Overview of the Biological Characteristics of Alewife (*Alosa pseudoharengus)* spawning runs on the Isthmus of Chignecto, New Brunswick, Canada.

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Abstract

Alewife *(Alosa pseudoharengus*) are an anadromous species of river herring that are found in the Atlantic Ocean, ranging from the coasts of North Carolina, USA to Newfoundland, Canada. Age-structured population models and other aspects of populations have not been determined for all Alewife populations in the Maritime Provinces. To inform population models, background information are examined including biological characteristics such as age, growth patterns and condition factor. Alewives were aged by enumerating annuli on scales. Alewife weight, fork length, total length and sex were collected in the field as a part of a preexisting project from 2013 to 2019 the Inner Bay of Fundy region. Here, the presence of spatial-temporal differences in fish size, condition factor, sex ratio or ages and potential changes or biases across river systems are identified. The results indicate that length-weight relationships and growth rates did trend upward between 2013 to 2019, with female Alewife growing at a faster rate than male Alewife. The determination of age revealed that the distribution of ages per sex during the spawning run was similar, with both sexes having a mean age of four. Similarly, average proportion of virgin spawners per age was four years of age for both sexes. The variance of Fulton's condition factor revealed that there is little difference in health for Alewife across the sample years and the four river systems. This information will help inform population management and protection for anadromous fish in Atlantic Canada, which will help researchers understand the influencing processes and biological characteristics driving alewife spawning runs. This thesis documents the validity of anecdotal observations on Alewife spawning run composition and provides resource managers with research recommendations and an improved understanding the ecological significance of run timing in the Inner Bay of Fundy.

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1 Literature Review

1.1 Research problem, Purpose and Objectives

Many global fish populations have experienced significant declines in abundance in recent decades, particularly those with commercial value such as Atlantic Salmon and Atlantic Mackerel (Deparment of Fisheries and Oceans Canada, 2016, 2019)). Well-informed management strategies are required to aid in population persistence and recovery. To do this, these management strategies require region-specific biological characteristics to understand the distribution, abundance and health of populations across geographical boundaries. Many species are data limited or deficient and do not include information regarding current or changing biological characteristics such as growth, length at age and timing of spawning events. When a series of statistical measures are applied to long-term records, the results of these demographic studies can be used to describe populations in detail, contributing to a more data comprehensive and detailed stock assessment thus allowing for higher resolution and improved legislation (Morris & Green, 2014). A resident population of Northern Atlantic Cod (*Gadus morhua. L*), that spawns inshore off Southern Labrador, Canada is an example of a spawning population that exemplifies the importance of biological characteristics (Morris & Green, 2002). Over the past 100 years, a component of this population has become resident to the inshore spawning region; despite no previous interaction from large fisheries, the resident population has endured fishing pressures as a result of the cod collapse (Morris & Green, 2002). Morris & Green (2002) used various biological characteristics of the resident Atlantic Cod populations to understand the mechanisms influencing year-class growth, age at sexual maturity and recruitment. From this study, researchers were able to determine the current stock characteristics and how they are related to those of the resident Atlantic Cod to the those of the Atlantic Northwest Cod in the

1990s, the cod population famously known for the “Cod Collapse in Newfoundland” during the late 20th century. Not only does this encourage the local fishery to reduce the pressure on this resident population, it emphasizes the importance for regionally specific management strategies to avoid a similar fate or a second cod fishery collapse (Morris & Green, 2002, 2014). Population characteristics including growth, size- and age-at-maturity, time of spawning, and movement patterns, such as those used study on the resident Atlantic Cod fishery are essential in understanding the status of fisheries and informing management practices (Babcock, Coleman, Karnauskas, & Gibson, 2013; Morris & Green, 2002). To estimate population characteristics, including mortality and age-growth parameters, researchers commonly use stock assessments and age-structured population models. With proper conditions, age-structured population models can be used to inform the species surplus production model, a model that combines recruitment, growth and mortality into a population production function (Tahvonen, 2008).

Age-structured population models and the background biological population characteristics needed for these have not been determined for all Alewife *(Alosa pseudoharengus)* populations in the Maritime Provinces. To inform such models, background information and current stock status must be compiled. This research will focus on the spatial-temporal differences in body size, condition factor, sex ratio or ages of three spawning runs in rivers of the Isthmus of Chignecto. Using seven years of data collected during a tagging process, this research will focus on Alewife spawning run composition and provide resource managers with an improved understanding the ecological significance of run timing. This thesis will also document the validity of anecdotal observations obtained during a tagging process in the Inner

Bay of Fundy including the impact of fishing selectivity, sex and age distribution, and increasing trends of fish size during the spawning run.

The research objectives are to:

- determine the relationship between fork length and weight and fork length and total length of Alewife to help understand length measurement patterns in growth over time, per sex.
- determine the proportion of virgin spawners in the spawning run, helping determine the spawning potential of the spawning run as well as the composition of the region-specific population.
- identify any variation of Fulton's condition factor (K) over four years, across multiple river systems, with a goal of determining and explaining spatial and temporal patterns per sex.
- identify any significant differences between male and female biological characteristics including fork length, total length, weight and Fulton Condition Factor, per year, with the goal of understanding these patterns while determining the mechanisms that influence patterns of biological characteristics across multiple river systems, per sex.

From the objectives of this thesis, biological characteristics will be presented an essential piece of data required during fisheries management stock assessments and analysis. When biological characteristics are included, fisheries management can provide an overview of the population framework. This framework will contribute to future research on biological reference points, eventually leading to a stronger legislation and a comprehensive stock assessment for Alewife within the Atlantic region.

