Detecting wild fish and zooplankton near fish farms during and after fallow periods in Southern Newfoundland

by

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Abstract

From November 2016 until September 2017, acoustic Doppler current profilers were deployed in two neighboring bays in Southern Newfoundland, East Bay and Cinq Island Bay. We set out to determine the influences that aquaculture had on wild fish abundance in the ecosystem during fallow periods. Fallow periods describe the times when farms were not stocked with fish. It was hypothesized that during a time where a fish farm was newly inactive there would be a different abundance of wild fish nearby than during a time when the farm was active. In our study, both East Bay and Cinq Island Bay were fallow prior to November until June/July of the following year. After that time, fish farms were restocked with Atlantic Salmon. The acoustic Doppler current profilers were configured to collect data without the typical averaging of acoustic pings into ensemble averages. This processing allowed for the instruments to act as fish detecting sonars. We calculated volume backscatter strength, fish counts, fish depths and target strengths of detected fish. Fish schools and diurnal migration patterns occurred frequently and on some occasions, high backscatter intensities persisted for several hours. Depths of fish appeared to be similar during November, December, January, March and April. Summer months of June, July, August and September had opposing depth distributions. In Summer months, there were fish primarily at shallow depths and in Winter months fish were primarily at deeper depths. Summarizing the entirety of the time series resulted in depths distributions throughout the entire water column in East Bay suggesting that diel vertical migrating species were commonly present. In contrast to this, Cinq Island Bay showed fish primarily at 50 meters, indicating that a different fish species frequented this area.

Similar results from target strength distributions suggested two species or behaviors present in East Bay and one species present in Cinq Island Bay. Shifts of fish types or behaviors in East Bay occurred during the same time periods as the beginning of fish farm activity and also the start of the Summer season. Both bays displayed concurrent increased fish counts in January and May with a larger wild fish abundance in East Bay than in Cinq Island Bay. The amount of fish in both bays differed during and after fallow periods which coincided with seasonal changes. Because of this timing, distinguishing the effects of fallow periods from seasonal changes was not possible. This study demonstrates the value of using acoustic monitoring methods for collecting data from aquaculture sites. Altering future studies to include longer time series, simultaneous fish sampling and multiple acoustic Doppler current profilers in each bay could provide additional important data that may lead to concrete conclusions about aquaculture influences on wild fish species.

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Chapter 1

Introduction

Over the past 30 years, aquaculture has progressed in Newfoundland. Fish farming, in particular, has expanded in Southern bays and ultimately benefits the economy within the province. In 1992, cod fisheries in Newfoundland collapsed from over fishing and this had detrimental effects on both the economy as well as the marine environment. To avoid similar catastrophic incidents, the sustainability of current practices in aquaculture are given considerable attention.

Exposing the natural environment to fish farming equipment and operations causes side effects. One understood repercussion of fish farming is the buildup of excess nutrients in the water column. Because fish feed sinks very quickly, it builds up underneath of net pens [20]. To counteract the accumulation of feed, fallow periods are utilized. Fallow periods are times during the year that fish are not present within net pens. During fallow periods, the ecosystem around the area is anticipated to return to its natural state. A study conducted in Norway concluded that benthic organisms experience partial growth during six month fallow periods at any time of year [43]. In Newfoundland, the Department of Fisheries and Oceans recognizes the need to determine the length of time that it takes for the benthic communities under net pens to flourish again [14]. Due to the lack of understanding the influences of fallow periods in Newfoundland, the length of time that farms are fallow varies.

Studying the influence of fallow periods on wild fish populations will aid in determining part of the effect that aquaculture has on the ecosystem in the province. Because of the influence of aquaculture on the ecosystem, the species that live and migrate to these areas are important to quantify. In the Southern bays of Newfoundland, fish species are attracted to bays with cage farming more than bays that do not have cage farming [18]. Understanding the impact of fallow periods on the fish species at farm sites is of equal importance to understanding the impact of fallow periods on the benthic organisms.

In order to investigate the role of fallow periods on fish aggregations around farms, a time series of fish accumulation during both active and inactive farming was collected. In this study, two acoustic Doppler current profilers (ADCP) were placed nearby to fish farms in two adjacent bays in Southern Newfoundland. ADCPs are relatively inexpensive and effective acoustic instruments that can be configured to detect fish present in a fixed location. By manipulating the values collected by the ADCPs, fish can be counted by setting threshold values for both volume backscatter intensities and the autocorrelation in the received signal [41]. Using volume backscatter and fish counts, target strengths of fish can be calculated. Because ADCPs store the depth of targets in the water column, coupling the fish counts and depths of targets can determine the depth of fish. Overall, ADCPs can provide useful information if they are configured properly and standard acoustic equations are applied.

The ADCPs were deployed for a total of ten months in 2016/2017. Within the deployment time, fish farms in both bays transitioned from a fallow period to an active period. It was hypothesized that when there was a fallow period, there would be a different amount of fish than during active farming. From the number of fish, the differences during active and inactive times of the year could be determined. Monitoring fish presence near farm sites provides a general idea of the consistency of occurrences. From there, the differences between fallow periods and active periods would be apparent. These differences could lead to further understanding of the impact of fish farms on wild fish species.

Chapter 2 provides background on aquaculture techniques, including the environmental impacts and history of fish farming in Newfoundland, underwater sound concepts and techniques and the basics of detecting fish using active underwater acoustics. Following this, Chapter 3 discusses the methods of the acoustic devices and the location of the study. After that, Chapter 4 goes into the calibration of the instrument, verifying the data collected, converting the data set into volume backscatter strength, fish amounts, target strengths and fish schools. Finishing off the thesis, Chapter 5 includes the conclusions that were drawn from the results of this study.

Chapter 2

Background

2.1 Aquaculture

Aquaculture describes the cultivating of any marine or freshwater organism. Historically, the modern era of aquaculture began in Asia with seaweed farming [28]. Four hundred years ago, seaweed was commonly used in many medicines and was the basis for drinks [28]. Later, the practice of farming seaweed was imitated to farm other marine and freshwater species. In 1852, the first salmon hatchery was built in France and was responsible for the distribution of fertilized fish eggs across all of Europe [28]. In 1865, the first hatchery for Atlantic Salmon opened in Ontario, Canada [28]. Not too long after, many developed countries created their own fish hatcheries. Since the 1800s, operations have advanced and had a lasting impression on the environment.

2.1.1 Environmental Impacts of Aquaculture

Farming fish modifies the ecosystem and impacts the environment both positively and negatively. Introducing farms to areas requires building, altering and potentially destroying the natural environment. Changes to the physical characteristics of the area include creating new habitats, changing water quality, altering typical wave action, increasing nutrient levels and shifting light availability [6]. Along with changing the habitat, the continuous existence of farms causes local species to modify their natural behaviors [6].

Aquaculture requires new equipment and structures in order to farm fish within bays. Building an operational structure, either on land or in the water, along with setting up open net pens nearby is necessary. In the water column, aquaculture structures can block penetrating light [6]. Along with changing the amount of light, the current and wave action will shift due to obstructions in the water column [6]. Farming structures also create artificial habitats for wild fish species [42]. Within the area, new artificial reefs occur because of increased availability for species to colonize and increased biodiversity [6]. New habitats provide shelter for juvenile fish species while also attracting larger adult fish species. In contrast, fish farms also damage resources through the destruction of natural habitats [29]. Consequently, the new ecosystem evolves and causes shifts to the preexisting food webs. Modification of relationships among species includes changing the predator-prey interactions between species while also adding new species [6]. Changes to the natural food chain can cause certain key species to die or be lost.

Along with introducing new permanent structures in the bays, fish farming will also effect the quality of water with the addition of associated waste. At fish farms, fish faeces and fish feed accumulate in the water and consequently influence the quality of water. It is estimated that three to five percent of fish feed strays from the pens and enters into the surrounding environment [32] [42]. Faeces will slowly sink while fish feed pellets will sink rapidly [20]. In a high flush area, faeces influence the community less than waste feed does due to their different sinking rates. Thus, fish feed accumulates quickly on the seafloor [20]. Even so, both faeces and fish feed are considerable influencers to the environment. As a result, the quality of water changes from the increased amount of waste associate with fish faeces and fish feed. Along with water quality, increased amount of nutrients from uneaten food attracts fish to these areas. Changing the diet of wild fish populations could cause malnutrition and strongly influence the fish migration or spawning patterns [31].

Aquaculture impacts the surrounding area in many ways and includes both physical and biological components that make up the ecosystem. The only way to understand the effects is to fully study every aspect that is being influenced by net pen structures as well as the waste that comes with farming.

2.1.2 The History of Aquaculture in Newfoundland

Throughout the world, with continued growth in human population, there is an ongoing need and associated struggles to sustain fisheries. As a result, the aquaculture industry attempts to contribute to feed communities. In Newfoundland and Labrador, aquaculture has an important role. As early as the 1970s, there were reports declaring the benefits that aquaculture would have on the economy of Newfoundland [39]. In

1991, the Economic Recovery Commission had a detailed discussion about the benefits of aquaculture. The Economic Recovery Commission stated that aquaculture, "could provide a stable environment for full-time employment and self-employment of several hundred people across the province [5]." In 1992, cod fishing halted and a moratorium was put into effect. This caused fisheries in Newfoundland to change. Fisheries diminished and aquaculture grew. Because of this shift in fisheries, the upkeep and sustainability of coastal fish farming sites was prioritized by government fisheries regulators.

The aquaculture industry in Newfoundland grew quickly since the cod fisheries collapsed. In 2016, there were 51 active fish farming licenses for salmon and steelhead trout [10]. Licensed aquaculture sites mostly reside in the Northern and Southern bays of Newfoundland and some salmonid hatcheries exist on the Western coast of Newfoundland (Figure 2.1). In the South, farming is highly dominated by salmonid farms, while in the North shellfish are farmed exclusively. As long ago as 1975, the South was recognized as a prime location for fish farming due to the large tidal changes, warmer water temperatures and shelter from the open ocean [39]. Because the Southern bays are most suitable for aquaculture, new farms continue to emerge. As more fish farms emerge, concerns of environmental impacts also grow.

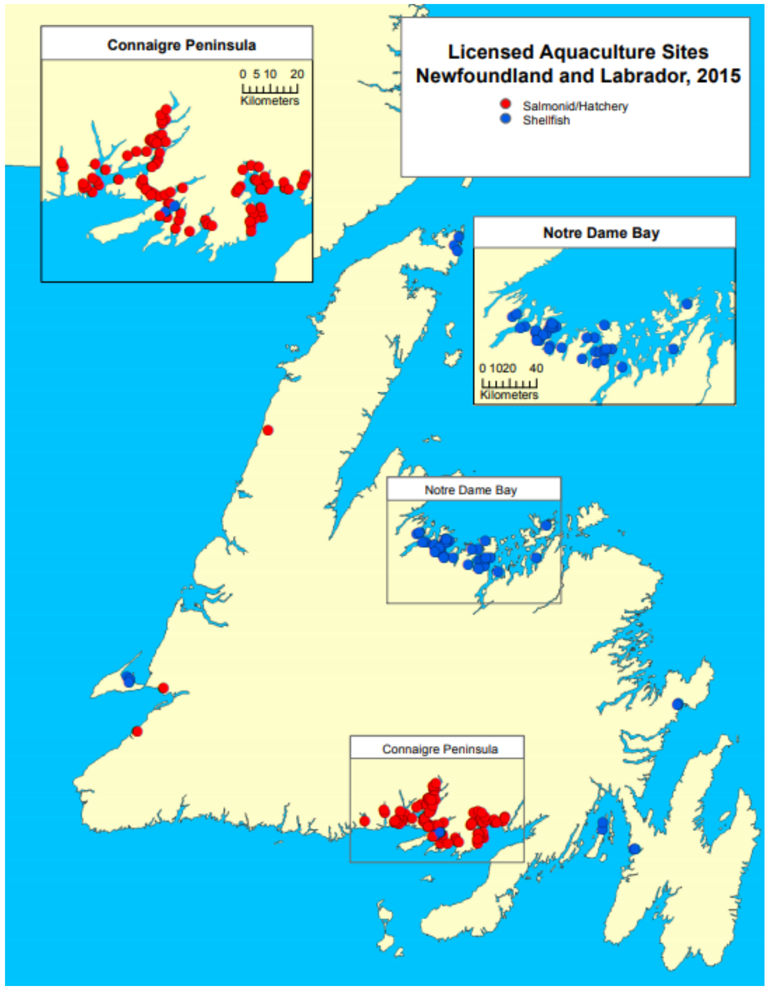


Figure 2.1: Distribution of licensed aquaculture sites in Newfoundland [9].

Salmon in Newfoundland are farmed in open net pens, which are secure, netted cages that are fully submerged in bays. Practicing aquaculture in open net pens requires enough current action to regularly flush out water [1]. The tidal flushing of bays enables excess nutrients to be extracted and replenished with sea water from the ocean. If there is not enough nutrient flushing, anoxia can arise as a consequence of the build up of faeces and excess feed that accumulates underneath net pens [38].

Generally, faeces require strong currents to distribute and dissolve them in the underwater environment [20]. On the other hand, farming equipment must be protected from very strong currents, waves and winds that could potentially damage gear. Inevitably, a balance between both flushing capacity and wave and wind action in bays is necessary for successful and sustainable fish farming.

2.1.2.1 Fish Farming in Southern Newfoundland

The Southern site for much salmonid farming in Newfoundland (Fig. 2.1), also known as the Coast of Bays, has a tidal range of two meters and long lasting tidal effects [10]. The tide change creates a desirable flush of water within bays. The flushing time, or the time is takes for a bay to completely replenish the water supply, is extremely important to consider in area of fish farming. In Southern Newfoundland, flushing times in bays vary from 30 to 70 days [10]. Belle Bay encompasses the study sites, East Bay and Cinq Island Bay, and is enclosed by Fortune Bay (Figs. 3.3, 3.4 and 3.5). Within the coast of bays, Belle Bay has a tidal flushing that was estimated to occur in 66-67 days [10]. As a result, aquaculture sites are regularly replenished with new water from the ocean.

