A Public Dataset of Annotated Killer Whale Calls and Detections for Species Detection and Ecotype Classification Models

Authors: (in no particular order)

Kaitlin Palmer, Fabio Frazo, James Pilkington, Harald Yerk, Holger Klinck, Lucy Quale, Holly LeBlond, Jenn Waldichuck, Scott Viers, Val Viers, Jasper Kanes, Thomas Doniol-Valcroze (listed on DFO data?), Lauren Laturnus, Olivia Murphy (on SIMRES metadata?), Malahat contributors (names?), Alex Harris, Ruth Joy

This list is not comprehensive nor in any particular order. Please add any missing names

# Affiliations

# Abstract

# Background and Summary

## Cultural Perspective?

If appropriate, I’d like to have our indigenous partners open the work with their perspective on the project and potentially what the killer whales mean to them.

Acoustics methods are important for marine mammals studies. Used in real time conservation and longitudinal studies. All methods rely on automated detectors to identify relatively rare sounds of animals and discriminate between species, and in the case of killer whales, between different ecotypes and lineages.

Killer whales (Orcinus orca) are arguably one of the best studied marine mammals on the planet. In the Pacific Northwest four ecotypes are present: Southern resident killer whales (SRKW), Bigg’s or transient killer whales, and offshore killer whales. While all represent the same species these groups are genetically and culturally distinct. Southern and Northern resident killer whales are obligate fish eaters and maintain stable matriarchal communities. Biggs killer whales feed exclusively on marine mammals and offshore killer whales are thought to specialize on sharks. As such each face different stressors. Southern Resident killer whales especially are faced with extinction due to lack of food, pollution in the environment, and acoustic masking from transiting vessels which hinder their ability to find food.

Presently there are approximately 75 individual SRKWs while Biggs population numbers greater than 500 individuals. There are significant and sustained efforts to improve the outcome for the SRKW population including habitat improvement and noise reduction efforts on both sides of the border. These efforts are based on critical habitat as determined by visual and acoustic detections of the population. Acoustic data are most valuable for times/locations where visual detections are not possible.

All killer whale acoustic signals can be grouped into three broad categories, echolocation clicks, whistles, and pulsed calls. Echolocation clicks are broadband impulsive sounds with the majority of the energy between 20 and 100 khz. Whistles are tonal calls typically used for social communication among individuals within a pod. These whistles have a broad frequency range, generally spanning from 0.5 to 25 kHz, and are involved in coordinating movements and maintaining group cohesion. Pulsed calls are distinct, complex vocalizations characterized by a series of discrete, pulsed sounds varying in frequency and amplitude. Unlike echolocation clicks and whistles, these calls are primarily used for social communication within pods, serving functions in group coordination, individual identification, and conveying social and behavioral cues.

# Methods

Machine learning models are only as good as the data used to train them. For acoustic ecology, data used to train the algorithm must be representative of the animals’ repertoire in order to be effective. Furthermore, many machine learning applications in conservation are targeted at longitudinal, or backwards looking studies in order to assess changes on the scale of years or decades. In species capable of cultural adaptation of their repertoires including humpback and killer whales, data for machine learning algorithms must represent signals that were previously heard in the environment (e.g. antiquated song, and killer whale calls from now diseased animals). We refer to the ideal dataset as “ecologically representative”. This means meaning that annotated audio signals encompass the range breadth of the target species calls as well as a good grasp of non-target signals likely to be encountered in the same habitat such as, in this case, anthropogenic sounds, humpback whales, and other odontocetes such as common dolphins which may be confounded with the target species.

HALLO project- data were initially collated for the HALLO project and individual data owners were invited to share their data publicly.

*Figure of PAMGUARD whistle moan detector output showing lots of detections on a single call*

*All photographic and bitmap images should be supplied in a bitmap image format such as TIFF, JPG or PSD. If saving TIFF files, please ensure that the compression option is selected to avoid very large file sizes. RESOLUTION NOT SPECIFIED, MAYBE 300DPI?*

*Map of area*

## Individual Datasets

The overall challenge dataset contains audio and annotations provided by a collaboration of businesses, not-for-profits and governmental organizations including OrcaSound, Ocean Networks Canada, the Canadian Department of Fisheries and Oceans, JASCO Applied Sciences and Malahat First Nations, and Saturna Island Marine Research & Education Society (SIMRES). Data were collected using a variety of instruments deployed in the Pacific Northwest including AMRs (https://www.jasco.com), Ocean Sonics IClistens, and Ocean Instruments soundtrap recorders in depths ranging from 18-253m. Data coverage varied, as time and funding allowed but covered a 9-year period between May 2013 and June 2022. Deployment, processing, and annotation details for each dataset are provided in the following sections.