1.2 Life History and Life Cycle

Alewife, commonly referred to as Gaspereau, are a species of river herring that spawn in watersheds from North Carolina, USA, to Newfoundland, Canada (Nau et al., 2017; Scott & Scott, 1988). Within the Maritime provinces of Canada, the Gaspereau, Miramichi, Margaree, Saint John and Tusket river populations (Gibson, Bowlby, & Keyser, 2017; Messieh, 1977), are considered ecologically, commercially and culturally significant.

Alewife populations may be anadromous or landlocked; this project will focus on anadromous Alewife populations, which typically grow larger than the landlocked populations (Department of Fisheries and Oceans, 1997). In anadromous populations, Alewife are usually less than 30cm in length and 400g in weight however this varies overtime between river systems (Department of Fisheries and Oceans, 1997; Mullen, Fay, & Moring, 1986). Length-weight relationships used in conjunction with Fulton's condition factor (k) are an important aspect of the management plans because they inform management on the growth patterns and population well-being on a temporal and spatial scales. This information helps determine the mechanisms that may influence growth patterns within a system as well as determining population projections.

Alewife are iteroparous Alosids; they reproduce up to five times during their lifespan of ten years (Loesch, 1987). Annual spawning runs are composed of individuals of varying ages and abundance of virgin spawners and repeat spawners. Most reach sexual maturity at ages three to six; however, there is evidence of Alewife as old as ten years, typically spawning four to six times during their lifetime (Loesch, 1987). In Atlantic Canada, spawning runs begin their migration upriver to their natal rivers in late April until mid-June, when the water temperature ranges from 5 °C to 10 °C (Mullen et al., 1986; Nau et al., 2017; Norden, 1967). Because fish spawn during a specified period of the year along with several time specific environmental factors, understanding spawning history and patterns can inform the changes associated with these factors.

During a spawning run, male and female Alewife are at their peak spawning stage as they arrive to a freshwater system. In some cases, spawning stage assessments, including estimated fecundity rates, are based on gonad mass, gonadosomatic index and visual characterization of spawning stage, which inform the spawning stage characterization for individual spawning populations (Stewart, 2019). However, in other cases such as in this thesis, spawning stage assessment is determined using spawning marks identified during the scale analysis to confirm sexual maturation.

1.3 Ecological Role

Ecologically, Alewife act as an important prey species in marine and freshwater ecosystems, contributing energy to the food chain for aquatic species as well as terrestrial predators such as birds of prey (Mullen et al., 1986). Anadromous Alewife serve as important links during spawning runs, contributing marine-derived nutrients to coastal and freshwater ecosystems and the food web dynamics and nutrient cycling through egg deposition, excretion and spawning migration mortality (Loesch, 1987; Mullen et al., 1986; Walters, Barnes, & Post, 2009). Natal river productivity, specifically the net primary production of freshwater and other anadromous fish, may be altered due to the exploitation of Alewife. However, due to the wide range of habitats and existing environmental factors present in spawning locations, determining which areas of habitat are being impacted the most is a difficult task (Gibson & Myers, 2003).

1.4 Species Significance

1.4.1 Economic

Alewife play a valuable role in fisheries economics in the Maritimes; they support both recreational and commercial fisheries during coastal migrations (Rulifson, 1994). These fisheries can lead to overexploitation, creating conflict because the optimal suggested harvesting and management strategies of renewable populations is one of the classic problems of resource economics (Tahvonen, 2009). Due to crashing mackerel stocks in the Atlantic Ocean, Alewife in the Maritimes have been increasingly used as bait in the lobster fishing industry which has led to increased exploitation (Nau et al., 2017).

1.4.2 Cultural

Collectively, river herring are culturally significant to many communities (Limburg & Waldman, 2009). It is common to harvest fish annually to feed coastal families or as bait for commercial lobster fisheries within its range. In addition to maintaining the appropriate maximum sustainable yields, management efforts also attempt to include recreational fishing, as it provided non-essential sustenance for the public (Hilborn & Walters, 1992). When a stock is not managed adequately, this tradition will eventually become forgotten due to reduced success rates and additional management regulations. For this reason, reduced yields from fisheries are among one of the major concerns impacting humans socially, culturally and economically. Fulfilling the cultural and economic objectives while following the most effective management methods among the multiple stocks in a region can be a difficult task (Hilborn & Walters, 1992).

1.5 Fishery

1.5.1 Regulations

Using evolving research, proper fisheries management encourages sustainable fish stocks, revised landing reporting and rates of conservation within a specific stock (Hilborn & Walters, 1992). Recent changes to Canada's Fisheries Act included protection for all fish and fish habitat and biodiversity and permits for development projects. Other actions involved turning policies into regulations, including Indigenous Traditional Ecological Knowledge in environmental assessments and an increased focus on habitat restoration and rebuilding of fish stocks (Department of Fisheries and Oceans, 2018b). These efforts are likely beneficial; however, current and historic regulations are not suitable on their own in determining the health of the fishery. When determining the health of an ecosystem and making decisions on stock assessment, four core categories are considered: biological, economic, recreational and social (Hilborn & Walters, 1992). Alewife fishery in the Maritime region has traditionally been regulated by seasonal, gear and license restrictions (DFO, 1997). Additional area-specific restrictions such as weekly two-day closures and a limited number of licenses distributed in each area have been increasingly applied (Department of Fisheries and Oceans, 1997). Without data on region-specific spawning populations, management strategies for Alewife stocks throughout the Maritime region have not excluded considerations of local fisheries health, although the expectation of maintaining harvests at their long-term mean levels remains (Gibson & Myers, 2003).

