Salish Sea Hydrophone Network
2008-2009 progress report

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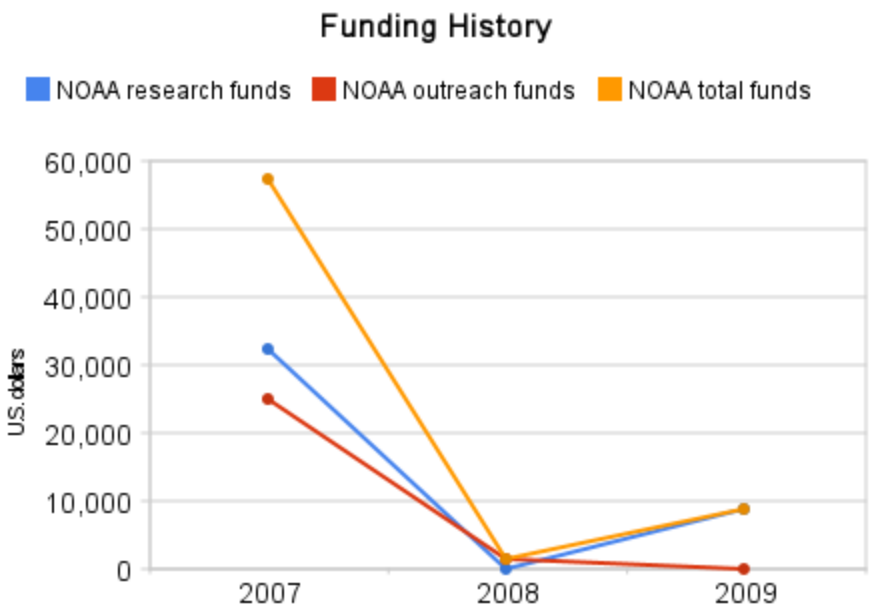
(A Google document with live links -- http://bit.ly/aigF22)

Introduction

A growing coalition of scientists, educators, managers, and citizens are working together to build and maintain a regional hydrophone network in the Salish Sea (Pacific Northwest U.S., Northeast Pacific). The network consists of cabled hydrophone systems deployed at network nodes around the region (red dots on the map) and a web site www.orcasound.net offering public access to real-time and pre-recorded audio streams. The network is part of the SeaSound Project of The Whale Museum and is an experiment in sharing and processing real-time underwater sound. What started at two sites along the west side of San Juan Island (the lighthouse at Lime Kiln [aka Whale Watch] State Park and Orcasound laboratory) has grown to a regional collaborative effort including nodes at the Port Townsend Marine Science Center, the Seattle Aquarium, and the Makah Tribe in Neah Bay. This expansion has helped to highlight differences in anthropogenic noise impacts around the Salish Sea, as well as furthering our abilities to acoustically detect southern resident killer whales (SRKWs) for citizen science, research, and stewardship projects.

Summary



This document reviews the progress made on the Salish Sea hydrophone project from September 1, 2008 through December 31, 2009. While our 2007-8 report covered the Federal fiscal year, here we are transitioning to a calendar year to optimize our seasonal work load.

As shown in the adjacent graph, no new NOAA funding was available during the 2008-9 fiscal year, except for $1400 from the NW Regional Office for outreach. Our research and outreach progress was accordingly limited. We maintained the network primarily with NOAA funds allocated in 2007-8. Thankfully, the Northwest Regional Office was able to provide $1,400 in small grants to support essential repairs and supplies. These new funds were used to purchase four back-up hydrophones -- two of which were immediately deployed at the Port Townsend node, headphones and hard drives to maintain review and acquisition of sound files at Lime Kiln that enrich educational activities, and an underwater camera to document dives for outreach programs.

Additionally, in the summer of 2009, some maintenance and enhancement of the Lime Kiln node was supported by non-NOAA funds. The Friday Harbor Labs Bioacoustics course contributed $4,300 to install the Reson TC 4032 hydrophone system for measuring source spectrum levels across the auditory frequency range of killer whales. Beam Reach Marine Science and Sustainability School spent $3,700 on two 4-element arrays and an AIS receiver to enable localization of sound sources -- from whales to ships -- and the subsequent computation of source levels from the Reson receive levels.

Due to limited funding, our goals for 2008-9 were limited to maintaining the five hydrophone node sites while improving upon our ability to address research and educational goals of the SRKW recovery plan. We did not expand the network, though we continued to nurture relationships with prospective future node hosts. Overall, we have continued to achieve our primary research goals: detecting orcas when their presence is otherwise unknown; and calibrated and quantified characterization of the underwater soundscape throughout southern resident critical habitat.

Our main accomplishments during this last year were to keep all the nodes running most of the time (with the exception of Neah Bay), calculate an acoustic versus visual detection rate for SRKW passing through Admiralty Inlet, and improve the interpretive displays at the Port Townsend Marine Science Center and the Seattle Aquarium. Val enabled a quantum leap in our ability to automatically upload, analyze, organize, and issue notifications based on detections made by the monitoring

computers. The human listening network grew and provided a suite of valuable detections: one that led to early photo-identification of a new calf; many related to a rare observation of J1 (Ruffles), apparently isolated from the rest of his pod; and another use of active sonar by the U.S. Navy in or near critical habitat of the SRKWs.

This report begins with a synopsis of the network and the flow of data from hydrophone to humans. After describing the current status of the network infrastructure, we summarize our research and education progress is subsequent sections. In the final section we make recommendations for enhancing the network to improve monitoring of whale movements and ambient/ anthropogenic sound. Interspersed throughout the report are accolades from network users (blue highlighting).

In "Research progress," we report on the performance and status of each hydrophone node in the network. We summarize equipment acquired and installed (including technical specifications), as well as known or anticipated limitations or problems associated with long-term operation of each node. We provide links to an on-line spreadsheet listing all detections by human listeners, an on-line archive of recordings (mp3 format) made by both humans and computers, and broadband and spectrum level raw data files.

In "Educational outreach progress," we provide updates for each node, but highlight the new exhibit at the Seattle Aquarium and the completion of the outdoor listening station at Port Townsend. We also discuss the growth of web site usage and citizen science activities associated with the network.

Synopsis of the network: hydrophones to humans

The network continues to become more complex. Previously, new complexity arose mostly in the physical infrastructure -- hydrophones, intertidal protectors, amplifiers, and monitoring computers. In late 2008 through 2009, the majority of new complexity was digital and human -- better detection, classification, and notification software, as well as enhanced networking of listeners, researchers, activists, managers, and marine end users.

This section illustrates the current complex of actions that take place as underwater sound signals make their way through our hydrophones to an array of humans interested in killer whales and the marine environment. We summarize the network activities in outline form to give an overview. Then we describe each step in greater detail.

- Sense (cabled hydrophones and pre-amplifiers convert sound waves into voltage signals)
- Measure (PC or external sound boards digitize signal; Windows XP-based WHO Listener software calibrates signals, computes average receive levels, and transforms from time to frequency domain)
- Detect
    - Automated detection:
        - Trigger (Who Listener algorithms discern what sounds are "unusual" or likely to be killer whales using PKT, PWR, or other schemes)

            - Record (Who Listener records the trigger and a brief period around it in .wav format. Recording is compressed in .mp3 format. It is also transformed, and plotted as spectrogram in .jpg format)
            - Transmit (.mp3 and .jpg are uploaded to server; trigger is inserted into database; new trigger notification via email every 5 minutes)
            - Analyze (human looks at trigger spectrogram and/or listens to trigger, either via email or bulk analysis with database query display)
            - Detect (human classifies sound as from a killer whale or deletes trigger)
        - Human detection:
            - Transmit (.mp3 audio stream to Texas and out to 20-40 listeners)
            - Analyze (humans listens and optionally classify calls, infer pod, direction, etc.);
            - Record (optionally rips stream to .mp3)
            - Detect (human classifies sound as from a killer whale)
- Notify (different users have distinct access levels)
    - Public: detection@ or Google spreadsheet log
    - Trained listener: locate@ email, possibly via upload form with password
    - Moderator: password-protected tweet and upload form (location to database and via email to locate@ list)
- Map
- Model
- Avoid

Sense

The hydrophone network starts at the hydrophones in the water. There have been a variety of models used over the years from ITC, CRT, and LabCore, with many of the nodes being shifted to LabCore hydrophones because of their durability and ease of use. They do however have a narrower frequency band than the other hydrophones that we have used. The signal from the hydrophone is amplified at the hydrophone (pre-amp) and then run through cables to a digitization board (either an external or internal sound board). This acoustic data is then ready for the measurement step. The cabled transition through the intertidal is often the weakest link in the network with much wear and tear occurring during winter storms. This has been eased at the Seattle Aquarium, Port Townsend and Neah Bay by the fact that the hydrophones are dropped from piers which are generally sited in protected waters and because a dive is not necessary to replace hydrophones or cables. Lime Kiln and Orcasound continue to pose an intertidal challenge which we have met with various iterations of cable protectors over the years and many snorkels and dives.