Another physical aspect that is important for aquaculture is the yearly temperature ranges. In particular, salmonids prosper in areas with temperatures ranging from 5 to 20°C [20]. At low temperatures of -0.5°C, ice crystals begin to form within the body of salmon and this is fatal [20]. Within the Coast of Bays, significant heating in the summer as well as cooling in the Winter occurs [10]. In Belle Bay, there is a strong pycnocline near the surface from Spring to Summer due to a freshwater influx that causes a two layer system seen in the temperature, salinity and dissolved oxygen characteristics of the bay in Figure 2.2 [10]. The most recent study in 2014 found that Southern Newfoundland had a range of average temperatures from 1°C to 12°C with minimums as low as -1.5°C and maximums as high as 20.5°C [10]. This temperature range is appropriate for salmonid hatcheries with some risks of fish stock mortality in the colder months.

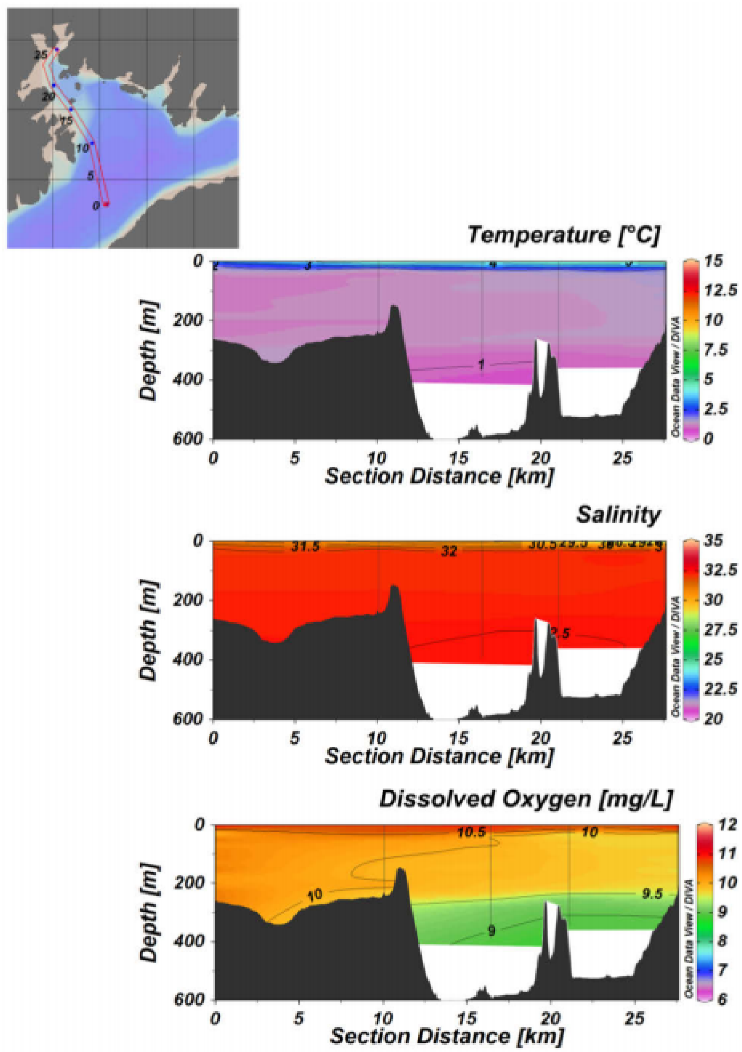


Figure 2.2: Temperature, salinity and dissolved oxygen profiles in Belle Bay in Southern Newfoundland in Summer 2014 [10].

Fallow periods describe the time that farms are left without any fish in their net pens in order to rejuvenate the ecosystem. In Newfoundland, a fallow period is required for salmonid farms. Current government research will help to justify the length of time for fallow periods by their correspondence to the time it takes for the benthic environment to return to the original state. Because regulations are still being adjusted, the set criteria for fallow periods is not the same for each farm in the province.

Fallow periods are intended to negate the effects that farming has on the ecosystem. Macrofauna communities in close proximity to net pens are subject to partial recovery during six month fallow periods no matter what time of year they are started [43]. During active and inactive farming, the macrofaunal species types shifted [43]. Specifically, opportunistic species are present during times of activity and were less present during fallow periods [43]. In Newfoundland, higher amounts of fish were associated with bays with sea cages than bays without sea cages [18]. Assessing fish activity nearby to aquaculture sites during active and fallow times periods would indicate if there was an impact on the nearby ecosystem that needed to be considered.

2.2 Underwater Acoustic Techniques

Echosound systems are commonly used in underwater surveys. A transducer is a device that converts pressure changes in the water into another form of energy, typically an electrical signal. Transducers work to transform sound to electrical signal and electrical signals to sound. In echosoundings, a transducer is used to transmit a short duration pulse of sound at a known frequency and sound that reflects off of targets in the water is received. After a specified time interval, another pulse of sound is transmitted. This process continues and results in a two dimension visual representation of targets at varying depths in time or space. If the transducer is stationary, the visualization will be varying over time and if the transducer is moving on a vessel, the visualization will be changing over space. Using the resulting display of targets, an echogram, a basic understanding of the underwater environment can be visualized.

2.2.1 Sound in Water

2.2.1.1 Key Concepts

Sound moves through the water as a fluctuation in pressure. In addition, these sound waves move through the water at a known frequency, f, which is measured in cycles per second. Critically, the frequency influences the properties of sound. For instance, the speed of sound in water, c, is the product of frequency and the wavelength, λ [37]. Mathmatically, the wavelength is described as the repeated cycle of a wave, $\lambda = \frac{2\pi}{k}$, where k is the wave number [37]. The wavelength is the distance between crests of a sine wave.

Imagine waves passing by one fixed location in the open ocean. As the frequency, or amount of cycles per second, increases the waves decrease in length. A higher frequency would correspond to a shorter wavelength. Short wavelengths do not travel as far as long wavelengths, but result in a higher resolution. High resolution data could capture smaller targets within the water column. Too high of a resolution can result in a decrease in range for fish detection and mainly zooplantonic species would be visible.

In echosounding, when the transmitted sound comes in contact with a target in the water, it will reflect sound with measurable characteristics. Additionally, transmitted sound varies by its pulse rate, or the frequency of pings over a time interval. By definition, the time interval of a ping is known as the pulse duration, τ, and directly relates to the range of frequencies, or bandwidth, that can be detected. For instance, a short pulse duration has a larger range of returned frequencies, or greater bandwidth in ADCPs. Overall, a basic understanding of underwater sound variables is important to use ADCPs for fish detection.

2.2.1.2 Sound Reflection

Many properties of sound in water are considered when determining the intensity of reflected sound. If the sound energy comes into contact with a target, energy gets transmitted back. This energy is known as backscatter [26]. While small targets will reflect sound in all directions, large targets will reflect sound in preferred directions [37] [26].

Sound that is received by the transducer can include both signal and noise. Basically, noise is sound that is unwanted while the signal is the sound that is desired. In underwater acoustics, a strong signal to noise ratio allows for better analysis of the sound because there would be a distinguishable contrast between the two.

Acoustic returns can be described by their reflectivity, as described by a consequence of target strengths. By definition, the target strength is the ratio of the reflected and incident sound intensity. Mathmatically, target strength, TS, is described as

$$TS = 10\log_{10}(\sigma_{bs}) \tag{2.1}$$

in dB re 1m^2, where σ_{bs} is the backscatter cross section in m^2 [25]. If a constant volume of targets is assumed σ_{bs} can be explained as

$$\sigma_{bs} = s_v v \ , \tag{2.2}$$

where s_v is the volume backscatter coeffecient in m^{-1} [25]. The sampled volume, v, is in m^3 and is found by

$$v = \frac{c\tau\Psi}{2} \ . \tag{2.3}$$

The equivalent beam angle, Ψ , is similar to the apex angle of a cone except in reference to a beam of sound. The Ψ is described by the following equation:

$$\Psi = \int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} b^4(\theta,\phi)sin(\theta)d\theta d\phi \ . \tag{2.4}$$

Ψ is typically expressed in dB and θ and ϕ describe the direction of the target relative to the origin of the transducer [25] [26].

From equation 2.1, target strength can be calculated using the volume backscatter coefficient, s_v:

$$TS = 10\log_{10}(s_v\frac{c\tau\Psi}{2}) \ . \tag{2.5}$$

The target strength of fish or zooplankton is influenced by a number of factors. Hazen and Horne state that the most influential, biological factor of target strength is the tilt, followed by the frequency, length and depth of the target [19]. Tilt is established by the orientation of a swim bladder within the fish and the shape of its body [19]. Along with physical qualities, the behavior of the species will determine some potential effects that the tilt will have. Many studies have found that the frequency is related to the length of the fish [15][22][23]. Interestingly, Demer and Martin found that target strength was dependent on the cross-sectional area of the species [8]. Additionally, target strength is dependent on the frequency of the transmitted sound [15][21]. Because of this dependence, the frequency of transmission is chosen specifically for the targets the user wants to see.

Some species move through the water column migrating from low to high depths. In one particular study, copepods were identified using their behavior during specific times of year [34]. Picco et al. found that species, such as *Calanoides acutus*, were apparent in their ADCP backscatter intensities due to their known migration patterns [34]. Migrating copepods are known to descend deep when sea ice accumulates and ascend shallow when the ice melts into bays of the Southern Ocean in Antarctica [36]. From target strength values, it is possible to identify species with known behaviors in their habitat.

2.2.1.3 Sound Absorption

As sound is transmitted from a transducer in water, the sound intensity will decrease as the range increases because of spreading and acoustic absorption [26]. Sound energy is lost due to absorption as it propagates through the medium.

Three components of water contribute to the absorption: boric acid, $MgSO^4$ and pure water. Each component is influenced by the frequency of the transmitted sound. For higher frequencies of 10 to 1000 kHz, $MgSO^4$ is the highest contributor to the excess absorption from salts in the ocean [16]. At frequencies above 200 kHz, pure water is the largest contribution to the absorption [16]. Overall an increase in range, coincides to an increase in the absorption of sound. It is extremely important to consider the parts of water when analyzing the absorption of sound.

In sea water, the absorption coefficient, α, is the sum of the absorption of pure water, term 3, and the additional absorption of the salts magnesium sulfate ($MgSO^4$), term 2, and boric acid, term 1. The absorption coefficient is given by

$$\alpha = \frac{A_1 P_1 f_1 f^2}{f^2 + f_1^2} + \frac{A_2 P_2 f_2 f^2}{f^2 + f_2^2} + A_3 P_3 f^2 \text{ [dB km}^{-1}] \; , \tag{2.6}$$

in terms of dB km^{-1} kHz^{-1} [17]. P is the pressure sensitivity of each component, f is the resonance frequency of salts and A is specific to the components and qualities of the water [17]. The first contribution to the equation (Equation 2.6) for absorption is boric acid [17]:

$$A_1 = \frac{8.86}{c} \times 10^{0.78pH-5} \; , \tag{2.7}$$

$$P_1 = 1 \text{ and} \tag{2.8}$$

$$f_1 = 2.8 \frac{S}{35}^{0.5} 10^{4-\frac{1245}{\Theta}} \; . \tag{2.9}$$

The speed of sound in water, c, is in m/s, $\Theta = 273 + T$, where T is the temperature in °C, S is the salinity in ppt and D is the depth in m [17]. The second contribution to the absorption equation (Equation 2.6) is from magnesium sulfate ($MgSO^4$) [16]:

$$A_2 = (21.44)\frac{S}{c}(1 + 0.025T) \; , \tag{2.10}$$

$$P_2 = 1 - (1.37 \times 10^{-4} D) + (6.2 \times 10^{-9} D^2) \text{ and} \tag{2.11}$$

$$f_2 = \frac{8.17 \times 10^{(8-1990)/\Theta}}{1 + 0.0018(S - 35)} \; . \tag{2.12}$$

The last contribution is from the viscosity of pure water at T $\leq$ 20 °C [16]:

$$A_3 = (4.937 \times 10^{-4}) - (2.59 \times 10^{-5} T) + (9.11 \times 10^{-7} T^2) - (1.50 \times 10^{-8} T^3) \text{ and} \tag{2.13}$$

$$P_3 = 1 - (3.83 \times 10^{-5} D) + (4.9 \times 10^{-10} D^2) \; . \tag{2.14}$$

2.2.2 Fish Detection using Active Underwater Acoustics

2.2.2.1 Basics of Active Acoustics

The process of transmitting sound into the water and observing the backscatter of the sound is known as active acoustics or sonar. Active acoustics can show a three dimensional picture of what is in the water column. Sonar captures the whole environment. For example, sonar can reflect off of fish, submarines, water-air interface and seafloor.

2.2.2.2 Acoustic Doppler Current Profilers

An ADCP is an instrument used in underwater acoustics that was originally developed to measure water velocities remotely (Figure 2.3). Using the concepts of the Doppler shift, the frequencies of the transmitted and returned sound waves are measured. By definition, the Doppler shift is the change in frequency that occurs through the process of reflection. The differences between the sent and received frequencies determines the speed of targets. For instance, if an ADCP transmits a pulse of sound at a specific frequency and the received sound has a frequency that is lower, the target is moving away from the ADCP [24]. By using four beams, velocities of targets are found and by definition includes both the direction and speed.

Figure 2.3: ADCP

Using ADCPs for water velocities requires the averaging of pings in order to get accurate results. This means that pings would occur in sequences and the resulting values are averaged. Within the water, fish appear as irregular events and averaging the pings would cause these abnormalities to disappear. By reconfiguring the ADCP to collect every ping instead of averages over multiple pings fish become visible in the data set. In this study, fish detections were captured using pings set to be ensembles of just one. Using ADCPs to detect fish is a successful alternative technique to split beam echosounders that is non-intrusive [35].

An ADCP can be configured as necessary and moored in a location to collect data. For instance, the configuration could include the pulse rate. In particular, the only limit to this approach of recording individual pings is how large of memory card and battery that is available. For example, the device can be set on the sea floor or moored in the water. Additionally, it can also be facing upwards, downwards, or even to the side. Along with being remotely operational, ADCPs are fairly inexpensive when compared to other similar acoustic instruments, like the scientific echosounder.

2.2.2.3 Using Moored Instruments for Fish Detection in Newfoundland

Newfoundland weather is extremely variable. Mostly, water temperature stay consistent throughout the year with some warming in Summer and cooling in Winter. In Newfoundland, there are times of the year where the sea ice is so thick that performing active scientific sampling is nearly impossible. With weather controlling ship times, scientific sampling is most convenient when it is done remotely. ADCPs are a method to provide year round sampling and can be critical in monitoring water remotely in areas where getting on a boat would be impossible or expensive.

