Status report
"A Small Regional Hydrophone Network in the Salish Sea"
March 14, 2007

Contractor: Val Veirs, The Whale Museum/Orcasound
Sub-contractor: Scott Veirs, Beam Reach
Sub-contractor: Ken Balcomb, Center for Whale Research

Introduction

The primary goals of deploying a hydrophone network in the Salish Sea were to continuously monitor ambient noise and detect killer whale presence/absence in the Salish Sea. A secondary priority was to raise interest in the marine environment and awareness about underwater noise by deploying hydrophones at facilities dedicated to public education. A final objective was to design and test novel deployment methods and technologies – including cables attached extant piers/pilings, wireless/buoy systems, hydrophone calibration, automated detection algorithms, and streaming audio distribution.

In pursuit of these objectives, we proposed (Appendix I) to deploy hydrophones at four locations on San Juan Island (Val's lab Orcasound; the Center for Whale Research, Lime Kiln Lighthouse; and False Bay) and at two in Puget Sound (Port Townsend Marine Science Center [PTMSC] and the Seattle Aquarium). In brief, this is the status of each deployment: Val has maintained the northernmost node (at Val's home/lab called Orcasound) nearly continuously; Ken has taken the lead on the design of a moored system and deployment of a prototype at the Center for Whale Research; Val and Scott succeeded in re-establishing the Lime Kiln node, but were thwarted again by winter storm damage; False Bay negotiations with Friday Harbor Labs are on hold; and Scott and Val have established single-hydrophone nodes at Port Townsend Marine Science Center and the Seattle Aquarium.

This report summarizes the progress made in the year since the project was first proposed on Feb 14, 2006. We provide a progress report, preliminary data from the new nodes of the network, a synopsis of funds spent, and plans for the remaining funds. The progress

report begins with a review of key technological achievements; the remainder reviews the status of each node, from north to south, and presents preliminary data where available.

General technological progress:

Calibration:

The Orcasound, Port Townsend, and Seattle Aquarium nodes have been calibrated using the Interocean Systems calibrated hydrophone (which was itself inter-calibrated by Joe Olson at the Navy/Keyport calibration facility on 5/26/06). Node calibration was accomplished by co-locating the node hydrophone with the Interocean Systems phone, reading the broadband sound pressure level off of the Interocean Systems analog display, and entering the value in the WHOdata software so that the incoming node hydrophone signal matched the observed Interocean Systems level. The resultant values for the calibration constant (as well as other WHOdata parameters) are automatically logged whenever any value is altered.

Hydrophone options:

We have purchased hydrophones from two local sources: Lab Corp Systems (LCS; Lon Brocklehurst) and Cetacean Research Technologies (CRT; Joe Olson). The LCS "LAB-001" hydrophones are less expensive ($200) and *remarkably* free from electrical and mechanical noise. The only disadvantage of the LCS phones is that we don't currently know their detailed frequency response (an eBay listing for "LAB-40" lists a frequency response of 5Hz to 85kHz, +/- 3dB. The CRT Sensor Technologies 54XRS hydrophone has a comparatively well-characterized frequency response curve, but is difficult to isolate from noise. Joe has implemented a solution to this problem at the Vashon Hydrophone Project and we acquired (in Feb 07) the equipment to retrofit and deploy Joe's hydrophone at the Seattle Aquarium. The solution involves an isolation amplifier ($175), two 12-V batteries ($100), and/or a solar trickle charger ($35).

Streaming solutions:

While we continue to seek local sponsors or providers, we are currently utilizing a commercial service called http://spacialnet.com (based in Texas) to distribute the hydrophone data streams to up to 20 listeners per node. While the WinAmp/Shoutcast streaming software at each node is free, the commercial distribution service costs $23/month/node. This adds up to ~$1000/yr for three nodes. While this is better than we projected in our initial ($50k) proposed budget (6 months at $300/month implies $3600/yr), we are confident that we can devise a more cost-effective solution, ideally through local sponsorship or discounts.