1.5.2 Fishing Selectivity

For various practical, economic and regulatory reasons, fishers select species and size during harvesting, often capturing more males than females, and larger female fish within a population (Davis & Schultz, 2009) To avoid the consequences of selective fisheries, guidelines and policies such as species and size limits, gear technology and spatial and temporal restrictions have been enforced in an attempt to avoid overfishing and improve fisheries management as a whole (Garcia et al., 2012).

For many river herring stock assessments, selectivity was not often considered or calculated in structured models (Billard, 2017). The Alewife fishery is strongly selective, typically targeting larger individuals; this was highlighted by Billard et al. (2018) when the biological characteristics sampled from a commercial fishery and a fishway in the Gaspereau River region indicated significant differences in age and size related to the structure of the spawning migration (Billard, 2018). Population characteristics and size composition are among two of the variables that differ depending on the region-specific population that is fished; this is known as size-selectivity. Size-selectivity is determined by factors including net material and mesh size, fish species, fish size, and behaviour. This is rarely accounted for in the creation of age-structured population models, in fishing practices that cause selectivity may also result in potentially inaccurate, differential fishing mortality rates (Billard, 2017). Overall, selective fisheries alter the composition of a population, consequently impacting the ecosystem and biodiversity of a region (Garcia et al., 2012).

1.5.3 Maritimes

Life-history traits, stock structure and population viability, are affected by commercial and recreational Alewife fishing (Jessop, 2003). In the Maritimes, reported landings were highest in 1980 at approximately 11,600 tonnes, decreasing to an average yearly landing of 6,200 tonnes from 1997 to 1999 (Gibson et al., 2017). Rigid and enforced fisheries management plans and declining populations decreased Alewife landings to 21 tonnes in 2010 (Department of Fisheries and Oceans, 2018a). In 2017, landings were a fraction of historical landings, with only 1,400 tonnes of fish harvested (Department of Fisheries and Oceans, 2018a). The recent decrease in landings may be attributed to the simultaneous decrease in population and the increase in management and conservation efforts. More specifically, on the Bay of Fundy, annual harvest ranges from 1960 to 1999 ranged from 860 tonnes to 6,700 tonnes (Department of Fisheries and Oceans, 1997). Since 1990, annual landings have ranged from 1,200 to 1,745 tonnes. Corrections for incomplete records and the absence of data for illegal catches have not been considered in this calculation. In the study area, within the innermost region of the Bay of Fundy and further referred to as the border region, the recorded annual landings are less than 100 tonnes (Nau et al., 2017).

Within the Bay of Fundy region, the largest Alewife fishery occurs in the Saint John River, New Brunswick. This thesis focuses on the Alewife fishery in the border region of the inner Bay of Fundy however two other fisheries are used for comparisons: the Gaspereau River, and the Shubenacadie River (Department of Fisheries and Oceans, 1997). These three fisheries are geographically, ecologically and economically diverse with varying harvest rates, regulations and restrictions. Gear used in the three Alewife fisheries varies depending on fishing location and the fisher preferences. Most fishers use a square dip-net on the Gaspereau River, however some use a gillnet or a drift net to catch the Alewife (McIntyre, Bradford, Davies, & Gibson, 2007). On the Shubenacadie River, fishers use drift gillnets and dip nets at weirs (DFO, 1997), and in the border region, fishers use drift gillnets and dip nets at barriers such as tide gates.

For a species that is susceptible to overharvest, knowledge of biological characteristics such as age and growth is essential for the sustainable management of these three fisheries to predict sustainability of harvest limits and quotas (Stewart et al., 2015). Although the three regions mentioned above support the recreational and commercial Alewife fisheries, the age, growth and size selectivity has only been modelled in the Gaspereau River region (Billard, 2017). When similar characteristics are determined for the remaining two regions, researchers can create biological reference points. Biological reference points are reference values based on management objectives of the stock, the biological characteristics of the population and the general characteristics of the fishery, such as fishing mortality rate and size selectivity (Billard, 2017; Gibson & Myers, 2003). Stock status can be determined by comparing biological reference points with existing stock assessments. In a report published by the Department of Fisheries and Oceans, the biological reference points for Alewife fisheries have been described for the Margaree River, Miramichi River, Mactaquac Headpond and the Gaspereau River. As biological reference points become more prevalent in fisheries management, these values need to exist for all regions where fisheries are active.

1.6 Anthropogenic Impact

In both marine and freshwater ecosystems, changes in habitat availability, increased predation, changing water temperatures, accidental by-catch and overfishing are among many environmental factors that cause declines in diadromous fish populations. These factors can lead to slower growth and lower reproductive success, two elements that may lead to population declines (Limburg & Waldman, 2009). Because of the variability of habitat requirements and life cycle-dependent preferences, it remains unclear which biological characteristic will be most highly affected by these changes. Climate change is one environmental factor that can be revealed in analyses using age-structured population models (Botsford, Holland, Samhouri, White, & Hastings, 2011).

In addition to intensive overfishing (both commercial and illegal), Alewife populations have also felt the impact of anthropogenic barriers including fishways, poorly installed culverts and tidal control gates during their annual upstream migrations (Nau et al., 2017). While blocking habitat connectivity, these barriers may also reduce water quality, increase temperatures and reduce oxygen levels in freshwater environments, and may have a significant influence on the ecosystem's productivity. When an anthropogenic structure is impassable, pooling events occur, allowing the Alewife to be easily captured by predators or illegal fishing activities. Consequently, there has been a decline in Alewife populations, specifically in areas where barriers are highly abundant (Atlantic States Marine Fisheries Council, 2017).

