2023

WWU_Geology_Cetaceon_Queen_Charlotte_Fault

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Internship Title: Depth Profile and Cetacean Sighting Analysis Along the Queen Charlotte Fault

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Internship Dates: 11/21/2022 - 3/15/2023

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Depth Profile and Cetacean Sighting Analysis Along the Queen Charlotte Fault

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498-B: Internship

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March 17, 2023

Introduction:

The Transform Obliquity on the Queen Charlotte fault and Earthquake Study (TOQUES) cruise occurred from July 18 – Aug 23 of 2021 in the N. Pacific Ocean. During this time, TOQUES was using ocean-bottom seismometers (OBS) and acoustic arrays to map the sub-surficial geological features of the Queen Charlotte Fault (QCF). Expendable bathymetry (XBT) was deployed to measure the temperature of the water column in order to determine the speed of sound of the water column. The XBT data were repurposed in this analysis and used to determine the mixed layer depth (MLD) in different regions of the N. Pacific Ocean. While performing this research, Protected Species Observers (PSO) were onboard to monitor for protected animals such as whales and dolphins. When a PSO observed a cetacean, they would inform the crew to stop acoustic activity to prevent disrupting the cetaceans who communicate via acoustic calls, clicks, and whistles. Once the cetaceans were no longer observed OBS activity would resume. The OBS and array systems were utilized in a transect where the TOQUES crew would "zig-zag" along the QCF collecting data (Figure 1). Due to the temporal and spatial extent of the TOQUES project, 123 separate cetacean observations were identified. When observations occurred, the PSO would identify the species and determine the abundance of the pod. The time of first and last observation were logged as well as the GPS coordinate of where the cetaceans were detected. The cetacean data the PSO's collected during the 36-day expedition was used in this analysis to determine probability of the presence or absence of cetaceans.

Since light attenuation through seawater decreases at depth, a shallower MLD is associated with an increase in surface chlorophyll – α content, which is used as a proxy for phytoplankton biomass (Cullen, 1982). Increased MLD infer a deeper nutrient depleted region for phytoplankton to occupy and receive less mean irradiance to sustain photosynthesis, therefore reducing the amount of primary productivity (Cullen & Eppley, 1980). Higher tropic levels are dependent on primary productivity. When productivity is high, primary consumers increase in abundance responding to the increased food availability. As the primary consumers population density grows, predator-prey interactions magnify and attract higher trophic levels such as bait fish, cephalopods, and subsequent cetaceans. The cetaceans observed during the TOQUES survey had intermediate trophic interaction scale levels between 3.2 and 4.21. These levels indicate that a majority of the observed cetaceans diet consists of primary or secondary consumers as a food source (Table 1).

Since the QCF lays at the boundary between the Pacific and N. American tectonic plates, its topography contains portions of the continental slope and continental rise which lay between the shelf and abyssal plain. The steep slope of the continental margin paired with the bifurcation of the N. Pacific current into the Alaskan and Californian currents adjacent to Haida Gwaii support vast primary production during the summer and winter months (Batten & Freeland, 2007). The hypothesis of this study was to see if MLD associated with the QCF would influence the presence or absence of cetaceans. Regions with shallower MLD would have higher abundance of cetaceans, due to an increase in primary production near the surface.

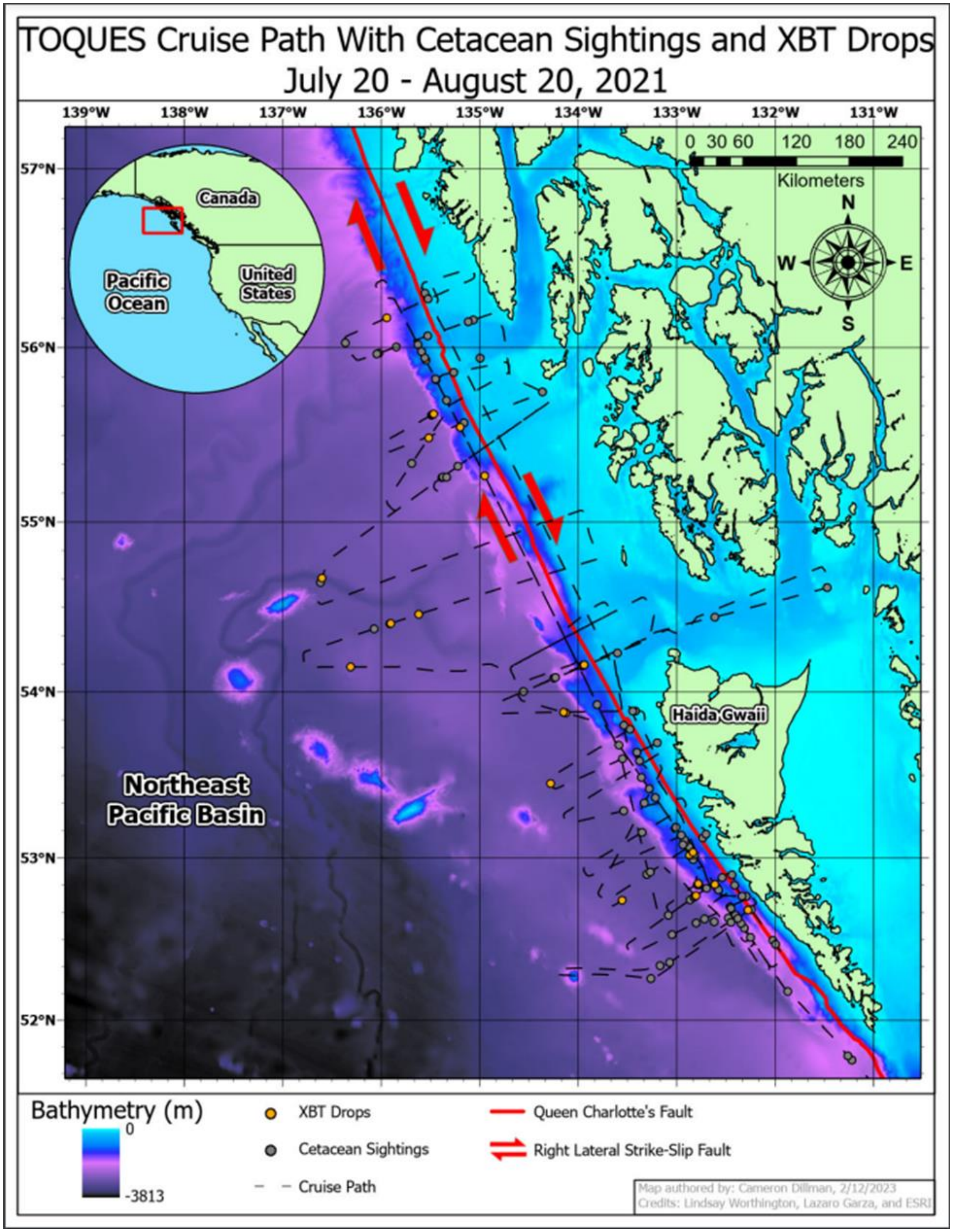

Figure 1. This is a map of the TOQUES 2021 cruise path, XBT drop locations, and cetacean sightings with a bathymetry DEM to display topographical characteristics of the seafloor (WGS 84, 250m resolution).

Background:

Phytoplankton are responsible for over 50% of the global primary productivity that sustain the higher trophic levels of the oceanic food web (Mahadevan, 2015). Oceanic surface waters are normally nutrient depleted or oligotrophic, minimizing phytoplankton growth. During upwelling events, nutrient rich water recently brought to the surface can sustain vast plankton blooms. Approximately 1/3 of phytoplankton are capable of vertical migration between the MLD and the thermocline (Wirtz & Smith, 2020). Vertical migration allows the acquisition of nutrients from the chemocline at depths and are independent of sub-mesoscale events driving nutrient rich waters to the euphotic zone (Wirtz & Smith, 2020).

Lateral transport of suspended particulate matter (SPM) can occur along the interface of the benthic sediment and nepheloid layer above the continental margin (McPhee-Shaw et al., 2004). Vertical transport of SPM can also occur along continental margins if the upwelling velocity surpasses the settling velocity of SPM (Gao & Jia, 2003). Sub-mesoscale processes such as Coriolis effects, buoyancy fronts, and surface forcing can support vertical velocities upwards of 100 m d^{-1}, dispersing nutrients towards the euphotic zone (Mahadevan, 2015). The dispersal of SPM laterally and vertically surrounding the shallow waters of the QCF may further increase the nutrient budget to the surrounding surface waters, enhancing phytoplankton biomass.

Iron has been proven to be a limiting nutrient source for primary productivity in equatorial waters of the Pacific Ocean (Martin, 1994). Although the Alaskan current is not along the equator, iron is still the limiting nutrient for primary productivity in most oceanic surface waters (Schoffman et al., 2016). Coastal regions of the NE Pacific are supplemented with dissolved organic nutrients such as iron and nitrogen via fresh water systems (Pierre, K. et al., 2021). The QCF is a geologically active region where portions of the Pacific plate are subducting under the N. American Plate or creating a right lateral strike-slip at the boundary (DeMets et al., 2010; Hyndman, 2015). Due to the tectonic nature of this region, the continental margin contains various volcanic features that aid in mixing bottom water and nutrients from the benthos up into intermediate nepheloid layers. Seeps and hydrothermal vents line portions of the QCF, at anticlinal-ridges, shelf-ridges, interfluvial-ridges, and guyot's along the continental margin (Prouty et al., 2020). The hydrothermal vent plumes contain a nutrient rich source of iron and magnesium which are capable of mixing and fertilizing surface waters (Le Bris et al. 2016). Other compounds given off by the seeps and hydrothermal vents include methane and sulfide. These compounds support chemosynthetic and methanotrophic bacteria which are other sources of primary production. Plumes created by seeps and vents along the QCF have been observed to be upwards of 700m tall and occur in waters that are 980m deep (Prouty et al., 2020). Other plumes are much shorter, but occur in shallower waters, allowing these nutrient rich plumes to reach between 150m and 75m below the surface (Prouty et al., 2020).

