Human versus automated detection of killer whale calls[1]

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Abstract:

When endangered southern resident killer whales enter the urban estuary known as the Salish Sea, their characteristic sound signals (calls, whistles, and echolocation clicks) blend with the noise from commercial ships bound for the ports of Vancouver, Seattle, and Tacoma. In such environments where signal-to-noise ratios are low or noise mimics signals, human listeners provide validation of automatic detections and increase overall detection rates. By giving both citizen scientists and computers real-time access to underwater sounds, the Salish Sea Hydrophone Network allows comparison of human and automated detection rates. In a case study where killer whales passed a proposed tidal turbine site 22 times, they were detected acoustically by the automated algorithm 14 times (64% detection rate), by human listeners 10 times (45%), and by either system 17 times (77%). During local daylight hours, human detection rates rose to nearly match automated levels and had zero false positives.

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I. Crowdsourcing real-time data streams

Over the last decade the proliferation of computers and mobile devices has fueled a rapid expansion of scientific data collection by citizen scientists (Delaney et al. 2007; Honicky et al. 2008; Cochran et al. 2009; Sullivan et al. 2009; Dickinson et al. 2010). Some projects crowdsource analysis of archived data sets (Orchive; WhaleFM; CamClikr), while others develop games in which humans are challenged to solve difficult computational problems (Cooper et al. 2010; EteRNA) or annotate large multimedia databases (Barrington et al., 2012).

Analysis of data streams by citizen scientists *in real-time* has many potential applications and benefits, but is comparatively rare. Furthermore the most popular live data sources rarely provide opportunities for citizen science. For example, wildlife web cameras like Cornell University’s BirdCams provide live feeds that are very popular, but only offer observers a chat room. Similarly, few of the growing number of live hydrophone streams (Table I) have offered listeners ways to become citizen scientists. One exception is OrcaLab which offers an in-browser chat room to discuss killer whale sounds heard via real-time audio streams (Orca Live) and an on-line archive that citizen scientists are indexing (Orchive).

In marine bioacoustics and passive marine mammal monitoring in particular, autonomous or cabled recording systems often accumulate large volumes of data. Software and humans can process such archives in search of patterns, but depending on the nature of the signal and the noise, it can be computationally-intensive and time-consuming (Mellinger et al., 2007; Munger et al., 2005). Furthermore, the detection procedure is often so specific that unexpected signals are missed.

We describe an alternative approach in which live audio streams from cabled hydrophones are provided to both computers and human listeners for real-time monitoring and signal detection.

Because continuous recordings are not archived, this technique greatly reduces demand for data storage and post-processing resources.

The main benefit of live streaming and real-time analysis is that presence or absence information can immediately guide mitigation, research, or stewardship. Live streaming also enlivens education and enhances marine environmental awareness by enabling students and stewards to monitor current ocean conditions. It motivates citizen scientists to monitor the data stream because they seem to enjoy being the first to discover something and knowing they are witnessing a natural phenomena as it happens.

II. Real-time detection of endangered killer whales by humans and computers

Both human and automated detection of real-time ocean sounds are useful in the noisy inland waters of Washington State and British Columbia known as the Salish Sea. Haro Strait between Vancouver Island and the San Juan Islands is the core summertime habitat of the southern resident killer whales (SRKWs) -- an iconic population that is listed as endangered on both sides of the U.S.-Canada border. The SRKWs should be easy to detect acoustically because they emit a wide range of distinct vocalizations, including pulsed calls, whistles, and echolocation clicks (Ford, 1989) and are acoustically active except when resting. Passive acoustic monitoring for SRKWs in the Salish Sea is complicated, however, because about 20 commercial ships transit Haro Strait daily (V. Veirs et al., in prep.). Many of these ships emit intense tones (Mckenna, 2011) or clicks that are similar to SRKW signals. Within this soundscape it is difficult to automatically detect killer whale vocalizations without ship noises generating an overwhelming number of false positives.

Yet, reliable real-time detection of SRKWs is needed to enable rapid responses by researchers who seek field data from SRKWs.   To meet these needs and surmount the automated detection challenge, we have provided real-time hydrophone audio streams to the public and asked citizen scientists to listen for whales (and other interesting sounds).