Along with environmental conditions, mooring an acoustic device to take measurements continuously is more affordable than making measurements on board a vessel throughout the year. Because of this cost, mooring an instrument is beneficial. Cochrane et al. found that a bottom mounted ADCP was able to collect temporal data accurately throughout the entire water column [4].

Most species of zooplankton and some fish species display diel vertical migration behaviors where these species ascend at dusk and descend during the day [3]. From the temporal data that ADCPs collect, the diel vertical migration patterns can be visualized in backscatter intensities.

Chapter 3

Field Program

The impacts that aquaculture has on the local environment includes the influx of nutrients in the water as well as the migration, intrusion and/or death of new and existing species. It was hypothesized that the amount of wild fish and their behavior nearby to farms would be different during times the farms were fallow than during times when the farms were active. Two ADCPs were deployed in Southern Newfoundland from November 2016 to September 2017 in bays where salmonid farms were located. During the ten month deployment, both farms transitioned from a fallow period to active farming.

3.1 Configurations of the ADCPs

RDI Teledyne WorkHorse Sentinel 600 kHz ADCPs were deployed to detect wild fish and zooplankton nearby to farms. The instruments were configured to be able to detect targets throughout the water column. Figure 3.1 shows the parameter settings used for the ADCPs during deployment.

ADCP Parameters	
Frequency (Hz)	614400
Number of Depth Cells	128
Depth Cell Size (cm)	40
Time per Ensemble (sec)	25
Time per Ping (sec)	25
Pings per Ensemble	1

Table 3.1: Parameters for both ADCPs were optimized to detect fish during deployment.

The ping rate, ensemble sizes and depth cells were set based on the locations of the devices and the frequency that provided high resolution data. High resolution was necessary to see fish and zooplankton in the water column. Both devices were operating at the same frequency: 614400 hertz.

Depth cells were used to section off parts of the resulting echoes by using horizontal lines across specific depth regions. In this study, bins, or depth cells, were 40 centimeters in length and from the ADCP there were 128 bins. This combination provided a total range of 51.2 meters.

The remainder of the ADCP parameters (Figure 3.1) relate to ping rates and ensembles. Broadband ADCPs use a series of coded pings for transmitted sounds to increase the bandwidth while keeping adequate signal power [40]. Typically, these ensembles were used to capture averaged changes in the water column. Because our ensembles included only one ping, the averaging did not occur. Instead any changes in the backscatter was stored in the data thus allowing fish detections.

3.2 Offshore Deployment Structure

One ADCP was deployed in Cinq Island Bay and the other in East Bay. These instruments were in the water for a total of ten months spanning from November 4, 2016 until September 14, 2017. On May 12, 2017, the memory card within the ADCPs was replaced. Because of the exchange in memory cards, data was not continuous and included a break in May. Both ADCPs were then redeployed and stayed in the water until September. The total deployment time, ten months, was opportunistic based upon the Department of Ocean and Fisheries in Newfoundland and their current research projects.

Both ADCPs were deployed in water of depths close to 60 meters and facing upwards. The ADCP was on a wire rope connecting two sets of floats (Fig. 3.1). On that same line and following the last set of floats was the acoustic release shackled to a chain anchor. The chains kept the whole set up tethered to the sea floor, while the floats kept the wire rope taut and the ADCP upward facing during the deployment (see Figure 3.2).

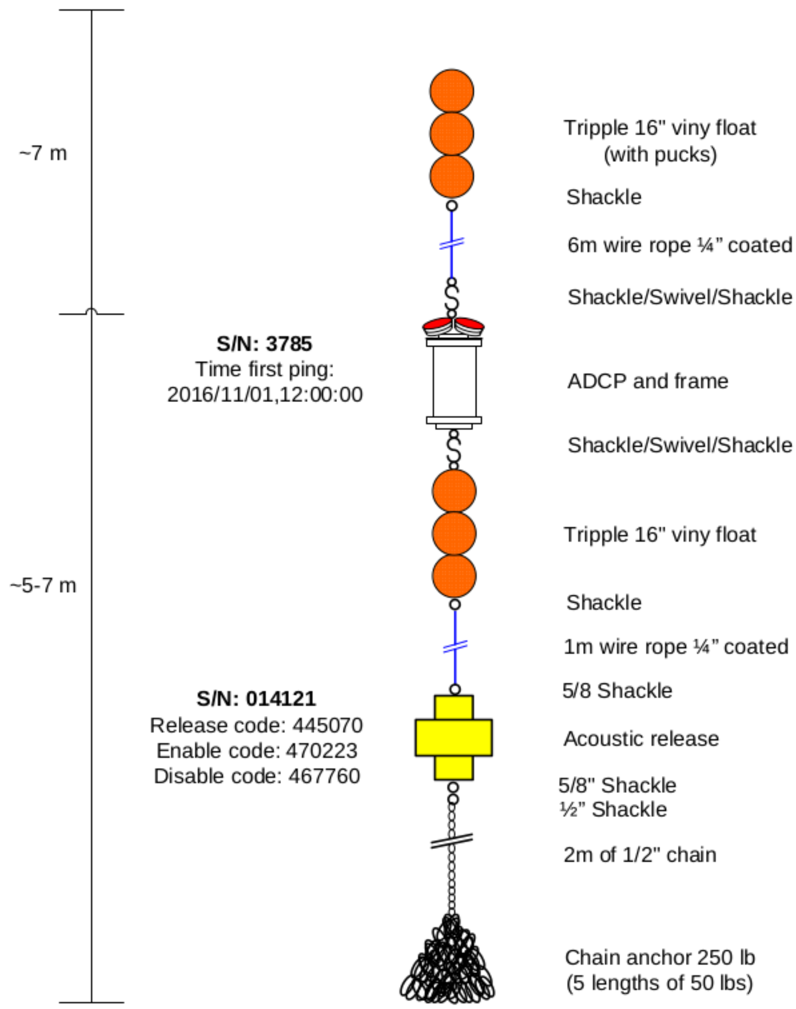
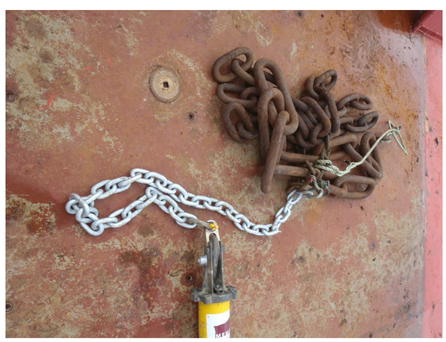


Figure 3.1: Diagram of ADCP deployment [12]

The ADCPs were configured to start collecting data while on deck prior to deployment so that the operation could be verified. They were released off the back of the boat chain first. When the devices were to be recovered from the bays, a signal was sent to the acoustic release (seen in yellow in Fig. 3.2b and 3.2c). The acoustic release would unhook and disconnected the wire with the ADCP and floats from the weighted chain. The loss of chains would allow for the floats to surface the ADCP. Crew on the boat could then retrieve the ADCPs.

(a) ADCP on the line

(b) Floats



(c) Weighted chains

Figure 3.2: Parts of the ADCP set up on deck [11]

3.3 Study Area

In this study, ADCPs were deployed in East Bay and Cinq Island Bay. These bays are located in the Northern area of Fortune Bay (Figure 3.4) and were prime areas due to the similarities in their biological and physical characteristics. Both bays were locations for fish farming, close in proximity and had previous fish surveys. Along with this, the depth at the farms are similar and rivers run into the both bays. Two similar study sites allowed for direct comparison.

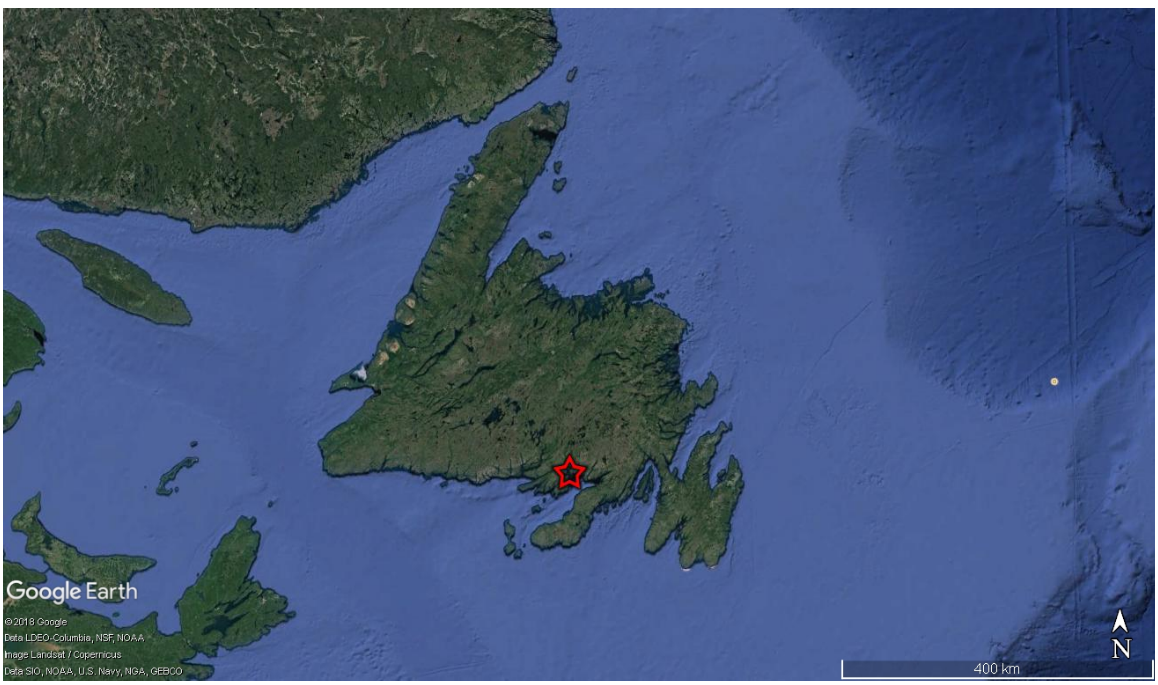


Figure 3.3: The study region for this project in the Southern bays of Newfoundland indicated by the red star

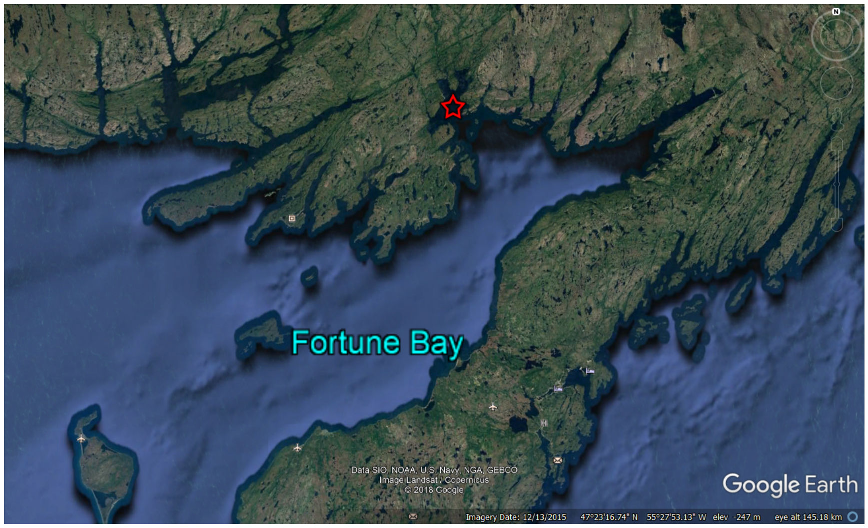


Figure 3.4: Belle Bay, marked by the red star, encompasses both East Bay and Cinq Island Cay within the Northern part of Fortune Bay

Figure 3.5: Fish farms are marked with pink targets and ADCP locations are designated with a photo of an ADCP in East Bay and Cinq Island Bay

3.4 Aquaculture Activity and Timeline

During the initial deployment, both farms in East Bay and Cinq Island Bay were in fallow periods. In June/July 2017, both fish farms were restocked with fish. Information about specific start and end dates of restocking was treated as proprietary by the farm operators and only approximate dates were given. An approximate timeline of farming activity in both bays is depicted in Figure 3.6.

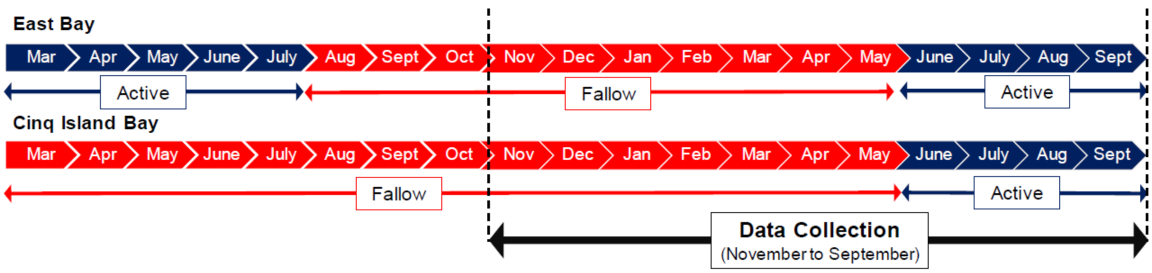


Figure 3.6: Timeline of activity in East Bay and Cinq Island Bay

The lengths of fallow periods in both bays were different. East Bay only had a fallow period of ten months from August 2016 to May 2017 while Cinq Island Bay had a longer fallow period of fifteen months from March 2016 to May 2017. The reasoning for the different fallow periods was not described by the operators. By chance, the ADCPs were deployed during the transition of aquaculture from fallow to active.

Chapter 4

Data Processing and Analysis

4.1 ADCP Calibration

In the lab, calibration of the ADCP was done to determine the sensitivity of each transducer by finding the slope of the echo intensities for each of the four beams. Echo intensities describe the reflective characteristics of sound and were necessary values to calculate volume backscatter strength, S_v (Equation 4.1). Using the slope of the inverse of counts per decibel in the calculation of volume backscatter strength, S_v, all four beams were calibrated to provide comparable measures.