Measure

As time and funding has allowed, we have calibrated each node using our Inter Oceans calibrated hydrophone. The general protocol involves placing the Inter Oceans hydrophone next to the streaming hydrophones while a large ship is passing by. This results in a loud and consistent sound source that can be used to cross-calibrate the two systems. The broadband sound pressure level (in dB re 1 microPa) measurement from the Inter Oceans calibrator (an analog dial) is then entered into the Who Listener software and is used to calibrate the voltage of the incoming acoustic time series, resulting in a calibrated amplitude measurement from the streaming hydrophones. Who Listener then computes average received levels at regular intervals and transforms the acoustic time series to the frequency domain to enable both time- and frequency-based detection routines.

Detect

Automated detection

Trigger

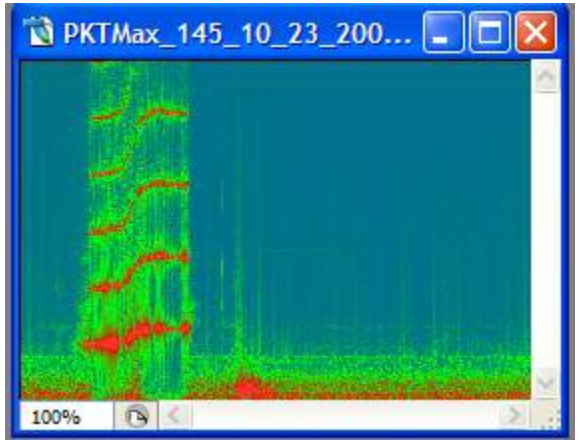
The WHO_Listener computer program triggers on 'interesting' sounds which pass frequency contour and amplitude profile tests. In its present configuration the frequency trigger seeks to detect orca calls, but exclude most "squeaky ship" noises. The trigger is activated by tonal signals that rise or fall for a duration similar to cataloged killer whale calls, but is not too repetitive. The amplitude trigger is activated when a sound has an average amplitude that exceeds a preceding running average by a specified threshold.

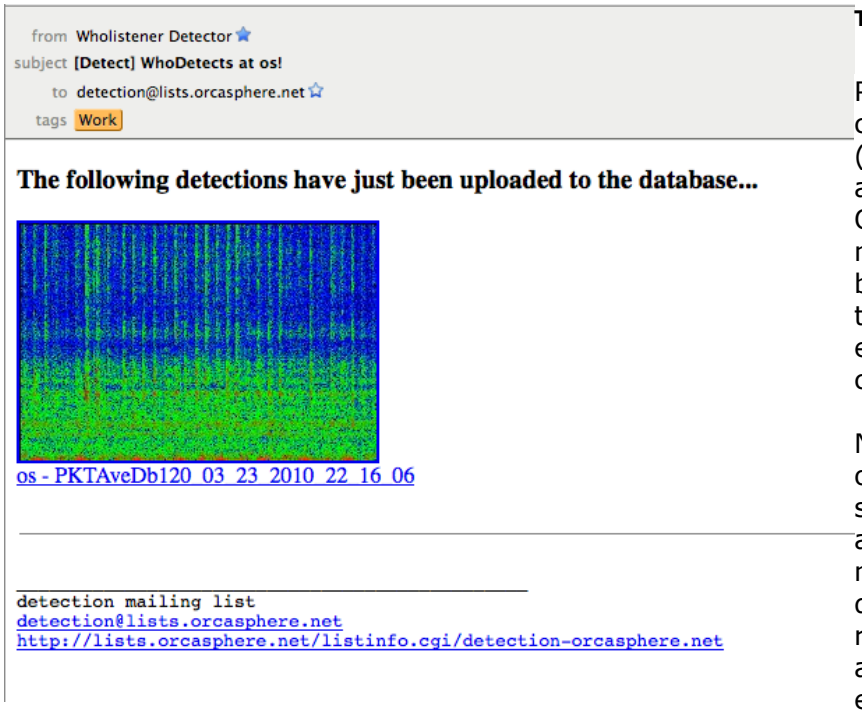
Record

Sounds are recorded as 16 bit WAV files at 44,100 hz sampling rate. These WAV files are stored in the monitoring computer at the location of the hydrophone node where the trigger occurred.

Analyze

The WAV files are then converted to mp3 files, to reduce their size, and a thumbnail image of a characteristic portion of the file is constructed. At right is an example of an image file (7 kilobyte .jpg) constructed to allow visual interpretation of the acoustic data file. This image shows the triggering portion within a 1 Mbyte WAV file. Conversion to mp3 reduces the size of these WAV files by more than a factor of 10 (from 1.025 Mbyte to 68 Kbyte in this case).





Transmit

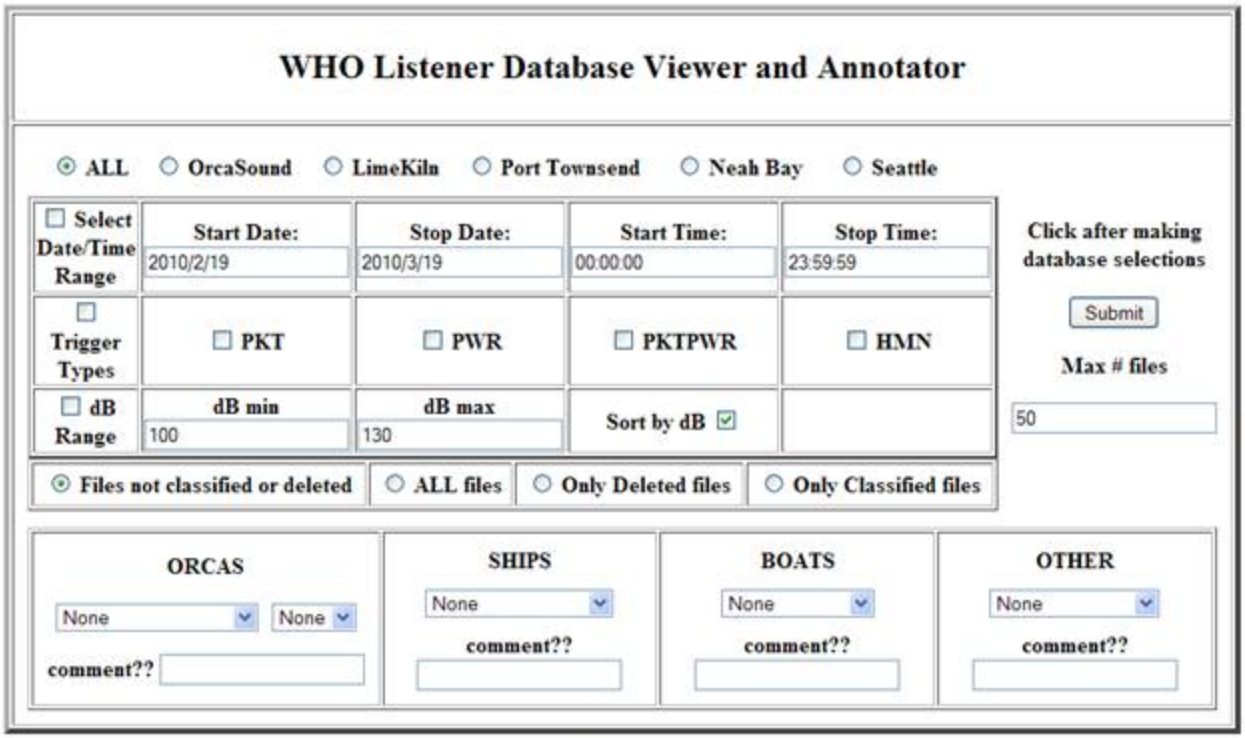
Previously, triggered recordings were archived on each node computer as .wav files and only assessed every few months (by accessing the node computer via a physical visit or remote access software). In 2009, Val added software to the Orcasound, Lime Kiln, and Port Townsend node computers that not only automatically compresses new triggered recordings, but also uploads them to a central server (orcasound.net). In this testing phase, the upload-and-notify frequency is once every 5 minutes, but the lag between detection and notification could easily be reduced to 30 seconds or less.

New scripts authored by Scott on the server then automatically organize the new recordings in a date-based directory structure. The node, recorded sound dB level, date, and time are all inserted into a mySQL database. Within less than 5 minutes from the time of a trigger at a hydrophone node, the database has been updated and the data are ready to be reviewed. Additionally, the scripts send an HTML email to the analysis team's distribution list with the spectrogram embedded and linked to the archived triggered recording (see example at left).