Node progress reports: (History, status, and results)

Orcasound (fixed array)

History:

The Orcasound array was established in 1999 with 8 ITC hydrophones (seven model 4066s; one broadband). It has gathered data nearly continuously since then, though only four hydrophones are still operational. Of the four remaining phones, only two are currently digitized. Digitization was via an 8-channel A/D board, but since its failure a 2-channel board has been utilized.

Status:

Orcasound has had four operational hydrophones throughout 2006. Two of these hydrophones have been monitored via a two-channel soundboard. Data from these two has been logged and triggering algorithms have recorded ephemeral sounds. Several times in December, 2006, and January and February 2007, the system went down when the island's electric power system failed for times longer than the uninterruptible power supply can maintain the system (a few hours). After these failures, a volunteer had to go to Orcasound and reset the computers, and often the DSL modem. Orcasound started streaming the signals from two hydrophones in late November, 2006, and has continued to do so except briefly after power failures. Calibrations were performed about once a month during 2006.

Results:

Please refer to our previous NOAA report on 18 months of broadband and spectral data from the Orcasound array. Analysis of the ephemeral recordings made during fall, 2006, as well as 2007 to date will be undertaken once Val returns to Orcasound (3/18/07).

(See Appendix 1 for comparison of levels with the other calibrated nodes.)

Center for Whale Research (wireless/buoy systems)

History:

Val, Scott, and Ken met in September, 2006, and divided labor and resources. We decided to dedicate $7000 of the $25k grant to development of a wireless/buoy system(s) by the CWR. The general plan was for Ken to work with Lon to develop and field test the system(s). Ken generously agreed to let Val and Scott have access to some older hydrophones he had purchased from Joe Olson for potential deployment at the cabled sites.

Status: (3/2/07 update from Ken)

Ken has contracted with LAB-Core Systems to produce two short range wireless hydrophone systems and receivers ($1,000 each), two long range wireless hydrophones

and receivers ($1,500 each), and one hydrophone array consisting of three hydrophones and 1000' of multi-pair wire ($2,000).

Ken has received the two short range wireless hydrophone systems and deployed them at CWR in September 2006. One of the systems was lost to currents, and the other was successfully deployed and recovered after two weeks. The recovered system will be redeployed in 2007. The hydrophone array will be deployed at CWR in 2007. The two long range wireless hydrophone systems are nearing completion and will be deployed in 2007.

Results: (3/2/07 update from Ken)

Detections of SRKWs coincided with detections on the Orcasound array. The wireless range of the short range system is approximately 400 yards and the hydrophone was sensitive to a range of 9 miles for shipping noise. The wireless range of the long range system is anticipated to be approximately 6 miles and the hydrophone sensitive to a range of 9 miles. The array is expected to be sensitive to range of 12 miles.

Lime Kiln State Park (cabled)

Status:

The two hydrophones that Val and Scott installed via a scuba dive in mid-2006 were disabled by the winter 2006-7 storms. The exact nature of the failure is not yet known.

We plan to install replacement hydrophones in mid-March after the worst of the winter storms have likely passed. The estimated cost will be ~$1500 for hydrophones, hardware, streaming costs, and cables, and ~$500 for SCUBA installation. We plan to maintain these hydrophones in 2007 for streaming, noise monitoring, automated call detection, and Lime Kiln's summertime researchers and visitors.

Port Townsend (proposed pair of hydrophones on an educational pier)

History:

During the winter studies of 2004, 2005, and 2006 Ken had discussions with PTMSC personnel on numerous occasions preparing for installation of a hydrophone system pending funding from NMFS.