The MLD will vary depending on multiple factors such as seasonal meteorological variation in atm pressure, rain, temperature, as well as upwelling and downwelling. Seasonal variations in MLD are generally deepest in the winter and shallowest in the summer, fluctuations are dependent on surface cooling and wind mixing of the surface layer (Oka et al., 2007). El Niño and La Niña events are products of Pacific Decadal Oscillation (PDO). La Niña is the product of strong trade winds forcing warm surface waters offshore resulting in upwelling of cold nutrient rich waters along the eastern boundary of the Alaskan current. Continued upwelling brings nutrient rich waters to the surface and move it seaward. La Niña occurred prior to the TOQUES excursion in 2021 but subsided during the summer months within the TOQUES experiment. The decline in wind force from the subsidence of La Niña during TOQUES minimized upwelling of nutrients and cold water (ENSO, 2023).

Plankton blooms are greeted annually by the migration of baleen cetaceans such as humpback and blue whales. Research has shown that blue whales are capable of determining the phenological timing of plankton blooms and associated krill biomass (Abrahams et al., 2019). Plasticity in blue whale annual migration corresponds to variation in SST fluctuations, which coincide with plankton blooms (Szesciorka et al., 2020). Most migratory cetaceans travel North during the late spring and early summer. They seek optimal foraging habitat to gain fat stores supplementing them during their southern migration toward their breeding grounds (Szesciorka et al., 2020; Ryan et al., 2019). Migration of humpback whales is also dependent on variability in acoustic sounding that coincides with plankton blooms. Research indicates that resident humpbacks are capable of notifying others about abundant food sources (Ryan et al., 2019).

The QCF and nearby submerged topological features and adjacent land masses supplement nutrients to the euphotic zone of the NE Pacific, the added nutrients are capable of allowing a near continuous annual primary production. The abundant phytoplankton blooms to this region support primary and secondary consumers that sustain migrant and resident cetaceans.

Methods:

Meteorological data (air temperature) was recorded using two Vaisala WXT520 units, which ran on a NOAA shipboard computer system. Sea surface water was measured using Sea-Bird Electronics SBE38 Temperature Sensor. Sea surface salinity (SSS) was measured by a SBE-45 TSG and recorded in PSU. Latitude and Longitude were recorded using two C-Nav 3050 DGPS units. These recorded measurements were continuous and had a minute-by-minute log of the ship path location, meteorological data, and sea surface conditions. A few instances occurred where one system would lag for a moment therefore all vector profiles containing an empty cell were omitted from the analysis.

XBT data was recorded on a Sippican T-5 and T-7 expendable bathymetry probes which had a max depth of 1,830m. 31 XBT drops occurred on the voyage, yet only 28 could be used in the analysis due to corrupted data. The XBT recorded seawater temperature and depth (among other variables), but these were the variables used to determine MLD. Each XBT depth profile was processed through MATLAB Ver. 9.12 using Chu & Fan (2017) methodology. Each XBT drop used was verified to have an accurate MLD and logged into the XBT master copy and used for a statistical analysis (Figure 4).

The MLD was applied to the Lat/Long of the XBT drop and processed through ArcGIS Pro Ver 3.1. The GPS locations were uploaded as WGS 84 coordinates, where Thiessen polygons were used to characterize regions around the XBT centroids (i.e. even partitioning surrounding XBT points) (Figure 2). The Thiessen polygons were used with the “intersect” tool with known locations of cetaceans to assign a MLD value to each cetacean in its proximity.

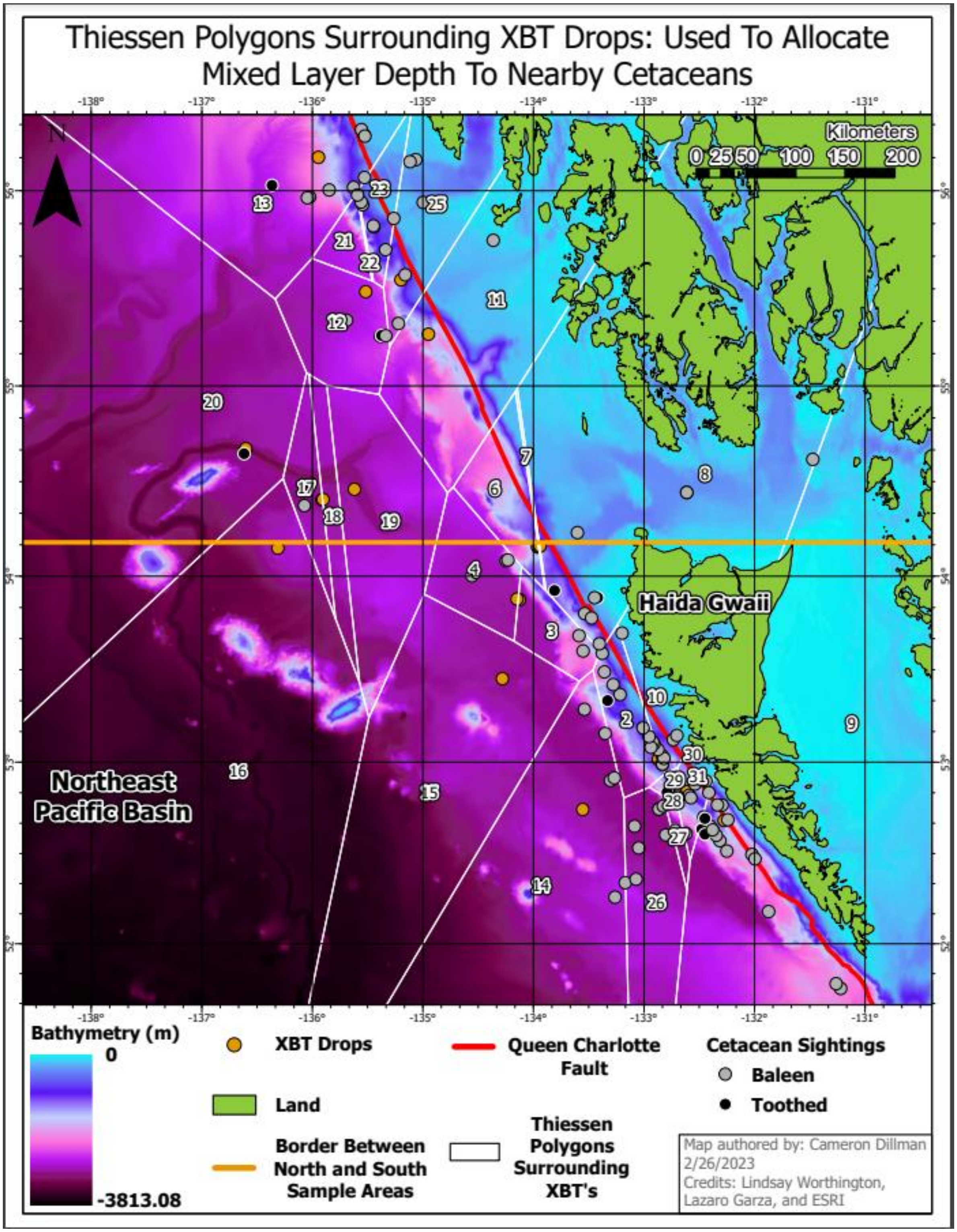

Figure 2. This map displays the XBT's and Thiessen polygons that are used to create boundaries around each XBT drop. This allows for allocation of MLD from each XBT to a spatial region which will be used to assign MLD to cetaceans intersecting each Thiessen polygon.

Spatial analysis was conducted on ArcGIS Pro Ver 3.1, where a regional bathymetry (250m resolution) was used to identify depths of the sea floor under the cruise path, cetaceans, XBT drops, and the QCF. The "extract multi values to points" geoprocessing tool was used to extract depth values from below the cruise path, cetacean sightings, XBT drops, and the QCF. The distance between surficial objects such as land were calculated by using the "raster calculator" geoprocessing tool and bathymetry raster. Depths below 0m were set to null values, and elevations above 0m set to the value of 1. The resulting raster was converted into a polygon using the "raster to polygon" geoprocessing tool containing only land. The distance values were extracted by using the "generate near table" geoprocessing tool using geodesic distance values between the cruise path, cetacean sightings, and land. The "surficial" distance from QCF was calculated in a similar fashion but had 2 additional steps. The surficial distance of the QCF was calculated using the "generate near table" geoprocessing tool and the depth values derived from the "extract multi values to points" geoprocessing tool. The Pythagorean theorem was used to determine the hypotenuse distance (c) between cetacean sightings and the QCF by using the surficial distance to QCF (a) and depth of QCF (b). Distance from QCF was incorporated in this analysis to determine whether or not the probability of cetacean presence was dependent on proximity to the QCF.

Topographical profiles of transects were determined using ArcGIS Pro Ver 3.1 and the "stack profile" geoprocessing tool. Each transect was a line feature and the 250m bathymetry as the DEM with elevation data (Figure 5). The X and Z tabular data of each topographical profile was exported to Excel. The topographical profiles were stacked on top of each other to display the variation of the seafloor surface West of the QCF. MLD from two XBT drops along each transect were incorporated into the same chart and labeled the same color as its' assigned transect. The line between both MLD depths created a slope and was used to visually analyze the change in MLD directly above the topographical features of the transect.

ArcGIS Pro was used to combine the ship log data and the known cetacean sightings by using the "table join" and "table relate" functions. The tables were joined using the date and time of the ship log and the cetaceans first and last date/time of observation. The newly joined table was then joined with a third table, the modified XBT/Thiessen polygon table which included MLD values along its assigned spatial region. The newly joined table incorporated the MLD and intersected cetaceans, which allocated MLD to each cetacean sighting.

Statistical analysis of the variables collected were conducted on RStudio Ver 4.2.2. A GLM model using Akaike Information Criteria (AIC) was performed on the entirety of the ship log and the known cetacean locations, derived distance measurements, and assigned MLD. Probability of baleen and toothed cetaceans were compared using delta values ≤ 2 generated by the AIC. Matlab Ver. 9.12 was used to graph the frequency of cetacean observations using histograms and a Weibull curve to display the distribution of baleen and toothed cetaceans and latitude. The Weibull curve was applied to the histogram because the frequency distribution along latitude was not normally distributed therefore a Gaussian curve was not applicable.