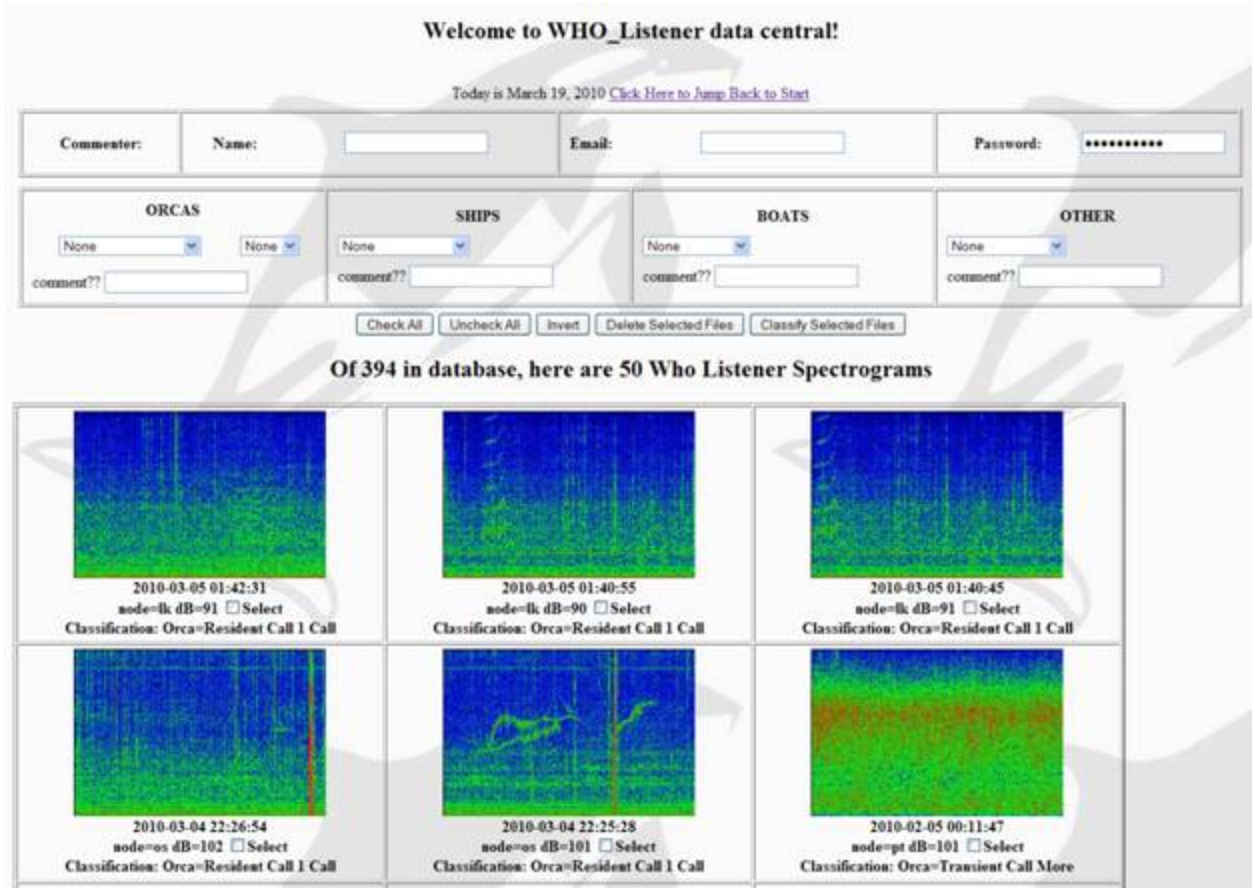
Analyze

The analyst then has a choice. Open the email to examine the most recent triggers (usually 1-2 triggers per email) or query the database and review a table of many recent triggers, possibly constrained to a particular node of interest, time period, trigger type, or dB range.

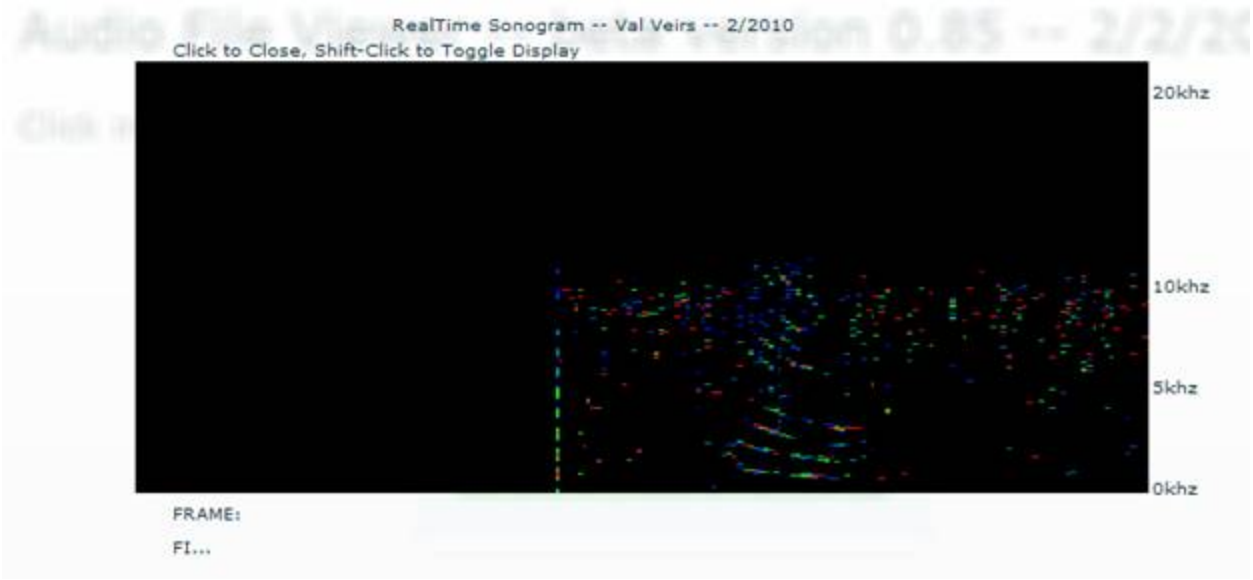
The current database query and classification program is at http://www.orcasound.net/php_vv/WHO_dbViewerAnnotater_II.shtml (see screenshot below). Via this web form, triggered sounds can be visually and aurally reviewed. Trained users can classify the sounds into categories such as orca calls, ship noise, speedboat noise, and other noises. Queries can be constructed by selecting from various menus to search the database for sounds based on node, date, time, dB level, orca classification(s), ship classification(s), boat classification(s), and other classification(s).



The figure above shows the database front end that allows users to both query the data base after selecting the various checkboxes and dropdown menu items as well as to classify sounds by assigning classification values to specific database sounds.



This screen shot (above) shows the result of a database query that includes orca calls. The analyst can scroll through the table of spectrograms, click the check boxes of sounds to be classified, and then specify and submit the classification via the form at the top of the page. To listen to the sound associated with a particular spectrogram, the analyst simply clicks on one of the spectrogram thumbnails; this activates a pop-up Flash player that displays a spectrogram which scrolls by in real-time as the audio plays (see snapshot below). (We are unaware of any other browser-based tool that can play a sound while simultaneously and instantaneously computing and displaying its spectrogram.)



Detect

Whether the review occurs via email or database query, the detection of killer whales is ultimately defined by the analyst. In the future, we could improve the confidence of the detection by verifying the classification with other analysts or computer-based classification software. It has not yet been implemented yet, but an obvious next step is to initiate an automatic notification whenever a qualified analyst uses the web-based form to classify one of the triggered recordings as a SRKW call.

Human detection

Transmit

A relatively novel aspect of the hydrophone network is that hydrophone signals are streamed live from each node in the network, in addition to being analyzed in real-time by the Who Listener software. This live streaming facilitates research by allowing human listeners to analyze the sound in real-time and report their detections of orca presence or absence. It also enlivens education and enhances marine environmental awareness by enabling students and stewards to monitor conditions in the habit of the endangered killer whales.

The live hydrophone signals are broadcast by a program called the WinAmp Shoutcast plugin from each node computer to a central streaming server (hosted by a company called Spacial Networks, spacialnet.com). The audio stream is then served to as many as 20-30 listeners per node who play the stream through free software like iTunes and WinAmp. The streams are accessed either through a web site (http://orcasound.net) where traffic is monitored using Google analytics or through a playlist maintained by the listener's player software.

Analyze

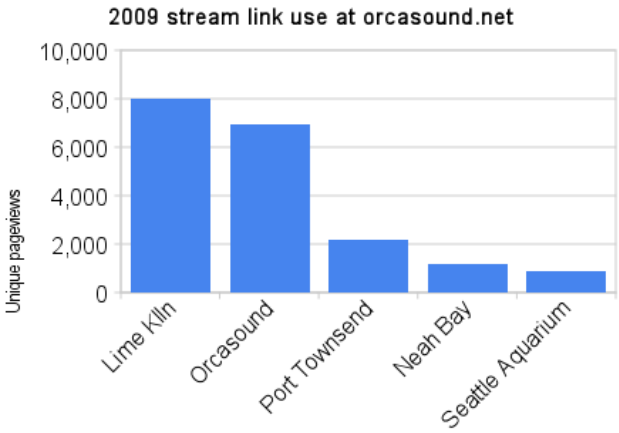
Human detection will presumably improve as the listening network grows. It should be particularly valuable to acquire new listeners in unique time zones, so that they can monitor the live streams when other listeners on the opposite side of the globe are sleeping.

We can gain two measures of the extent and behavior of the human detection network. First, we analyze the access log for the web site and quantify usage of the links to the audio streams. (In the educational section below, we undertake a more general analysis of web site usage to assess the outreach impact of the web site.) Second, we analyze the spacialnet.com log files which track connetions to the streaming server (a good measure of listening sessions).

Web site analysis

For the period 1/1/09-12/31/09 the total number of clicks on the "Listen to..." links was 25,471 page views or 18,857 unique page views. These 2009 values are up 28% and 25% respectively compared to 2008.