Without prior knowledge of Ken's efforts, Scott approached the PTMSC through Cinnamon Moffett and Anne Murphy:
02/17/06 Anne Murphy of PTMSC supports concept and starts coordination
06/07/06 Scott tours PTMSC site with Anne
09/25/06 Val, Scott, and Keith attempt initial deployment

10/31/06 Scott and Keith complete initial deployment
12/06/06 Keith restarts after power failure and burns first DVD and sends to Scott
01/29/07 Keith burns second DVD and sends to Scott

Status:

The Port Townsend node currently consists of one LCS hydrophone deployed through the pier (from within the teaching classroom), across the tops of the pilings, and down a piling that is located ~5m in from the northeast corner of the pier. The hydrophone is located about 2m above the bottom, ~4m below the surface (at zero tide), and ~8m below the bottom of the pier. The cable is armored in the intertidal within a PVC pipe that is lashed to the piling (via SCUBA dive: see photos at http://orcasound.net/ptmsc.html). We also attempted to deploy a CRT hydrophone that was working (in air) after being salvaged from Lime Kiln, but it failed to function once at depth. Keith Brkich has been extremely helpful in deploying and maintaining the PTMSC node and we are looking forward to further collaborations, including incorporating the hydrophone system further into the Center's educational efforts.

Results:

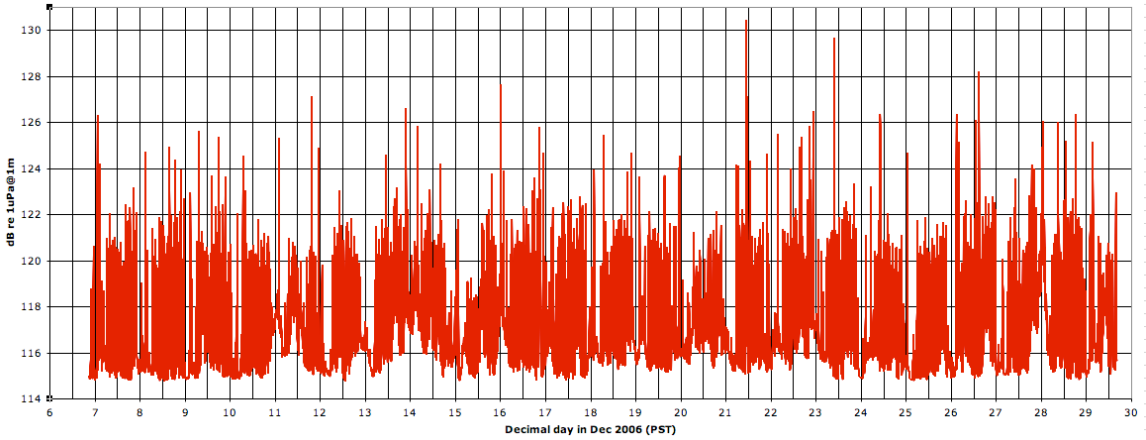
Overall, the PT node has functioned well, providing a low-noise signal that has been archived successfully and streamed live with few interruptions. We now have a baseline measurement of ambient noise in the Admiralty Inlet area.

Drawbacks of the installation are some splash-down noise associated with the Marine Science Center aquarium discharges, intermittent pump noise, and some local creaks and tones that are reminiscent of killer whale calls (possibly nearby mooring buoys during heightened wave action?). Related to this, Ken has monitored the PT hydrophone episodically since installation and he notes that there seems to be a creaking dock sound during some tide and current conditions; it sounds similar to KW calls, but it can usually be disregarded after listening for ten to twenty minutes.

Since installation of the node, a few opportunities have arisen to test whether KW calls can be sensed and detected automatically at the PT node. Based on visual sightings, we know killer whales passed through Admiralty Inlet during particular days when the hydrophone system was functional. Thus far, the automatic call detections have not recorded killer whale calls or clicks during the days when the sightings occurred or the conceivable period when the whales could have been transiting the Inlet.