### OrcaSound

Orcasound has been collecting and annotating audio data as part of google summer of code challenges as well as

Start and End provided for some calls but not false positive detections. Frequency bounds are not provided for any detection

**Deployment**

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Instrument** | **Date Start** | **Date Stop** | **SRKW** | **Biggs** | **NRKW** | **Offshore** |
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**Processing**

Data were collected at a 32kh sample rate but a strong 12khz low-pass filter was applied rendering an effective sample rate of 24khz.

**Annotation**

Files flagged by citizen scientists were reviewed by expert analysts for the presence of SRKW calls. For files with calls present, the expert reviewer noted the start and end time of the call. Frequency bounds were not recorded and are thus noted as ‘NAN’ in the frequency bounds columns of the annotations file. Files without identifiable SRKW calls were labeled as ‘noise’ but no time bounds were provided. All noise labels were converted to the ‘Abiotic’ class in the SpeciesClasss column.

### Ocean Networks Canada

**Deployment**

Acoustic data were collected using an Ocean Sonics SC2 (<https://oceansonics.com/>) recording system deployed on the Barkley Canyon Upper Slope platform of ONC’s North-East Pacific Time-series Underwater Networked Experiments observatory. The hydrophone was mounted 1 m above the sea floor and sampled continuously at 64 kHz. data that did not contain classified signals were archived after review by regional navies.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Instrument** | **Date Start** | **Date Stop** | **SRKW** | **Biggs** | **NRKW** | **Offshore** | **HW** |
| Barkley Canyon Upper Slope | Ocean Sonics SC2 | 2013-05-16 | 2015-06-13 | 129 | 315 | 0 | 418 | 2946 |

**Processing**

The hydrophone model used applies an anti-aliasing filter during data collection and digitization, yielding a 32kHz bandwidth with reduced apparent sound intensities above 25.6kHz. Data were evaluated for the presence of killer whales and other species in three separate efforts with varying protocols for each. All manual validation was done initially done using JASCO Applied Science’s PAMLab software. Annotations were produced using a logarithmic spectrogram display with different spectral settings in 4 different bands, enabling multi-species identification across the full bandwidth in a single pass. All visible signals were considered for annotation, and no signal-to-noise ratio threshold was used. Annotations initially made in PAMLAB were reviewed for accuracy, signal diversity, and completeness using Raven Pro. No automatic detection algorithms were applied during any part of the analysis.

**Annotation**

Pulsed Calls only

In the first annotation effort, every second file for each of the first four days of the month were reviewed for the presence of marine mammal signals. If a marine mammal call or signal was found, the signal was annotated. For killer whales, all pulsed signals within the file were annotated if present. Some whistles were annotated but echolocation clicks were not annotated. As no detectors were used in this analysis, each element in the annotation table represents an individual call. Other species presence was noted only on a file basis, e.g. only one whistle of a common dolphin encounter was annotated.

The first effort produced one annotation per species per file for every other file of the first 4 days of each month in 2014. Annotations were produced using a logarithmic spectrogram display with different spectral settings in 4 different bands, enabling multi-species identification across the full bandwidth in a single pass. All visible signals were considered for annotation, and no signal-to-noise ratio threshold was used. Files within the supplied file list not associated with an annotation contained no detections and therefore were not reviewed by the trained analyst.

This line of questioning brings up an important point to consider though that I hadn’t thought of! In the files with confirmed orca calls, I annotated every *orca  pulsed call*, but not every other sound. So there are echolocation clicks that weren’t annotated, and possibly some whistles (though I think maybe I annotated all the whistles too – I’d have to review to confirm). Also, the files from 2013 I *only* annotated orcas – they were added after the fact to increase the orca call class size and include other ecotypes. There may be other species in the 2013 files that I didn’t annotate.

may be assumed to have no marine mammal sounds, though it is worth noting that these files have not been reviewed and it is possible some sounds were missed.   
  