The chart shown at right breaks the total unique page views down by node to demonstrate that Lime Kiln and Orcasound are about 3-4 times as popular (and presumably well-monitored) as Port Townsend, which in turn is about twice as popular as Neah Bay and the Seattle Aquarium. The ranking of popularity was the same in 2008, except that Orcasound was slightly more popular then Lime Kiln. In 2009, about 81% of the unique clicks on the listen links targeted Lime Kiln or Orcasound.



Listening log analysis

At the date of this writing we have only been able to acquire spacialnet.com log files from a small portion of 2009. Thus, we cannot report the total number of audio stream connections or hours until the complete log files are recovered.

Record (optionally)

Some listeners have installed (often free) stream "ripping" software that allows them to record the live stream. The software typically creates a .wav or .mp3 file on their personal computer. In some cases, listeners archive or publish these recordings on their own web sites and/or blogs. In others, they email them to the network managers who verify, convert if necessary, and then upload them to the orcasound.net mp3 archive.

Detect

Detections are usually determined by the individual listener. In some cases, there is an assessment of a proposed detection -- either through email exchanges, phone calls, or the public collaborative listening log (a Google spreadsheet, 2009 | 2010) which conveniently has a "chat" window.

Notify

The population of listeners and web site visitors, along with a growing cadre of researchers, stewards, and educators have been helping test key elements of the real-time notification system.

When a news listener detects a killer whale sound, they can email detection@orcasound.net the public email address listed on the orcasound.net home page. Experienced listeners who have registered on the locate@ email distribution list can send a report to that list directly, or -- if they have been given the password -- may submit their report via a web-based form.

From August 2008 to December 2009, detection@orcasound.net has received 17 notifications, many from very excited first-time listeners and in a few cases before more experienced listeners or the automated systems reported a killer whale detection. Here are a few examples:

- December 22, 2009 from Shari Martens as J pod exited Admiralty Inlet: "Every single time, it brings such joy! Like hearing from a long lost friend! Right now I am in Westlake a suburb of Cleveland, Ohio. But, I also have a home in Windsor, ON Canada."
- September 9, 2009 from Laura Swan in Wheaton, IL: "I am listening to the Hydrophone at Lime Kiln Point and am currently hearing whales. It started at 3:17pm Central time (1:17 San Juan time), a gap for 2 minutes and then again at 3:19pm - 3:23pm after which the sounds (clicking and squeaks) are much further apart and appear to be gone by 3:27pm. Please let me know how else I can help! (I am excited since this is the first time I've heard them on the hydrophone.)"
- February 19, 2009 from Chrissy McClean of the Port Townsend Marine Science Center: "Turned on the hydrphone during our 'sound underwater' class for 3rd graders and heard orca calls. Visually confirmed with at least two individuals in southern Admiralty Inlet."

The locate@ listserve now has about 59 members who receive locations in real-time emails or daily summaries. Of this total which is almost triple the total 1.5 years ago, 18 subscribed in 2009. Prominent members added during the reporting period are Navy Region Northwest (via a special email address that is monitored by the Region Watch Commander, ROC Bangor to improve Navy awareness of killer whale locations), Brian Polagye of the University of Washington, Alison Agness of NOAA, Amy Traxler and Cindy Hansen of The Whale Museum, Darcie Larson of the Seattle Aquarium, Dom Tollitt of the Sea Mammal Research Unit.

As of February, 2010, the twitter.com/killerwhales feed (currently private) has 36 followers, double the number a year ago. It has provided 177 updates since its inception on 5/27/07, 96 of them in the last year. A prominent member added during the report period is David Dicks of the Puget Sound Partnership.

Model, map, and avoid

In 2009, we made some preliminary steps towards mapping historic location data and real-time "hearings" -- locations of whales determined by detection of sounds on the hydrophone network. These initial efforts are discussed in the Recommendations section.

Research progress

The research goals of the network are to measure ambient noise levels and detect SRKWs in different parts of their range, ideally in real-time. Overall, we have met both goals during the report period.

We continued to measure ambient noise levels at Lime Kiln, Orcasound, Port Townsend, and the Seattle Aquarium. We also began to do so at Neah Bay in mid-2009. There have been some gaps in the ambient noise records due to power and computer outages, as well software stoppages. Re-calibration of our standard as well as all network nodes is an increasing priority, for without more regular calibrations, we risk being unable to assess receive level drift when a hydrophone fails.

The detection of killer whale presence by humans and computers has been nearly continuous, in part because our streaming software is now more resilient, restarting automatically in many cases when power is lost. Below, we document the status and performance of each node, along with other notes and links. We also present a synopsis of key research progress at each node.

Orcasound node

Status: 4 refurbished hydrophones re-deployed 1/3/10 on re-furbished "tripod" stands (see photo at right)

Performance: Continuous streaming and data collection of calibrated sound pressure levels from a single ITC hydrophone, with minor power outages related to on-Island blackouts. Other hydrophones in the 4-element array failed over the report period and were recovered by SCUBA divers for refurbishment.

Existing equipment: 4 ITC hydrophones with custom pre-amps; shore box with amplifiers (refurbished); Windows XP desktop.

New equipment acquired: None.

Prospects for long-term operation: Good. Val and Leslie are on-Island nearly year-round and are deeply committed to the project. Most significant risk to hardware is likely purse seiner or shrimp trawler entanglement which has been minimized by deploying hydrophone stands <~40m from the shoreline.

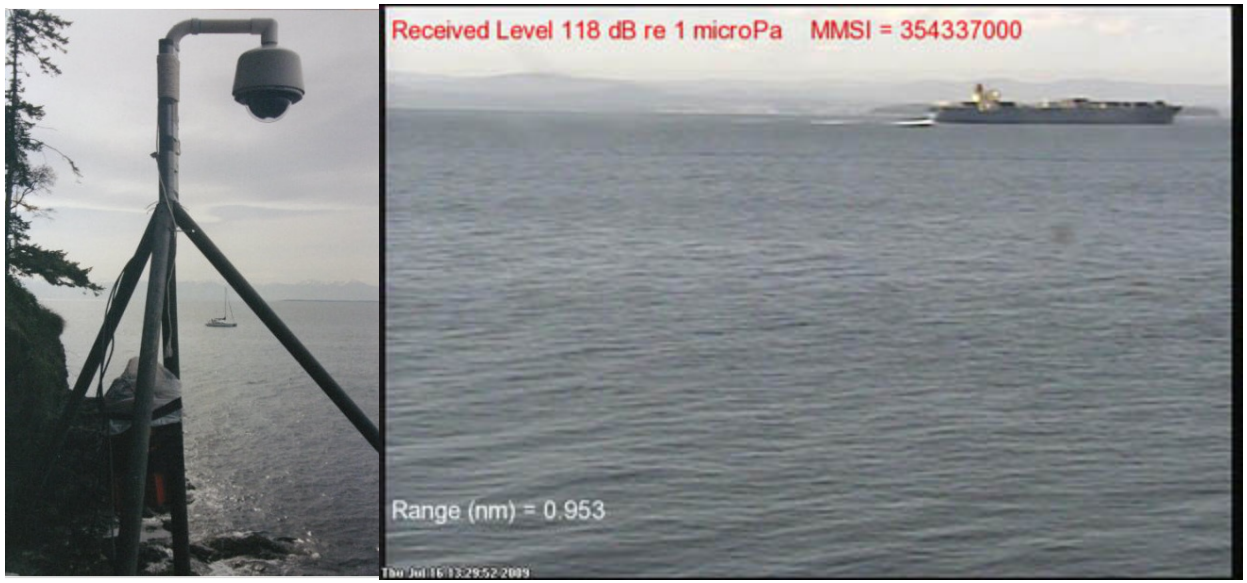
Links to meta/data:

- Detection log (select tab associated with node of interest)
- Human recordings (Flash-based player | raw data directory)
- Automated recordings (Query tool | raw data directory)
- Receive levels

The Orcasound hydrophones contributed to a number of killer whale detections along with the Lime Kiln node. These detections are summarized in the next section about the Lime Kiln node, but we emphasize that the Orcasound node is not simply a redundant node; rather, it often detects killer whales first when they are approaching from the north and in combination with the Lime Kiln node, it indicates the direction of travel along Haro Strait.

Last summer we developed a ship detector system using the Automatic Information System (AIS) and a video camera. Funded with non-NOAA money, this system ran for several months at OrcaSound as a proof of concept that might be of value to the hydrophone network project. The camera is a Pelco pan/tilt/zoom analog security camera that is controlled via a RS422 serial line. An AIS radio is monitored by a computer program that Val wrote. As ship locations and ID's come in, the program directs the video camera to point to the relative bearing of the passing ship. When the ship crosses a predetermined bearing (usually 270 deg true), the computer program grabs a frame from the video camera and overlays the received level of the underwater sound at the time, the identification number (MMSI) of the ship, the range from the hydrophone to the ship and the date/time

of the photograph. Simultaneously, the program records a short WAV file of the underwater sound. The program can track up to 5 ships simultaneously. Here is a photo of the camera, an example photograph and a montage of some of the hundreds of ships that were photographed and whose underwater noise was recorded in June and July, 2009.



This software is now running at Lime Kiln (without the video camera portion). We also experimented with live streaming of the video and synchronized underwater sound and live web control of the pan/tilt/zoom features of the camera.