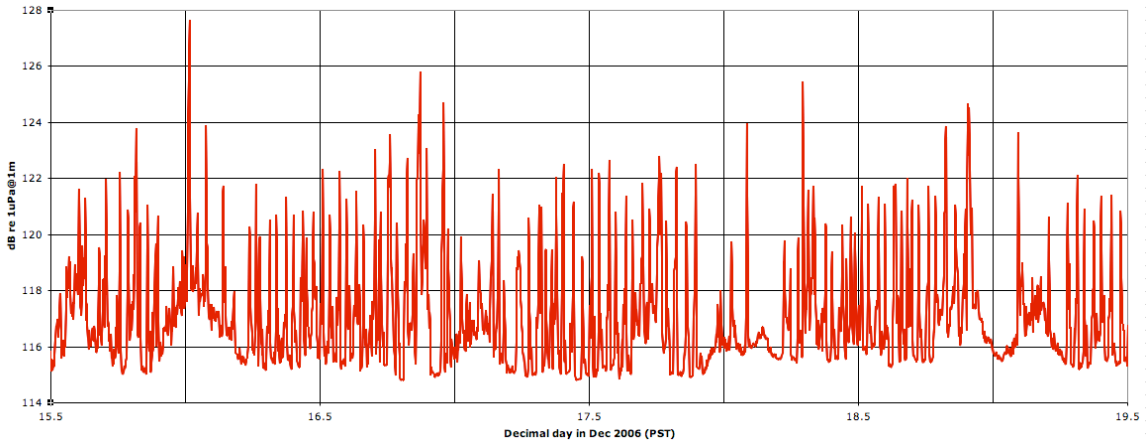
Broadband levels:

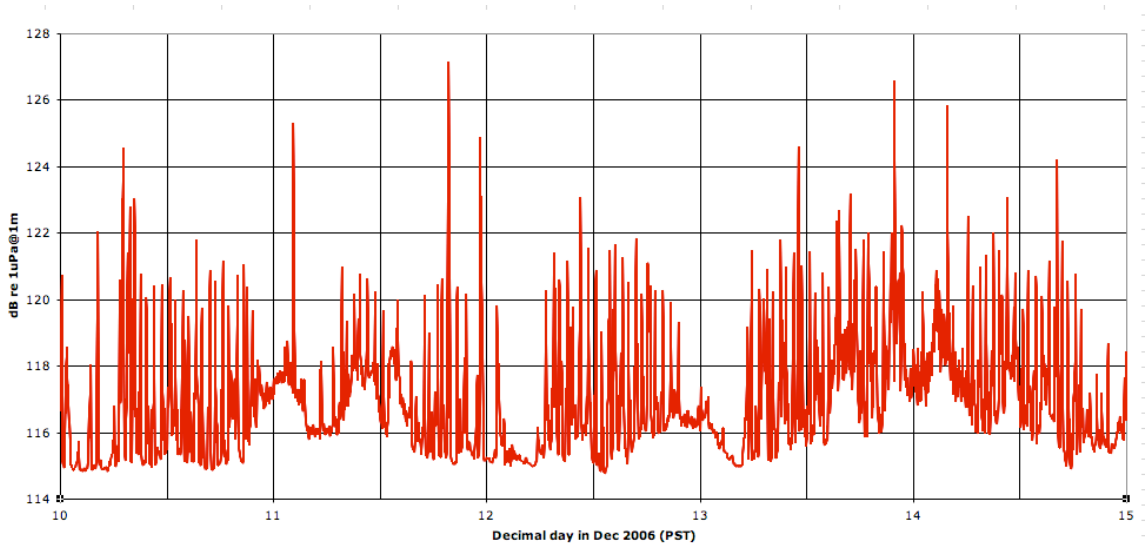
The broadband data acquired in December, 2006, are shown in the following figure. Based on all data in the plot, the mean SPL is 116.9dB, the minimum is 114.7dB, and the maximum is 130.4dB. As expected, the time series from Port Townsend reveal a diurnal pattern that is dominated by the local ferries and shipping traffic in Admiralty Inlet.



During December, 2006, the 30-minute ferry run between Port Townsend and Keystone occurred 32 times/day. We expected noise levels to increase in association with the ferry schedule from 6:30 a.m. through 9:45 p.m. In general the maximum daily values occur when the ferries are active, but the expected hiatus between 10 p.m. and 6 a.m. is often interrupted or obscured (probably by commercial ship traffic, but also possibly by a swishing sound with no known source).