In the border region, three fishways were assessed from 2013 to 2016, and the impact of anthropogenic barriers was found to vary based on a fish's body size, age (spawning experience) and sex (Nau et al., 2017). More specifically, fishways are size-selective allowing larger fish, previous spawners and males to pass more easily than smaller fish, which can affect the spawning migration, as well as the number of individuals entering the fishways (attraction rates; 85 to 98%), and annual passage rates (64% to 97%) (Nau et al., 2017). Using these data, organizations such as Ducks Unlimited Canada and Department of Fisheries and Oceans (DFO) have created partnerships to improve conservation and habitat availability. This has been done by introducing river-specific management plans and directly improving fish passage throughout by increasing regional monitoring efforts and by improving the designs of structures such as fishways to decrease the impact of anthropogenic barriers (author's personal observation, RB., 2019; Stewart, 2019).

1.7 Conservation Status

Recent declines in abundance for Alewife populations within North American waters has been a result of overexploitation, increased predation and ocean warming (Department of Fisheries and Oceans, 2018b)**.** Currently, they are designated as a mid-priority candidate that may require future attention or protection as determined by the Committee on the Status of Endangered Wildlife in Canada (Atlantic States Marine Fisheries Council, 2017; Committee on the Status of Endangered Wildlife in Canada, 2016; Davis & Schultz, 2009). Multiple organizations within the USA have identified Alewife as a species requiring management action; they were previously listed under the Endangered Species Act,and were listed as a species of concern by the National Marine Fisheries Service and the Atlantic States Marine Fisheries Commissions. Later, an update published in 2019 by the National Oceanic and Atmospheric Administration determined that Alewife are no longer identified as threatened or endangered based on four population segments (Canada, Northern England, Southern New England and Mid-Atlantic) (National Oceanic and Atmospheric Administration (NOAA), 2019).

2 Methods

2.1 Study Area

Data for this project was collected by Acadia University's Coastal Ecology Lab (CEL) and Ducks Unlimited Canada (DUC) as a part of a multi-year tagging project. The tagging project focuses on documenting and facilitating Alewife passage in four river systems located near the interprovincial barriers between New Brunswick and Nova Scotia (Missaquash, LaPlanche, LaCoupe and Tantramar (Robinson Brook's tributary).The four rivers connect to the Atlantic Ocean in Westmorland County NB at Cumberland Basin. On each river, there is either a Denil fishway (Miassaquash, Laplanche and LaCoupe) or a culvert that acts as a barrier for fish passage.

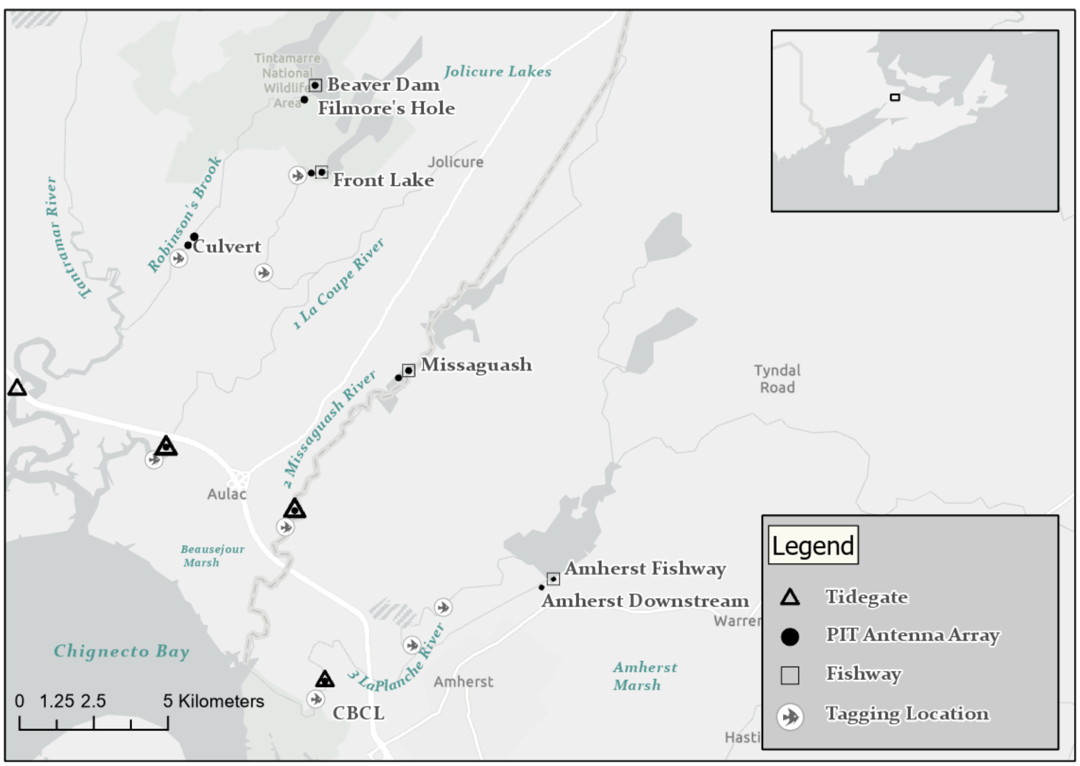

Figure 1 Map of Tantramar, LaCoupe , Missaquash, and LaPlanche rivers, barriers (culvert on Robinson's Brook, and fishways at Front Lake, Missaquash, Amherst) and sampling sites on the Isthmus of Chignecto between the border region of New Brunswick and Nova Scotia.