Lime Kiln node

Status: 4 Labcore 40 hydrophones and 1 Reson TC4032 hydrophone.

Performance: During the winter 2008-2009, the refurbished Navy sonobuoy hydrophones failed on several occasions due to storms, which included the cable being completely severed multiple times. After several fixes they finally stopped working in the Spring of 2009. A temporary hydrophone was installed and used until the early summer of 2009 when a concerted effort was made to refurbish the hardware at Lime Kiln with funding from Beam Reach and Chuck Greene's bioacoustic class at the UW Friday Harbor Labs. Picture at right depicts a new hydrophone mounting base. Since then the hydrophones have been streaming most of the time. The Labcore hdydrophones form two arrays at Lime Kiln, one in front of the light house and one at Deadman's Bay. These are used for localization while the Reson hydrophone is used for broadband measurements. The array at Deadman's failed in the Fall of 2009 and is still not working because funding for dives has not been available.

Existing equipment: 8 Labcore-40 hydrophones and 1 Reson TC4032 hydrophone. Custom built computer.

New equipment acquired: All of the existing equipment was newly acquired.

Prospects for long-term operation: Good for the array off the light house. We installed a new cable protector through the intertidal which seems to be helping to protect the cables from damage. A follow up dive on this array in January showed that the hardware was faring well under water. The Deadman's Bay array is unknown at this point.

Links to meta/data:

- Detection log (select tab associated with node of interest)
- Human recordings (Flash-based player | raw data directory)
- Automated recordings (Query tool | raw data directory)
- Receive levels

In 2009, there were two rare and interesting observations facilitated by the hydrophones at Lime Kiln (and Orcasound). First was the detection of a U.S. Navy submarine and its surface ships using underwater communications systems and active sonar in spring, 2009. Second was the discovery of a new calf photographed on 11/11/09 that may not have been documented (as early as it was) without the early warning from listening network members who heard the calf's pod on the Orcasound hydrophone at 10:55 despite the members being widely spread out in Haro Strait.

The Navy's acoustic activity was monitored through the hydrophone network during much of the night of April 7, 2009, beginning around 7 p.m. The incident clearly would not have been observed without the hydrophone network and is described, including audio recordings, on the Beam Reach blog.

The following accolades and comments (via Orca Network email) demonstrate how a small contribution of the hydrophone network (and follow-up documentation by other means) can lead to a grand expansion of public awareness regarding marine environment issues and SRKW recovery:

> Nov. 11
> Thanks to Scott's hydrophone reports, I was able to head out to Lime Kiln (west San Juan Island) and look for the residents he heard. At about 2 PM we had Js and Ks head south, very spread out across Haro Strait. While its always exciting to see orcas in November, it was an extra special encounter since we saw J28 Polaris with what looks very much like a brand new calf! (See picture above.) At the age of 16 this would make her a first-time mother (as far as we know). I wrote a little more about the experience and posted a few more pictures at my blog.
> Monika Wieland, San Juan Island
>
> Later CWR wrote (via OrcaNetwork):
>
> New calf J46 - named "Star"
> A Star is born! On November 11, 2009 a brand new baby whale was seen in J pod swimming next to its mother at mid-day near the west side of San Juan Island. A few hours later at sunset the new baby and its extended family swam past the Victoria, BC waterfront before turning back toward Admiralty Inlet and Puget Sound for the night. On the 12th and 13th of November the new baby and family traveled extensively near Seattle, WA where they were received with great media excitement; and, on the 14th of November they were back near Victoria, BC. This family tour of the endangered whales' core habitat with a new baby seemed to be like "showing off" for a well- wishing crowd of humans that swarm the shores and waters watching them, but really they were looking for food - salmon. Puget Sound Chum salmon are in season for the whales' diet in early winter, but Chinook salmon are their mainstay diet year-round throughout their range, and they too are endangered.
>
> The new baby is designated J46, and we are going to call it "Star", for the role that it will play in showing the human inhabitants in this region that it is important to clean up Puget Sound and restore healthy abundant salmon populations to the Pacific Northwest. That mission brings a message to all of the relevant human nations - USA, Canada, First Nations, Treaty, and non-Treaty - that the first intelligent mammal residents of the region are also investing in these efforts. We could not ask for a more charismatic indicator, a baby whale, to measure the success of our renewed efforts for restoration. J pod is the most watched family of whales in the Pacific Northwest, or perhaps in the world; and, this is the first year in recent decades that they have produced three babies within one year. We will all be watching, here and worldwide, carefully and respectfully, to see if they beat the odds and all survive. This is the reality show that really means something.
> Center for Whale Research, San Juan Island

Beyond the main goals of detecting SRKW and measuring background noise levels, we have been working on understanding the impacts of shipping noise on SRKW vocalizations. The four element hydrophone arrays in front of the light house and at Deadman's were modeled beforehand to determine placement to allow us to localize SRKW vocalizations accurately as they passed by. The Reson hydrophone is then used for measurements of received level because of its higher frequency response. The Reson is also used for received level measurements of ships passing the lighthouse. Using the software mentioned above and an AIS receiver we automatically record passing ships at their closest point of approach, and have been collecting a catalog of these ship noise recordings since the fall, 2009. The range measurement from the AIS is also recorded allowing us to calculate source levels. These measurements along with localized SRKW calls should allow us to determine if there is an impact from shipping noise on SRKW acoustic communication.

Port Townsend node

Status: Dual hydrophones are providing audio stream, automated detections, noise levels, and a signal for the recently completed outdoor stereo listening station.

Performance: Single Labcore-40 hydrophone failed and was replaced with two refurbished Labcore-40 hydrophones purchased by Lynne at a reduced cost.

Existing equipment: PC running Windows XP Professional, Griiffin iMike; ~24" monitor; desktop speakers; Cetacean Research hydrophone and battery removed.

New equipment acquired: Dual hydrophones and cables; wall-mounted speakers and outdoor control box.

Prospects for long-term operation: Good. Thanks to the excitement caused by the arrival of the transient killer whale skeleton, the Center has gained substantial internal momentum and is funding or applying for funds to broaden the educational outreach impact of the hydrophones, and possibly improve the Internet infrastructure that enables the audio streaming.

Links to meta/data:

- Detection log (select tab associated with node of interest)
- Human recordings (Flash-based player | raw data directory)
- Automated recordings (Query tool | raw data directory)
- Receive levels

In 2009, we confirmed that the Port Townsend node could detect SRKWs even when they were located on the Keystone side of Admiralty Inlet (~6 km away). We also learned that this detection distance decreases with ambient noise level.

Concerted efforts at maintaining vigilant land-based observations around Admiralty Inlet in late 2009 allow us to estimate

detections rates with greater confidence than ever before. Of 22 known transits of the Inlet (entering or exiting Puget Sound), human listeners detected 38% and automated algorithms detected 57%.

Neah Bay node

Status: The node is non-operational due to a computer failure. To our knowledge all other infrastructure is in working order.

Performance: Streamed well through most of the reporting period. Logged ambient noise and automated detections June-October, 2009.

Existing equipment: Windows XP computer, custom amplifier box, ~200m cable, and dual recycled sonobuoy hydrophones with custom pre-amps.

New equipment acquired: Who Listener software installed and logging data June-October, 2009.

Prospects for long-term operation: Good. Our agreement with the Makah Tribe is still in place. We just need to get a new computer out there and functioning again. Further coordination with the Cultural Research Center would strengthen the Tribe's commitment to the project, particularly the hosting of the hardware and DSL connection at the pellet plant dock.

Links to meta/data:

- Detection log (select tab associated with node of interest)
- Human recordings (Flash-based player | raw data directory)
- Automated recordings (Query tool | raw data directory)
- Receive levels

The Neah Bay hydrophone system was installed on May 18, 2008, and came on line in July, 2008, after the Makah Tribe donated a DSL connection for the node. Despite intermittent radio interference, the node provided many new recordings including pile driving samples at a known distance and evidence that male harbor seals vocalize in the vicinity.

While no cetacean sounds have been recorded yet at Neah Bay, one human listener (Annie Reese) reported hearing faint killer whale calls on 9/28/09 at 11 p.m. PST. The next day, J, K, and L pods were observed at Constance Bank by Ken Balcomb.

The Who Listener monitoring software was installed on the Neah Bay when the system was calibrated on 6/12/09. Receive level data and automated detections were collected until the computer failed. Once the computer is recovered from Neah Bay (scheduled for spring, 2009), the automated detections and raw receive level data will be uploaded to the orcasound.net server (see links above).

Seattle Aquarium node

Status: Working well, including supporting completed listening station in the killer whale exhibit.

Performance: Near continuous streaming and logging of ambient noise data in 2009.

Existing equipment: Labcore-40 hydrophone with ~30m cable; Sony laptop (failed in 2009).

New equipment acquired: New Eee PC (borrowed from Beam Reach)

Prospects for long-term operation: Although our primary contact, Brooke Nelson, is departing for Maine, Darcie Larson will continue to act as a liason and Michael Darling is dedicated to maintaining the exhibit and research effort.

Links to meta/data:

- Detection log (select tab associated with node of interest)
- Human recordings (Flash-based player | raw data directory)
- Automated recordings (Query tool | raw data directory)
- Receive levels

No new research highlights, except that the explosive sound reported once previously was automatically detected multiple times in 2009.