Results:

A total of 123 cetacean observances occurred during the TOQUES survey, with a total of 388 total cetaceans. The largest pod size was 50 (Risso's dolphin), followed by 45 Pacific white sided dolphins. Two north pacific right whale's (NPRW) were observed in a pod. The NPRW are hypothesized to have 40 individuals remaining in the Pacific Ocean and are considered functionally extinct (Botha et al., 2023). Ten total species were observed during the TOQUES cruise and can be seen in Table 1, the cetaceans ranged from 3.2 to 4.21 on trophic interaction level.

Table 1. This table displays the cetacean species observation during the TOQUES cruise report. It displays the cetaceans common name, scientific name, diet, trophic level, frequency of observations, and the largest pod size observed. Trophic level information was gathered using the Trites (2019) chart.

Common Name	Scientific Name	Type	Diet	Trophic Level	Observations	Largest Pod Observed
Sei Whale	*Balaenoptera borealis*	Baleen	Plankton, krill, small fish, and cephalopods	3.43	3	1
Risso's Dolphin	*Grampus griseus*	Toothed	Fish, krill, and cephalopods	4.21	1	50
Pacific White-Sided Dolphin	*Lagenorhynchus obliquidens*	Toothed	Small fish and cephalopods	4.21	2	45
North Pacific Right Whale	*Eubalaena japonica*	Baleen	Zooplankton, copepods, euphausiids, and cyprids	3.2	1	2
Northern Right Whale Dolphin	*Lissodelphis borealis*	Toothed	Small fish and cephalopods	4.21	1	4
Humpback Whale	*Megaptera novaeangliae*	Baleen	Krill and small fish	3.35	85	5
Fin Whale	*Balaenoptera physalus*	Baleen	Krill, small schooling fish, and squid	3.43	16	7
Dall's Porpoise	*Phocoenoides dalli*	Toothed	Small schooling fish, smelts, cephalopods, crabs, and shrimp	4.08	10	10
Common Minke Whale	*Balaenoptera acutorostrata*	Baleen	Crustaceans, plankton, and small schooling fish	3.43	1	1
Blue Whale	*Balaenoptera musculus*	Baleen	Krill, fish, and copepods	3.43	3	4

The distribution of toothed and baleen cetaceans also varied by latitude and were positively skewed as seen in Figure 3. Both baleen and toothed cetaceans had increased frequencies in observances the farther North, indicating a preference for higher latitudes.

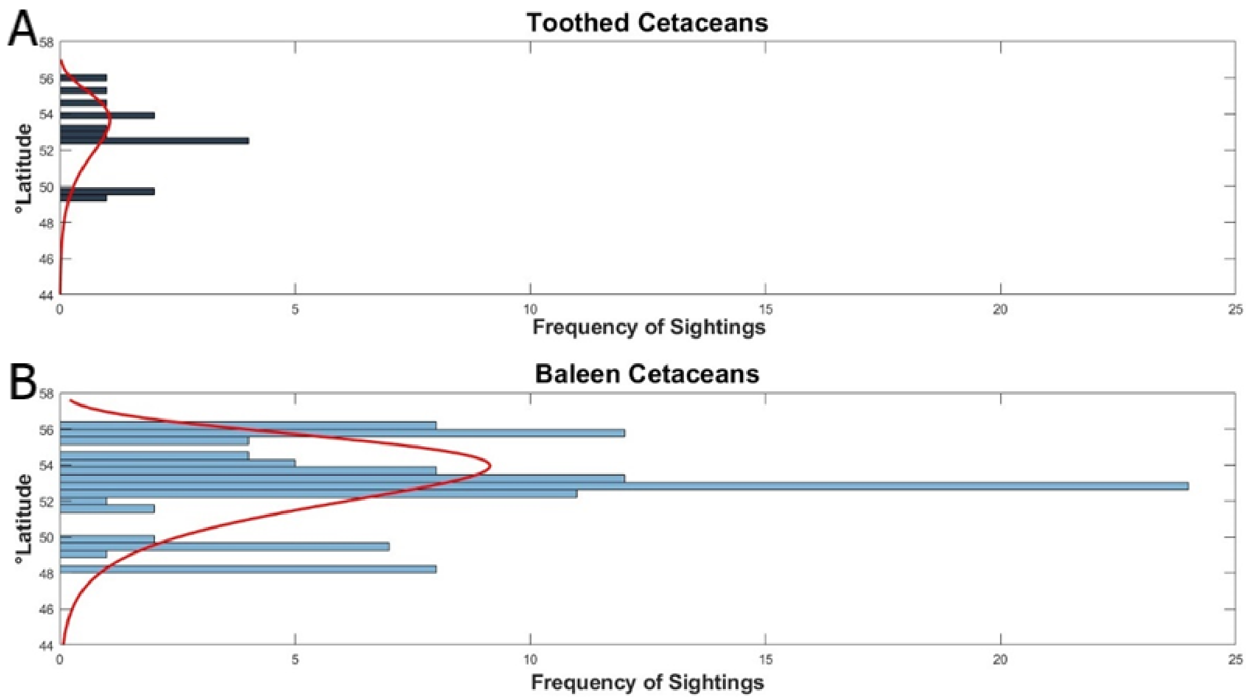

Figure 3. This figure depicts the frequency of cetacean sightings and latitude using histograms oriented 90° and a curve superimposed to determine if their distribution is normal or not. In graph A, toothed cetaceans are positively skewed, indicating a preference for higher latitudes. In graph B, baleen cetaceans are also positively skewed, indicating a preference for higher latitudes.

Depth profiles were generated for each of the XT drops and were visually checked to verify accuracy of the MLD. The accuracy of Chu and Fan (2017) is observed in XBT drop numbers 4 and 8 in Figure 4, where the location of the MLD occurs at the top of the thermocline. Chu & Fan (2017) used a plethora of slope and depth parameters that confined the MLD to an appropriate depth. Other methods used the entire depth profile and would incorrectly identify MLD at depths between 70-100m depth, usually occurring at a salt wedge. The transects running perpendicular to the QCF (Figure 5) had similar slopes when compared to the MLD slope (Figure 6) of the associated MLD. This could indicate near vertical translation of topographical surface expression into the MLD.

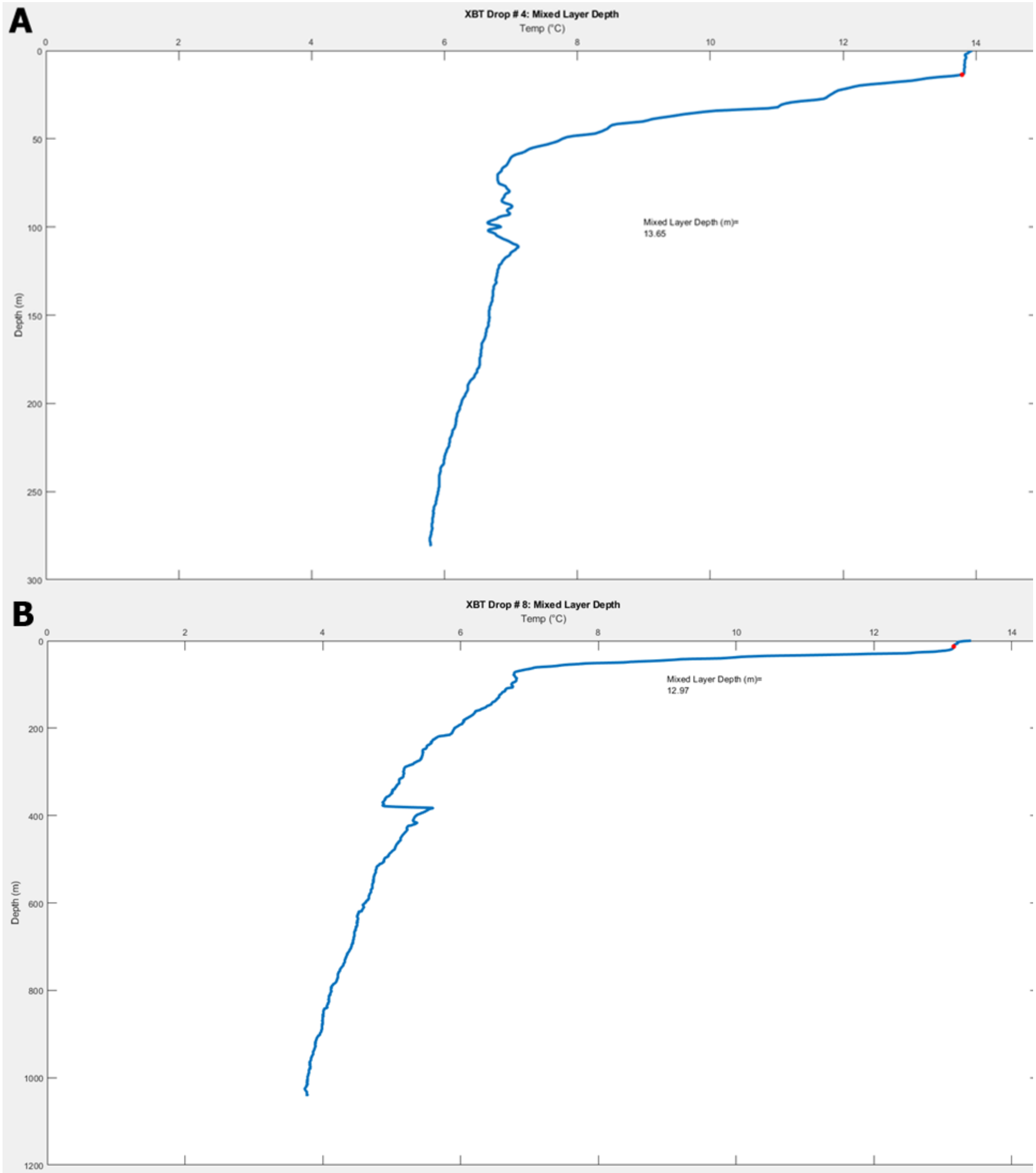

Figure 4. Graph A is a temperature depth profile from XBT drop #4 with a red dop displaying the location of the MLD. Graph B is a temperature depth profile from XBT drop #8 with a red dop displaying the location of the MLD.