The following two plots show characteristic sub-sections of the December data. Contrary to our expectations, the daily minimum value does not always occur during the nighttime. Rather, the lowest daily levels commonly occur during the day between ferry runs while the nighttime noise level frequently climbs (~2dB) above the long-term average (~117dB) and frequently includes maximum daily levels. Sound samples indicate that these nighttime increases in noise are due to commercial ships. On some days, the background level is raised similar amounts during the daytime, presumably by commercial ships that are transiting the Inlet when the ferries are active.





An implication of this diurnal pattern is that monitoring for killer whale calls or clicks along the Puget Sound shipping channel may be complicated by the increased noise that occurs during the nighttime hours (when the visual sighting network is least effective).

(See Appendix 1 for comparison of levels with the other calibrated nodes.)

Sound files:

The second DVD contains 92 sound files from Dec 7 – Dec 29, 2006. Most files appear to have been triggered by ship noise or "swishing" sounds (unknown source, possibly sand moving in strong currents).

One file (clip at: FUNdB116_12_09_2006_17_22_47.wav) may contain some L pod calls, though they are very faint and could be the creaking dock or buoy sound mentioned above. The only relevant Orca Network sighting records indicate that K pod was split around then, with about half of the pod off Kingston and the other half with L87 heading west at Race Rocks on Dec 12/07/06. K pod was again sighted around noon on 12/09/06 off Seattle (West Point). This sound triggered the "Fundamental frequency" algorithm in the automated detector. We anticipate further tests of this algorithm this spring when killer whales and visual sightings become more common.

Seattle Aquarium (proposed pair of hydrophones on an educational pier)

History:

Ken had discussions with the President of Seattle Aquarium Society in 2005 and proposed the project to the Board of Directors of the Seattle Aquarium Society on 24 January, 2006. The proposal was enthusiastically received and accepted, pending funding from NMFS.

Without knowledge of Ken's efforts, Scott approached the Aquarium via Brooke Nelson in early 2006:
04/18/06 Initial meeting with Brooke and Kathy
06/23/06 Initial research proposal submitted
07/19/06 Scott gets go-ahead on proposal in large group meeting
08/29/06 Final agreement with Seattle Aquarium signed
10/17/06 Scott meets with Andrew to choose deployment location
12/20/06 Hydrophone deployed, but laptop power problem
01/12/07 Data collection and streaming initiated

Status:

The node currently consists of one of Lon's hydrophones and a recycled 500MHz laptop. The system has been streaming continuously since 1/12/07. It's noteworthy that the hydrophone has weathered 60km/hr gusts and associated waves during the December/January storms without failure, despite simply dangling beneath the Aquarium pier (no intertidal protection or connection to the pilings). The seafloor is about 14m beneath the pier and the hydrophone is about 5m above bottom.

Brooke Nelson and Andrew Mannery have provided fantastic support during planning, deployment, and initial data acquisition. Under their guidance in 2007, we expect to begin integrating the hydrophone signal and products into extant and future Aquarium displays.

We have purchased a hydrophone From Joe Olson and have not deployed it at the Aquarium because of line noise. We understand Joe has solved this problem recently at the Vashon Hydrophone Project installation with an isolation amplifier. We are in the process of installing the amplifier and associated gear at the Aquarium this spring to begin the side-by-side test of Lon's and Joe's hydrophones in a pier-based deployment.

Results:

Scott downloaded ~4 Gb of data on 2/7/07, some of which is presented here. The relatively noisy environment of Elliott Bay caused the automated detection algorithms to trigger more than expected, so the recorded sound files (each 60s and 10-20Mb) quickly filled the laptop disk space. Consequently, we have sound files and power spectrum levels from Jan 12-16, and mean broadband levels from Jan 12-23 (see figures below). The record duration was shortened to 10s to conserve disk space immediately and upon further analysis of the sound files the detection algorithms will be adjusted to ignore ship and other common anthropogenic sounds.