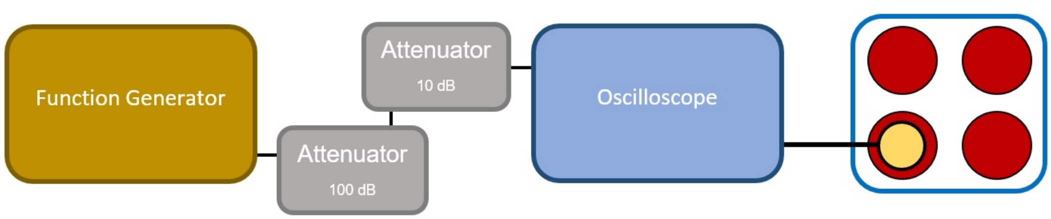
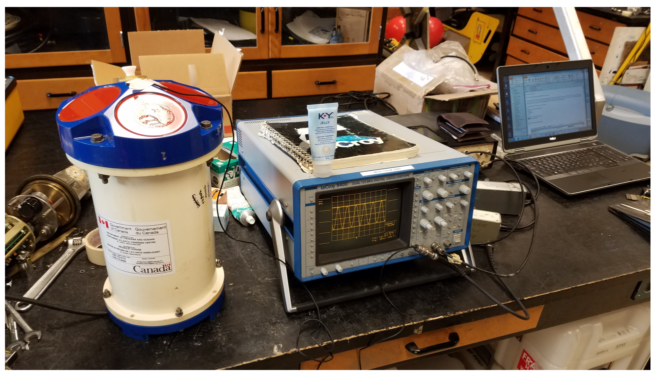
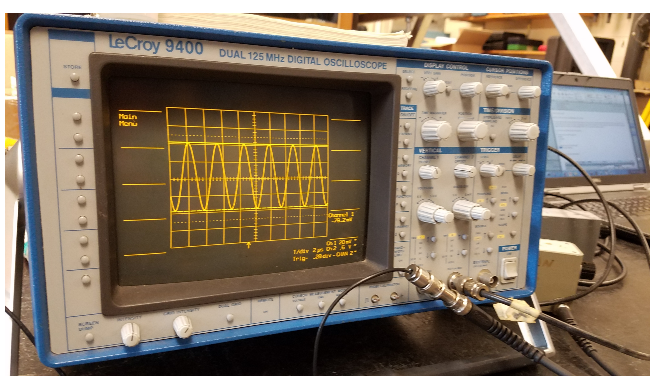


Figure 4.1: Diagram of ADCP calibration

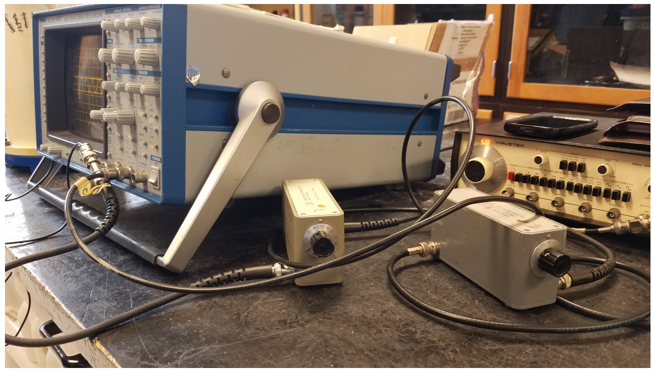
The calibration process included the use of a function generator, attenuators, an oscilloscope and a transducer (Figure 4.1). A known frequency was transmitted to each beam directly using a transducer acoustically coupled to the face of the ADCP transducer with lubricant. The attenuation reduced the amplitude so that the signal was measurable and was adjusted in 5 decibel increments and the received echo intensity in voltage was recorded. A plot was produced for this data and the slope of counts per decibel was calculated.



(a) Calibration of ADCP



(b) The screen of the oscilloscope during calibration



(c) Attenuators used during calibration

Figure 4.2: ADCPs calibrated in the lab

By calculating the actual received echo intensities, the offset of each beam could be determined. The S_v (Equation 4.1) calculation used the calibration values from the lab measurements as the K_c values for each beams. Deines described K_c as the conversion factor for the signal from counts to decibels [7]. For the ADCP deployed in East Bay, the K_c values were 0.38, 0.43, 0.39 and 0.43 for beams 1, 2, 3 and 4. For the ADCP deployed in Cinq Island Bay, the K_c values were 0.41, 0.39, 0.40 and 0.40 for beams 1, 2, 3 and 4.

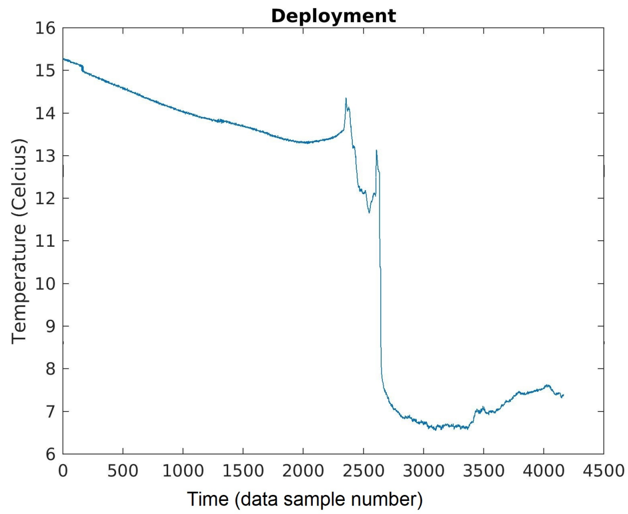
4.2 Data Verification

Before data could be accurately analyzed, memory cards from the ADCPs were verified by cross referencing the time of deployment with the location of the deployment. Doing this verification confirmed that the notes that were taken in the field describe the locations of the ADCPs accurately. Field notes collected during each of the deployments included the serial numbers of the instrument, the time of release and the location of the deployments. The four deployments were labeled as A, B, C and D in Table 4.1.

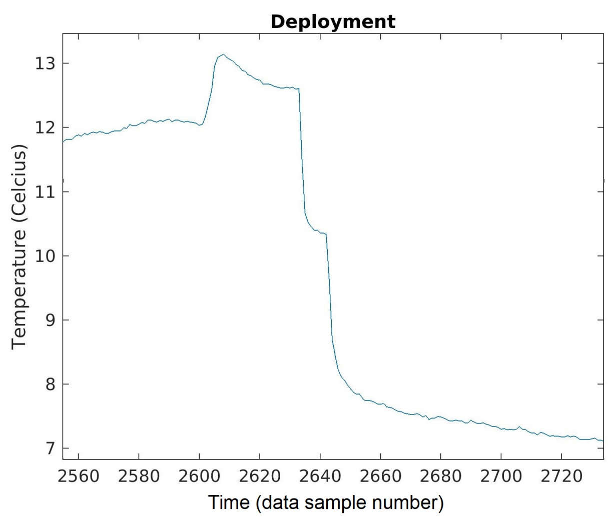
	Deployment Time	Deployment Location	Serial Number
A	November 4, 2016 at 14:45 NST	47° 37.3849’ N, 55° 26.4176’ W	2069
B	November 4, 2016 at 15:28 NST	47° 42.2840’ N, 55° 23.0449’ W	3785
C	May 12, 2017 at 07:51 NST	47° 37.993’ N, 55° 26.4133’ W	2069
D	Mat 12, 2017 at 09:57 NST	47° 42.278’ N, 55° 23.038’ W	3785

Table 4.1: Notes from offshore deployments (A, B, C and D) including the time, location and instrument serial number.

To determine the memory card that coincided with deployments A, B, C and D in Table 4.1, temperature changes were examined. The ADCPs measured temperatures while they were turned on. The sudden temperature changes that occurs when the instrument enters the water indicated the exact time of deployment within the data sets. An example of this is shown by Figure 4.3. Each data set was labeled 1, 2, 3 and 4 in Table 4.2 and included the time of deployment collected within the ADCP’s memory cards.



(a) Temperature measurements show abrupt changes when changing from air to water



(b) Expanded view of the time of deployment

Figure 4.3: Temperature changes observed during deployment

The notes for A, B, C and D (Table 4.1) were coordinated to the data sets 1, 2, 3 and 4 (Table 4.2). Because the device times were not equivalent to the actual times, the order of occurrence verified the actual deployments. By doing this, it was apparent that deployment A and data set 2 matched, deployment B and data set 1 matched, deployment C and data set 3 match and deployment D and data set 4 matched.

	Deployment Time
1	November 4, 2016 at 15:26 NST
2	November 4, 2016 at 14:49 NST
3	May 12, 2017 at 10:22 NST
4	Mat 12, 2017 at 12:27 NST

Table 4.2: Abrupt temperatures observed by ADCPs were converted into date and time.

4.3 Converting Echo Intensities into Volume Backscatter Strength

Deines described a way to calculate volume backscatter strength originally in 1999 [7]. Before calibration, the raw data of echo intensities did not account for issues that arose from the range of scatterers and the temperature and power of the transducer. Converting into S_v corrects for the behavior of sound under water.

4.3.1 Volume Backscatter Strength Equation

Based on the sonar equation, the equation for volume backscatter strength takes into account the range of targets, temperature, acoustic absorption and characteristics of the sound source. In 2017, Mullison added to the classic Deines' equation correcting the signal to noise ratio term to more accurately account for low sound levels [7] [27]:

$$Sv = C + 10\log_{10}((T_x 273.26)R^2) - L_{DBM} - P_{DBW} + 2\alpha R + 10\log_{10}(10^{K_c(E-E_r)/10} - 1)\ . \tag{4.1}$$

S_v is in dB re $4\pi m^{-1}$ [7] [27]. The C in equation 4.1 is the constant specific to the instrument. For both of the ADCPs in our study C was equal to -133.5 dB re 1 μPa accounting for the transducer diameter, self noise, power into the water and the bandwidth [7]. The temperature of the transducer, T_x, was measured throughout the deployment by the ADCP in °C. The range along the beam to the scatterers in meters, R, is calculated by the ADCP during deployment. This included the transmit pulse length, L_{DBM}, in meters and the transmit power, P_{DBW}, in watts. K_c is a factor which we determined experimentally that is used to convert the amplitude counts to decibels and is described in section 4.1. E is the measured Returned Signal Strength Indicator (RSSI) amplitude for each bin along each beam in counts, and E_r is the measured RSSI amplitude in the absence of any signal in counts [7]. Essentially, E was the raw echo intensity and E_r is the noise floor of the instrument. E_r was determined by finding the minimums observed for echo intensities throughout the deployments. The absorption coefficient, α, describes the amount of signal lost over range due to acoustic absorption and was calculated following the equation from Fraçois and Garrison (Equation 2.6) [7] [17].

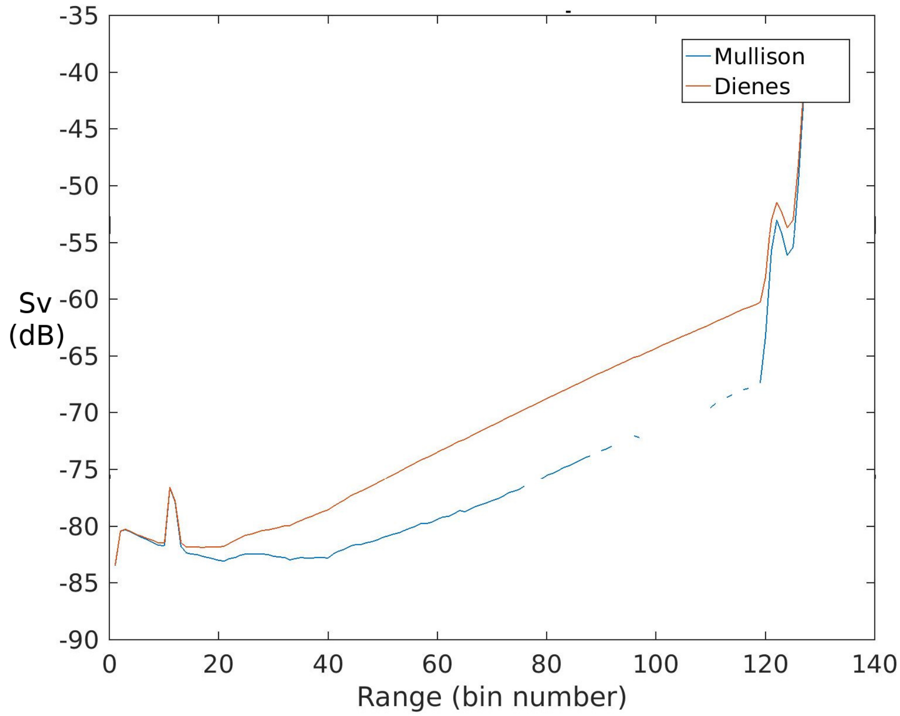


Figure 4.4: Comparing Deines' original equation for S_v and Mullison's equation for S_v

Deines's original backscatter estimation described the signal as $K_c(E - E_r)$ [7]. Mullison addressed a problem with the original Deines equation stating that the signal should include the signal to noise ratio by adding the correction $\frac{10^{\frac{K_c E}{10}} - 10^{\frac{K_c E_r}{10}}}{10^{\frac{K_c E_r}{10}}}$ [27]. In Figure 4.4, the difference between the volume backscatter intensity calculated using Deines's equation and Mullison's equation was apparent with an offset of approximately 5 dB. Obviously, Deines's equation overestimated the S_v compared to Mullison's equation at low signal levels which is seen by the mean corrected signal level ramping up with range.

4.3.2 Volume Backscatter Strength Results

The volume backscatter strength for the whole time series is plotted in Figures 4.5, 4.6, 4.7 and 4.8. The changes in color in the figure represent the intensity of the volume backscatter strength. The warmer colors align with higher intensities while the cooler colors align with lower intensities. Depth increases from top to bottom, time increases from left to right, and the surface of the water is in red and yellow at the top. The set of floats are visible at 47 meters throughout the whole time series and seen most prevalent in Figures 4.6 and 4.7. This is expected based off of the geometry of the moorings seen in Figure 3.1.