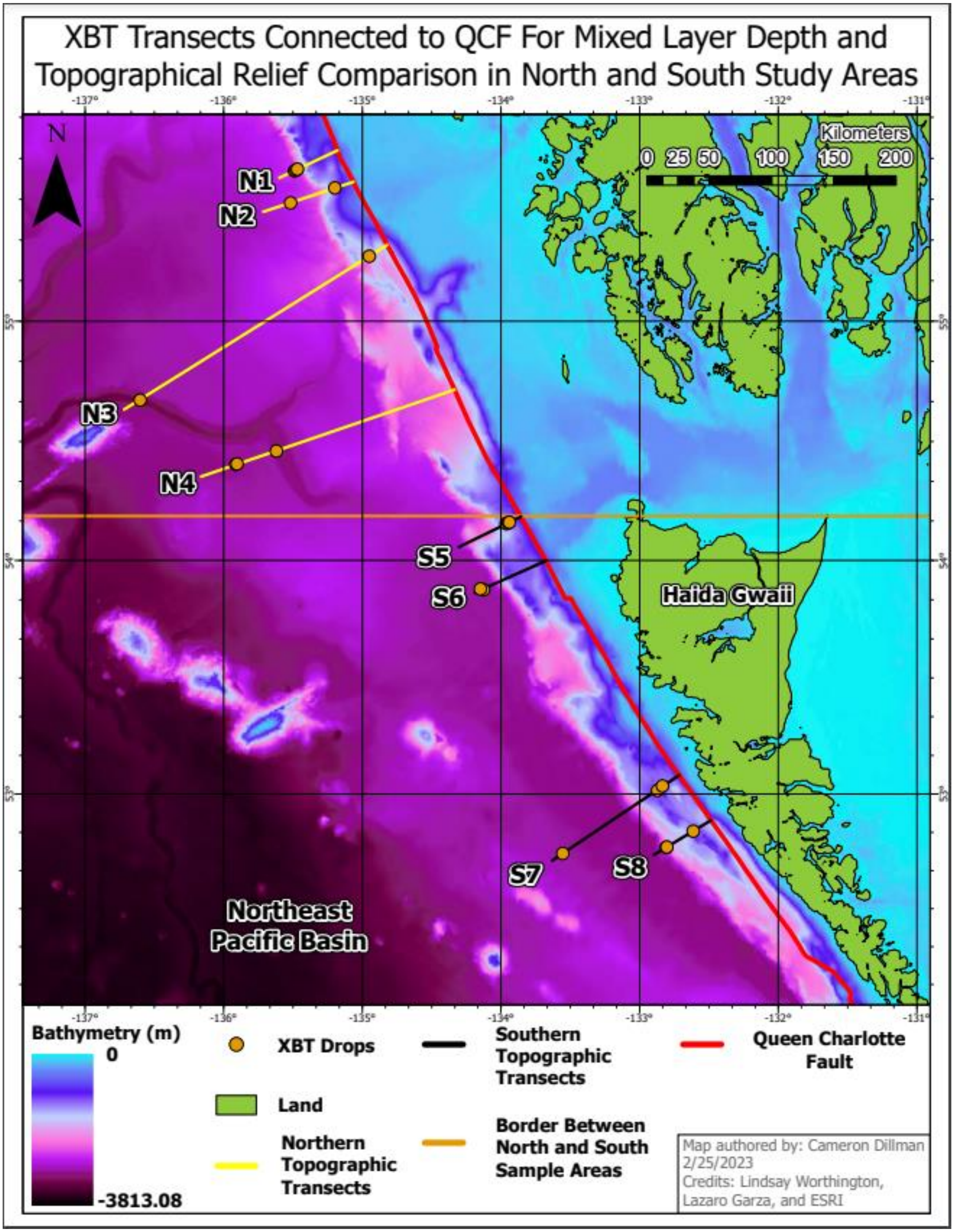

Figure 5. This is a map of Haida Gwaii and surrounding waters. The Queen Charlotte Fault has 8 transects lined up perpendicularly with it, where multiple XBT's were dopped.

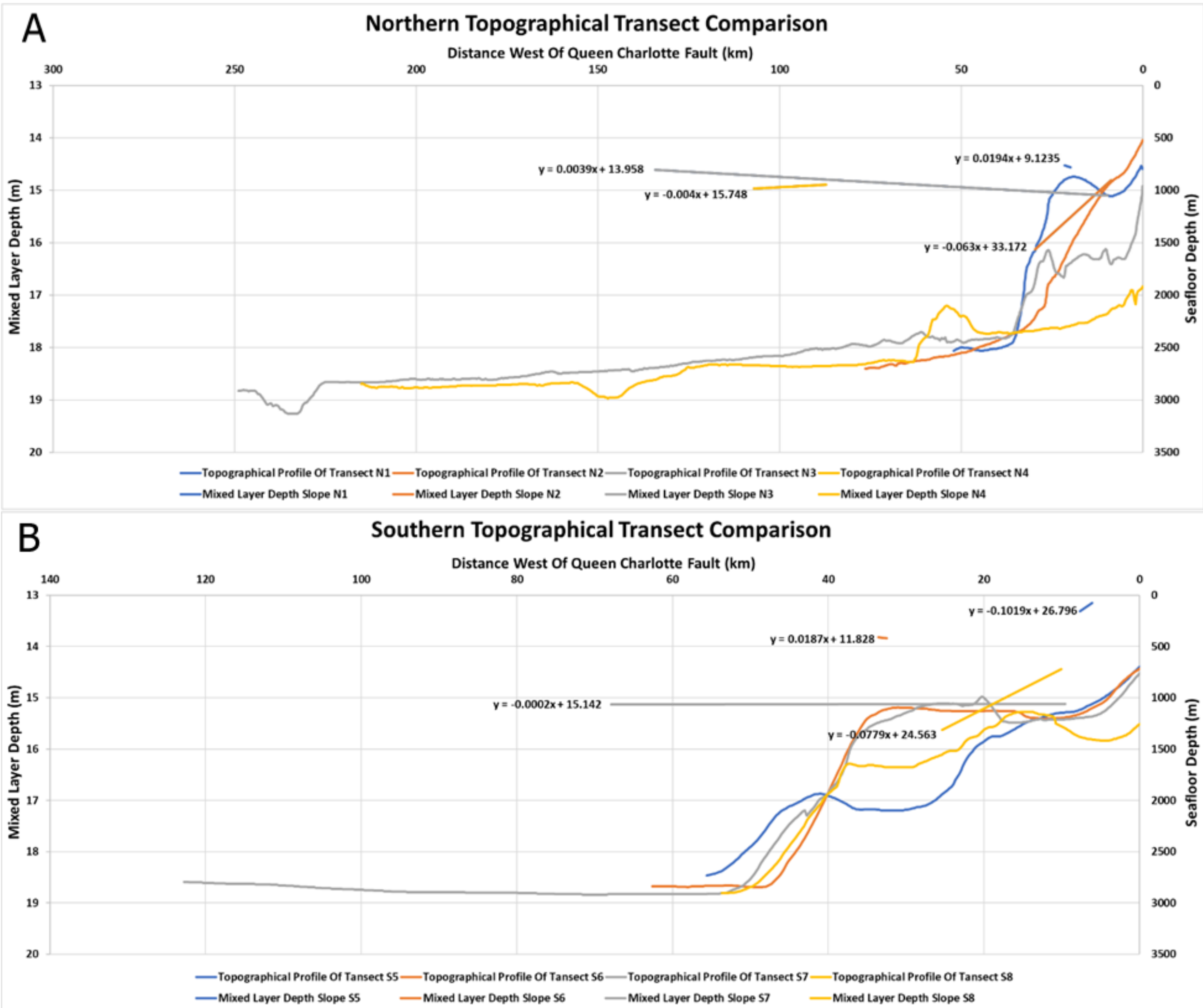

Figure 6. Figures A and B depict the topographical profiles of the transects seen in Figure 5 as well as the mixed layer depth slopes that were gathered from XBT data. MLD slope is on a secondary vertical axis, to show the depth of both XBT's involved with each slope profile. Graph A and B show MLD slopes that are similar to the topographical features that lay directly below them. When topographical features increase, so do the mixed layer depths. When they decrease, the MLD slope decreases (excluding transect N3 and S7).

The AIC model produced an array of delta values. The models with delta values ≤ 2 were selected (Table 2) and used to predict the probability of the presence of cetaceans based on each models' constituent variables. The parsimonious model for baleen cetaceans included eight of the nine variables recorded (distance from land, air temperature, SST, longitude, maximum depth, distance from QCF, MLD, and salinity). The best fitting GLM model determined by AIC to predict the presence of baleen cetaceans did not appear to be parsimonious, yet did account for 48% of the presence of baleen cetaceans. The parsimonious model for toothed cetaceans included five variables (Table 2) (distance from land, air temperature, latitude, longitude, and practical salinity units) and accounted for 6% of the presence of toothed cetaceans. Combining the response variables into an "All" category created similar results to the baleen model, with 8 of the 9 variables used (Table 2) (Distance from land, air temperature, SST, latitude, maximum depth, distance from QCF, MLD, and salinity) and is responsible for 46% of the presence of all cetaceans.

Table 2. This table depicts the parsimonious models to predict the presence of baleen, toothed, or all cetaceans. The cutoff value of ≤ 2 was used for a delta value to limit the applicable models. K indicates the number of variables used in the parsimonious model including 1 null model. LL stands for the log likelihood; deviance is the deviance of the model compared to the null model. AICc is the Akaike score. The Delta AIC stands for the difference between the best model and the other models. The AIC Weight describes the presence of the response variable as a percentage.