Broadband levels:

The broadband received sound pressure levels under the Aquarium are higher than at any other node in the network. The daily minimum of ~129dB is near the daily maximum

levels observed in Haro Strait. We have some concern that these levels include a contribution from the Aquarium pumps and are coordinating with Andrew Mannery to make measurements when the pumps are turned off during brief maintenance periods.

For the representative period shown in the following figure, the minimum SPL is 127.5 dB, the maximum is 144 dB, and the mean is 130 dB. The minimum values occur between 2-6 a.m. each day and the maximum values coincide with the local ferry schedule. On January 14 (a Sunday), the combined schedules indicate that 22 ferries departed Seattle for Bainbridge Island (between 6:10 a.m & 2:10 a.m)., while 26 made the 35-minute trip from Bainbridge to Seattle (between 5:20 a.m & 1:25 a.m). The approximate number of relative maxima (exceeding 137 dB) on that day is ~24.

We believe a closer temporal analysis could determine what acoustic contribution is due to the Seattle/Bainbridge vessels versus the ferries making the 14 trips to/from Bremerton and 3 to/from Vashon. There is a notable reduction in noise levels (particularly during the weekends) between the 6:10 a.m. Seattle-Bainbridge departure and the next arrival at ~7:40. During one such hiatus on Jan 13 (below) a SPL spike was recorded at ~4 a.m. that is likely due to a non-ferry vessel.

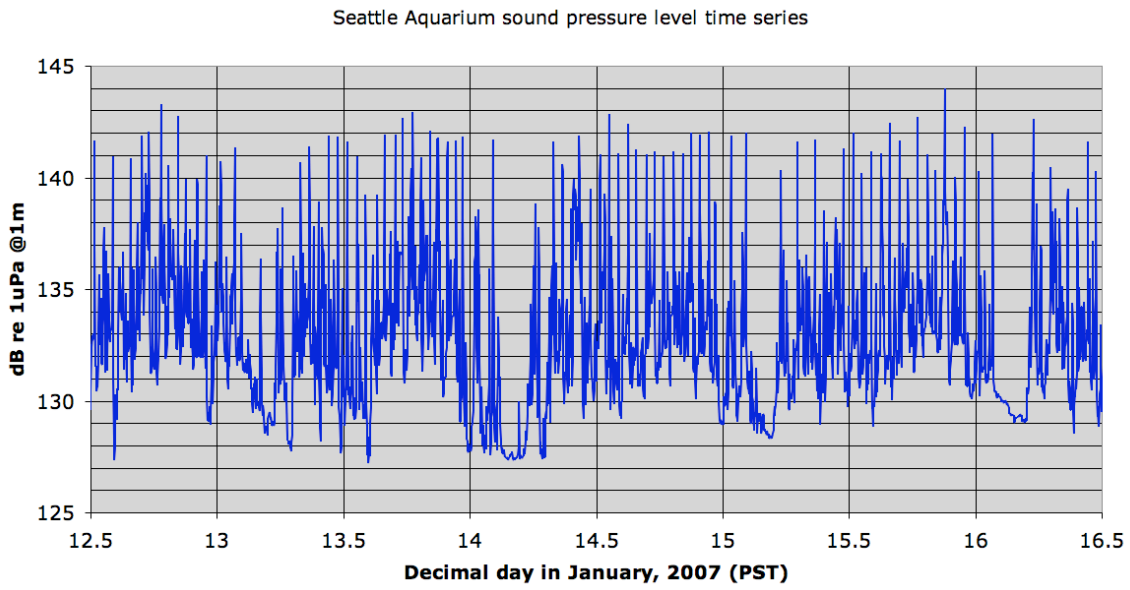


Figure 1: A 4-day example time series of sound pressure level under Seattle Aquarium pier (from noon on Friday 1/12/07 through noon on Tuesday 1/16/07).

(See Appendix 1 for comparison of levels with the other calibrated nodes.)

Sound files:

The most interesting automated detection of an unusual sound to date is what appears to be an detonation from an unknown source. The intensity of the sound (receive level of 141 dB) triggered the "Power" algorithm of the automatic detector.

