability. We will relate terminal impacts on light and other under-terminal environmental characteristics to the state of knowledge about juvenile salmon behavioral responses to different light stimuli, spectral and intensity perception thresholds, and other effects imposed by such over-water structures. The UW-BSML team will use mark-and-recapture experiments with chum and/or chinook fry to evaluate the behavioral responses and performance at three ferry terminal sites. In addition to varying ferry terminal design, dimension, and setting, these manipulated release experiments will be conducted during different seasonal and diel conditions. Fish behavior will be evaluated by a combination of hydroacoustics, video and diver observations, and net sampling. Fish performance will be measured as migration rate and consumption of preferred prey. The composition and extent of refuge habitat, with particular emphasis on eelgrass, will be assessed along transects adjacent to and beneath terminals in order to evaluate disruption in the juvenile salmon migratory corridor. Benthic and epibenthic invertebrate prey assemblages will also be sampled along the same transects to assess the terminals' impacts on prey production and availability in relation to the preys' habitat requirements. Predator populations and behavior will be assessed as activity time budgets relative to the availability of juvenile salmon.

Summary

This research will provide rigorous descriptive and experimental results about juvenile salmon migration in the environmental and operational context of WSDOT ferry terminals conditions and activities. The net interaction of light and other factors, such as salmon prey and predator composition, distribution and abundance will demonstrate the importance of local conditions and mitigating factors on the successful migration of juvenile salmon past WSDOT ferry terminals. These results will establish the impacts of existing facilities as well as mitigation criteria to minimize or eliminate impacts from future WSDOT ferry projects. Although ferry terminals represent only a minor proportion of over-water structures potentially affecting juvenile salmon migrations along Puget Sound, and may pose fewer impacts due to their design and location, the results of this study should nonetheless advance our state of knowledge about how to identify and mitigate for shoreline development impacts to juvenile salmon.

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[1] http://weber.u.washington.edu/~newwsdot/home.html

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