The second effort added approximately 2 to 20 annotations per file to files containing Pacific white-sided dolphin pulsed calls, and an annotation for every orca call in the 2014 data set, as these classes were not large enough for training an effective classifier.   
  
The third effort added one annotation per orca call for every file flagged as containing orcas in the previously-made weak-label annotations for the full 2013 to 2015 Barkley Canyon deployment period of Ocean Sonics hydrophone icListen HF 1251, as orcas were uncommon during the annotated time periods.

All files originally identified as containing marine mammal signals have been manually reviewed a second time using species-specific spectrogram settings in Raven Pro to fix erroneous or misclassified annotations. During the review process, some humpback whale and blue whale annotations were added or replaced to improve the diversity of signals in the data set. Delphinid click annotations, which were not originally annotated to species due to insufficient bandwidth to capture the full click structure, were updated to differentiate between Risso’s dolphin, Pacific white-sided dolphin, and other delphinids clicks based on their literature descriptions and comparison to broader bandwidth data containing clicks from these species recently collected from the same location.

### Department of Fisheries and Oceans Canada

Two groups within DFO provided datasets to the challenge, the Yerk and Pilkington labs. Data processing methods were consistent across projects within each lab but varied slightly between each lab.

#### Pilkington

**Deployment**

The Pilkingon lab provided data from two deployment locations. As with all DFO deployments, exact locations are not provided.

This dataset is based on roughly 116 days of duty-cycled audio data recorded with a SM2M autonomous recorder deployed on the northern mainland coast of British Columbia. The recording effort focused on the winter months, and the batteries depleted earlier than anticipated. The dataset consists of the full deployment’s duty-cycled recordings converted to FLAC (for ease of sharing), as well as a table of the associated automated detections that were identified to species and sound type by human analysts. This dataset was not initially intended to be used in the training of detectors/classifiers.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Instrument** | **Date Start** | **Date Stop** | **SRKW** | **Biggs** | **NRKW** | **Offshore** | **HW** |
| West coast of  Vancouver Island. | AURAL-M2 | 2011-02-15 | 2012-05-25 | 48 | 5336 | 4558 | 258 | 95861 |
| mainland coast of British Columbia. | SM2M | 2013-10-10 | 2014-02-04 | 0 | 2309 | 3501 | 947 | 26058 |

**Processing**

The raw audio recordings (WAV) were post-processed using the Whistle and Moan Detector in PAMGuard version 1.12.08 (Gillespie et al. 2013). The detector was user- configured with a high-pass filter of 800Hz to limit the number of humpback whale detections and lessen the manual validation burden. The SNR detection threshold was set to 6dB. All detections in the first two seconds of each file were excluded because the detection algorithm produces several false detections within this period. The automated detections from the detector were stored in an Excel spreadsheet

**Annotation**

All detections **including whistles and pulsed calls** were aurally and visually reviewed using PAMGuard and identified to species (for biotic) and sound type (for abiotic). Where applicable and as time allowed, detections were also acoustically identified to intra-specific groupings including ecotype. Note that files may contain more identifiable calls than the annotations indicate. These manual reviews were conducted by trained and experienced analysts. A small portion of annotations contain question marks for both the KW class and the Ecotype class. As these calls were validated to ecotype we assume that KW class is certain and the question mark is removed.

Note that individual detections may be separate components of the same discrete call (ie harmonics or sidebands), thus, not every detection represents a unique vocalization. The PAMGuard Whistle and Moan detector detects individual contours, so all individual harmonics within a call would constitute separate detections if they meet the detector’s criteria (this happens quite frequently). Also, the settings of the detector mean that independent tones (like from multiple individuals) that cross or overlap in frequency and time may be detected as a single detection.

Note that the original WAV files were used in post-processing with the detector. These WAV files were converted to FLAC in the creation of dataset KkHK0R2F-NML1 for sharing. If FLAC are limiting for your purposes, the WAV files are also available if necessary – get in touch with the dataset contacts.