Baleen	Variable Combinations	K	LL	Deviance	AICc	Delta AIC	AIC Weight
	DistLandkm + MLDm + PythagDistQCFkm + SeaTemp + AirTemp + PSU + MaxDepth + Lat	9	-6480.94	12961.88	12979.88	0.00	0.48
	DistLandkm + MLDm + PythagDistQCFkm + SeaTemp + AirTemp + PSU + MaxDepth + Long	9	-6481.73	12963.47	12981.47	1.59	0.22
	DistLandkm + MLDm + PythagDistQCFkm + SeaTemp + AirTemp + PSU + MaxDepth + Long + Lat	10	-6480.91	12961.82	12981.82	1.94	0.18

Toothed	Variable Combinations	K	LL	Deviance	AICc	Delta AIC	AIC Weight
	DistLandkm + AirTemp + PSU + Long + Lat	6	-531.36	1062.72	1074.72	0.00	0.06
	DistLandkm + SeaTemp + AirTemp + PSU + Long + Lat	7	-530.59	1061.18	1075.18	0.46	0.05
	DistLandkm + SeaTemp + AirTemp + PSU	5	-532.70	1065.39	1075.39	0.68	0.04
	PythagDistQCFkm + AirTemp + PSU + Long + Lat	6	-531.90	1063.80	1075.80	1.08	0.03
	DistLandkm + MLDm + AirTemp + PSU + Long + Lat	7	-531.14	1062.28	1076.28	1.57	0.03
	DistLandkm + PythagDistQCFkm + SeaTemp + AirTemp + PSU	6	-532.21	1064.41	1076.41	1.70	0.03
	DistLandkm + SeaTemp + AirTemp + PSU + Lat	6	-532.29	1064.58	1076.58	1.86	0.02
	DistLandkm + PythagDistQCFkm + AirTemp + PSU + Long + Lat	7	-531.31	1062.63	1076.63	1.91	0.02
	DistLandkm + AirTemp + PSU + MaxDepth + Long + Lat	7	-531.35	1062.70	1076.70	1.98	0.02

All Cetaceans	Variable Combinations	K	LL	Deviance	AICc	Delta AIC	AIC Weight
	DistLandkm + MLDm + PythagDistQCFkm + SeaTemp + AirTemp + PSU + MaxDepth + Long	9	-6737.96	13475.91	13493.91	0.00	0.46
	DistLandkm + MLDm + PythagDistQCFkm + SeaTemp + AirTemp + PSU + MaxDepth + Lat	9	-6738.38	13476.77	13494.77	0.85	0.30
	DistLandkm + MLDm + PythagDistQCFkm + SeaTemp + AirTemp + PSU + MaxDepth + Long + Lat	10	-6737.88	13475.77	13495.77	1.85	0.18

Probability of detection for each model had egregious results (Table 3) and are most likely due to design and setup of the observation and non-detection method. The "parsimonious" model used for Baleen and All had low probabilities, except for air temperature, which seemed to have a positive correlation with probability of detection. By the time air temperatures exceeded 34°C, the probability of detecting Baleen cetacean or All cetaceans was over 10%. Toothed cetaceans had similar results with low probabilities of detection, except for the PSU category, which showed a rapid increase in probability of detection from 0% probability at 32 PSU, to 81.4% by 34 PSU.

Probability curves for various response variables were plotted using log transformed data against a Bernoulli scale. The probability of detection for All cetaceans decreased from 7.4% to 1.17 % from 10km and 130km distances from the QCF respectively (Figure 7). Whereas the probability of detection for All cetaceans decreased from 6.96% at 8°C SST down to 3.06% at 13°C SST (Figure 8). Air temperature had a positive correlation with probability of detection with All cetaceans and increases from 2.09% to 10.3% at 5°C and 35°C respective air temperatures.

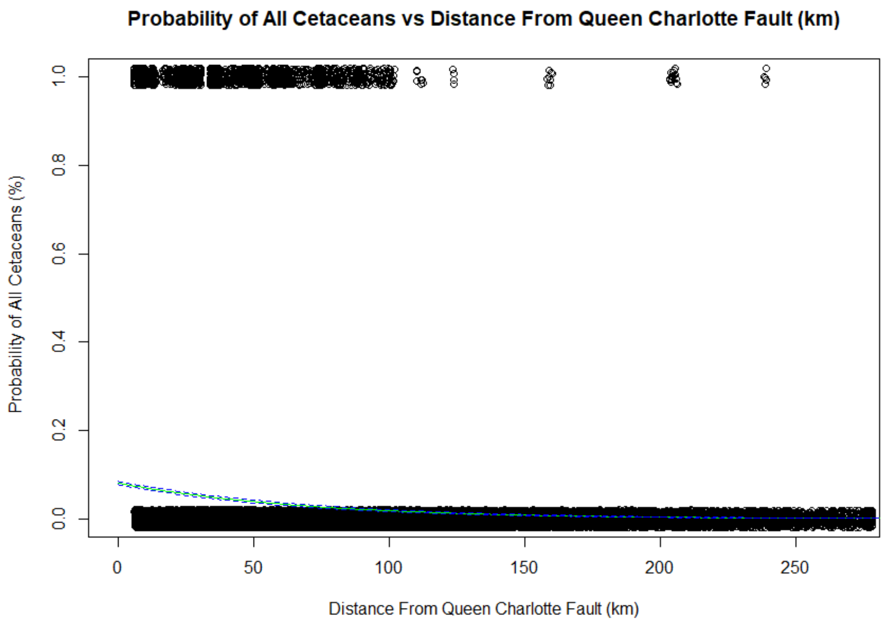

Figure 7. Log transformed probability curve including standard error to determine the presence of baleen and toothed cetaceans versus the distance from the Queen Charlotte Fault.

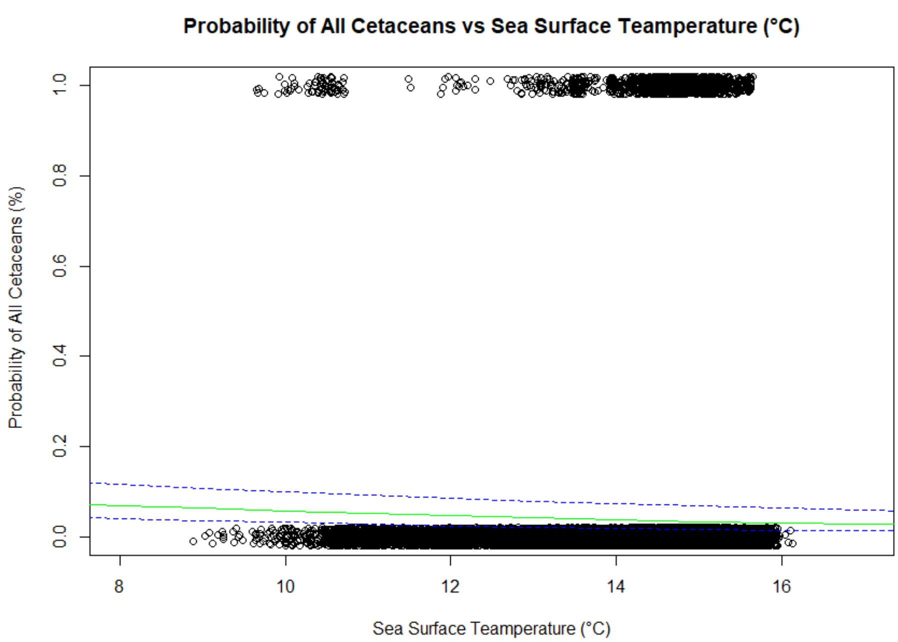

Figure 8. Log transformed probability curve including standard error to determine the presence of baleen and toothed cetacean's versus SST.

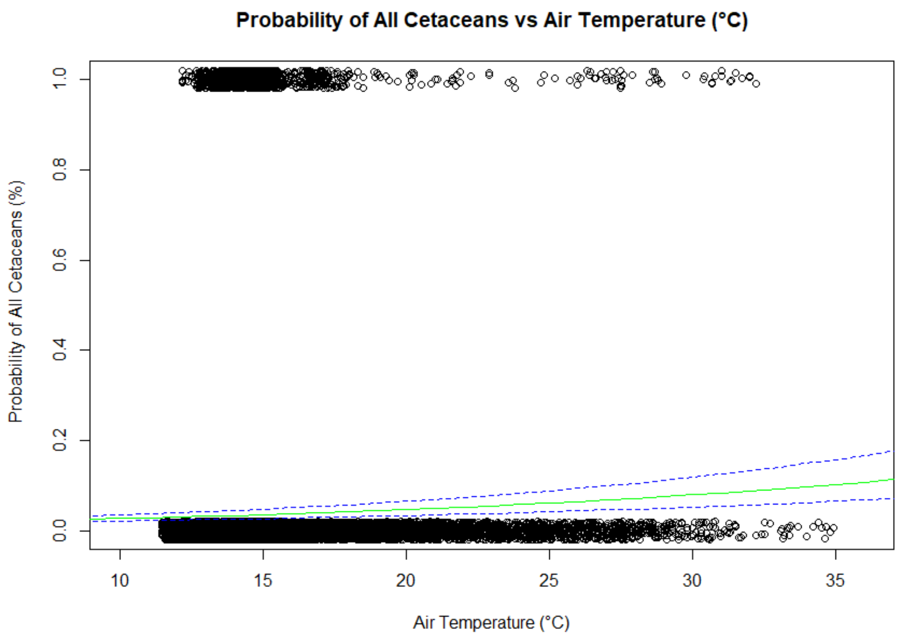

Figure 9. This graph is a log transformed probability curve including standard error to determine the presence of baleen and toothed cetacean's versus air temperature.

Table 3. This table uses the models with the lowest delta value to determine the probability of each response variable used in the model. Variables with specific values are listed next to their subsequent probability.