Financial overview:

The following table shows the status of the $25,000 grant that modified the existing "SeaSound" contract between NOAA and the Whale Museum in 2006. The total expenses to date are broken down by sub/contractor and by node. We also include the projected cost of finishing the 2006 planned deployments, repairing the Lime Kiln node, and streaming via the commercial service through June, 2007.

Expense breakdown by sub/contractor		
Beam Reach		$2,754.59
Orcasound		$8,512.56
Whale Museum (overhead)		$4,000.00
CWR		$7,000.00
TOTAL		$22,267.15
Grant total		$25,000.00
Available balance (as of 3/15/07)		$2,732.85
Projected expenses	Hours	
CRT+cable for PTMSC		$1,056.56
Two car batteries		$80.00
Solar trickle charger (PTMSC)?		$100.00
Isolation amplifier for PTMSC		$171.55
Additional streaming expenses		$414.00
Additional SEAQ labor/maintenance	15	$750.00
New phones, cables, materials: Lime Kiln spring 07		$1,500.00
Scuba dive installation: Lime Kiln spring 07	10	$500.00
Total		$4,572.11
Expense breakdown by node (as of 3/15/07)		
Port Townsend		$4,492.36
Seattle Aquarium		$2,148.98
Orcasound		$2,500.00
Lime Kiln		$1,150.00
CWR		$7,000.00
TWM overhead		$4,000.00
General labor/materials		$423.81
Streaming		$552.00
Total		$22,267.15
Remaining		$2,732.85
Projected		$4,572.11
Balance		$(1,839.26)

In our proposed budget, we expected deployment of each node to cost ~$3,600 ($2,200 labor and $1400 hardware). Port Townsend exceeds our budgeted cost primarily because of the labor involved in deploying and maintaining the node. Three separate trips were required to get the node functional (Val and Scott the first time, Val the second time, and Scott/Keith scuba diving the final time). Depending on how the Lime Kiln repair goes and whether Joe's system at the Aquarium requires monthly battery changes, we may elect to put reduce projected costs at PTMSC by deploying one of Lon's phones ($300) instead of one of Joe's ($1500). With such flexibility we expect to complete the intended work within budget.

APPENDIX I: Preliminary comparison of broadband wintertime sound pressure levels in the Salish Sea

The following table makes a rough, preliminary comparison of wintertime sound pressure level statistics at Orcasound, Port Townsend, and Seattle nodes. Comparisons will be improved when data from the same time periods are available from all nodes and the contribution of pump/pier noise to the minimum and mean values is ascertained.

SPL (dB re 1uPa@1m)	**Orcasound Oct-Apr (ref report: 04/21/06)**	**PTMSC Dec 07-28 2006**	**Seattle Jan 12-16, 2007**
Mean	115	117	130
Min	~95	115	127
Max	~130	130	140

While the means at Orcasound and Port Townsend are similar, the Seattle mean is much higher. This is likely due to the abundant, nearby ferry traffic in Elliot Bay.

The minima differ widely. Our best explanation for the difference is that the pier and or aquarium-related pumps are adding substantial energy to the underwater environment. Another possibility is that other noise sources – either industrial, pier-related, or natural – are not present at the Orcasound array.

The maximum values are similar at Orcasound and Port Townsend because the commercial ships likely have the highest source levels and pass the nodes at comparable distances. The higher maximum receive levels at the Seattle hydrophone are probably due to the proximity of the ferry dock to the Seattle hydrophone.

APPENDIX II: INITIAL PROPOSAL

To: Dr. Brad Hanson
From: Val Veirs and Scott Veirs
Date: Feb. 14, 2006 – Happy Valentine's Day!
Re: Proposal for Small Regional Hydrophone Network in the Salish Sea

Continuous monitoring of underwater sound enables natural and anthropogenic noise to be characterized quantitatively. A network of hydrophones in the habitat of the southern resident orcas would begin to map ambient and anthropogenic noise, the latter a potential risk factor for the population.

