**Golden Lake Hydroacoustic Data Analysis Readme file**

* **Data preparation:** This analysis utilized 70kHz split-beam hydroacoustic data collected from Golden Lake in 2009, 2010, and 2022.   
    
  **Data were imported into Echoview 15 and visually inspected for data integrity, completeness, and noise. Analysis transects were defined within the software and off transect segments were excluded from analysis. Bottom lines were generated using Echoview bottom detection algorithms. Generated bottom lines were closely inspected to ensure they did not include and bottom echoes which, if included, could greatly inflate acoustic abundance estimates.   
    
  Single target detection algorithms within Echoview were used to identify echoes originating from individual fish. Fish tracking algorithms were then used to group multiple echoes originating from single fish. Target strength (TS) distributions are derived from mean target strengths of fish tracks. Visual inspection of echograms was used to tune the fish tracking algorithm as the 4D tracking is sensitive to changes in boat speed and surface conditions which may cause the transducer to move more off the main axis of travel. Target strength is a measure of the size of individual fish expressed on a decibel (log) scale. Smaller fish have a more negative target strength.   
    
  Analysis limits were set to include the water column beginning at 3 metres in depth to 0.5 metres above bottom. The upper limit was set to exclude a strong layer of scattering near the surface that was likely Mysis. A range dependent minimum TS threshold of -60 dB was used for echo integration to further exclude potential scattering from Mysis. This threshold is approximately equivalent to a rainbow smelt of 25mm total length.**
* **Echo Integration Analysis Overview**: Echo integration was used to estimate fish abundance by integrating backscattering strength (Sv) within cells of defined distance and depth intervals across different depth layers. This approach allows for the estimation of fish density and total biomass within analysis cells. Total backscattering strength can be thought of as the total sound energy reflected from objects (generally fish) within the volume of interest and is proportional to biomass. This measure of “biomass” can be converted to fish density if the average size (TS) of fish within an analysis cell is known.
* **Size Classification and Fish Targets**: Fish were categorized into three size classes defined by target (TS), which relates to fish length using the Rudstam TS-length relationship for smelt (Rudstam et. al, 2003). Size classes were determined after inspection of TS histograms, using natural breaks in the distribution, and were defined as follows:  
  + **Class 1**: Small fish (approximately 25-60 mm)
  + **Class 2**: Medium fish (approximately 60-190 mm)
  + **Class 3**: Large fish (approximately 190-225 mm)

Although specific breakpoints are used in the analysis, the TS range of an individual fish has a broad distribution, varying by as much as 15dB or more, meaning there is overlap in these defined size classes. The same size classes are used for analysis each year for purposes of comparison. The surveys in 2010 and 2022 were two weeks later than the 2009 survey meaning Young-of-Year (YOY) fish were likely a little larger in these years. This is visible in the TS distributions.

* **Sawada Index Calculation**: The Sawada Index (Sawada, 1993) was calculated for each cell to assess the degree to which high densities of fish within an analysis cell could influence results through an overestimation of average target strength within a cell . Cells with a Sawada Index greater than 0.1 were identified and the layer-wide mean TS, and distribution was used to estimate and partition density.
* **Calculation of Elementary Distance Sampling Unit Size**: Variograms were generated and inspected to determine the appropriate size of elementary distance sampling units (EDSUs) for analysis, ensuring spatial structure was properly accounted for in the survey design. Echo integration was used to estimate fish abundance by integrating backscattering strength (Sv) across different depth layers following the “mixed-species” method described by Simmonds and MacLennan (2005). This approach allows for the estimation of fish density and total biomass within predefined depth intervals.
* **Fish Density Estimation**: Fish densities within each 150m x 2m analysis cell were calculated using two methods:
  1. **Cell-Specific Proportions**: If 30 or more targets were present within a cell, fish density was calculated using mean TS and proportions of each size class within the cell.
  2. **Transect-Wide Proportions**: If fewer than 30 targets were found, mean TS and proportions from the entire transect depth layer were applied to estimate fish density.
* **Lakewide Density and Abundance**: Densities were extrapolated to provide lakewide estimates by layer and year. Average densities were calculated for each layer and extrapolated based on lake volume for each depth range. This provided total abundance estimates for each size class.  
    
  \*\*Note: As with any sampling method hydroacoustic surveys have inherent sources of bias from detection limitations and sampling error. All estimates of abundance should be considered relative estimates.
* **Bootstrapping for Confidence Intervals**: To represent the uncertainty in estimates, bootstrapping was performed. Mean fish densities per analysis cell were resampled 1000 times to generate bootstrapped confidence intervals for each layer and size class. Summarizing these estimates provided confidence intervals for lakewide fish abundance.
* **Visualization**: Visualization of results are provided in several plots and tables:
  + **Distribution of Fish Track Target Strength:** histograms of target strength for fish tracks identified within each survey overlaid with the analysis size classes. Estimated fish length, converted from observed target strength is provided on the upper x axis in a log scale.
  + **Bubble Plot**: Mean fish density for each size class is plotted spatially on a lake map, aggregated by thermal zone.
  + **Density Histograms**: Mean density per layer with confidence intervals is plotted, displaying vertical distribution by year and size class.
  + **Total Abundance Bar Plot**: Lakewide fish abundance for each size class by year is presented as a bar plot, with bootstrapped confidence intervals shown as whiskers.
* **Glossary of Common Hydroacoustic Terms**:
  + **Elementary Distance Sampling Unit (EDSU)**: The unit of distance along a transect for which acoustic data are analyzed. An appropriate EDSU size helps ensure that the cell sample size is appropriate to capture spatial structure in the data while also trying to ensure that an adequate number of targets are in each analysis bin.
  + **Echo Integration**: A method used to estimate fish biomass by integrating the backscattering strength from fish over a defined volume of water.
  + **Target Strength (TS)**: A measure of the strength of the echo returned by a single fish, expressed in decibels (dB). It is used to estimate fish size. More negative values are represent smaller targets.
  + **Backscattering Strength (Sv)**: A measure of the reflected acoustic energy from a unit volume of water, used to estimate fish density.
  + **Sawada Index**: An index used to evaluate the reliability of fish density estimates, particularly to assess the risk of overlapping echoes (shadowing). Fish density can be underestimated in cells with high Sawada Index values (Sawada, 1993)
  + **Bootstrapping**: A statistical resampling method used to estimate the variability and confidence intervals of a dataset.
  + **Epilimnion, Metalimnion, Hypolimnion**: Layers of a stratified lake, with epilimnion being the upper, warm layer, metalimnion the middle layer (often the thermocline), and hypolimnion the lower, cold layer.
  + **Nautical Area Scattering Coefficient (NASC)**: A measure of the total backscattering from fish within a given area, often used to estimate fish abundance.
  + **Logarithm**: A mathematical function that represents the power to which a fixed number (the base) must be raised to produce a given number. In hydroacoustic analysis, logarithms are commonly used to express values like target strength (TS) in decibels (dB) to handle the large range of values more easily.