Baleen

Variable		% probability		% probability		% probability		% probability		% probability		% probability		% probability
Distance from Land (km)	5km	6.84	10km	6.3	15km	5.8	20km	5.32	25km	4.89	30km	4.5	35km	4.13
Mixed Layer Depth (m)	6m	0.88	8m	1.22	10m	1.68	12m	2.31	14m	3.17	16m	4.34	18m	5.9
Distance from QCF (km)	10km	6.81	50km	3.73	90km	2.01	130km	1.08	170km	0.57	210km	0.3	250km	0.16
Sea Surface Temperature (°C)	8°C	7.57	10°C	5.94	12°C	4.65	14°C	3.62	16°C	2.82	17°C	2.49	18°C	2.19
Air Temperature (°C)	5°C	1.92	10°C	2.57	15°C	3.43	20°C	4.58	25°C	6.1	30°C	8.03	35°C	10.5
Sea Surface Salinity (PSU)	28psu	4.72	29psu	4.33	30psu	3.97	31psu	3.64	32psu	3.33	33psu	3.05	34psu	2.8
Maximum Depth (m)	75m	3.58	500m	3.54	1000m	3.5	1500m	3.44	2000m	3.39	2500m	3.34	3000m	3.29
Longitude (Decimal ° W)	131°	8.82	132°	6.32	133°	4.5	134°	3.18	135°	2.24	136°	1.58	137°	1.11

Toothed

Variable		% probability		% probability		% probability		% probability		% probability		% probability		% probability
Distance from Land (km)	5km	0.25	10km	0.24	15km	0.23	20km	0.22	25km	0.21	30km	0.2	35km	0.19
Air Temperature (°C)	5°C	0.34	10°C	0.24	15°C	0.16	20°C	0.1	25°C	0.08	30°C	0.05	35°C	0.04
Sea Surface Salinity (PSU)	28psu	0	29psu	0	30psu	0	31psu	0	32psu	0.29	33psu	10.3	34psu	81.8
Latitude (Decimal °)	51°	0.77	52°	0.44	53°	0.25	54°	0.141	55°	0.08	56°	0.05	57°	0.03
Longitude (Decimal ° W)	131°	0.58	132°	0.37	133°	0.24	134°	0.15	135°	0.1	136°	0.06	137°	0.04

All Cetaceans

Variable		% probability		% probability		% probability		% probability		% probability		% probability		% probability
Distance from Land (km)	5km	7.06	10km	6.52	15km	6.01	20km	5.54	25km	5.1	30km	4.7	35km	4.3
Mixed Layer Depth (m)	13m	2.84	13.5m	3.07	14m	3.32	14.5m	3.59	15m	3.88	15.5m	4.19	16m	4.53
Distance from QCF (km)	10km	7.04	50km	3.92	90km	2.15	130km	1.17	170km	0.63	210km	0.34	250km	0.18
Sea Surface Temperature (°C)	8°C	6.96	10°C	5.69	12°C	4.63	14°C	3.77	16°C	3.06	17°C	2.75	18°C	2.48
Air Temperature (°C)	5°C	2.09	10°C	2.75	15°C	3.6	20°C	4.71	25°C	6.14	30°C	7.98	35°C	10.3
Sea Surface Salinity (PSU)	28psu	4.09	29psu	3.95	30psu	3.81	31psu	3.68	32psu	3.56	33psu	3.43	34psu	3.31
Maximum Depth (m)	75m	3.73	500m	3.69	1000m	3.66	1500m	3.62	2000m	3.58	2500m	3.54	3000m	3.51
Longitude (Decimal ° W)	131°	9.33	132°	6.667	133°	4.72	134°	3.33	135°	2.33	136°	1.63	137°	1.14

Discussion:

- Research on determining mixed layer depth was difficult. Many of the older MLD methods used vague explanations on determining upper and lower depth values in which to constrain MLD. This caused erroneous results, therefore accurately determining the MLD deemed challenging (Price & Weller, 1986; Thompson & Fine, 2003). Newer methods were more accurate and able to be automated by using additional parameters to minimize error. The Chu & Fan (2017) method was used in determining the MLD (Janecki et al., 2022; Chu & Fan 2017).
- Previous literature had indicated using calculus to find the inflection point to determine the MLD. Unfortunately, this method was extremely inaccurate using lines of best fit to mimic the curve using polynomials. The polynomial curves fit a majority of the profile and generated fabulous R^2 values. Regrettably, the line of best fit did not match the depth profiles in the surface waters, where the seawater density/temperatures fluctuated rapidly at minute depths. This made the velocity and acceleration of the temperature profile inaccurate and can be seen in Figure 10 even though it had a R^2 value of 0.969.

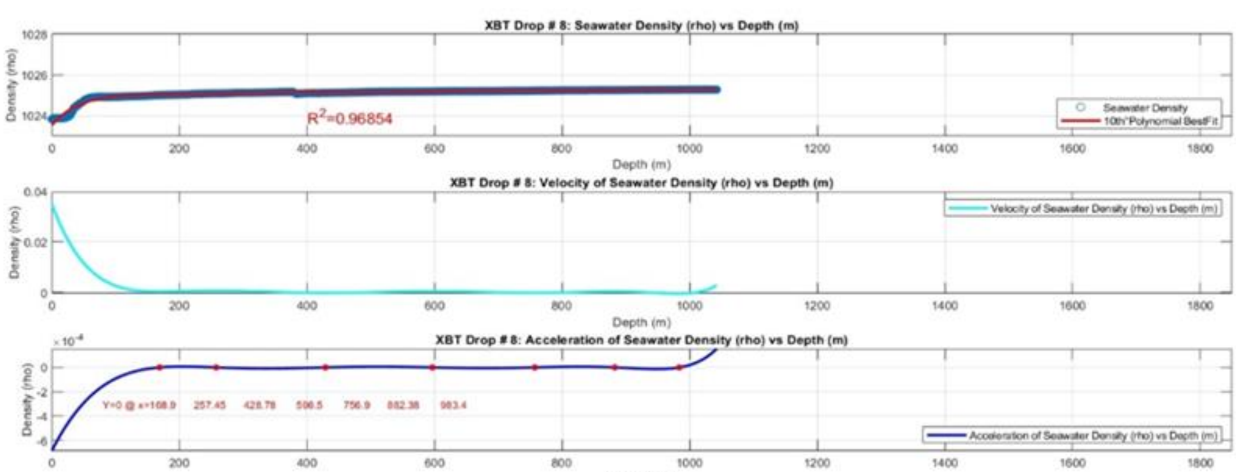

Figure 10. This set of stacked graphs was an attempt of using a polynomial best fit line and its velocity and acceleration to determine inflection points. The dots and values on the acceleration chart indicate the potential depths of the MLD, which can be verified to be grossly inaccurate…

- Issues arose in the data analysis because the whale sightings were only positive observations. In order to complete a presence and absence analysis, absences needed to be recorded as well. In order to make absence values and continue a statistical analysis of cetacean sightings, I used the entire ship log with its lat/long coordinates. Everywhere a cetacean was observed and the period of time in which the cetacean was present, I marked the baleen or toothed cetacean as observed. Periods of observation lasted from anywhere between 3 and 87 minutes hence observations were inflated and render a bias in the experiment. Also, 46,600 data points from the minute-by-minute ship log were used as non-detections, grossly skewing the analysis towards non-detection.
- The ship path also created a bias in analysis. Regions between 52° and 54° lat and –132° and -134° long were heavily surveyed, increasing the duration of time spent within the region resulting in an uneven sample distribution along the QCF.
- The data collected and used for analysis was unfortunately not collected for an ecological statistical analysis. This made analytical design extremely complicated and tedious. It could explain why there are high independent variable counts for the AIC determined "parsimonious model".
- The independent variables measured did not include biotic variables. If time constraints were not an issue, I would have incorporated chlorophyll – α content of the surface

water using the dates and locations of the cetacean detections. Satellite imagery of oceanic surficial chlorophyll – α content could be used as a proxy for phytoplankton biomass. Since primary production is followed by the presence of higher trophic levels and cetaceans, it could have been included as a biotic variable and used in the detection of cetaceans.

- The temporal period of the TOQUES survey also creates a bias due to recordings only taken during the months of July and August. This minimizes the presence of migratory cetaceans during other seasons.

Acknowledgements:

I would like to thank Lazaro Garza for the secondary data that he collected along the Queen Charlotte Fault. I am grateful for his accommodations and support through this analysis. Learning to code on a new platform was extremely difficult, his guidance was necessary for my success in completing this internship in a timely manner. Thank you for the support Lazaro! I could not have done this without him.