2.2 Field Sampling

During the May 2013- June 2019 period more than 9,200 Alewife have been tagged using Passive Integrated Transponders (PIT) tags at various sites that are outfitted with Radio-Frequency Identification (RFID) telemetry systems, known as detection arrays. During this tagging process, fish morphometrics were recorded, including fork length, total length, weight and sex. Scale samples were collected for a subset of tagged fish for scale aging and future genetics work. Scales have traditionally been used to determine age and growth as non-lethal age assessment tool, where other age determination methods age, including otoliths require lethal sampling (Devries & Frie, 1996). Scales were removed from behind the pectoral fin, by scraping from the fin towards the tail with a biopsy needle, which was also used to insert the PIT tag. Sampled scales (approximately n=5), were placed into labeled envelopes with the individuals tag number and the other morphometric data. A source of error could be bias sampling of scales, which were collected during the first three weeks of the spawning run each year. In future studies, scale selection should be evenly spread throughout the spawning run to ensure consistent, non-bias data.

2.3 Age Determination and Spawning Stage Assessment

Scales were dried and washed with a mild dish soap to remove any sediment or residue. Cleaned scales were mounted onto a microscope slide and visualized using a projection microscope. This technique is based on the appearance of marks on each scale, including annuli marks which indicate the annual growth related to the changes in growth patterns during different periods of the year; relatively fast growth in spring and summer and low growth during fall and winter, which results in a darker ring (Devries & Frie, 1996; Marcy, 1961). Scale projections were used to define annuli, which are translucent bands that marked different growth periods. This method is the most direct and accurate method for quantifying fish age from scales (Devries & Frie, 1996). Despite the many advantages, this method has limitations. In some cases, it is difficult to determine the annuli marks on scale due to regrowth or regeneration that occurs after a scale is removed or damaged. In these cases, visible growth patterns are inaccurate, and may not reflect the proper age or inferred characteristics. As a result of this inaccuracy, these scales are discarded and removed from analyses.

Spawning marks also are present on many scales. This is a result of reabsorption, also referred to as eroding, that occurs when fish experiences severe stress such as spawning events (known as the "Crichton effect"; (Devries & Frie, 1996; Simkiss, 1974). These marks typically appeared near the periphery of the scale which can often be a source of error during the age determination process. When these marks were absent, I assumed that the fish would attempt to spawn in the current year because a portion of the scale has been eroded and reabsorbed during the spawning run. Additionally, all fish caught in the border region during the study had reached sexual maturity (author's personal observation, RB., 2019; Nau et al., 2017). To avoid miscounting, the outermost marking is always interpreted as an annulus and factored into the total age (Judy, 1961; Marcy, 1961). Once the annuli and spawning marks are counted, a year is added to the scale edge because the samples are collected when the Alewife enter freshwater, meaning they will continue their migration upstream to spawn for their first or another year (Marcy, 1961). Similarly, an additional year is added to account for potential erosion of the scale edge during the current spawning migration (Judy, 1961).

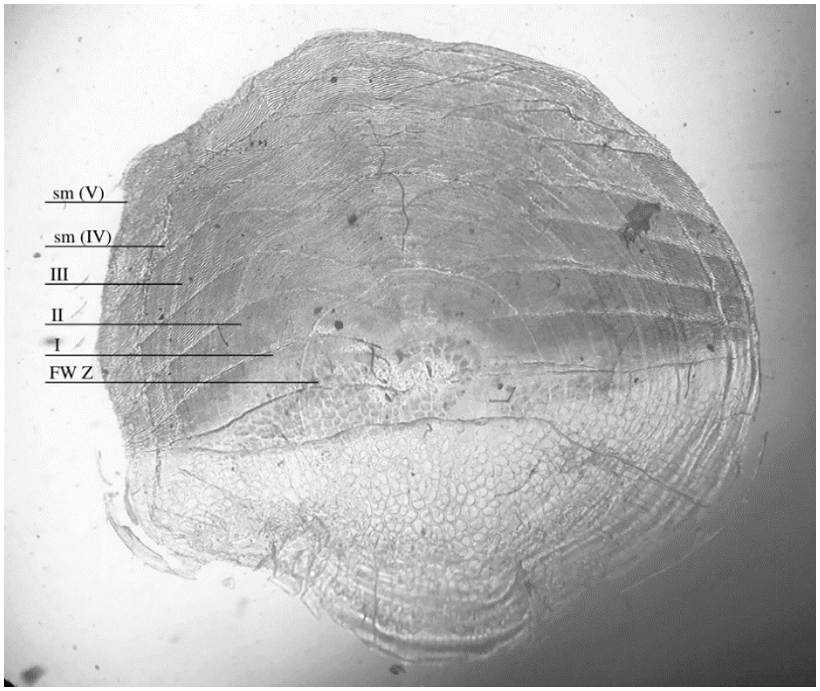

Figure 2 Scale from a five-year old female Alewife (*Alsoa psedoharengus*) spawning for the second time. Roman numerals representing annuli, FW2 freshwater zone and spawning marks (sm). Created following Marcy (1961).

2.4 Fulton Condition Factor

Fulton condition factor (K) was used to evaluate the well-being and growth of Alewife sampled during the study. This is an index of fish condition calculated by dividing the weight of a fish by the cubed length of the fish, multiplying that value by a scaling constant (Anderson & Newmann, 1996**).** Fulton condition factor was determined for each year, and each river system to determine any significant differences. These means were calculated by averaging annual mean conditions over four years, during the spawning run.

$$\boldsymbol{K = \left(\frac{W}{L^3}\right) X\ 100{,}000}$$

2.5 Statistical Analysis

Statistical analyses including an independent t-test with a significance level of 0.05 and correlation coefficient were done using R version 3.6.1 (R Core Team, 2019) to determine the relationship between length measurements and weight, the distribution of age by sex, the varying characteristics by age and sex, proportion of virgin spawners and condition factor. Similar methods, and a two-way ANOVA was used to analyze the four biological characteristics (fork length, total length, weight, and condition factor) for each sex by sample year, distinguishing variation over time.