4.3.2.1 December 2016 to May 2017

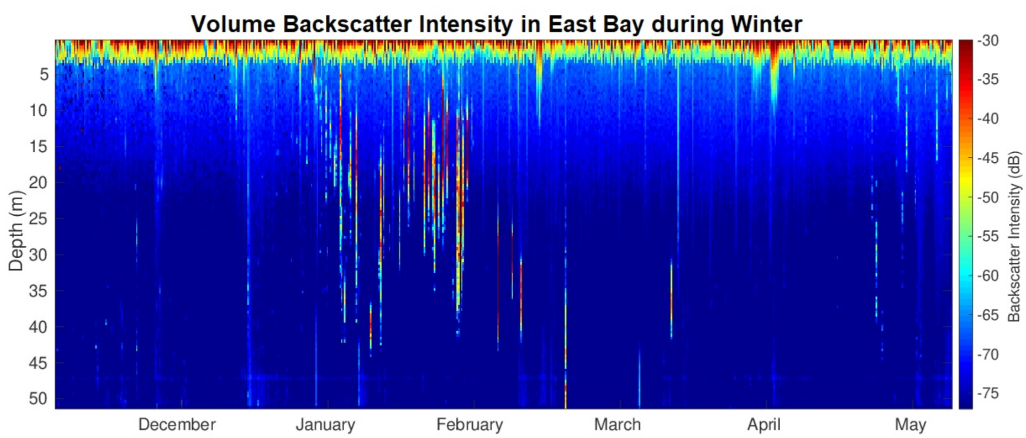


Figure 4.5: Volume backscatter in East Bay

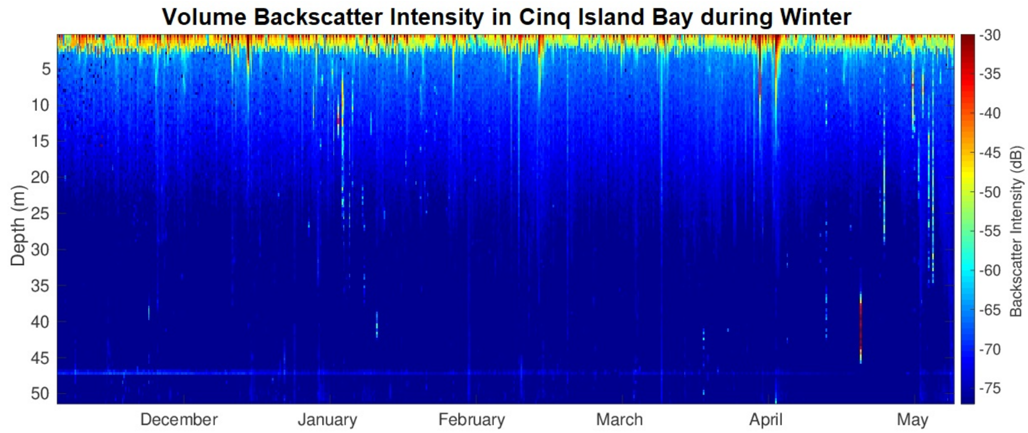


Figure 4.6: Volume backscatter in Cinq Island Bay.

In Figures 4.5 and 4.6, volume backscatter is calculated in both East Bay and Cinq Island Bay from November 2016 to May 2017. The volume backscatter in the background shows a slight gradient that is deep blue closer to the ADCP and fades to a lighter blue further away. This gradient corresponds to the increase in S_v that is apparent in Figure 4.4. As a result of the background noise level, the further away from the ADCP, or the closer to the surface that the sound got, the higher the background S_v is. Acoustic absorption effects Equation 4.1 for S_v resulting in the increase that is visible in the gradient in Figures 4.5 and 4.6.

In East Bay (Figure 4.5), there are strong volume backscatter intensities from January to February. These backscatter events range from -50 to -30 dB. In Cinq Island Bay (Figure 4.6) there is one strong concentration of volume backscatter intensity in January that ranges from -50 to -45 dB. Cinq Island Bay also has two strong backscatter events in May ranging from -60 dB to -55 dB and -50 to -45 dB.

4.3.2.2 May 2017 to September 2017

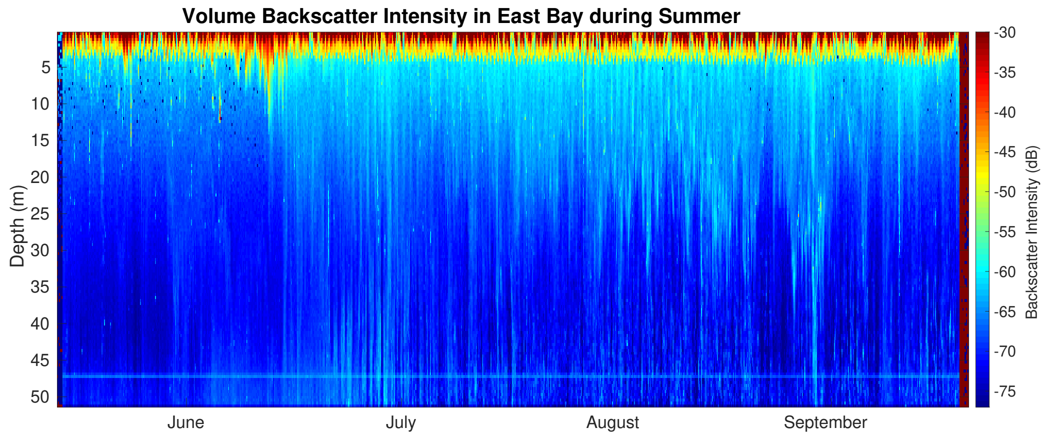


Figure 4.7: Volume backscatter in East Bay during Summer months

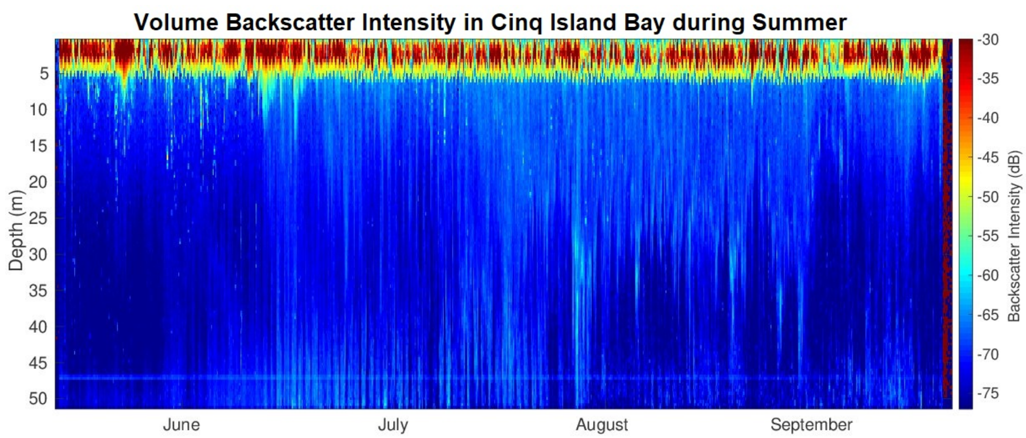


Figure 4.8: Volume backscatter in Cinq Island Bay during Summer months

In the Summer months (Figure 4.7 and 4.8), there are backscatter events occurring at -60 dB in stripe like patterns signifying diurnal events. East Bay has consistent backscatter intensity of -60 dB occurring in the upper 20 meters of the water column (Figure 4.7). For instance, the beginning of September has a deep event of higher backscatter intensity in the water column. Cinq Island Bay has less consistent but still apparent backscatter intensity events close to -60 dB (Figure 4.8). The depths of these backscatter intensities are less defined and ranges from 7 meters to 30 meters from June to September and from 35 to 45 meters from June to July.

4.3.2.3 Total Volume Backscatter

In Figures 4.9 and 4.10, the depth integrated sum and standard deviation of volume backscatter show the variations that occurs from targets within the water column in East Bay (pink) and Cinq Island Bay (blue). Both bays are extremely different from January to May 2017 but very similar from November to December 2016 and from May to September 2017. The differences noted from January 2017 to May 2017 show high and sporadic peaks indicating variability of fish detections in the volume backscatter. Similarities in both bays from June until September 2017 indicate lack of variability in volume backscatter and coincided with the time of year where fish farms were restocked with salmon as well as the shift in seasons from Spring to Summer. Even though the instrument was redeployed at the start of this similarity, days before redeployment signs of this occurrence are noticeable in Figure 4.9 and demonstrates it is not a measurement artifact.

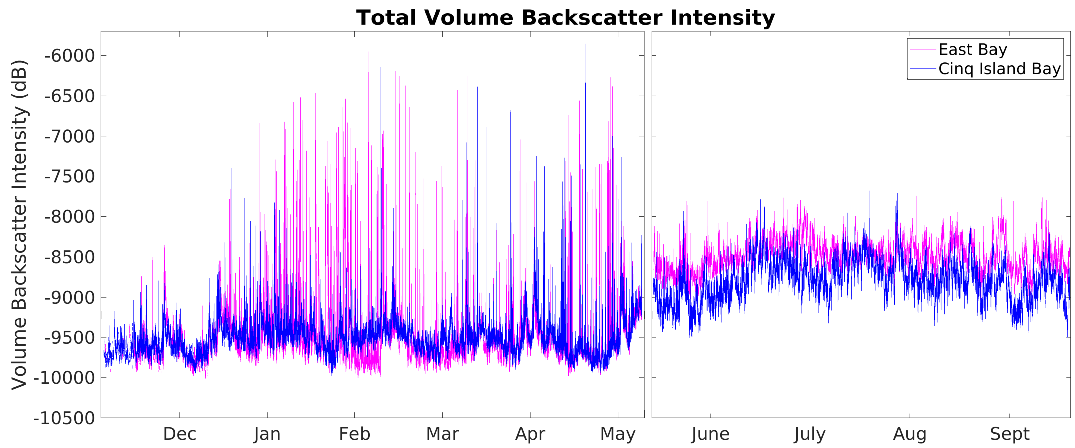


Figure 4.9: The depth integration of the volume backscatter strength during the deployment in both East Bay and Cinq Island Bay

Figure 4.10 shows the standard deviation of the depth integrated volume backscatter throughout the time series. East Bay has higher variability in the volume backscatter from January to March 2017 and in May 2017. There are some random peaks in variability occurring in East Bay during November as well. In Cinq Island Bay, there are high variations in volume backscatter year round with the highest standard deviations occurring during December, February, March, April and May. All of these high variance events in Cinq Island Bay only last a short time equivalent to just a few days. From May 2017 to September 2017 there are values that are consistent in both bays. Over the whole ten months, East Bay shows higher levels of variance events. This variance suggests that there were more abnormalities occurring in the water column in East Bay. We interpret this variability to indicate the activity of fish schools.

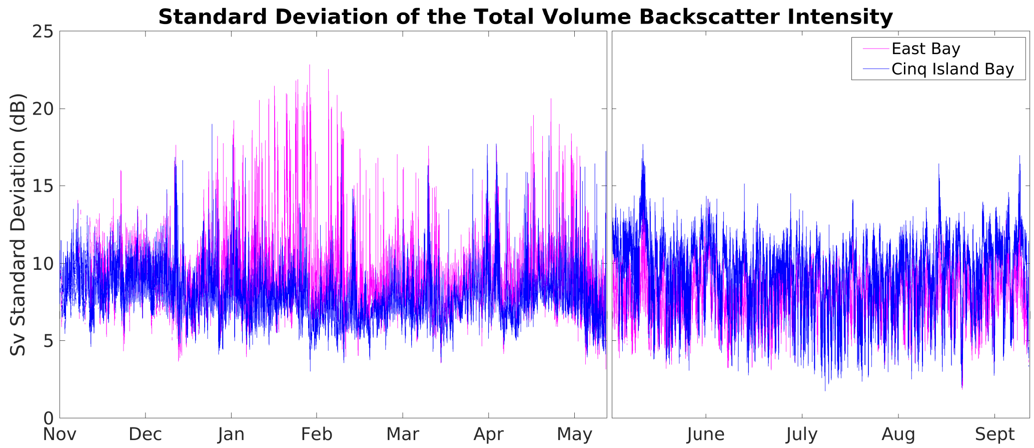


Figure 4.10: Standard deviation of the depth integration volume backscatter

4.4 Determining the Amount of Fish

To determine the number of fish, two threshold values were set to distinguish discrete targets in the water and decrease uncertainty of fish detections. Only when both of these threshold values were met, would the system identify that a fish was found. These values were tallied to arrive at a value for the amount of fish during the whole time series.

4.4.1 Setting Thresholds

Thresholds used to find fish were set on both the volume backscatter coefficient and the autocorrelation of the transmitted and received sound. This procedure directly followed the research by Tollefsen and Zedel [41]. In their study, discrete targets were found in both tow tank and river trials by setting thresholds to both the backscatter and autocorrelation while using moored ADCPs [41]. Discrete targets within the water column, such as fish, were successfully identified [41]. Meeting both threshold values identify a fish but meeting only one threshold would indicate some other objects in the water column.

4.4.1.1 Volume Backscatter

Volume backscatter was an important threshold to have for fish detections because there was always a large difference between the volume backscatter of fish compared to that of the water. This is clearly depicted in Figures 4.5, 4.6, 4.7, 4.8 and 4.11. Fish show up in backscatter plots as red, orange and yellow lines throughout the time series. These colors represent higher backscatter values from -60 to -30 dB. Other occurrences of strong volume backscatter are caused by air bubbles introduced into the water by surface wave action, plankton and the floats that were above the ADCPs. Both the surface and floats were continuously observed and for this reason, the calculations for fish detections only used depths that avoided both the surface influence as well as the floats.

To determine the threshold for volume backscatter, the lowest observed background values were used. Figure 4.4 show the average of volume backscatter observed. The highest S_v was found to be at -60 dB and this number was maintained throughout the analysis. In Figure 4.11, the persistence of targets at -60 dB was visible and thus we set the volume backscatter threshold to be -60 dB. Anything less than -60 dB would be range dependent noise due to the limitations of the ADCP.

4.4.1.2 Autocorrelation

The other parameter used for target detection was autocorrelation of the signal. This parameter allowed us to distinguish fish from large groups of small scatterers. An ADCP's autocorrelation value can range from 0 to 256 and the device itself normally expects a correlation of 128 from volume backscatter [41]. The threshold that was set for autocorrelation was 155. This higher than normal autocorrelation is associated with strong discrete targets in the ADCP data and is a characteristic that was consistent within our data set. This process used both the plot for volume backscatter coefficient (Figure 4.11) and autocorrelation in parallel (Figure 4.11). Examining both figures, there were times that one threshold was met and another was not; only when both thresholds are exceeded did the system accept the detection as a fish.