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Code for mixed layer depth (TD: used -1 for temperature vector)

```
%%% script for running mixed layer depth%%%
%%% Computing Gth, preparing for ELG from Chu and Fan, (2017) method%%%%%
function [ist,slop17,i17,dep,Var,isteps,I30,flag]=getslop17(dep,Var,TD)
% function [ist,slop17,i17,dep,Var,isteps,I30,flag]=getslop17(dep,Var,TD);
% Var: variable (potential density, temperature)
% TD: 1; density, -1:temperature
% output:
% ist: an integer i with zi = z1 in Eq(2)
% slop17: Gth between z(0.1) and z(0.7) in Eq(3)
% i17: all integers {k} from z(0.1) to z(0.7) in Fig. 1
% dep: depth (m) >0
% data pairs (dep, Var) must be removed if diff(dep)<=0
% isteps: N+1 integers 20, 2, …, 2N in Eq(14)
% flag: 0: normal
%   1: few (<=2) observational points from 10 m to 40 m
%   2: total observational points <=5
%   3: maximum depth <20 m
%   4: starting point with depth deeper than 50 m
%   5: difference above 20 m > different below 20 m
%   6: maximum difference < 1.0 °C (temp) or < 0.01 kg/m3 (dens)
%   7: no thermocline
%   8: thermocline gradient is too small (<0.001 °C/m)
%   9: two neighboring profiles have big difference (>5 °C)
if ~exist('TD','var'), TD=-1; end

slop17=[]; i17=[]; isteps=[]; ist=[]; I30=[]; flag=0;
```

```
if max(abs(diff(Var)))>5
   flag=9; return;
end

Isteps=2.^(0:6)+1;

%Var=Var(dep>3); dep=dep(dep>3);
ii=find(dep<=800); dep=dep(ii); Var=Var(ii);
ii=find(diff(dep)<=0);
while(~isempty(ii))
   dep(ii)=[]; Var(ii)=[];
   ii=find(diff(dep)<=0);
end
Varr=Var*TD;

% if the data not good and return
if length(dep)<6, flag=2; return; end
if dep(end)<20, flag=3; return; end
if dep(1)>50, flag=4; return; end
max20=max(Varr(dep<20))-min(Varr(dep<20));
maxdeep=max(Varr(dep>20))-min(Varr(dep>20));

if max20>maxdeep, flag=5; return; end

%N=length(dep);

% set the start depth as the minimum slope above 20m depth.M
ii=find(dep<20);
```

```
if(length(ii)>2)
   slp=abs(diff(Varr(ii))./diff(dep(ii)));
   [~,ist]=min(slp);
else
   ist=1;
end

%%% Determining IOD using ELG from Chu and Fan, (2017) method%%%%%

Vist=Varr(ist);
Varr=Varr-Vist;
[Vmax,imax]=max(Varr(ist:end));
imax=imax-1+ist;

% estimate the number of data points in thermocline (pycnocline)

if((Vist<40 && Vmax<=1) || (Vist>40 && Vmax<=0.01)), ist=[]; flag=6; return; end

i17=(find(Varr(ist:imax)<0.1*Vmax,1,'last'):find(Varr(ist:imax)>=0.7*Vmax,1))+ist-1;

I30=find(Varr(ist:end)>=0.3*Vmax,1)+ist-1;

if(isempty(i17)), ist=[]; flag=7; return; end

n17=length(i17);

isteps=Isteps(Isteps<=n17);
if isteps(end)<32 && isteps(end)~=n17
```

```
   isteps=cat(2,isteps,n17);
end
Nsp=length(isteps);

vv=Varr(i17(1)+1:end)-Varr(i17(1));
dd=dep(i17(1)+1:end)-dep(i17(1));
ii=find(dd>=2);
if length(ii)>3
   slop17=vv(ii)./dd(ii);
else
   slop17=vv./dd;
end

slop17=prctile(slop17,50);

if((Vist<40 && slop17<1e-3) || (Vist>=40 && slop17<1e-5)), ist=[]; flag=8; return; end
% Nsp=min(Nsp,5);
% isteps=isteps(1:Nsp)-1;
% update ist
vv=Varr(1:i17(1));
dv=abs(vv-mode(vv)); dv=dv(end:-1:1);
[~,ist]=min(dv); ist=length(dv)+1-ist;
if sum(dep>=10 & dep<=40)<2, flag=1; end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%% Analytical profile for aplying functions from Chu and Fan, (2017) method%%%%
```

```
function [mld,Ii,Q,Vmld]=ELGMLDCore(dep,Var,ist,slop17,i17,isteps,TD)
% function [mld,Ii,Q,Vmld]=ELGMLDCore(dep,Var,ist,slop17,i17,isteps,TD);
% input:
% The input (dep,Var,ist,slop17,i17,isteps) are obtained from the output
% of the Matlab function depicted in Appendix A.
% TD: temp:-1, density: +1
% output:
% mld: mixed layer depth (m)
% Ii: identification index
% Q: qulity index
% Vmld: variable (temperature, density, …) at the mixed layer depth such as T-H

if ~exist('TD','var'), TD=-1; end
mld=NaN; Q=NaN; Vmld=NaN; Ii=NaN;

Var=TD*Var;

if isempty(ist), return; end
N=length(dep);

refslop=0.5*slop17;
n17=length(i17);

for i=ist:length(dep)-isteps(end)
   slops=(Var(i+isteps)-Var(i))./(dep(i+isteps)-dep(i));
      if min(slops)>=refslop
         mld=dep(i); Vmld=TD*Var(i);
         i15mld=find(dep<=1.5*mld);
```

```
i3=i15mld(i15mld<=i+n17);
i1=(1:i)';
A1=sum((Var(i1)-mean(Var(i1))).^2);

i2=i3(i3>i);

if(length(i2)<3), A2=0;
else
p2=polyfit(dep(i2),Var(i2),1);
v2=polyval(p2,dep(i2));
A2=sum((Var(i2)-v2).^2);
end

if(length(i3)>=3)
p3=polyfit(dep(i3),Var(i3),1);
v3=polyval(p3,dep(i3));
A3=sum((Var(i3)-v3).^2)+eps;
Ii=max(-1,1-(A1+A2)/A3);
end

N1=i-1;
i2=find(dep<=1.5*mld);
N2=length(i2)-1;
if(N2<=0)
i2=(i:min(i+1,N))';
N2=length(i2)-1;
end
if(N2==0 || N1==0)
```

```
        return;
        end


        mu=mean(Var(i1));
        A1=std(Var(i1)-mu);
        A2=std(Var(i2)-mu)+eps;
        if(A2==0), disp([mu,N2]); disp([i2, Var(i2)]); 'RG'; return; end
        Q=1-A1/A2;
% if(Q<=0), Q=NaN; mld=NaN; end
        return;
      end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
gsw_check_functions
%%%Loading an individual XBT drop table %%%
A=load('../XBT_Data_Cleaned_Derived_Variables/T5_31_Including_Derived_Density.csv')
%%%%% column order = [ 1 = time(seconds), 2 = resistance (ohms), 3 = depth (meters), 4 = Temp (°C), 5 = Sound velocity (m/s), 6 = Practical Salinity (psu), 7 = Absolute Salinity, 8 = Absolute Sea pressure (dBar), 9 = Seawater density (rho = kg/m^3), 10 = Seawater Density (Sigma-t), 11 = Depth (meters)%%%%%
%%%Calling up vectors from XBT derived columns to obtain CT, consertvative temp%%%%
SA = A(:,7)
t = A(:,4)
p = A(:,8)
depth = A(:,3)
%Going to run GSW CT program %%%%
CT = gsw_CT_from_t(SA,t,p)
%%%% Going to run GSW sigma0 to obtain potential density vector which will be used in code for thermocline determination%%%
sigma0_CT_exact = gsw_sigma0_CT_exact(SA,CT)
```

%%%%%%%% Making new table w/ new variables%%%%%%%

T = [A CT sigma0_CT_exact]

%%%%% New column order = [1 = time(seconds), 2 = resistance (ohms), 3 = depth (meters), 4 = Temp (°C), 5 = Sound velocity (m/s), 6 = Practical Salinity (psu), 7 = Absolute Salinity, 8 = Sea pressure (dBar), 9 = Seawater density (rho = kg/m^3), 10 = Seawater Density (Sigma-t), 11 = Depth (meters), 12 (conservative temperature °C), 13 (Potential Density)]%%%%

%%%%%% writing table including new variables%%%%%

writematrix(T,"T5_31_All_Variables.csv")

%%%% Assigning variables to align with script%%%

dens = T(:,13)

temp = T(:,4)

dep_c = T(:,3)

%%

Code for Histogram and weibull curve

%%%Running baleen cetacean code for Histogram w/ weibull curve%%%%%%

ABaleen=load('Baleen_Cleaned.csv')

%%%Setting vectors for latitude and for abundance%%%%%

LatBaleen = ABaleen(:,1)

%%%%setting up subplot format

subplot(3,1,2)

%%%% Using histfit for the baleen data and weibull curve in order to show skewed data, and alter histogram color%%%%%

hBaleen = histfit(LatBaleen,[20],'weibull','FaceColor','#CACFD2')

hBaleen(1).FaceColor = ['#7FB3D5'];

xlim([44, 58])

ylim([0, 30])

title("Baleen Cetaceans",'fontweight','bold','fontsize',20)

xlabel('°Latitude','fontweight','bold','fontsize',16)

%%%Rotating histogram 90 degrees so it visually pairs with latitude%%%%

set(gca,'view',[90 -90])

```
hold on

%%%%%%toothed
AToothed=load('Toothed_Cleaned.csv')
%%%Setting vectors for latitude and for abundance%%%%%
LatToothed = AToothed(:,1)
subplot(3,1,1)
hToothed = histfit(LatToothed,[20],'weibull')
hToothed(1).FaceColor = ['#2C3E50'];
xlim([44, 58])
ylim([0, 30])
title("Toothed Cetaceans",'fontweight','bold','fontsize',20)
xlabel('°Latitude','fontweight','bold','fontsize',16)
set(gca,'view',[90 -90])
hold off

%%%%%%all cetaceans
AAll=load('CleanedWhaleMaster.csv')
%%%Setting vectors for latitude and for abundance%%%%%
LatAll = AAll(:,1)
subplot(3,1,3)
hAll = histfit(LatAll,[20],'weibull')
hAll(1).FaceColor = ['#2471A3'];
xlim([44, 58])
ylim([0, 30])
title("All Cetaceans",'fontweight','bold','fontsize',20)
xlabel('°Latitude','fontweight','bold','fontsize',16)
set(gca,'view',[90 -90])
```

```
ylabel('Frequency of Sightings','fontweight','bold','fontsize',16)
hold off
```