#### Yerk

The Yerk lab provided data from four deployment locations, Carmanah, Swanson Channel, and two locations Strait of Georgia.

**Deployment**

Four locations were chosen for the study area. Carmanah Point, Swanson Channel and the Northern and Southern Ends of the Strait of Georgia. Exact locations are not disclosed. A soundtrap (www.oceaninstruments.co.nz) was used for the carmanah point location and AMARS were used for all other deployments. For the Strait of Georgia locations instruments were deployed for approximately one month in 2021, recovered and new instruments were re-deployed briefly at the same locations. Audio data were continuously sampled at either 192 khz for the SoundTrap or 256 kHz for the AMARs.

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| **Location** | **Instrument** | **Date Start** | **Date Stop** | **SRKW** | | **Biggs** | **NRKW** | **Offshore** | **HW** |
| Carmanah Point | ST6249 | 2022-03-08 | 2022-06-29 | 1610 | 694 | | 364 | 0 | 131 |
| Swanson Channel | AMAR 777 | 2021-11-13 | 2022-01-09 | 5630 | 25 | | 0 | 0 | 1660 |
| Strait of Georgia North | AMAR 610 | 2021-09-05 | 2021-10-01 | 4184 | 593 | | 0 | 0 | 0 |
|  | AMAR 617 | 2021-11-28 | 2021-11-30 | 0 | 324 | | 0 | 0 | 42 |
| Strait of Georgia South | AMAR 607 | 2021-11-11 | 2021-11-18 | 159 | 191 | | 0 | 0 | 221 |
|  | AMAR 779 | 2021-09-04 | 2021-10-01 | 2070 | 71 | | 0 | 0 | 114 |

**Processing**

Audio recordings were processed with the PAMGuard (Gillespie et al. 2013) whistle and moan detector (v. 2.02.03) for the presence of potential killer whale calls. Data were downsampled within Pamguard to 48 kHz and a 2khz high-pass filter was applied to reduce the number of humpback calls that needed to be validated. A nominal sensitivity of -164.1 dB or -176.2 was set for AMARs and the SoundTrap respectively. An 8 dB SNR detection threshold was applied to the whistle and moan detector. All other default settings for the whistle and moan detector were used.

**Annotation**

All PAMGuard detections were evaluated for the presence of killer whales by expert analysts and annotated as such. Annotations included whistles and pulsed calls but echolocation clicks were not included as they were rarely discovered by the whistle and moan detector.

### JASCO Malahat First Nation

**Deployment**

The Malahat Nation engaged JASCO Applied Sciences to 6 locations in and around Haro Strait of which four had detections of killer whales and were donated to this dataset. All deployments used AMAR recorders.

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| **Location** | **Instrument** | **Date Start** | **Date Stop** | **SRKW** | **Biggs** | **NRKW** | **Offshore** |
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**Processing**

**Annotation**

### SIMRES

**Deployment**

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Instrument** | **Date Start** | **Date Stop** | **SRKW** | **Biggs** | **NRKW** | **Offshore** |
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**Processing**

**Annotation**

## Technical Validation

All potential killer whale detections were reviewed by expert analysts at their respective institutes. Calls and detections that were of dubious origin due to low SNR or unfamiliar structure were not included in the dataset or tagged as uncertain. Calls associated with SIMRES were linked with concurrent sightings of SRKW animals.

## Data Records

An annotation file is provided as a CSV that includes links to audio files. The following describes each column in the annotation file.

**Annotations Labels**

**SoundFile** – audio file from which the annotation was derived

**StartTime** – seconds into the SoundFile representing the beginning of the annotation

**EndTime** – Seconds into the SoundFile representing the end of the call annotation

**Low Frequency** – low frequency bound of the annotation, in Hz

**High Frequency** – high frequency bound of the annotation, in Hz

**UTC** – UTC time at the beginning of each annotation (StartTime)

**ClassSpecies**- Character string with four options, Killer Whale (KW), Humback Whale (HW), Abiotic (AB), and Undetermined Biological sound (UndBio).

**KW**- bool indicating whether or not the annotate denotated that the annotation represented a killer whale call

**KW\_certain** – bool indicating whether or not the annotator was certain that the annotation was a KW. This is often represented by a question mark in the annotations. For ONC data, annotators listed all potential species that the thought the call could come from.