3 Results

3.1 Length and Weight Relationship

A total of 9383 Alewife were tagged across four different river systems each spring from 2013 to 2019. The mean (± SD) fork length for those tagged was 230 mm ± 18 (range from 113mm to 310mm) and a mean (± SD) total length of 261 mm ± 20 (range from 141mm to 378mm).The mean (± SD) weight of those tagged was 177g ± 46 (range from 70 to 430 (g). (Figure 4).

Using a correlation coefficients to measure the strength of the relationship between fork and total length, a strong positive relationship between the two values was found ($r=0.95$, $P<0.00001$), with a mean difference of 32 mm ±3.7. This mean difference of 32mm is likely to be influenced by outliers may be a result of errors during field sampling. The weight-length relationship for Alewife in this region was determined based on total length and weight, this information can be used to determine the growth pattern. This relationship also revealed a positive correlation, again with the exception of a few outliers ($r=0.79$, $P<0.00001$).

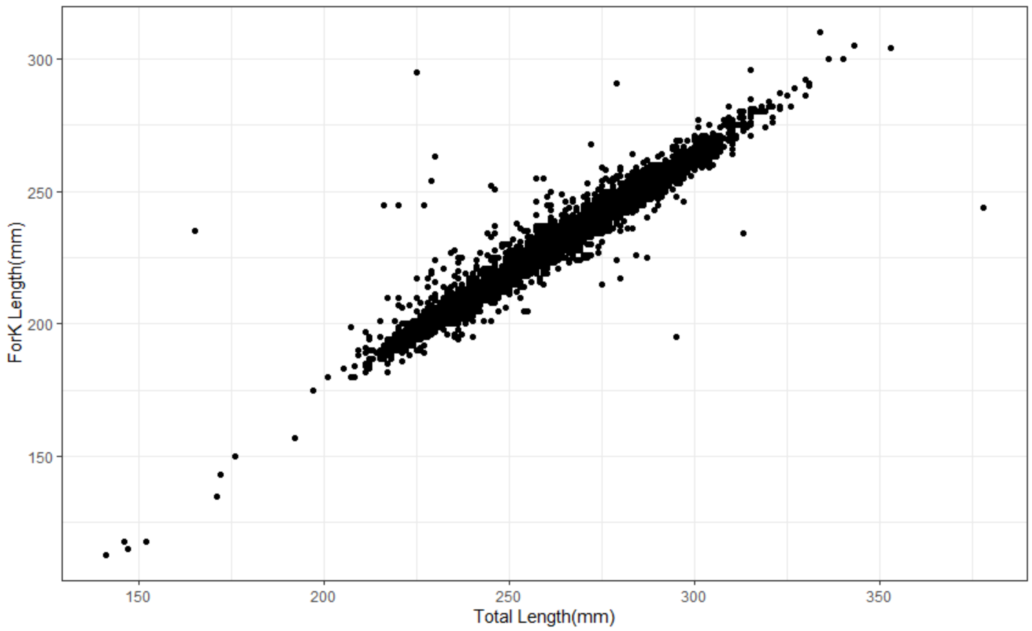

Figure 3: Fork length (mm) – total length (mm) relationship for Alewife from four river systems on the Isthmus of Chignecto during 2013-2019 (n=9383), (r=0.95, P < 0.00001).

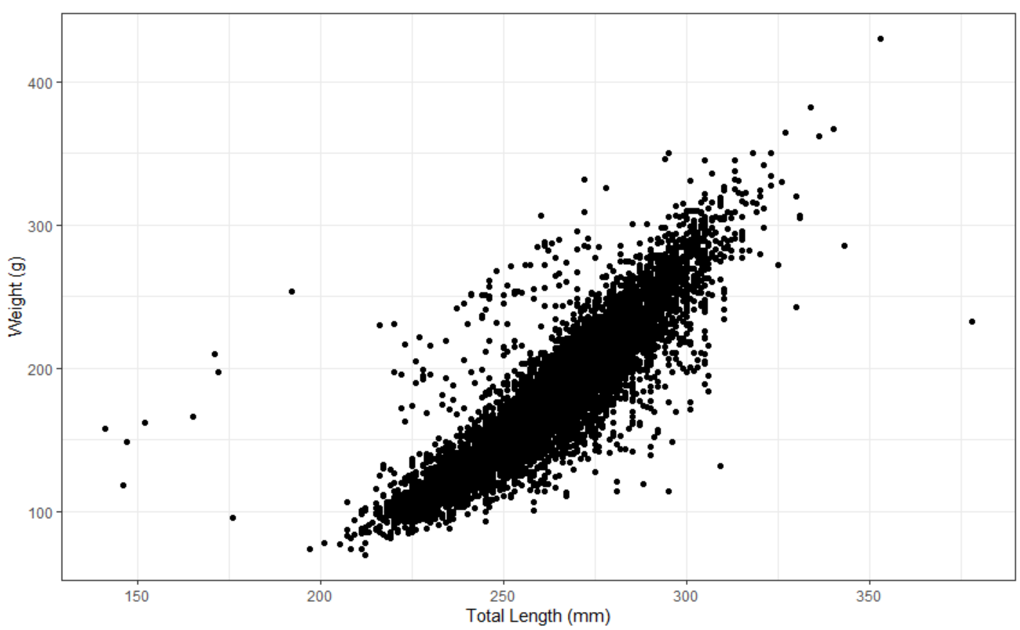

Figure 4: Weight (g) – total length (mm) relationship for Alewife from four river systems on the Isthmus of Chignecto during 2013 to 2019 (n=9383), (r=0.79, P < 0.00001)