Code for depth profiles with velocity and acceleration and inflection points

```
%%%%%attempting with sigma and depth reversed%%%
A=load('T5_8_Including_Derived_Density.csv')
%%%%%Including depth%%%%
Depth = A(:,3)
%%% including seawater density %%%%%%
rho = A(:,9)
%%%setting x and y variables to density and depth%%%%%
y = rho
x = Depth
%%%%plotting graph%%%%%%
plot(x,y,'o')
grid on
title('XBT Drop # 8: Seawater Density (rho) vs Depth (m)')
ylabel('Seawater Density (rho)')
xlabel('Depth (m)')
xlim([0 1850])
ylim([1023 1028])
%%%%%Determining residuals%%%%%
[p,~,mu] = polyfit(x,y,10)
polynomialcoeffecients = polyfit(x,y,10); %%%%Coefecients
yfit = polyval(polynomialcoeffecients,x); %%%%estimated regression line
SStot = sum((y-mean(y)).^2); %%%Total sum of squares
SSres = sum((y-yfit).^2);  %%%%%risidual sm of squares
RSquaredValue = 1-SSres/SStot; %%% R^2 value
```

```
%%%Graphing best fit line%%%%

f = polyval(p,x,[],mu);

hold on

plot(x,f, 'LineWidth', 2,'color','r')

hold off

%%%Making Legend For Plot%%%%

legend('Seawater Density', '10th°Polynomial BestFit','Location', 'Northwest')

%%%Typying r squared value on graph%%%%

text(800,1018,['R^2=' num2str(RSquaredValue)],'color','r','FontSize',12);

%%%%Getting Polynomial variables (should be 11 digits (first is x^10, then x^9, then
x^8...)%%%%%%

BestfitEquation= polyfit(x,y,10)

%%%%getting derivative of bestfit equation%%%%

kprime = polyder(BestfitEquation) %%%Should have 10 values, starting with x^9, x^8, x^7....)

%%%Graphing 1st derivative of bestfit%%%%%%

kprimegraph = plot(x,polyval(kprime,x),'LineWidth', 2,'color','g')

grid on

title('XBT Drop # 8: Velocity of Seawater Density (rho) vs Depth (m)')

xlabel('Depth (m)')

ylabel('Seawater Density(rho)')

xlim([0 1850])

%%%%Adding legend to Derivative Graph%%%%%%

legend('Velocity of Seawater Density (rho) vs Depth (m)','Location', 'Northwest')

%%%%%Getting second derivative of bestfit equation%%%%%%

kdoubleprime = polyder(kprime) %%%Should have 9 values, starting with x^8, x^7, x^6....)

%%%Graphing 2nd derivative of bestfit%%%%%%

kdoubleprimegraph = plot(x,polyval(kdoubleprime,x),'LineWidth', 2,'color','black')

grid on

%%%%Labeling title and axis%%%%
```

```
title('XBT Drop # 8: Acceleration of Seawater Density (rho) vs Depth (m)')

xlabel('Depth (m)')

ylabel('Seawater Density(rho)')

xlim([0 1850])

%%%%Adding legend to 2nd Derivative Graph%%%%%%

legend('Acceleration of Seawater Density (rho) vs Depth (m)','Location', 'Southwest')

%%%%Checking for where acceleration of density vs depth makes contact with 0 (inflection
point)%%%%%

%%%%Making vector of 2nd derivative in order to find where signs change from negative to
positive (point of inflection)%%%%

kDubPrimeVector = polyval(kdoubleprime,x)

%%%%Using vector function to determine inflection%%%

KDubPrimeGraph= plot(x,kDubPrimeVector)

%%%Using Spline function in order to find y=0 points%%%%%

KDubKdub = spline(x,kDubPrimeVector)

fnplt(KDubKdub)

%%%Making y=0 at x values table%%%%

XEqualsZero = fnzeros(KDubKdub)

%%%Making zeros into vecotr format%%%%

XZero = XEqualsZero(1,:)

%%%Setting spline boundaries%%%%%

nz = size(XEqualsZero,2);

hold on

plot(XEqualsZero(1,:),zeros(1,nz),'o',XEqualsZero(2,:),zeros(1,nz),'o','MarkerSize',3,'LineWidth',
2,'color','black')

grid on

title('XBT Drop # 8: Acceleration of Seawater Density (rho) vs Depth (m)')

xlabel('Depth (m)')

ylabel('Seawater Density(rho)')

xlim([0 1850])
```

```
hold off
legend('Acceleration of Seawater Density (rho) vs Depth (m)','Location', 'Southwest')
%%%adding text of x vlues where y=0 , num2str(vector,rounding to precision of 5 digits)%%%
num2str(XZero)
text(80,-0.0003,['Y=0 @ x=' num2str(XZero,5)],'color','r','FontSize',8);
%%%Actual Depth Profiles%%%
DepthProfile = plot(rho , Depth,'LineWidth', 2,'color','b')
grid on
%%%Labeling axis and titles%%%%
title('XBT Drop # 8: Depth Profile')
xlabel('Seawater Density (rho)')
ylabel('Depth (m)')
ylim([0 1850])
xlim([1023 1028])
%%%%Moving X axis above graph%%%%
set(gca, 'XAxisLocation', 'top')
%%%%Reversing y axis%%%
set(gca,'Ydir','reverse')
%%% Putting the 3 graphs together for visual acuity - using the subplot command%%%%
%%%Subplot 1 is depth profile%%%%
subplot(3,1,1)
%%%%plotting graph%%%
plot(x,y,'o')
grid on
title('XBT Drop # 8: Seawater Density (rho) vs Depth (m)')
ylabel('Density (rho)')
xlabel('Depth (m)')
xlim([0 1850])
```

```
ylim([1023 1028])
hold on
plot(x,f, 'LineWidth', 2,'color','r')
hold off
%%%Making Legend For Plot%%%%
legend('Seawater Density', '10th°Polynomial BestFit','Location', 'SouthEast')
%%%Typying r squared value on graph%%%%
text(400,1024,['R^2=' num2str(RSquaredValue)],'color','r','FontSize',12)
%%%Subplot 2 velocity of best fit line%%%
subplot(3,1,2)
plot(x,polyval(kprime,x),'LineWidth', 2,'color','c')
grid on
title('XBT Drop # 8: Velocity of Seawater Density (rho) vs Depth (m)')
xlabel('Depth (m)')
ylabel('Density (rho)')
xlim([0 1850])
legend('Velocity of Seawater Density (rho) vs Depth (m)','Location', 'Northeast')
%%%%Subplot 3 - acceleration of best fit line%%%%%%
subplot(3,1,3)
plot(x,polyval(kdoubleprime,x),'LineWidth', 2,'color','blue')
grid on
title('XBT Drop # 8: Acceleration of Seawater Density (rho) vs Depth (m)')
xlabel('Depth (m)')
ylabel('Density (rho)')
xlim([0 1850])
hold on
plot(XEqualsZero(1,:),zeros(1,nz),'o',XEqualsZero(2,:),zeros(1,nz),'o','MarkerSize',3,'LineWidth',
2,'color','r')
hold off
```

```
legend('Acceleration of Seawater Density (rho) vs Depth (m)','Location', 'Southeast')
%%%%adding text of x vlues where y=0 , num2str(vector,rounding to precision of 5 digits)%%%
num2str(XZero)
text(80,-0.0003,['Y=0 @ x=' num2str(XZero,5)],'color','r','FontSize',8);
%%%%%Roots function to find zeros of 2nd derivative%%%%
YZero = roots(kdoubleprime)
%%%Multiplying the polynomial by each root value to find the inflection point%%%%%%
Inflection1 = (BestfitEquation*YZero(1,1))
Inflection2 = (BestfitEquation*YZero(2,1))
Inflection3 = (BestfitEquation*YZero(3,1))
Inflection4 = (BestfitEquation*YZero(4,1))
Inflection5 = (BestfitEquation*YZero(5,1))
Inflection6 = (BestfitEquation*YZero(6,1))
Inflection7 = (BestfitEquation*YZero(7,1))
Inflection8 = (BestfitEquation*YZero(8,1))
Inflection9 = (BestfitEquation*YZero(9,1))
```

Code for trapping depth

```
%% Using integrals to find trapping depth%%%%
A=load('T5_2_Including_Derived_Density.csv')
%%%%% Making depth (m) a vector%%%%
Depth = A(:,3)
%%% Making temperature (°C) a vector%%%
Temp = A(:,4)
%%% Renaming Temp and depth vectors as x and y variables%%%%%
x = Temp
y = Depth
%%% Making duplicate vectors to manipulate for integrating%%%
```

```
t = Temp

z = Depth

%%%%% Plotting x and y vectors to assess plot

plot(x,y,'MarkerFaceColor','g')

grid on

%%%% Moving X axis above graph%%%%

set(gca, 'XAxisLocation', 'top')

%%%%Reversing y axis%%%

set(gca,'Ydir','reverse')

%%% Determining t and z values nearest to arbitrary 40m depth index%%%%

[~, idx] = min( abs(z - 40) );

ttest = t(idx);

ztest = z(idx);

%%%% Omitting points below arbitrary depths of 40m on t and z vectors, will use as max range
for integration%%%

t(((idx):end),:)=[]

z(((idx):end),:)=[]

%%% Determining t and z values nearest 2m depth to determine index number index, will use
for min depth for integrating depth and temp to find trapping depth%%%%

[~, idx] = min( abs(z - 2) );

closest_t = t(idx);

closest_z = z(idx);

%%%% Omitting points above arbitrary depths of 2m on t and z vectors, will use as min range
for integration%%%

t((1:(idx)-1),:)=[]

z((1:(idx)-1),:)=[]

%%% Integrating temperature vector with respect to depth vector – value will be negative, so
multiply by negative 1 in later steps%%%%%

q = trapz(t,z)
```

```
%%% Isolating the first and last vector row for temp to use as upper and Lowerbounds of temperature%%%%

DeltaTemp = (t(1:1)) - (t(end))

%%% Determining trapping depth from Price et al (1986)%%%

TrappingDepth = -(q / DeltaTemp)


%%% Getting max t and z vector values to scale graph for area%%%%

[zmax,idx_max] = max(z) ;

[tmax,idx_max] = max(t) ;

%%

%%% Determining x and y values nearest trapping depth index, will use to plot point on graph%%%%

[~, idx] = min( abs(y - TrappingDepth) );

closest_x = x(idx);

closest_y = y(idx)

%%% Getting max x and y vector values to scale graph individually%%%%

[ymax,idx_max] = max(y) ;

[xmax,idx_max] = max(x) ;

%%% Plotting graph%%%%%

plot(x,y,'MarkerFaceColor','g')

grid on

%%%% Moving X axis above graph%%%%

set(gca, 'XAxisLocation', 'top')

%%%% Reversing y axis%%%

set(gca,'Ydir','reverse')

title('XBT Drop # 2: Trapping Depth Determination')

xlabel('Temp (°C)')

ylabel('Depth (m)')

%%% Setting limits on x and y axis%%%%
```

```
xlim([0 (max(x)+1)])

ylim([0 max(y)])

hold on

%%% Plotting location of trapping depth%%%

plot(closest_x, closest_y, 'r.', 'LineWidth', 2, 'MarkerSize', 25)

txt = {'Trapping Depth (m)=' (num2str(closest_y)),'Temp (°C)=' (num2str(closest_x))};

text(7,800,txt)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%% Shading integral area with gray using hex codes with no edge color%%%%

area(t,z, 'facecolor','#ECEEF0','edgecolor','none')

%%% Getting min and max t and z vector values to scale graph individually%%%%

[zmax,idx_max] = max(z) ;

[tmax,idx_max] = max(t) ;

%%% Making new x and y vectors w/ lmits for shading area for visual on integral%%%%

%%% Using ttest for lower bounds and tmax as upper bounds for y = 0 line%%%

x2= (ttest):0.001:(tmax)

y2 = 0*x2

plot(x2,y2,'color','k','linewidth','.5')

%%%%%%%%%This seems to not work with plotting even though it did in previous
graphs...%%%

%%% Now making vertical line from specific point at 40m arbitrary depth%%%

x3 = [(tmax),(tmax)]

y3 = [0,(zmax)]

plot (x3,y3, 'color','k')

hold off

%%% Shading integral area with gray using hex codes with no edge color%%%%

area(t,z, 'facecolor','#ECEEF0','edgecolor','none')
```