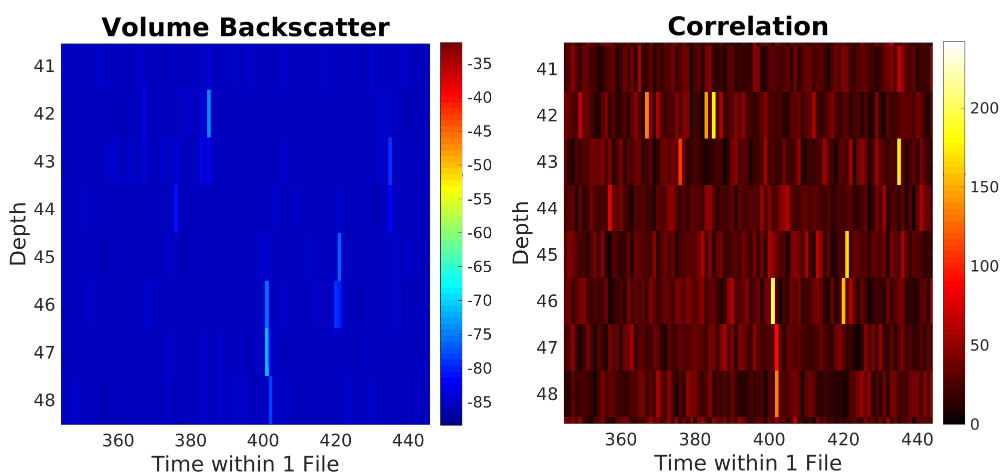


Figure 4.11: An example of a zoomed in view of the echogram of backscatter and autocorrelation used to verify the thresholds

4.4.2 Time Series Analysis

The volume backscatter strength along with correlation values were used to identify the number of fish. From this information, the frequency of fish occurrences could determine the activity levels characteristic of different times of the year. Specifically, the abundance of fish around aquaculture sites during fallow and active periods would provide a look into the influence that it could have on wild fish species distributions in Newfoundland.

Fish detections from the data and the results are summed as a total over depth. Fish counts show in Figure 4.12 both East Bay and Cinq Island Bay having an increase in discrete targets during January and May and low amounts of fish from November to December and in March. There is an obvious transition from high number of target detections during cooler months to a low amount of targets in warmer months. This transition could be related to the change of fish farms from fallow to active or may be due to seasonal differences.

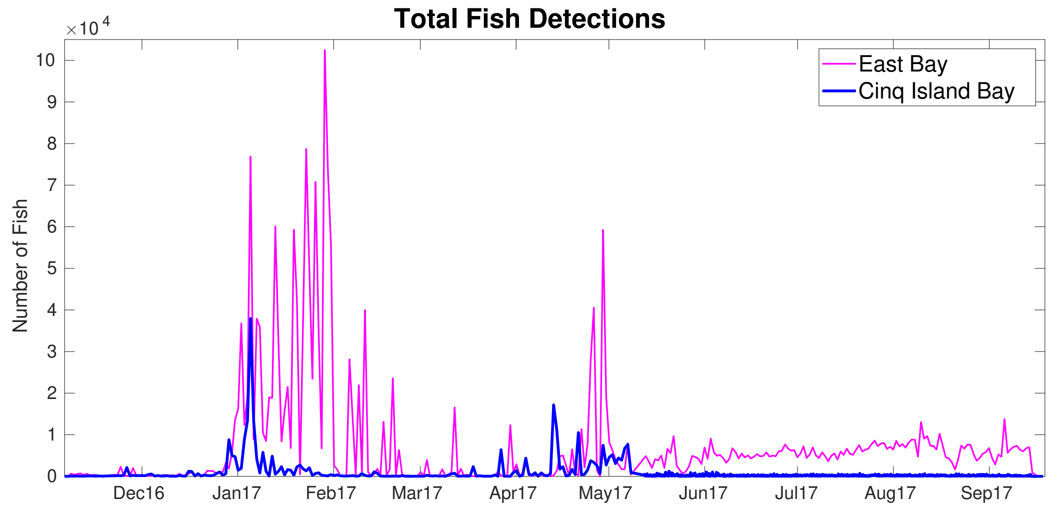


Figure 4.12: The total number of fish in both bays shows variations throughout the time series.

Total fish detections in Figure 4.12 show the amount of wild fish near aquaculture sites in both bays. From November to early January, nearly no fish are detected in both East Bay and Cinq Island Bay. During January, East Bay has close to 80,000 occurrences of fish and there are approximately 40,000 fish during the same time in Cinq Island Bay. During February, East Bay has an increase in fish with numbers reaching as high as 100,000 per day while Cinq Island Bay has less than 2,500 fish per day. Large numbers of fish are apparent in East Bay between January and March and in May while Cinq Island Bay has large amounts of fish in January and from mid April to May. A large increase of 60,000 fish occur in East Bay in May while Cinq Island Bay has close to 10,000 fish detections.

In warmer months, fish amounts are much lower in both bays. East Bay has a much larger shift from colder months to warmer months than Cinq Island Bay did.

East Bay has about 5,000 per day while Cinq Island Bay hovers around 1,000 per day. Additionally, these observations were very consistent day to day. Overall, the amount of fish in both bays from mid May to September is lower than from January to the beginning of May.

To see if there was a significant difference between the two bays, a z-test was done following the technique described by Edmondson and Druce [13]. The z-test required the data to be interval level data, independent samples and a large sample size. The null hypothesis stated that there was no difference between the bays and the alternative hypothesis stated that there was a difference between the bays. Using the table of z critical values in Edmondson and Druce, the z critical value used was 1.645 with a 95% confidence level [13]. If the calculated z value was larger than the z critical, than the null hypothesis was rejected in favor of the alternative hypothesis.

The z-test allows for clarification that there was a significant difference or similarity between two data sets. The equation for the z statistic was

$$z = \frac{\bar{x} - \bar{y}}{\hat{\sigma}} \tag{4.2}$$

where $\bar{x}$ and $\bar{y}$ were the means of both data sets and

$$\hat{\sigma} = \sqrt{\frac{{s_x}^2}{n_x} + \frac{{s_y}^2}{n_y}} \tag{4.3}$$

where s_x and s_y were the squared standard deviations, or variances, of the data sets and n_x and n_y were the sample sizes for each data set.

The first z test was used to determine if there was a difference between the two bays during the entire time series. The z value was calculated to be 22.0 and so we concluded there was a significant difference in wild fish occurrence between the two bays. The only time of year where the two bays were not significantly different from each other was from November to January (with a calculated z value of 1.12). During that time period, there was little fish activity in either bay.

The second z test determined if there was a difference in the amount of fish during the fallow period and after the fallow period. The z value calculated for East Bay was 2.3487 and the z value for Cinq Island Bay was 13.5503. Both of these z values were larger than the z critical value (1.6450). These values indicated that there was a significant difference in both bays during and after fallow periods. The result was consistent with the visual appearance of Figure 4.12. Differences during and after fallow periods could have been caused by the fallow period itself, or maybe seasonal effects.

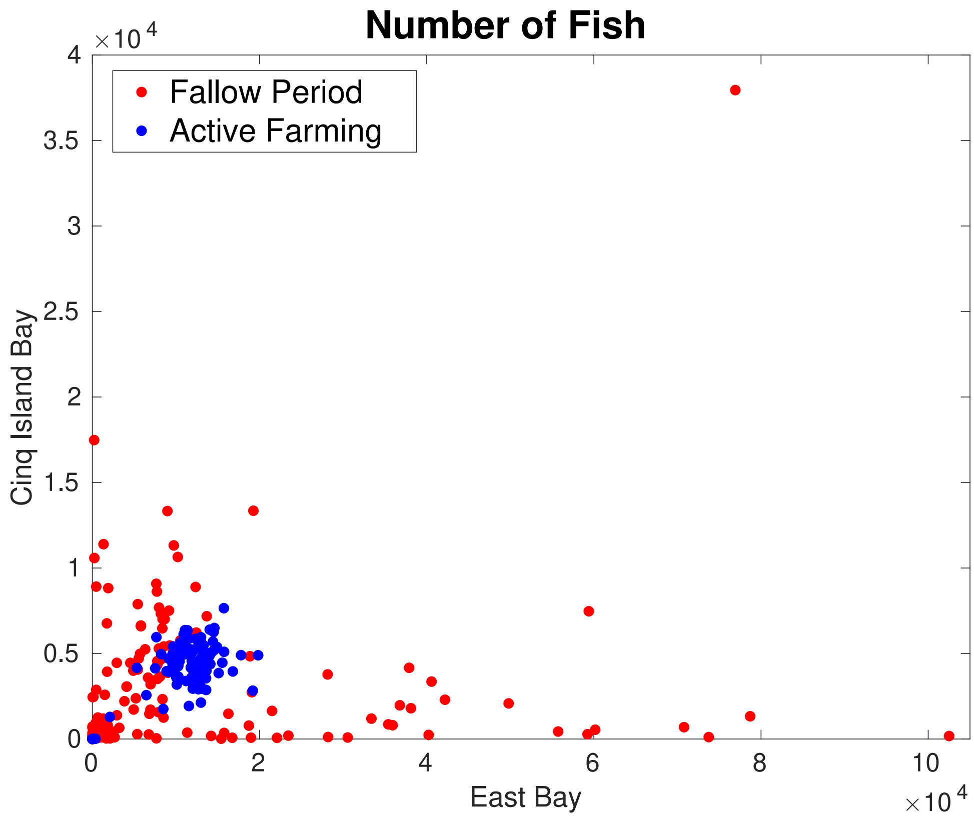


Figure 4.13: The daily number of fish in East Bay compared to Cinq Island Bay

Given the large differences between the actual fish detections rates in the two bays, the degree to which fish detections were correlated between the two bays was explored. For this purpose, values of fish detections in Cinq Island Bay are plotted against the corresponding detections in East Bay (Figure 4.13). The correlation between the two bays is calculated during and after fallow periods. During the fallow period, prior to the start of data collection until June 2017, there seems to be no correlation with fish detections occurring in the two bays (Figure 4.13). In contrast, during the period of active farming the fish detections seems clustered and the amount in East Bay is much larger. The data from Figure 4.13 suggests that when the farms are active or during Summer, there is a correlation between bays and when the farms are not active or during Winter, the correlation is extremely weak. Using the daily sum of fish detections, the correlation coefficient, R^2, during the fallow period was 0.0546 and the R^2 value after farms became active was 0.2713. This difference in correlation was due to the numerous times during the fallow period that fish were only present in East Bay and not present in Cinq Island Bay.

4.4.3 Depths of Fish

Different species of fish tend to migrate to different depths in the water column as a common predator avoidance strategy. Fish detections were sorted into 0.4 meter depth bins and then averaged for the entire time series. The results are presented using a bar graph in Figure 4.14. Because this information was accumulated over the whole time series, it ignores changes in time.

Fish in East Bay are present throughout the water column with the most dominant occurrence being near the surface and between 30 and 35 meters. In contrast, fish in Cinq Island Bay are clustered at 50 meters in depth. This difference in behavior could suggest that either the fish in both bays were different species or that a dominant species was found in only one bay.

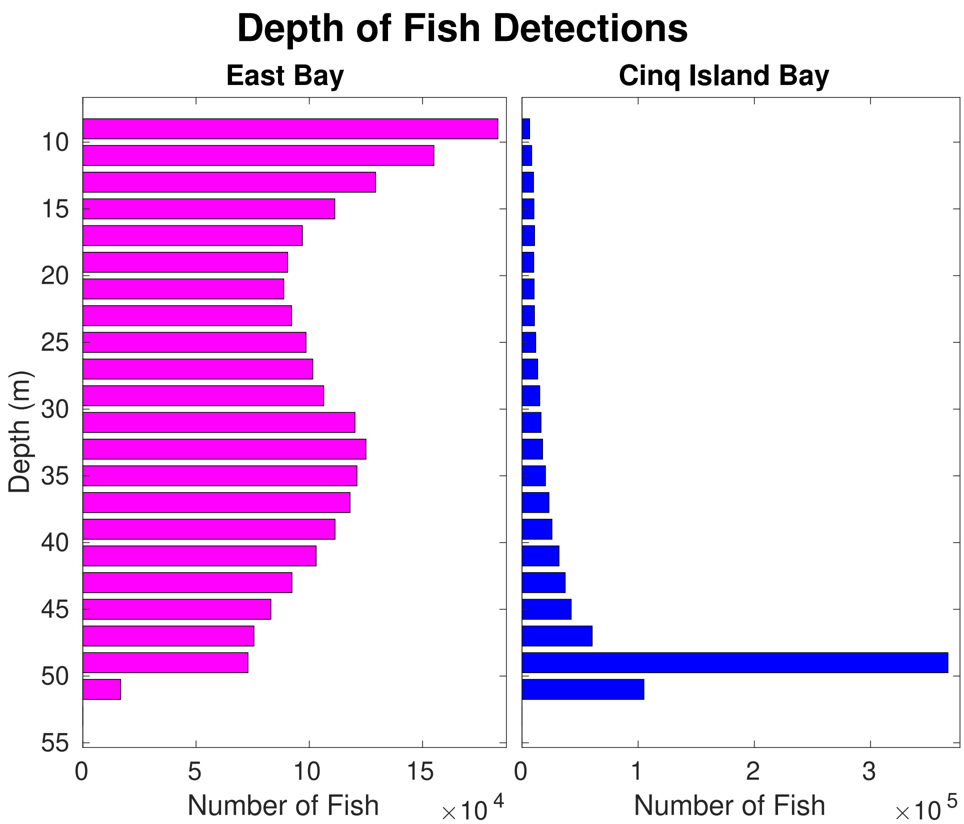
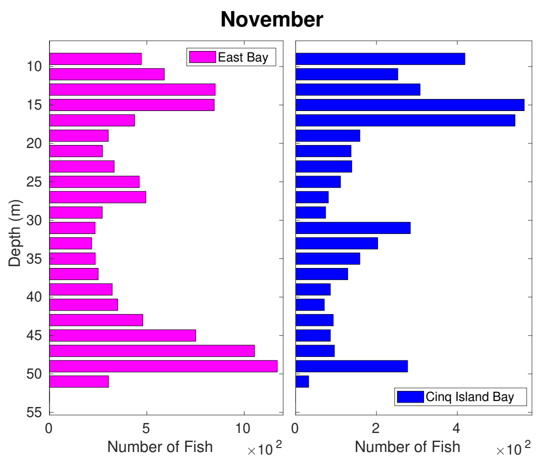
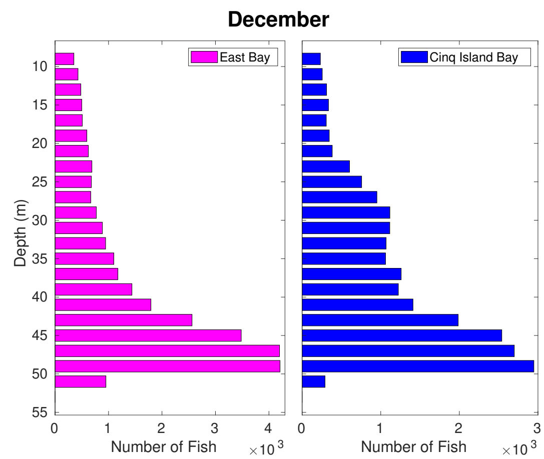


Figure 4.14: The amount of fish at each depth in the water column averaged over the whole time series showed contrasting results for East Bay and Cinq Island Bay.