**Ecotype** – Ecotype of the killer whale annotation. SRKW- Southern Resident Killer Whale, BKW- Biggs killer whale, NRKW- Northern Resident Killer Whale, or OKW- Offshore Killer Whale

**Data Provider**- Character indicating the data provider

**Dep**- Character, deployment location

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | **Annotations** | | | |
| **Dataset Provider** | **Deployment Location** | **Lat, Lon** | **Depth (m)** | **fs (khz)** | **All Annotations** | **Annotation Level** | **KW** | **Und. Bio** | **Abiotic** |
| **Orca Sound** |  |  |  |  |  | File? |  |  |  |
| **ONC** | Berkley Canyon | 48.426, 126.174 | 40 | 64 | 14120 | Call, pulsed only |  |  |  |
| **DFO\_** **Pilkington** | West Vancouver Island |  | 114 | 16.384 | 114056 | Detection |  |  |  |
|  | Northern Mainland British Colombia |  | 35 | 16 | 44818 | Detection |  |  |  |
| **DFO\_Yerk** | Carmanah Point |  | 55 | 192 | 3129 | Detection |  |  |  |
|  | Swanson Channel |  | 72 | 256 | 7698 | Detection |  |  |  |
|  | Strait of Georgia North |  | 193 | 256 | 5334 | Detection |  |  |  |
|  | Strait of Georgia South |  | 245 | 256 | 2981 | Detection |  |  |  |
| **JASCO/Malahat** | Station 1 | 48.634, 123.505 |  | 64 | 36936 | Call | 29606 | 3 | 5947 |
|  | Station 2 | 48.715, 123.436 |  |  |  | Call |  |  |  |
|  | Station 3 | 48.686, 123.274 |  |  |  | Call |  |  |  |
|  | Station 4 | 48.507, 123.211 |  |  |  | Call |  |  |  |
|  | Station 5 | 48.495, 124.540 |  |  |  | Call |  |  |  |
|  | Station 6 | 48.775, 123.343 |  |  |  | Call |  |  |  |
| **SIMRES** | Tekteksen (East Point), Saturna Island, BC | 48.780, 123.052 | 18 | 128 | 1342 | Call, pulsed, whistles and echolcation | 1242 | 23 | 0 |
|  |  |  |  |  |  |  |  |  |  |

## Usage Notes

*The Usage Notes can contain brief instructions to assist other researchers with reuse of the data. This may include discussion of software packages that are suitable for analysing the assay data files, suggested downstream processing steps (e.g. normalization, etc.), or tips for integrating or comparing the data records with other datasets. Authors are encouraged to provide code, programs or data-processing workflows if they may help others understand or use the data. Please see our* [*code availability policy*](http://www.nature.com/sdata/policies/editorial-and-publishing-policies#code-avail) *for advice on supplying custom code alongside Data Descriptor manuscripts.*

*For studies involving privacy or safety controls on public access to the data, this section should describe in detail these controls, including how authors can apply to access the data, what criteria will be used to determine who may access the data, and any limitations on data use.*

Data for this project represent a large collaboration of groups and institutions and each dataset was processed in accordance with each groups project goals. Post processing of the annotations was done to provide a uniform system for machine learning algorithms. However, users should consider details from each deployment carefully to determine whether they wish to do any additional post-processing. For example, multiple annotations from the DFO datasets may represent different harmonics of the same call. Alternatively, data derived from ONC projects considered only pulled calls. Thus, unannotated whistles and echolocation clicks may be present in some files. See individual datasets above for details.

## Code Availability

Data and annotations were collated using R and available here. https://github.com/JPalmerK/DCLDE2026

# Acknowledgements

# Author Contributions

# Competing Interests

# Figures

# Figure Legends

# Tables

# References

# Notes to Authors

Each section in the methods should contain the following sections

**Deployment –** sample rate, deployment depth, hydrophone, recorder, are all files included or only files with annotations?

**Processing –** How ere the data processed? Filters? Detectors (.e.g Pamguard version, whistle moan detector including settings parameters)

**Annotation-** Which type of signals were annotated? KW pulsed calls only? KW whistles and pulsed calls? What was annotated, the detections? The file only?