Educational outreach progress

Live and recorded sound from the Network has supported successful outreach efforts both globally and regionally. On the Internet, the Orcasound web site (http://orcasound.net) provides the public and a growing global network of listeners free access to both live and recorded audio streams from the five network nodes. Regionally, the live audio streams and sounds recorded through the Network support educational programs and exhibits at The Whale Museum, Whale Watch State Park, Port Townsend Marine Science Center, and Seattle Aquarium.

The virtual audiences for our outreach activities are quantified below in our analysis of web site usage. The real-world audiences for our outreach activities are the visitors to the partner nodes (extant and potential). The following table presents

recent estimates of the number of visitors to each node:

Location	visitors per year	school children per year
The Whale Museum	30,000	9,000
Lime Kiln State Park	170,000	>3,000
Port Townsend Marine Science Center	20,000	6,000
Seattle Aquarium	735,000	155,000 (youth, see breakdown below)
Deception Pass State Park (West Beach)	~3,000,000	Not known
Total	~3,955,000	>174,000

There is also growing evidence, like the following excerpt, that live hydrophone signals are used by the whale watch industry to supplement their sighting information. This ultimately results in enhancing the educational outreach benefits to the whale watch customers.

> Oct. 26, 2009 (clipped from Orca Network email)
> We had an early start and had been fortunate to hear whales on the hydrophones (OrcaSound.net) from San Juan Island before leaving dock. We met up with about 30 whales from L Pod just rounding Turn Point into Boundary Pass at approximately 10:30 AM. A small group of Dall's Porpoise were also in the area, but left rather quickly as L Pod approached. The whales were in slow travel/resting mode, in 3 loose groups. The interesting thing was that they were not necessarily grouped by matrilines and several seemed to be more age-segregated than by family. The matrilines observed were L26's, L37's, L4's, L21's, L9's, and L35's. It was incredibly quiet in Boundary Pass, no freighters, and we were the only vessel with the whales until the Maple Leaf sailboat glided up. We left the whales at 11:15 AM, still headed eastbound in Boundary Pass near Blunden Island. A photo of one group is attached (300mm zoom and cropped). It was a very peaceful and beautiful orca encounter, with whale blows hanging in the cool, fall air. -- Joan Lopez, Naturalist, Vancouver Whale Watch

Citizen science

The most successful educational activity of the Network has been the organic, grass-roots growth of a global listening network since we began providing free audio streams in 2007. Listening live for orca calls has become a citizen science opportunity that has entrained about 100 regular and 10 expert users around the globe. New listeners use the Salish Sea sound tutor to recognize orca calls and even learn to tell which pod is present based on the calls each pod uses most often. Then when they hear killer whales they email detection@orcasound.net, an administrator verifies their discovery, and notifies the listening network via an email list-serve and Twitter feed. Expert listeners log their observations in a collaborative Google spreadsheet

and voluntarily record the stream, later submitting their data to a central archive. Listeners use a wiki of web cams and other real-time sensors around the Salish Sea to contextualize the underwater sounds and if they don't hear anything interesting live, they browse recordings using Flash-based "greatest hits" players embedded within the orcasound.net web site.

The Google spreadsheet that allows citizen scientists to collaborate in logging observations about the sounds on each hydrophone node (current, active log | 2009 log). These logs have proved invaluable for providing background metadata and to allow for us to focus our research efforts at appropriate times. In 2008 the log sheets had columns to enter the date, time and notes. A further column was added in 2009 to allow us to track who was logging the observations. These logs have seen steady growth, with most of the observations occurring at Orcasound, Lime Kiln and Port Townsend (see table below). In addition a core group of these observers have also been recording the audio streams on their own computers when the hear SRKW and then passing these on to Scott for uploading to orcasound.net.

		Orcasound	Lime Kiln	Port Townsend	Neah Bay	Seattle Aquarium	TOTAL
Aug-Dec 2008	count	52	70	118	81	4	325
Jan-Dec 2009	count	247	380	155	21	10	813
Jan-Dec 2009	# of known observers	13	18	12	3	3	26

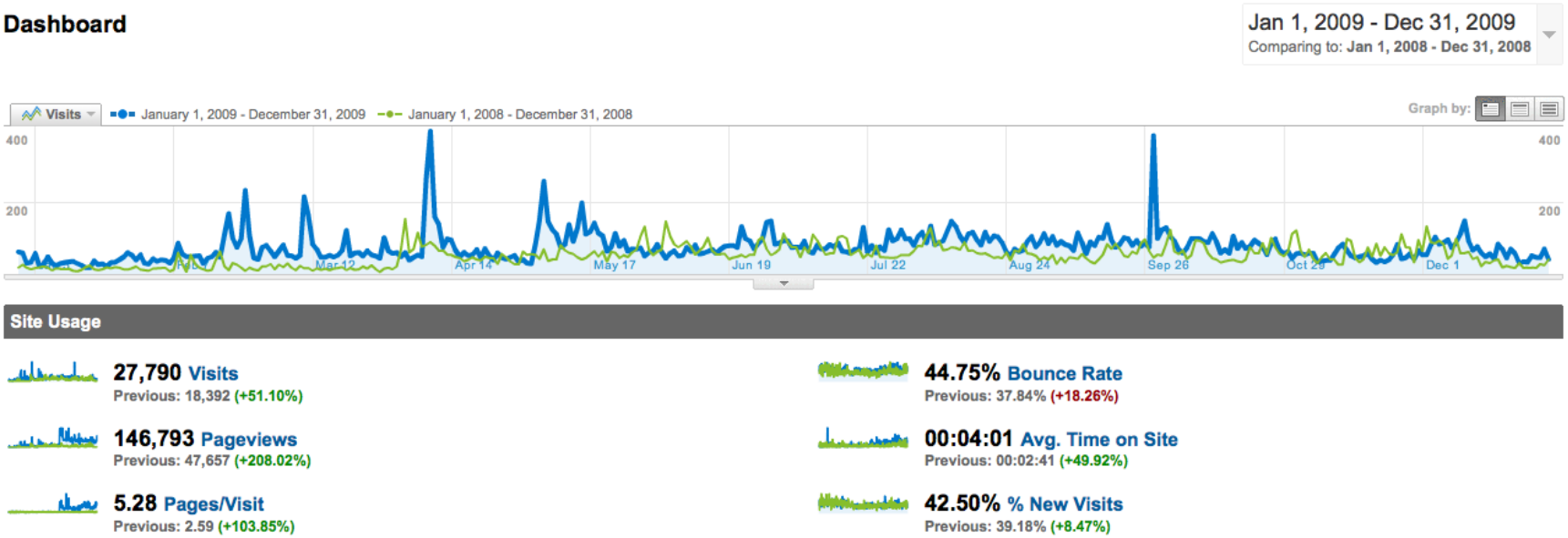
Note: the actual total number of known observers is lower than the sum of this row because many observers log observations at multiple nodes.

Scott has developed an "externship" -- step-by-step listening guide -- and associated handouts to help train docents and citizen scientists (e.g. larger groups at Port Townsend in 2008 and the Sound Waters 2010 conference).

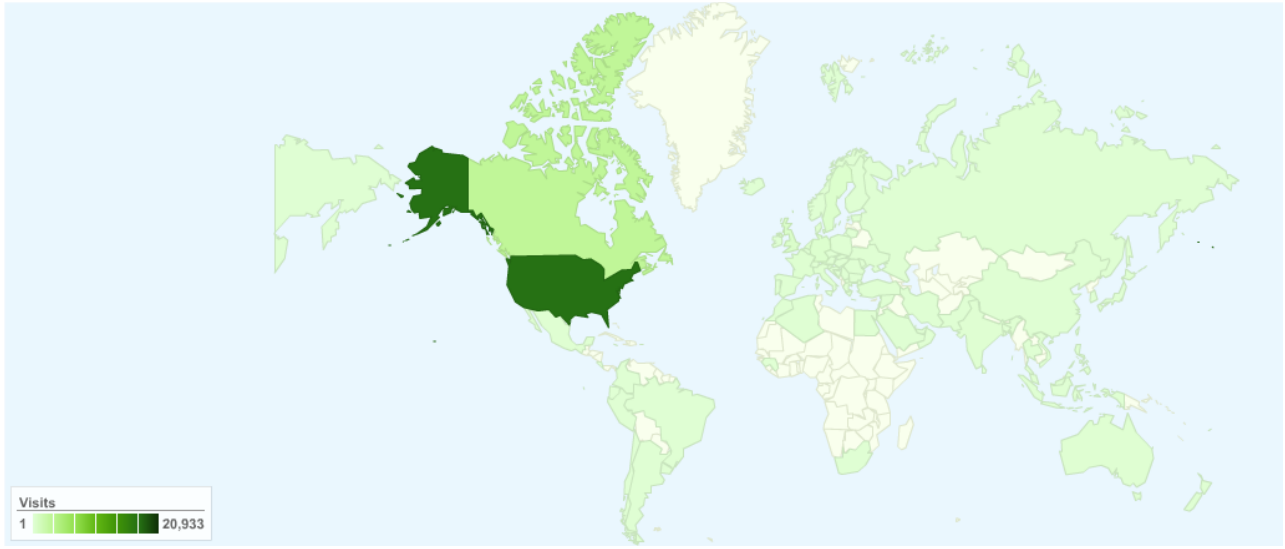
Web site access log analysis

Quantification of web site usage (web visitors and stream listeners) measures how human listeners facilitate our research goals (by providing detection and logging services) and our outreach goals (by notifying the network of listening opportunities). Of course, active members of the listening network are also learning about SRKWs so constitute a major educational outreach audience themselves.