Real-time acoustic detections by a combination of humans and computers supplement location reports from sighting networks, particularly at night and during inclement weather. These new detections also help define SRKW habitat use and nighttime acoustic behavior.

Real-time locations of SRKWs are also useful for mitigating potential impacts on the population. In the event of an oil spill, the Northwest Area Contingency Plan will need up-to-date locations to guide decisions. Tidal power turbines and pile driving projects could reduce the potential risks they pose to SRKWs with knowledge of their real-time distribution. If ship noise proves to be a significant risk to SRKWs, then whale locations could be used to reroute vessels or adjust their speed – just as is done for North Atlantic right whales in Massachusetts Bay (Clark et al., 2010).

Real-time notification of live listening opportunities enables novel educational and outreach activities designed to facilitate the recovery and conservation of the SRKW population. The established popularity of orcas can combine with the inherent excitement of listening live to the ocean in exhibits at marine educational centers around the region.

III. The Salish Sea Hydrophone Network

The Salish Sea Hydrophone Network is a cooperative effort of scientists, educators, managers, and citizens in the Pacific Northwest (Fig.1). The Network is an outgrowth of the SeaSound project – an effort initiated by The Whale Museum in the 1970s to monitor underwater sound at Lime Kiln [aka Whale Watch] State Park on the west side of San Juan Island. In the early 2000s Val Veirs developed the Orcasound laboratory 5 km to the north and then led The Whale Museum to revamp the Lime Kiln node. Since 2006 the Network has grown and been maintained through funding from the National Oceanic and Atmospheric Administration and additional financial support from Colorado College, Beam Reach, the Washington Department of Fish and Wildlife, and individual Network members.

Today the network consists of cabled hydrophone systems deployed across the critical habitat of SRKWs (Fig. 1) and a web site – orcasound.net – that offers public access to real-time and pre-recorded audio streams. In addition to the original partners (The Whale Museum at Lime Kiln, and Orcasound laboratory), regional collaborators that host hydrophone nodes now also include 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 levels around the Salish Sea, patterns of SRKW critical habitat use, as well as furthering our abilities to acoustically detect SRKWs for citizen science, research, and stewardship projects.

With broader access to the Internet the Network has become a global experiment in sharing and processing real-time underwater sound. Development of outreach activities by the Network partners, as well as educational and advocacy organizations like Orca Network and Killer Whale Tales, has led to better detection, classification, and notification software systems, as well as enhanced networking of listeners, researchers, activists, managers, and marine end users.

Taken together, this Network of hydrophones, computers, and humans has evolved into an automated and crowdsourced acoustic detection system. Hydrophones sense underwater sound and shoreside computers digitize the signal. Software and citizen scientists detect signals, classify sounds, and notify Network members.

A. Network hardware

A typical Network node has at least two hydrophones installed on site for redundancy and to enable stereo listening. We have tried many makes and models over the years but are currently using a combination of hydrophones manufactured by International Transducer Corporation, Cetacean Research Technology, Reson, and LabCore. Most of the nodes now use LabCore hydrophones because of their relatively low cost ($300), durability, ease of use, and minimization of cable and flow noise. The LabCore40 hydrophones however have a narrower and less-flat frequency response than other hydrophones we have used. In general Network hydrophones have been chosen to be sensitive from at least 500 Hz to 15 kHz. All hydrophones are located within 100 m of the shoreline and are deployed at depths of 5-15 m for ease of maintenance.

At Lime Kiln and Orcasound where wave and tidal power are high, we mount hydrophones on weighted stands and use intertidal cable protectors. At nodes where a dock structure is available (the Seattle Aquarium, Port Townsend, and Neah Bay), the most successful deployment method is simply dangling the hydrophone vertically into the sea between pilings. The analog signal is digitized (48000 samples/sec, 16 bit) using a sound board in a Desktop with an uninterrupted power supply, or more recently a netbook with batteries capable of enduring brief electrical outages. An Internet connection with an upload bandwidth of at least 100 kbps supports the audio stream and our other data transmission needs.

B. Detection by computers

WHO_Listener (Washington Hydrophone Observatory Listener) is a computer program that monitors a real-time audio feed and triggers on ephemeral sounds. The program is written in C++ using Microsoft's Visual Studio (2008) and consists of the following independently-running threads (Fig. 2): data acquisition, spectral analysis, amplitude calculation, noise monitoring, event triggering, event reporting, and Internet uploading.