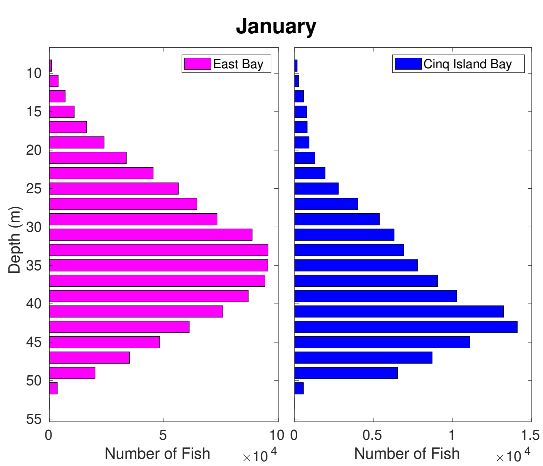
Fish in East Bay are more apparent in all depths while the fish in Cinq Island Bay are more present at lower depths near 50 meters. It is important to note that different scales are used in Figure 4.14. If the cluster of fish at 50 meters are ignored in Cinq Island Bay, the differences between the depth distribution of fish would be less striking. The distribution of fish depths in Cinq Island Bay would still have high amounts near 50 meters, but there would also be peaks in fish at 15 meters and between 40 and 50 meters. For distribution purposes, we cannot just ignore the increase of fish at 50 meters in Cinq Island Bay. For instance, species that migrate to and from the surface would likely be those present in East Bay. In order to further understand the differences in fish behavior, depth distributions were generated on a monthly basis (Figure 4.15).



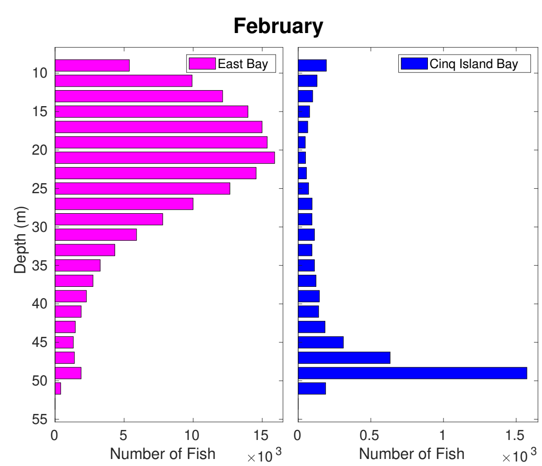
(a) November



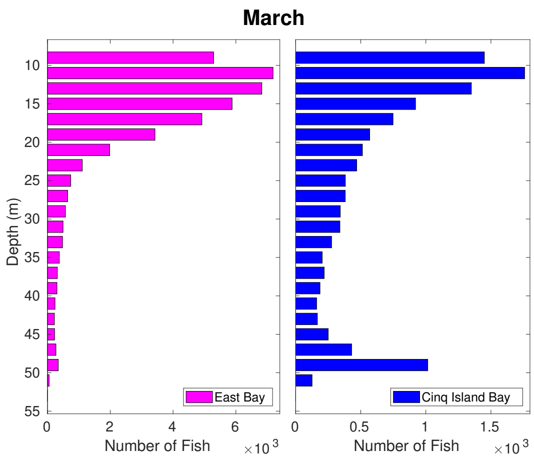
(b) December



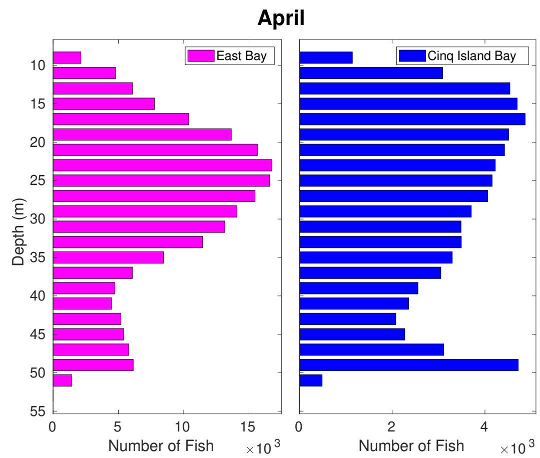
(c) January



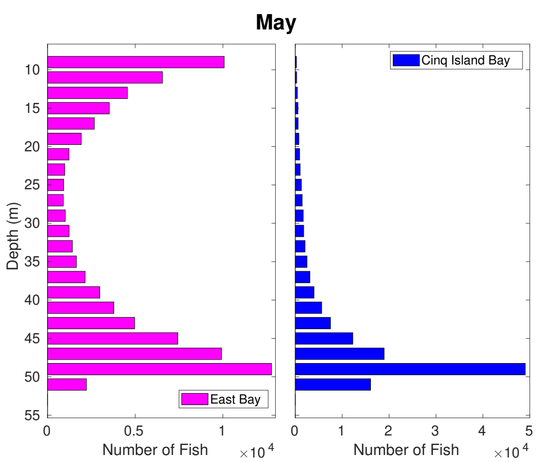
(d) February



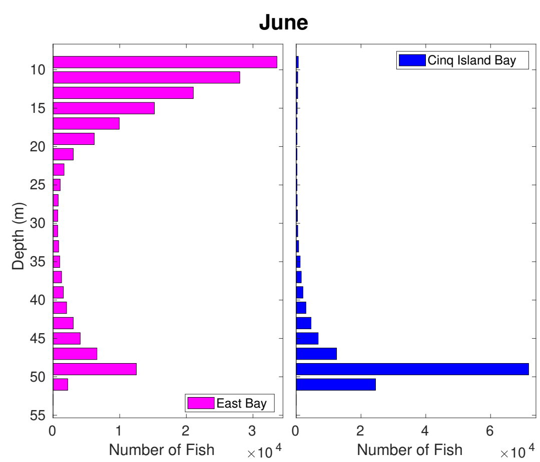
(e) March



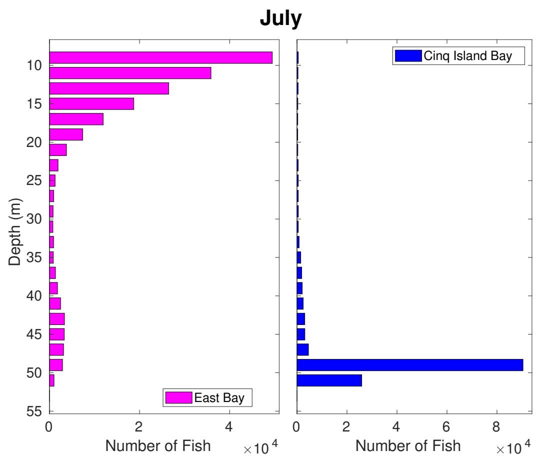
(f) April



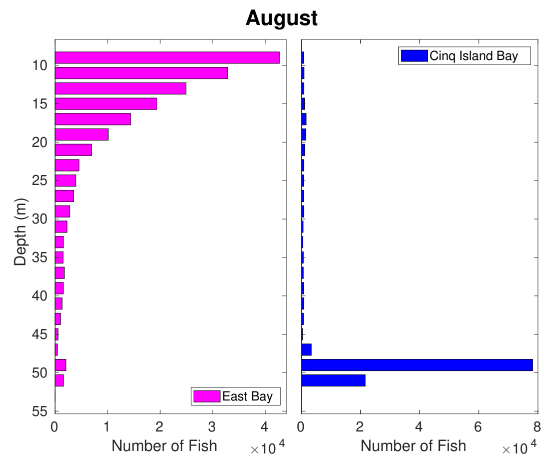
(g) May



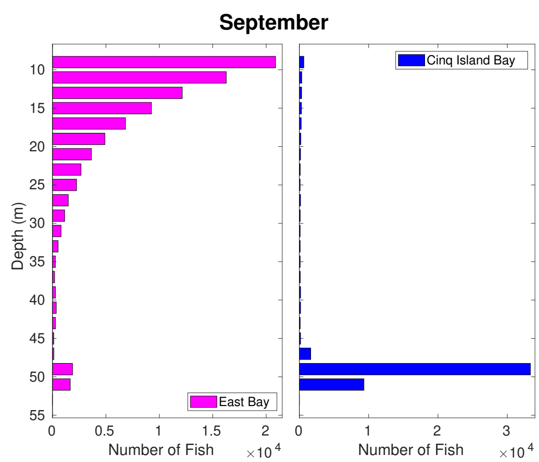
(h) June



(i) July



(j) August



(k) September

Figure 4.15: Monthly depth distributions of fish

In November, there were very similar trends in fish distributions (Figure 4.15a). Both East Bay and Cinq Island Bay had peaks at the surface, in mid depths around 30 meters and close to the ADCP at 50 meters. In December, fish were distributed near the ADCP at 50 meters in both bays with a slight peak visible at 30 meters in Cinq Island Bay. In January, the same fish depths were again seen in both bays with a mid depth distribution of fish at around 40 meters. In February, there was a distinct change; in East Bay, fish are located near the surface from 15 to 25 meters in depth while in Cinq Island Bay, fish were located near the ADCP at 50 meters in depth. In March, a shift again occurred with both East Bay and Cinq Island Bay displaying the same surface distributions of fish near 12 meters and Cinq Island Bay having a slight peak at 50 meters. In April, detections were still near the ADCP and surface distributions moved slightly lower in the water column to 20 meters. In May and June, Cinq Island Bay had no fish near the surface while East Bay had almost 10,000 fish at 10 meters. Additionally, both bays had an increase of fish at 50 meters. In July, August and September, opposing distributions between both bays occurred with East Bay having a large distribution of fish near the surface at 10 meters and Cinq Island Bay having a large distribution of fish near the ADCP at 50 meters.

4.5 Target Strength

Target strength describes the reflectivity of targets within the water column and can be used to discern the relative size of discrete targets. As stated in section 2.2.1.2, target strength is related to characteristics of the target. Individual target behavior give rise to a distribution of target strengths. Fish tilt is known to be an important factor to that distribution. In addition, for a single beam system, fish location within the acoustic beam will give rise to a distribution of target strengths with the maximum corresponding to targets occurring at the beam axis.

4.5.1 Comparison between East Bay and Cinq Island Bay

East Bay has a bimodal distribution of target strengths seen in Figure 4.16. The values extend the whole range from -80 dB to -35 dB. The two distinct peaks of occurrences were at -75 dB and at -50 dB. Target strengths around -75 dB occur in over 29,000 fish detections while target strengths around -50 dB occur over 17,500 times. Two distribution peaks occur only because of two different species or two types of behaviors of one species. This distribution parallels the behavior differences found for depth distributions in Figure 4.14 and Figures 4.15a to 4.15k.

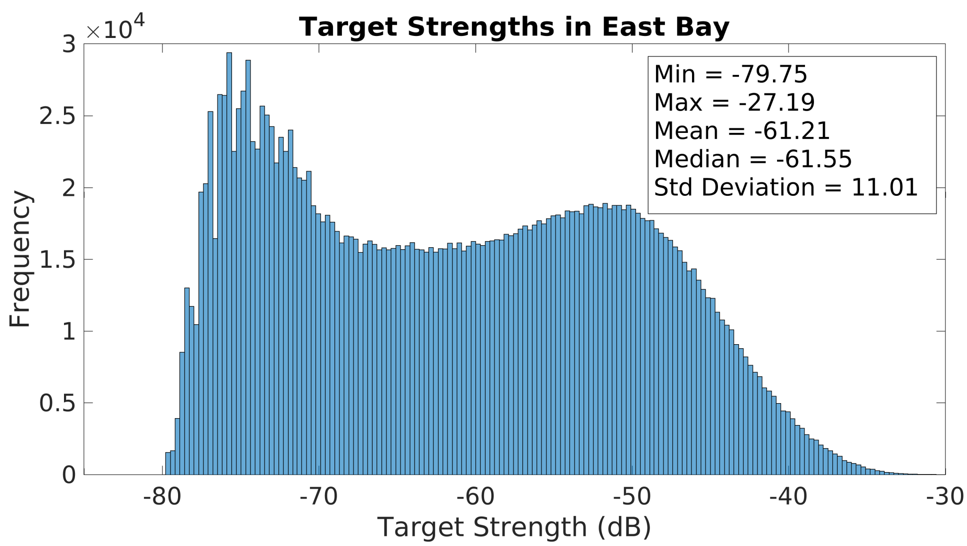


Figure 4.16: The range of target strength (dB re 1 m) values in East Bay over the entire ten months

Cinq Island Bay has a more normal distribution of target strengths (Figure 4.17). There is one size dominating the fish detections during data collection. This fish size was in between the two distinct fish sizes found in East Bay. The results show only one distinct fish size from the target strength distributions and it is consistent with the results for fish depth distributions in Figure 4.14 and Figures 4.15a to 4.15k. The fish in Cinq Island Bay frequent target strengths around -67 dB in approximately 7,000 instances. Similar to East Bay, the target strength values range from -80 dB to -35 dB.