The following screenshot from the Google Analytics report for orcasound.net shows the 2009 (blue) vs 2008 (green) statistics. All metrics have increased except the bounce rate. One indication of network growth is that the annual number of visits is up ~50% (to ~28,000 which is the same order of magnitude as the number of "Listen to..." link clicks) while the number of pageviews has quadrupled. The number of pages per visit has increased, indicating that many visitors are browsing deeper into the web site, though about 1/3 still visit only a single page and then bounce (depart the site).



The ~28,000 visits came from 95 different countries, predominantly the U.S. and Canada (see graphic below). Of these, 12,187 were absolutely unique visitors (excludes return visits from the same IP address). About half of the total visits are from users who only visit the site once; some 36% are much more loyal, revisiting the site 9-200 times, or more.



Status reports for each educational outreach location

Educational outreach projects in 2009 were coordinated in part through a social networking site: http://orcasound.ning.com/ This group has 20 members and utilizes ning.com tools for photo-sharing, discussion forums, reference/resource organization, and more.

The Whale Museum

In February 2008, The Whale Museum opened its refurbished exhibit halls to the public. Upstairs, at the entrance to the main hall there is new computer-based acoustics exhibit designed to introduce visitors to the underwater sounds of the Salish Sea. The visitor interacts with the computer using a large illuminated trackball and a large illuminated 'mouse' button.

Three of the exhibits teach the viewer/listener about the acoustic environment of the Salish Sea. A large screen LCD screen allows the user to click on the various OrcaSound.net nodes and listen to the current sounds. A second part plays characteristic underwater sounds recorded at a wide variety of places around the San Juan Islands and a third portion of the display shows seasonal and diurnal patterns in underwater noise centering on the ubiquitous examples of ship noise and the summer - daytime frequency of speedboats.

The other three exhibits use a similar large LCD screen to teach visitors about the vocalizations of the Southern Residents

showing the increase in source level that the whales use to overcome increasing background noise, a demonstration of the increase in the length of orca calls that has been published by Foote, Osborne and Hoezel, and a reconstruction of a conversation between a mother and her calf that was recorded on a linear hydrophone array by Beam Reach students while at sea on the Gato Verde.

These exhibits run 8 hours or more each day and have been very reliable. The coding was done by Val in the Python language.

Since the new acoustics exhibits opened, many visitors have viewed the exhibit halls. Some tarry for extended periods over the six acoustics exhibits and some just pass by seeming 'afraid' to interact with the Big Blue Ball and the Big Blue Button. One visitor happened to be a writer for the New York Times who is writing about underwater noises. We have been in continuing communication with her about underwater sounds in this region.

Lime Kiln

At the Lighthouse at Lime Kiln State Park, The Whale Museum has maintained the hydrophones and the low-power FM radio transmitter that allows park visitors to hear the underwater sounds of Haro Strait. Docents at the Lighthouse put a solar powered FM receiver out each day and visitors can turn the radio on via a timer. They can listen to the sounds. After a period (up to 20 minutes) the timer turns the radio off so that it isn't always blasting the often obnoxious sounds of speedboats and large ships. Val replaced the timer this year because the old one wore out from so much use.

The FM transmitter was causing interference with the audio equipment at Lime Kiln and was thus turned off in October 2009. Since SRKW and visitors at Lime Kiln are infrequent during the winter months we have not fixed the transmitter yet, but hope to do so this Spring. Last Spring the Beam Reach students helped Jason and Val do a major cleaning of the light house and reorganization of acoustic equipment. Another cleaning session with Beam Reach students is planned again this spring. In addition The Whale Museum is hoping to install another computer inside the lighthouse that would give visitors access to the hydrophone nodes and interpretive material, much in the way the Seattle Aquarium's new exhibit works. If a local wifi network can be created at the light house we could also provide access to this interpretive material (including audio) to visitors with wifi enabled devices (smart phones, ipod touches, etc.).

Port Townsend

In March, 2008, we installed a stereo speaker system on the outside wall of the Port Townsend Marine Science Center. These two speakers face the water and visitors can turn on a timer and listen to the real-time sounds while they look for the source of the sounds: ships or speed boats or ferries. Docents or PTMSC staff can adjust the volume at the stereo amplifier in the adjacent classroom.

The hydrophone at Port Townsend failed this past winter and was replaced with two of the hydrophones that Lynne Barre purchased for us. This set of hydrophones (four total) had visual blemishes but worked fine, so LabCore donated the hydrophones to us (estimated cost of donation $250 per hydrophone). $100 was charged for the 150 feet of cable that they added to each hydrophones so they could be used in our nodes.

In 2009 we completed the outdoor stereo listening station at Port Townsend Marine Science Center where visitors can simultaneously view and hear the "Puget Soundscape." While the stereo speaker system was installed on the outside wall of the building on the pier in March, 2008, the supporting signage had to await re-siding of the building in 2009. The sign was installed on October 15, 2009. Its content was developed by Chrissy McClean and Libby Palmer, with advice from Scott and Val Veirs, images donated by Jeff Hogan, and design/production by a local firm.

The outdoor listening station, interior monitoring computer, and the web-based audio streams have all been utilized in teaching guests, visiting students, and the general public about underwater noise pollution and killer whale conservation. In 2009, the Center held a training for their docents (taught by Scott Veirs) in which they learned how to interpret the monitoring computer for visitors and how to participate in citizen science efforts while listening to the live streams from home.

Accolades -- *January 27, 2010 email from Chrissy McLean: "One of the maintanance guys was talking to me this morning about the hydrophone sign and speakers -- he was amazed when he turned it on to hear the ferry all the way over by Keystone, saying "I had no idea how far sound travels out there"-- hooray, success!"*

The Center hosted about 1,000 3rd and 4th grade students for Free Classes on Orcas and Sound Underwater. These programs are targeted at underserved schools on the Olympic Peninsula. In addition to learning about orca communication and the impacts of underwater noise, they also learned about the hydrophone network and its use by researchers to study orcas. One teacher commented, "Interest in local marine life has grown tremendously as a result. We study salmon extensively and the tie

in with the Orca food chain became more important. [The classes] also raised interest in the overall health of the Sound."

Seattle Aquarium

In 2009 we helped create an acoustics exhibit at the Seattle Aquarium. The Aquarium now hosts a listening station where visitors use a trackball to navigate a map of the live audio streams and images linked to recorded sounds from each Network location. This listening stations is located in the Family Activity Center (FAC)– a marine mammal hub adjacent to the big underwater dome. While fur seals and sea otters dive past visitors one side of the room, the majority of the space is dedicated to presenting the parallels between our human families and those of our regional icon, the killer whale, or orca.

The listening station project was proposed by Brooke Nelson and Scott, managed by Michael Darling, and implemented by Scott (web design/html/ php); Val Veirs (Java coding); Grant Glover, Jesse, Zach, Gary, and team at Pacific Studio (art and kiosk fabrication); and Steve Harvey and Richard Ramsby (demolition, Internet, and installation).

Since the station needed Internet access for the live streams, we decided to host content on-line, primarily for ease of maintenance, trouble-shooting, and future enhancement. If you don't have a chance to visit the Aquarium and test it out in person, you can view the pages here: http://orcasound.net/sakiosk/

The site delivers sound through a Java-based audio player called jlGui that can handle both recorded mp3 files and Shoutcast streams while embedded and hidden within a browser window. There are also some nice photos and words to go along with the sounds. In the Aquarium, the content is presented on a 22" monitor (using 1280×768 resolution) by an Eee PC running Firefox with the Open Kiosk plugin over Windows XP Home. A nice feature of this Eee PC is you can set it to keep running when the case is closed; that enabled us to fit it easily in the constrained space behind the mural.

The highlights of watching folks try it out on the first day were hearing a 9 year-old boy walk away saying "That was really cool," and a mother telling her child as they departed, "How would you feel if you had to listen to that all day?" Google Analytics suggests that thus far, about 20 unique visitors per day are listening to the underwater sounds for an average of about 2 minutes.