In the data acquisition (DAQ) thread, mono or stereo audio streams from a analog-to-digital sound card are sent to a ring buffer containing the most recent 10 seconds of audio data. The purpose of the ring buffer is to maintain access to earlier data needed by the triggering and reporting threads. Each time that a new datum is added to the ring, the oldest datum is overwritten and the event is posted to other threads.

1. Spectral analysis

The spectral analysis thread takes data from the ring buffer and computes power spectral densities (Fourier transform size 2048, Hanning window, 10% overlap). From these spectra, the thread calculates short- and long-term average spectra. The short-term average power spectrum is calculated by adding 10% of the new value of each frequency component to 90% of the previous average. For the long term average, the weightings are 1% and 99%, respectively. These choices result in e-folding times of about 0.5 and 5 seconds respectively.

2. Amplitude calculation

The amplitude thread also takes data from the ring buffer and calculates short- and long-term averages of the RMS amplitude using the same weighting scheme as in the spectral analysis. Calibration of the amplitude signals is applied here.

3. Noise monitoring

Every 5 seconds the power spectrum is saved to maintain a running average of power statistics (means and standard deviations). Every ½ hour, these statistics are written to an archive text file on the node computer.

4. Event triggering

WHO_Listener has two detectors designed to trigger on SRKW signals. The peak-tracking detector (PKT) is an energy sum detector. It monitors the evolution of peaks in the power spectrum and triggers when harmonic structure and duration are consistent with typical SRKW calls. The power-excursion detector (PWR) is an amplitude detector. It monitors signal power and triggers when the signal power briefly exceeds a threshold typical of nearby SRKW calls, whistles, or clicks (or other ephemeral sounds).

The peak-tracking detection is accomplished by computing the scalar product of sequential third Fourier transforms. The averaged spectral densities from the spectral thread are themselves Fourier transformed yielding a function similar to the cepstrum without the cepstrum's intermediate log transformation. Then a final Fourier transform is applied yielding a function of frequency that is sensitive to killer whale calls. A scalar parameter for tracking such tonal sounds is constructed by taking the scalar product of the lower-frequency portion this third Fourier transform of the original time-series data with the immediately previous such transform (delayed 0.1 seconds). This parameter (PKT) rises and falls smoothly when receiving signals that have continuous and relatively simple frequency structure similar to killer whale calls.

The parameter used for the power-excursion detector (PWR) is the logarithm of the ratio of the short-term (signal) and long-term (background) integrated power spectra that are computed in the spectral analysis thread.

Both triggers have amplitude and timing criteria; the trigger must remain between specified amplitude thresholds continuously within a specified time interval before a detection is logged. When either the spectral signature (PKT) or the power amplitude (PWR) rises above a starting threshold, a flag is raised reporting that a trigger may be starting. From that moment on, a timer assesses incoming spectra or average signal power. If the trigger signal remains above the starting and ending Schmidt trigger thresholds within the specified time interval, then an event has been detected. After tuning during real-time operation, we initiate the start of a trigger when a trigger parameter rises above 120% of a specified threshold and teminate when the signal drops below 80% of that threshold. The thresholds that we use are 0.7 for PKT and 10 for PWR and the minimum and maximum duration of a trigger must be between 0.5 and 5 seconds. With these parameter settings, killer whale calls are rarely missed (not detected). This triggering process is thus not based on an absolute amplitude threshold and can detect quiet calls when background noise levels are low.

5. Event reporting

Whenever a trigger occurs, a detection is written to disk. This involves going back in time in the ring buffer by a specified number of seconds prior to the start of the trigger (usually 2 seconds) and then copying data from the ring buffer until some time (usually 5 seconds) after the event trigger has terminated. A WAV file is generated with metadata encoded in the WAV file. Metadata including node location, sampling rate, word size, number of channels, etc. are stored in the header of a (16-bit, 44.1 kHz sampling rate) WAV file and date/time and dB levels are stored in a constructed filename. These WAV files are stored in the monitoring computer at the location of the hydrophone node where the trigger occurred.