3.2 Age Determination

To determine age, a subsample of 334 Alewife scale samples were selected and analyzed, a total of 3.5% of the data set. One hundred twenty-eight of the samples examined were female, 193 were male and the sex of the remaining 13 samples was undetermined and therefore excluded for a portion of the analyses below (Figure 4). Multiple samples were discarded because all recovered scales were regenerated. Fish that were sampled had a range of three to six years of age at the time of tagging. Weight, total length and fork length were plotted for each age to determine any variation within each age by sex (Figure 6).

There was no interaction between age and sex on weight (two-way ANOVA, $F_{2,328}$ =2.95, p=0.537) but weight increases with age (two-way ANOVA, $F_{2,328}$ =2.02, p<0.0001) and females were larger than males (two-way ANOVA, $F_{1,328}$=72.4, p<0.0001). Similarly, there was no interaction between age and sex on total length or fork length (two-way ANOVA, $F_{2,328}$=2.29, p=0.103 and $F_{1,328}$=1.39, p=0.263, respectively). However, total length and fork length both increase with age (two-way ANOVA, $F_{1,328}$=291, p<0.0001 and $F_{1,328}$=271, p<0.0001, respectively). Lastly, females grew to have be longer than males for both total and fork length (two-way ANOVA, $F_{2,328}$=67.6, p<0.0001 and $F_{2,328}$=60.4, p<0.0001, respectively).

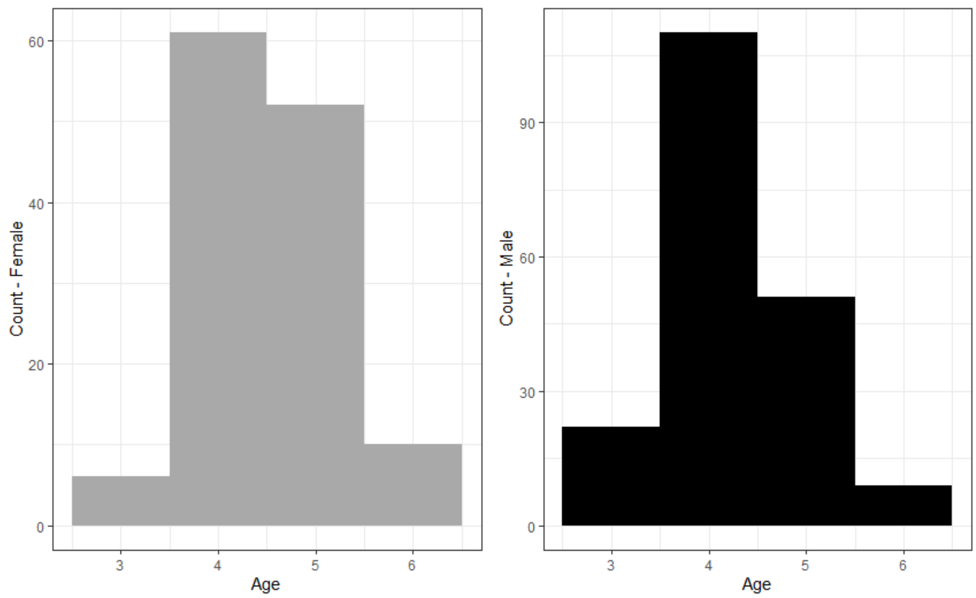

Figure 5 Distribution of age of (A) female (n=128) and (B) male (n=193) Alewife sampled from 4 river systems within the Isthmus of Chignecto.