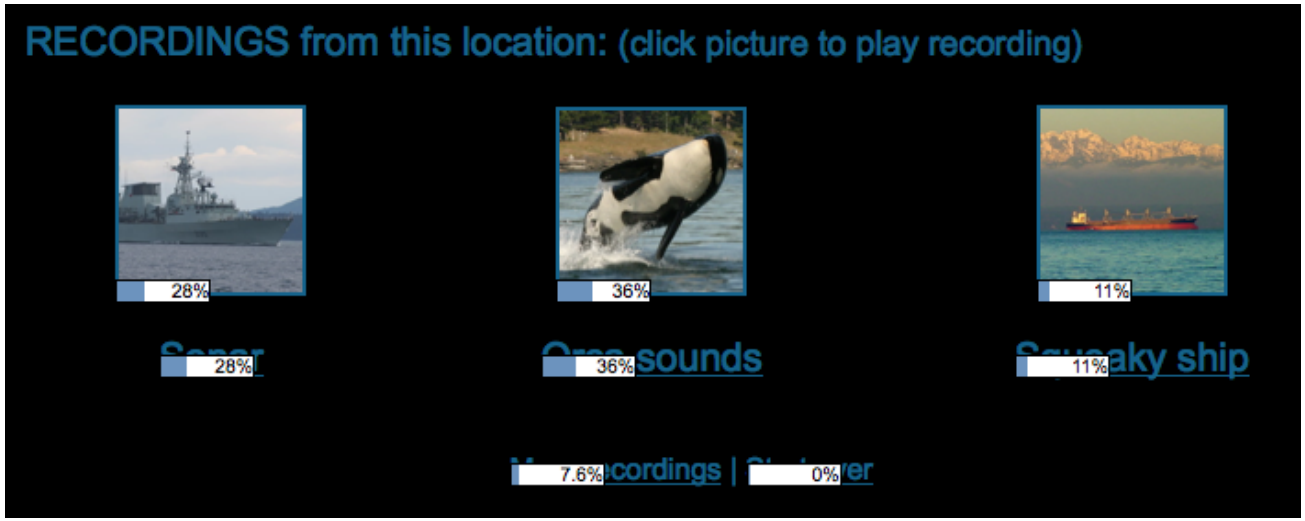
More photos of the listening station

Steve Harvey of the Aquarium has led the maintenance of the exhibit. He reports replacing about 1 headphone per month (a $10/month cost borne voluntarily by the Aquarium) and having to reset the Firefox kiosk browser and associated javascript stream player about once per week on average.

One advantage of implementing the listening station content as a web site is that we can use Google Analytics to monitor usage patterns. Since the site was launched on July 30 through December 31, 2009, the sakiosk portion of the orcasound.net site experienced 80,500 total pageviews. This works out to ~500 average pageviews/day (max ~1500; min 48). (Visitors and visits are not good metrics as new Aquarium patrons typically use the kiosk less than 30 minutes after the previous patron and are thus categorized by Google as the same visitor...) The following table shows how the total pageviews are distributed across the most popular 5 web pages on the sakiosk site.

Pages	Pageviews	% Pageviews
/sakiosk/sounds/calls.php	8,426	10.45%
/sakiosk/sounds/orcasounds.php	7,335	9.10%
/sakiosk/sounds/mystery.php	6,845	8.49%
/sakiosk/sounds/clicks.php	4,801	5.96%
/sakiosk/sounds/seal.php	4,633	5.75%

A general pattern is that links associated with animals or curiosity ("mystery question mark or SCUBA diver) win the most clicks on any given page. The following screengrab with overlain Google click rates for links on that page demonstrates this tendency (percentages don't sum to 100 because ~20% of clicks are on the adjacent map of live listening links).



Neah Bay

We have had another conversation with Janine Bowchamp. In 2009, she gave us a tour of the Makah Cultural and Research Center's classroom in Neah Bay (see photo below). She expressed interest in using the hydrophone sounds in some of their classroom activities. In anticipation of supporting such activities, we have created an archive of Neah Bay sounds at http://orcasound.net/nb

Recommended improvements

Improve calibration of ambient sound pressure levels

Our ability to monitor trends in ambient noise spectrum and broadband levels in the Salish Sea is dependent on our ability to calibrate the hydrophones across the network. At the moment this is done with a single Inter Ocean calibration hydrophone (sensitive from 20 Hz to 10 kHz) . This hydrophone has not itself been calibrated for a number of years. It is in desperate need of recalibration, and a second calibration unit is needed to allow double checking of the calibration units on a regular basis as well as even more frequent calibration of each of the nodes. With the expansion of the network it is not logistically possible to move one calibration unit around fast enough to calibrate the nodes on a regular enough basis. We need a calibration unit based on San Juan while the other travels to more distant nodes or to a calibration facility.

Ideally, a new calibration unit would have a flat frequency response up to at least 100kHz to also calibrate field hydrophones like the Reson at Lime Kiln. Combined with the localization array and Automatic Information System deployed at Lime Kiln in 2009, such a calibration would enable us to report source spectrum levels for vessel and whale sounds across the auditory response frequencies of killer whales.

Refine automated detection and classification

The new trigger database and software makes it quick and easy to review the triggers, classify them, and detect orca calls. However, before we can have the WHO Listener system reliably alert orca researchers to the presence of orca calls (rather than any unusual sound), we still need to work on ways to reduce the number of false positive triggers. We will continue to make steady progress at the maintenance funding level by refining our algorithms, but recommend increased resources be applied to the problem.

Foremost, Val should be properly compensated for his Herculean efforts with support to refine the automated detection, upload, notification, and classification system he has pioneered. With continued or increased funding he could implement the genetic-tree classification scheme he presented at the 2009 conference of the Acoustical Society of America. This could set up a competition between automated classification methods and human classification using the annotation tools Val has running on the orcasound.net server.

Val and the Network could also benefit from opportunities to collaborate with other experts in the field, possibly through a workshop addressing the automated detection and classification of killer whale calls in noisy environments. It would be ideal to migrate from our current suite of custom detection and classification software to an open-source software project like PAMGUARD, in which our detection algorithms could be supplemented with existing ones for marine mammal calls, clicks, and whistles.

Bush point prospect

The hydrophone at Port Townsend has inadvertently become of major use to researchers trying to determine the usage of Admiralty Inlet by SRKW in respect to both the Snohomish PUD and Navy's proposals to place tidal turbines in that area. The Port Townsend hydrophone and efforts by Snohomish contractors has allowed us to quantify our detection rates and get better estimates of detection ranges in that area. In addition hydrophone detections have also helped in notifying researchers so they could undertake field responses in the area.

If these projects are going to go forward there will be a need to detect SRKW in Admiralty Inlet so that turbines can be shut down. Automatic passive acoustic detections will likely play a large role in that effort. As such we feel that it is important to try and fund new nodes in this area such as the node we have previously proposed at Bush Point. This would allow for detections of SRKW coming from the south into Admiralty Inlet. We have also developed good contacts at a site near Deception Pass State Park.

In addition a broadband high quality hydrophone would be a good addition to the Port Townsend node to help better quantify background noise levels in Admiralty Inlet, pre- and post- turbine installation. This would also allow us (with the addition of an AIS receiver) to expand our efforts at Lime Kiln where we have been using a calibrated Reson hydrophone to catalog and

measure commercial ships that utilize the Salish Sea. We would thus be able to measure the majority of international shipping heading to the ports of Vancouver, Seattle, and Tacoma.

Docent and wireless outreach

In order to expand the interpretive outreach of the hydrophone system we have applied for funding, along with our partner organizations, to expand the interactive content on our web sites and at each of the nodes. This would involve more interpretive material to improve the environmental literacy of the public and specifically the conservation concerns for this particular species. Each node would be outfitted with expanded wifi to allow access to the content and audio streams from the public's own portable devices. The training of docents would also occur to help facilitate the interpretive experiences of visitors. We have unfortunately not found funding for this project yet.

Improve orcasound.net web site

- Make upload form a focal point for reporting (on orcasound.net) that is accessible based on member access model (Wordpress plugin).
- The form data should be verified and then generate simultaneously: tweet, locate@ email, database entry, and map/ model update.

Add streaming video from Lime Kiln

Both research and educational outreach activities would be enriched if streaming video was available along with the underwater audio stream. We recommend building on the early strides that Val and his students have made at Orcasound and shifting to Lime Kiln as a test bed. An early goal would be to provide live video from the real lighthouse to the lighthouse exhibit within The Whale Museum. Beginning with Lime Kiln would also give the greatest value at other nodes (PT, SA, NB, OS) because the SRKWs approach closest to shore most frequently at Lime Kiln.

Ideally, we would use a combination of pan-tilt-zoom video (to enable web-based interactivity for viewers) and three 60-degree fixed field-of-view web cameras (one in each of the lighthouse upper windows to enable motion-detection software for research and automated notification). We anticipate the imagery from these cameras will be useful for whale watching, ship monitoring, and contextualizing other underwater sounds.

Enable geographic mapping and notification

- Expand initial effort to map current and predicted locations to identify and anticipate listening opportunities ($3000 grant in late 2009 to Beam Reach from the Northwest Fund for the Environment).

- Improve tools to visualize historic Orca Master data set and make available to the public.
- Enhance web-based open-source GIS prototype to enable geographically-triggered or constrained notifications (e.g. for Whale Trail listening/viewing opportunities, oil spill avoidance, tidal power shut down, etc.
- Develop models that predict SRKW models as probability surfaces that heed bathymetric constraints and are less simplistic than the simple velocity filter (expanding circle based on mean swim speed) now used in the prototype map interface.
- Use the real-time reported and predicted locations to help managers mitigate or prevent new impacts on the SRKWs, ideally by avoiding collisions or dangerous juxtapositions (e.g. of SRKWs and oil tankers, Navy sonar sources, seismic surveys, pile driving, spinning tidal turbines, etc).