6. Internet uploading

If WAV files have been created recently (within the last 5 minutes), then the ~1 MB WAV files are converted to ~100 kB MP3 files and a ~10 kB thumbnail image of the spectrogram of the trigger is created. These compressed files are uploaded to orcasound.net where every 5 minutes server-side scripts archive the detections, enter metadata for each in a mySQL database, and send analysts an HTML email with the thumbnails embedded and linked to the archived detections.

C. Detection by humans

From each Network node, live hydrophone signals are broadcast as 48 kbps stereo MP3 streams by the WinAmp Shoutcast plugin to a commercial streaming server. The audio stream is served to as many as 20 simultaneous listeners per node who play the stream through free software like iTunes and WinAmp. Demand for the Lime Kiln audio was high enough in the summer of 2011 to warrant increasing the maximum number of listeners to 30.

The streams are accessed either through links on the orcasound.net web site or through a playlist maintained by the listener's MP3 stream player software. Web site traffic (measured with Google Analytics) during the period of April 2007 through April 2012 averaged 30 unique visitors per day, but has a strong seasonal pattern. Visitors per day rises from a mid-winter low of about 10 to a summertime average of ~100, with occasional spikes to 200-350. Listeners are predominantly from the U.S. (75%), Canada (13%), Europe (8%), and Australia (0.5%).

The web site introduces citizen scientists to the Network by stating scientific and educational goals and describing each node. It also offers links to a “sound tutor” page and ways to contribute to the observational effort.

The sound tutor page presents recordings of common Salish Sea sounds, including the SRKW calls most often used by each pod, and links to online libraries of SRKW calls. By comparing the common calls and call libraries to “greatest hits” of the Network, listeners quickly learn to ignore ships while monitoring the live data stream for signals of interest. In the first 6 months of 2012, there have been 487 page views of the sound tutor page. Further learning occurs through occasional formal trainings or through iterative email exchanges between citizen scientists and Network administrators.

Other links on the website enable citizen scientists to report detections. Beginning listeners can do this via email (detection@orcasound.net) to Network administrators. Intermediate listeners log their listening sessions along with others in a collaborative Google spreadsheet (that automatically notifies administrators when new edits occur). Advanced listeners are invited to join an unmoderated email distribution list (locate@orcasphere.net) through which they can communicate their detections and often preliminary classifications with other citizen scientists.

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 analysts who verify, convert if necessary, and then upload them to the orcasound.net detection archive.

With advanced listeners, it is not uncommon for metadata to be reported along with detections, including: classifications of recorded sounds as SRKW calls, clicks or whistles; acoustic inference of pod identity; or deduction of direction of travel from multi-node detection sequences. The end product of the human detection system is the same as that yielded by the automated system: a SRKW signal is detected in near-real-time.

D. Classification

Whether detections are received from humans or node computers, the next step is for an analyst to classify the detection(s) and notify the Network of SRKW presence or absence. The analyst can review the detection in two ways: open the email to examine the most recent detections (usually 1-2 per email); or review many detections by querying the database based on a particular node of interest, time period, trigger type, and/or dB range. With the current database query and classification web forms, triggered sounds can be visually and aurally reviewed.

Trained users can classify the detections 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).

A database front end allows users to query the database after selecting the various checkboxes and drop-down menu items. Advanced listeners can classify sounds by annotating database sounds with predetermined classification categories or tags.

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.

Whether the review occurs via near-real-time email or a subsequent database query, the detection of killer whales is ultimately classified by humans (listeners and analysts), not by software. With the database of spectrograms of detections, the analyst can quickly assess a whole sequence of recent detections or review all sounds received in a day in just a few minutes. The system also allows the analyst to create an HTML summary of the detections and spectrograms.

In the future, we could improve the confidence of the detection by verifying the classification with other analysts or computer-based classification software. This has not 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.

E. Notification

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. Notification from the automated detection system comes in up to three forms, depending on the urgency and complexity of the notice: a text message via a private Twitter feed (http://twitter.com/killerwhales); an email via the locate@ list; and/or a blog post.

The most detailed level of analysis is a blog post by an analyst on the orcasound.net/wp web site that includes the detections and spectrograms. A link to the post or an abbreviated classification is circulated to the locate email list, and if a real-time listening opportunity still exists, the detection is also reported via the Twitter feed.