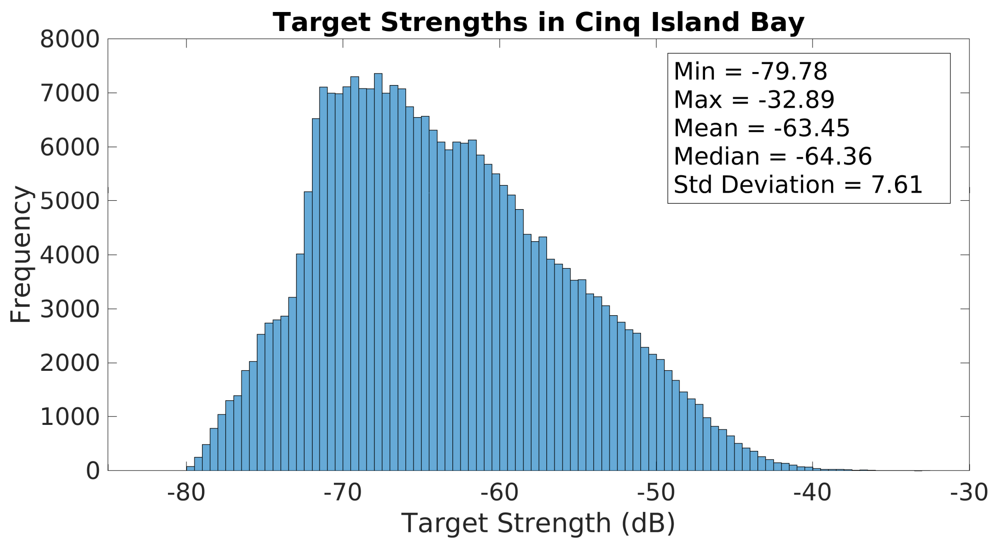


Figure 4.17: The range of target strength (dB re 1 m) values in Cinq Island Bay over the entire ten months

4.5.2 Seasonal Differences in Both Bays

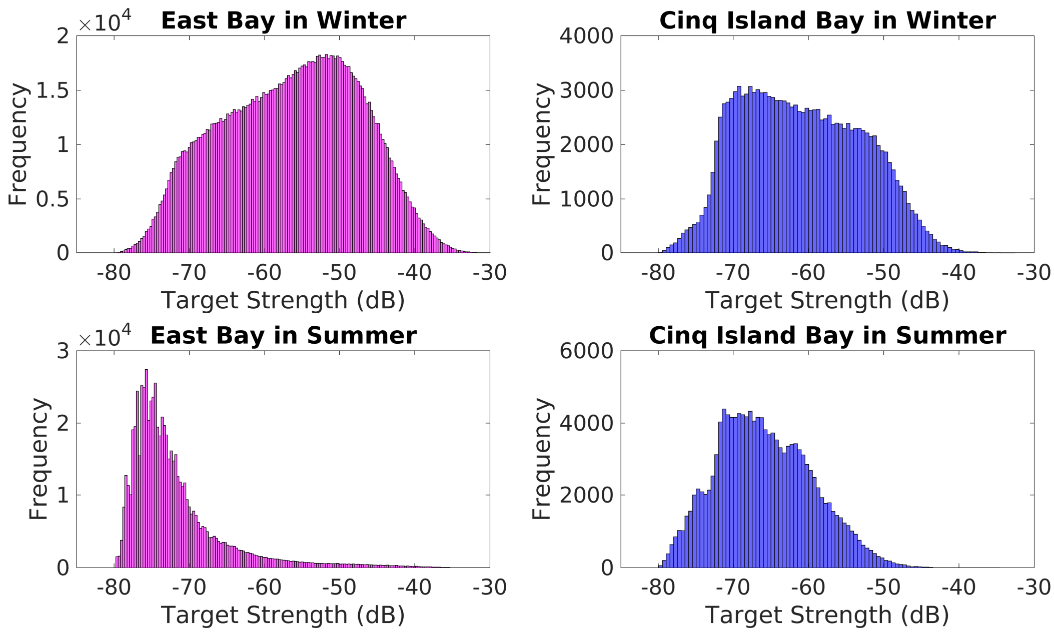


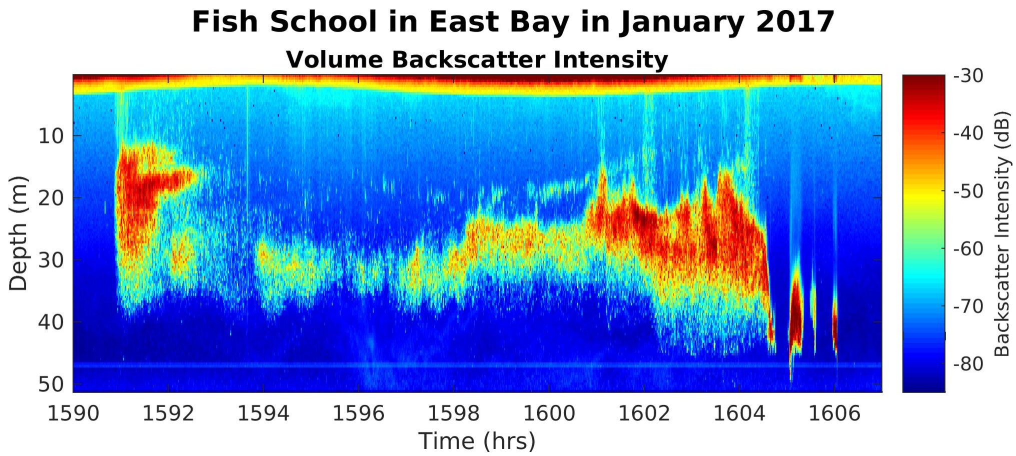
Figure 4.18: Distribution of target strengths from Winter months (November to mid May) to Summer months (mid May to September)

By breaking target strength distributions into Winter and Summer (Figure 4.18), it can be seen that the bimodal distribution of target strengths in East Bay (Figure 4.16) was related to the time of year. From November to May, target strengths in East Bay peak at -52 dB and in Cinq Island Bay peak at -72 dB (Figure 4.18). There is another smaller peak seen in both bays during this time at -72 dB in East Bay and at -52 dB in Cinq Island Bay. From May to September, the distribution of target strengths in East Bay peaked at -75 dB and the target strength in Cinq Island Bay peaked at -68 dB. There was a shift in community structure, in size or in behavior after May in both bays that could have resulted from addition of new species into the environment.

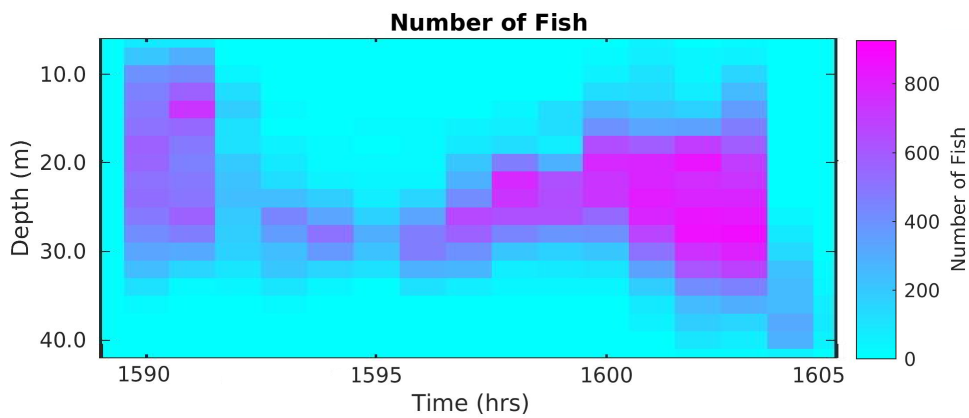
Based upon a study from Demer and Martin, zooplankton target strengths can range from -89.0 dB to -69.1 dB using a device with a frequency of 420 kHz or from -77.7 dB to -61.2 dB using a device with a frequency of 1 MHz [8]. In both East Bay and Cinq Island Bay during Winter and Summer, most of the target strength values range from -75 dB to -70 dB and appear to be zooplankton (Figure 4.18). Armstrong and Edwards found that Sandeels (*Ammodytes marinus*) have a target strength ranging from -45 dB to -55 dB using a device with a frequency of 38 kHz and have a 4 dB higher target strength range using a frequency of 120 kHz [2]. Sandeels are closely related to the American Sand Lance (*Ammodytes americanus*) and Northern Sand Lance (*Ammodytes dubius*). Both species, American Sand Lance and Northern Sand Lance, are common in inshore waters in Newfoundland [30]. In both East Bay and Cinq Island Bay in Winter, the second target strength peak in Figure 4.18 at -50 dB are consistent with Sand Lance presence.

4.6 Fish Schools

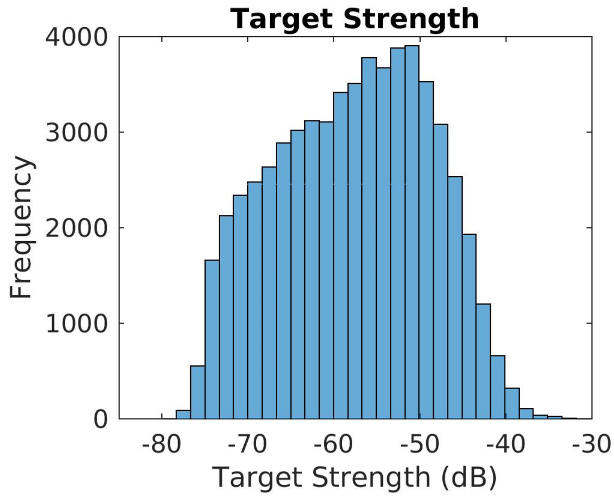
Fish schools appeared during the ten month observation period, sometimes hourly and other times daily. Looking at Figure 4.5, the extent of fish activity prevailed in January and February in East Bay. An example of a fish school is shown in Figure 4.19. The volume backscatter was strong in some parts reaching a maximum of -30 dB while other parts had averages of -65 dB.



(a) Backscatter of fish school during January



(b) Number of fish in fish school during January



(c) Target strength of fish in fish school during January

Figure 4.19: Backscatter, amount of fish, target strength of a sample fish school

In the case of Figure 4.19a, the fish school was persistent 15 hours and the amount of fish in this school exceeds 800 based on calculations described in Section 4.4. This particular fish school has a target strengths averaging at -57.8 dB with a standard deviation of 8.96 dB seen in Figure 4.19c. Likely, this fish species caused the highest peak of target strengths in East Bay during Winter months due to the target strengths similarities in Figures 4.16 and 4.19. Sand Lance school during the day in Winter months to feed on zooplankton and bury in the sand during the night [33]. The school in Figure 4.19 and the others that occur during the same time period are consistent with feeding behaviors of Sand Lance.

Chapter 5

Conclusions

Collecting long time series data nearby to aquaculture sites using an ADCP allowed for an analysis of the influence of fallow periods and/or seasonal cycles. From ADCP data, we are able to look at the abundance of fish, time of year that fish were present and the target strengths of these species. From this information, we can compare and contrast two adjacent bays in Southern Newfoundland. The data collected with the ADCP allowed for recognition of fish behaviors and distinguishing fish types based on behaviors.

We hypothesized that aquaculture farming activity would make a difference in the amount of fish that were present during times of farm inactivity. We were unable to see the immediate impact that both bays experienced once the farms were fallow due to the lack of data during that time. But, we were able to see the difference when the farms were active again and when the seasons transitioned from Spring to Summer months. Differences at this transitional time were apparent in the amount of fish, depths of fish and the target strengths of fish.

The amount of fish in both bays was drastically different with higher numbers of fish in East Bay than in Cinq Island Bay from November 2016 to September 2017 (Figure 4.12). During the Winter months of January and February, East Bay had more than two times the amount of fish detections as Cinq Island Bay. Even though the difference in the amounts of fish between bays was large, the trends of fish increases and decreases paralleled over time. Both bays had less fish from May until September with a 95% confidence level based on the z test (Section 4.4.2). Peaks in fish detections occurred during January, February and May and a constant amount of fish occurred from mid-May to September in both bays.

There were distinct differences in the sizes of fish present based on depth distributions and target strengths. The target strength values show that from November to May both bays had two distinct sizes of targets present relating to the two peaks of target strengths at -73 dB and -50 dB in Figures 4.16 and 4.17. From May to September, this switches and East Bay has a different size target dominating the area while Cinq Island Bay still has one of the two target sizes from Winter months lingering.

Evaluating the depths of fish during the entire ten month period showed that East Bay had a potentially vertical migratory species or two fish species that were present in two depths of the water column (Figures 4.14 and 4.15). On the other hand, Cinq Island Bay had fish only in one depth region. Both bays followed a similar trend in depths of fish during each monthly interval seen in Figures 4.15a-c and e-f. Figures 4.15 d and g-k show that both bays have opposing depths as well. From this, we gathered that half of the year (during Winter) a similar species was present in both bays while the other half of the year (during Summer) a different species dominating the area in East Bay.

Unfortunately, data related to seasonal differences between the two bays was not available prior to this study. For this reason, it is difficult to ignore a potential seasonal impact on fish populations in these bays. Therefore, without extending our data collection to target seasonal differences, we cannot conclude whether the difference in fish detected from May to June was due to the farms becoming active again after a fallow period or if this was due, in whole or in part, to the change in seasons from Spring to Summer.

In order to improve on this work, future studies would need to include collection of year round data (covering multiple years) in the absence of fallow periods as well as multiple years of data with fallow periods during different seasons (if possible). Another option for the study could include a bay with no fish farms that could serve as the control. This would provide enough data to fully explain seasonal differences versus the influence of farming on fish populations. Future studies should use two different frequencies so that multiple sizes of targets would be apparent. Additionally, direct collection of species coinciding with the use of ADCPs can aid in identifying species that were present and distinguish fish from zooplankton.

Chapter 6

Summary

Aquaculture in Newfoundland is relatively new and therefore the effects that arise, particularly to the ecosystem, are not fully understood. In order to evaluate the impact that fish farms have on wild fish species, we deployed ADCPs nearby to two open net pens. The two locations, East Bay and Cinq Island Bay, were similar in physical attributes and geographic location. During the course of ten months while the ADCPs were deployed, the fish farms went from fallow periods to active farming.

ADCPs were configured to capture every received signal instead of the typical averaging in order to locate every fish within the water column. From the data that was collected, the volume backscatter was calculated and used to determine the relative abundance of fish over time. From there, the target strengths of fish were calculated as well as the depths of fish.

The results showed a trend that coincided with both aquaculture activities and seasonal changes thus making it difficult to draw a clear conclusion without further experimental data. The amount of fish, the depths of fish and the target strengths of fish all changed throughout the course of year.

Furthering this research can grasp the impact that fish farms may have on wild fish. Using ADCPs to determine this would be relatively cheap and easy to do. With further research including multiple years of data and experiments that can separate seasonal differences from those related to farming, important conclusions about the influences of aquaculture on the ecosystem could be determined.

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