A network could also detect individual orcas that vocalize or echolocate locally (within ~5-10 km when ambient noise is minimal, ~95 dB). If maintained throughout the year, detections could help define the summer and winter distribution of southern residents. Combining those distributions with maps of ambient noise and of other potential impacts (like contaminated sediments, or failed fisheries) is a fundamental step in defining a recovery plan for this endangered species.

Finally, a network of hydrophones could interact synergistically with the public in two ways. First, hydrophones co-located with facilities dedicated to public education offer the benefit of raising interest in the marine environment and awareness about underwater noise. For museums or aquariums with exhibits that focus on sonic organisms, a live stream from the organism's natural habitat could enrich the public's in-house experience. Second, we believe the public may eventually prove to be the best event detection tool in large, real-time data streams like those that will emanate from a hydrophone network. For example, the "Luna Live" hydrophone is listened to continuously by collaborative teams who span the globe (and therefore sleep at different times). (Note: This is a "future" goal, as this proposal does not include funds for large-scale public streaming of data.)

We propose to build, install, and operate a Small Regional Hydrophone Network (SRHN) in Puget Sound and the San Juan Islands. This will be a small-scale test of deploying hydrophones and linking them together via the Internet. Our plan is to deploy hydrophones at four locations on San Juan Island and at two in Puget Sound. On San Juan Island we will deploy hydrophones at Val's research site on Smugglers Cove Road (OrcaSound), at the Center for Whale Research, at Lime Kiln State Park, and at False Bay. Down sound, we propose to install a hydrophone off the dock at the Seattle Aquarium and off the dock at the Port Townsend Marine Science Center. These two locations are attractive as they both have docks which greatly simplify intertidal protection and they are centers of public outreach.

Each of these nodes will have (1) two calibrated[1] hydrophones with marine cables and inter-tidal protection, (2) a computer with sound board input, (3) streaming software on the computer, (4) data-logging software running 24/7 (archiving long term averages of sound levels and frequency distributions and scanning for and saving "interesting" events) and (5) broadband Internet access. Thus each node will record statistics on ambient noise conditions and record transient sounds with frequency signatures that match orca vocalizations (events). Each node will also enable local listeners to become more aware of underwater sounds by visually correlating the hydrophone signal with surface activities. To enable the public to make such correlations at the more remote sites on San Juan Islands, two nodes (OrcaSound and Lime Kiln) will have pan-tilt-zoom video cameras streaming video of the above-water scene. The pan-tilt-zoom camera at OrcaSound is already in place and streaming from that camera was demonstrated in a short test in December 2005. Finally, at each node, local users will be able to access the entire network's hydrophone signals for listening and for computer display.

At the Whale Museum in Friday Harbor we will install a central computer and pattern recognizing software that will automatically upload "events" from each node and analyze, summarize and archive detections of "orca-like" vocalizations. This central computer will also back-up the background underwater sound summaries computed at each of the network nodes. These data will be used to study the annual distribution of southern residents. Highlights from the detected calls, the live streams, and the statistical summaries will be incorporated into a display in the museum's exhibit space.

Our Phase I goal is to install the first nodes of this Regional Hydrophone Network (RHN) late this spring, in time for the orcas' arrival in the San Juan Islands this year. Phase II will start in July. Over the summer the "down-Sound" hydrophones will be installed and incorporated into the RHN. In the fall, the "control and archiving and display" node at the Whale Museum will be constructed and installed, completing Phase II.

The cost of putting together the six hydrophone nodes, writing the necessary software, installing the nodes, designing and constructing the Whale Museum display node, and operating the system for the summer and fall of 2006 comes to $50,000. This total can be broken down into 2 phases – Spring, and Summer - Fall 2006 with the costs running approximately $25,000 for each of the 2 phases.

The breakdown of these costs is shown in the spreadsheet titled
CC_BeamReach_NOAA.xls

[1] Colorado College Physics Department has just purchased a 902 Acoustic Listening & Calibration System from Interocean Systems, www.interoceansystems.com, for in-field calibration. We will use this to perform a calibration on each hydrophone – data archiving system at the time of deployment.