As of June, 2012, the locate@ listserve has 107 members who receive locations in real-time emails or daily summaries. List membership is doubling every two years. List members include 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) and SRKW recovery managers at the Northwest Regional Office of NOAA/NMFS.

As of June, 2012, the Twitter feed feed (currently private) has 60 followers, a number that is also doubling every 2 years. The feed has provided 446 updates since its inception on 5/27/07, 61 of them in the 12 months prior to June, 2012).

IV. Results

Admiralty Inlet is the gateway from the Pacific Ocean into Puget Sound (Fig. 1). Its strong and consistent tidal currents have made it of interest as a potential tidal power site by both the Snohomish County Power Utility District (SnoPUD) and the U.S. Navy. In the fall, SRKWs commonly begin transiting Admiralty Inlet in pursuit of chum salmon returning to Puget Sound rivers. Transits continue a few times per month through the spring.

The potential impacts of tidal turbines on SRKWs during these transits motivated SnoPUD to fund a field study of how SRKWs use of the Inlet.   A study area off Admiralty Head was monitored from land and sea from October, 2009, through April, 2010. The intensive sighting and listening effort at the study area and photo identification of SRKWs confirming when they were outside of the study area enabled us to quantify both human and automated detection rates during this time period.

Admiralty Inlet is a challenging site to conduct acoustic detections due to current velocities and high shipping traffic. All shipping headed to and from the ports of Seattle, Tacoma and Everett pass through this body of water. Mean sound pressure levels (0.156 - 30 kHz) in this location have been reported at 117 dB re 1 μPa, with levels exceeding 100 dB re 1 μPa 99% of the time (Bassett, Thomson, & Polagye, 2010).

Of the 22 times that SRKW transited the study area they were detected acoustically via the PTMSC hydrophone 14 times (64%) by the automated algorithm and 10 times (45%) by human listeners and overall, combining both approaches SRKW were detected 17 times (77%).

Of the total transits, we know that 14 occurred during the local daylight hours when the majority of listeners were likely to be awake. The rates of detection of daylight transits were higher: 79% by the automated system, 71% by human listeners, and 93% combined.

The Admiralty Inlet field study included a component that required researchers to collect data on SRKW transits from land and from a research vessel. The acoustic detections were an integral part of notifying these crews in enough time that they could collect data. Of the 14 daytime transits, rapid response crews observed whales during 10 transits (71%) thus demonstrating the value of this system to fulfilling the boat-based research objectives.

V. Discussion

Given that we know killer whales can remain silent while resting for hours at a time and that noisy ships can mask distant vocalizations, we consider our acoustic detection of about two thirds of the SRKW transits through Admiralty Inlet a success. Although use of passive acoustic monitoring (PAM) for SRKW detection will always have some limitations, we believe the automated and human detection rates can still be improved through simple means: iterative testing and redesign of the automated triggering algorithms and global growth and education of the human listening network.

Passive acoustic monitoring with the cabled hydrophone system at the Port Townsend Marine Science Center enabled detection of many transits which would otherwise have gone undetected. PAM was critical in learning that SRKWs do move through Admiralty Inlet at night. If we assume our detection rate was constant throughout the study, then our in-situ results suggest that SRKW vocalize at levels that are detectable from the shoreline during about half of their nighttime transits of Admiralty Inlet. The automated detectors caught half of the 8 nighttime transits, while humans only caught one. This proves that acoustic monitoring is particularly helpful when sighting networks are inoperable, even in a noisy urban estuary. It also indicates that globalizing the human listening network (across a wider range of time zones) could dramatically improve detection rates when it is nighttime for the SRKWs.

While a friendly competition between human and automated detection systems has promoted the advancement of both approaches, the best detection results were obtained through a combination of the systems. The automated system provides continuity when the human system is small or distracted. The human system offers discovery of novel sounds, detection of signals in noise, and nuanced classification – all of which are currently challenging computational problems.

Overall, human listeners have proven to be excellent detectors of any novel signal in our predominantly monotonous marine soundscape. This may be due in part because human brains are capable of pre-attentive auditory change perception (Risto Näätänen, 2000). This has been demonstrated by hydrophone listeners who can play a live stream in the background for hours as they work on other tasks (or even sleep!) and still notice the first faint calls of approaching killer whales. To evoke higher-level auditory processing, an auditory stimulus must violate a rule (or perceived pattern) established by preceding stimuli (R Näätänen et al., 2007). We speculate that by training listeners which marine sounds are commonplace – through online tutoring and listening experience – their minds establish that shipping noise is the "rule." Thereafter, signal detection can be elicited by a killer whale call or other unusual stimulus in humans who aren't consciously paying attention.

An unexpected benefit of real-time detection by humans has been the role the public have played in not only monitoring but also mitigating underwater noise pollution. Citizen scientists have proven highly effective at detecting rare or novel signals in the Salish Sea soundscape. In some cases, the signals have been due to biological sources (like male harbor seals), but in others listeners detected potentially harmful anthropogenic sounds, including: mid-frequency active sonar, ship-to-submarine communications, underwater detonations, pile driving, and exceptionally loud ships. Especially in response to hearing the military noises, citizens were surprisingly efficient at seeking out responsible authorities, asking that the noise abate, and documenting the noise incidents publicly.

A. The classification challenge

The online database and web-based analysis tools have made it easier to review detections and classify orca calls. However, classifying the numerous false positives generated by WHO_Listener triggering on ship noise across the Network is still tedious. To enable the automated detection system to provide reliable real-time notifications of SRKW presence/absence we need to automate the classification of the detections.

Prior to automation, however, we intend to compare results from a genetic-tree classification scheme (Veirs, 2009) with classifications generated by humans. One approach is to invite untrained listeners to judge similarity and thereby build a classification tree (Rehn et al., 2010). Another is to set up a direct competition between automated methods and human classification, scored with a reference library of calls.

We have already begun to invite our most-skilled listeners to classify detections in the online database. A product of this effort will be a population of false detections that can be used to test, refine, and supplement the WHO_Listener triggers.

B. Real-time citizen science within social networks

In the last couple years we have witnessed a rapid rise in public discussion of Network hydrophone signals on Facebook and other social networks. This growth has exceeded the use of the communication tools we created for our listeners (the detection@ email address, the Google spreadsheet, the locate@ email list, and the Twitter feed). While this may be due to shortcomings of our tools, we believe it is primarily because of the increased membership of social networks, in particular those that focus on topics related to killer whales. The Orca Network Facebook page, for example, often has the richest available observational data contained in wall posts made by the 13,000 users (as of June, 2012) who like the page.

Unfortunately, the data they generate are easily lost to science because they occur in de-centralized threaded conversations that are time-consuming to monitor. It is also difficult to maintain data standards within many social networks (e.g. time zone) and to archive or organize the observations in ways that enable further analysis.

A new challenge we face is how to utilize such enthusiastic citizen scientists and the observations they voluntarily make. Our citizen scientists need training to use of web-based tools like the email list, Twitter feed, and forms for reporting or querying data. In contrast, many potential citizen scientists are already familiar with how to post information to social networks. This leaves us pondering whether to create bioacoustic research opportunities within existing social networks (e.g. by developing apps) or to enable citizen scientists to use their social network identity to login to our web site where they can use improved tools to participate in killer whale research.

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TABLES

Table I caption:

Live or near-real-time public hydrophone audio streams**.**

Table I:

Salish Sea Hydrophone Network	http://orcasound.net
Orca Live	http://orca-live.net
Victoria Experimental Network Under the Sea (VENUS)	http://venus.uvic.ca/data/live-audio/
Neptune Canada	http://www.neptunecanada.ca/news/sound-gallery/
Pacific Wild	http://www.pacificwild.org
Hawaiian humpback	http://jupiterfoundation.org
Whalesong humpback	http://www.whalesong.net/
PALAOA Antarctica	http://icecast.awi.de:8000/PALAOA.MP3
Listening to the Deep Ocean Environment	http://listentothedeep.com

FIGURE CAPTIONS

Figure 1:

Distribution of nodes (black dots) in the Salish Sea Hydrophone network. The Admiralty Inlet study site is located adjacent to Port Townsend to the east-northeast.

Figure 2:

Data flow in the WHO_Listener PAM program. Hydrophones signals from digital acquisition (DAQ) are stored temporarily in a ring buffer. After averages are computed over two time intervals, transformations are made to construct triggers for frequency dependent events (PKT) and for amplitude dependent events (PWR). Detections are archived locally and uploaded to an on-line database.