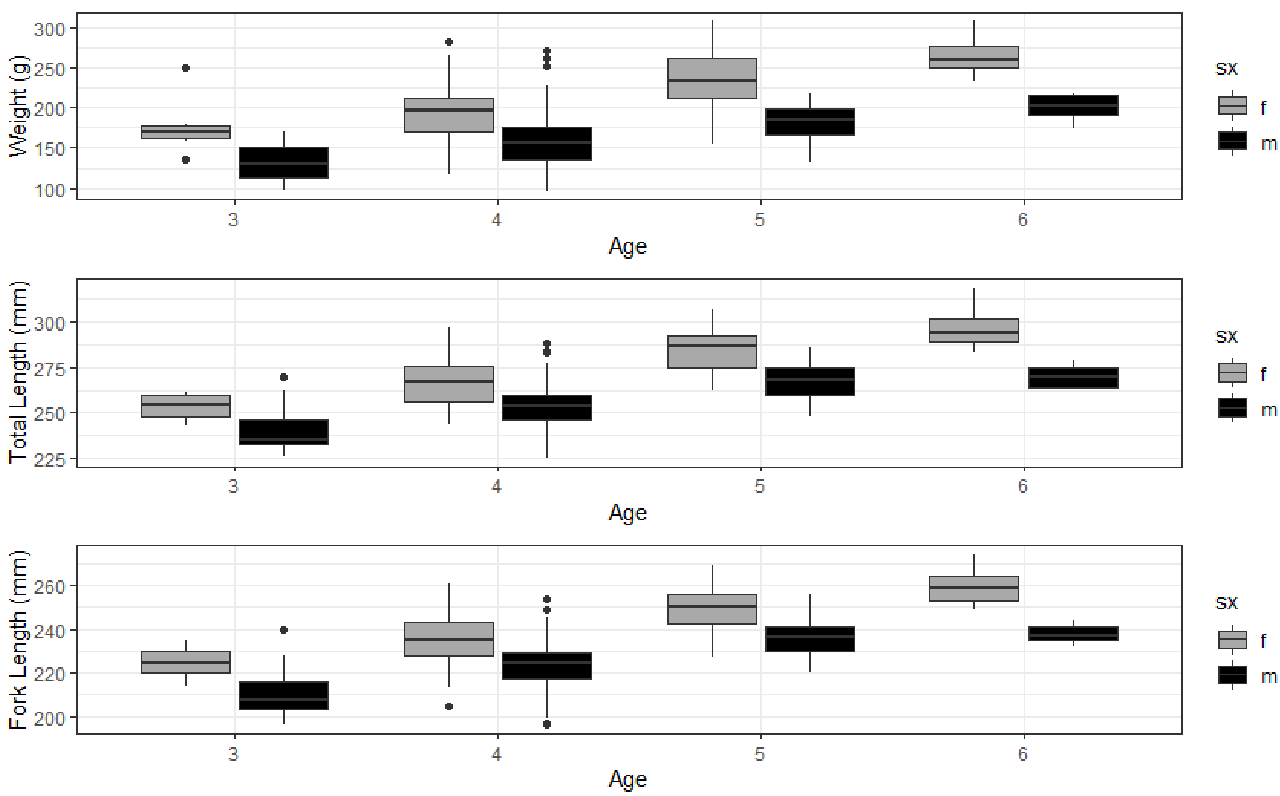

Figure 6 Weight (g), total length (mm) and fork length (mm) plotted for each determined age for both male (n=193) and females (n=128), values are recorded as mean and standard deviation.

3.3 Virgin Spawners

Most Alewife spawned for the first time at age three or four, however both male and female Alewife had a larger proportion of first time spawners during the fourth year. Female Alewife spawned more frequently at the age of four, with 63.3% of all samples, compared to 53.4% of males spawning at age four. By age five, all fish sampled had spawned at least once. For the purpose of this analysis, it is assumed that once an Alewife spawns, it will continue to do so each subsequent year.

Table 1 Age at first spawning of Alewife expressed as a percentage of the total number of specimens examined per sex.

Sex	**Number Examined**	**Year of first spawning (%)**		
		III	**IV**	**V**
Male	193	44.6	53.4	2
Female	128	33.6	63.3	3.1
Undetermined	13	61.5	38.5	—

3.4 Fulton Condition Factor

Fulton condition factor was determined for each year, and each river system to determine any significant differences (Table 2). In this study, Fulton condition factor values were calculated for all fish, where the mean for all fish was 0.973 ±0.015 (mean ± SD), and the lowest and highest estimations were found to be 0.908 ±0.01 to 1.022 ±0.03 (mean ± SD) for the total of each year (Table 2). From 2016 to 2019, female Alewife (n=2485) had a mean condition factor of 1.017± 0.01 (mean ± SD), male Alewife (n=2908) had a mean condition factor of 0.982 ± 0.02 (mean ± SD). Females had a higher condition factor than males (one-way ANOVA, $F_{2,331}$=6.1, $p < 0.002$). There was no interaction between year of study and river on condition factor (two-way ANOVA, $F_{3,326}$=0.65, p= 0.58) but condition factor did vary across river (two-way ANOVA, $F_{3,328}$=58.8, $p<0.0001$).

Table 2: Comparison of the Fulton Type-Index of Condition (K) for each year of study, per site (LP = LaPlanche River, TM = Tantramar River, LC= LaCoupe River and MS= Missaquash), values are recorded as mean and standard deviation.

Year	K (total)	K (per site)			
		LP	TR	LC	MS
2013	0.908 ±0.01	0.893 ±0.01	0.871 ±0.001	0.908 ±0.01	0.939 ±0.01
2014	0.967 ±0.01	0.974 ±0.01	—	0.915 ±0.01	0.998 ±0.01
2015	0.937 ±0.01	0.938 ±0.01	—	0.934 ±0.01	0.938 ±0.006
2016	1.007 ±0.001	1.018 ±0.01	—	0.967 ±0.01	1.024 ±0.001
2017	0.979 ±0.01	0.949 ±0.01	—	0.952 ±0.01	1.004 ±0.04
2018	1.022 ±0.03	1.049 ±0.01	1.001 ±0.02	0.995 ±0.02	1.039 ±0.04
2019	0.989 ±0.01	0.981 ±0.01	0.982 ±0.01	0.977 ±0.02	1.006 ±0.01
All	0.973 ±0.015	0.967 ±0.01	0.970 ±0.01	0.946 ±0.01	0.998 ±0.02

3.5 Variance in Biological Characteristics

For all Alewife sampled from 2016 to 2019, biological characteristics were compared by year and sex (*n*=5608). Field technicians who collected Alewife data before 2016 failed to reach a confident determination of sex during the tagging process, this information was therefore excluded for the purpose of this analysis. Using Fulton's Condition Factor, the total length, fork length and weight measurements of the subset of Alewife were compared to determine any significant differences (each variable was subject to a slight yet consistently increase in each year sample year). Over four years, the mean values of these characteristics have increased from 229 mm ±15.8 to 238 mm ±14.8 for fork length, 261 mm ±17.9 to 270 mm ±17.0 for total length and weigh from 183 grams ± 42.0 to 197 grams ± 40.7.

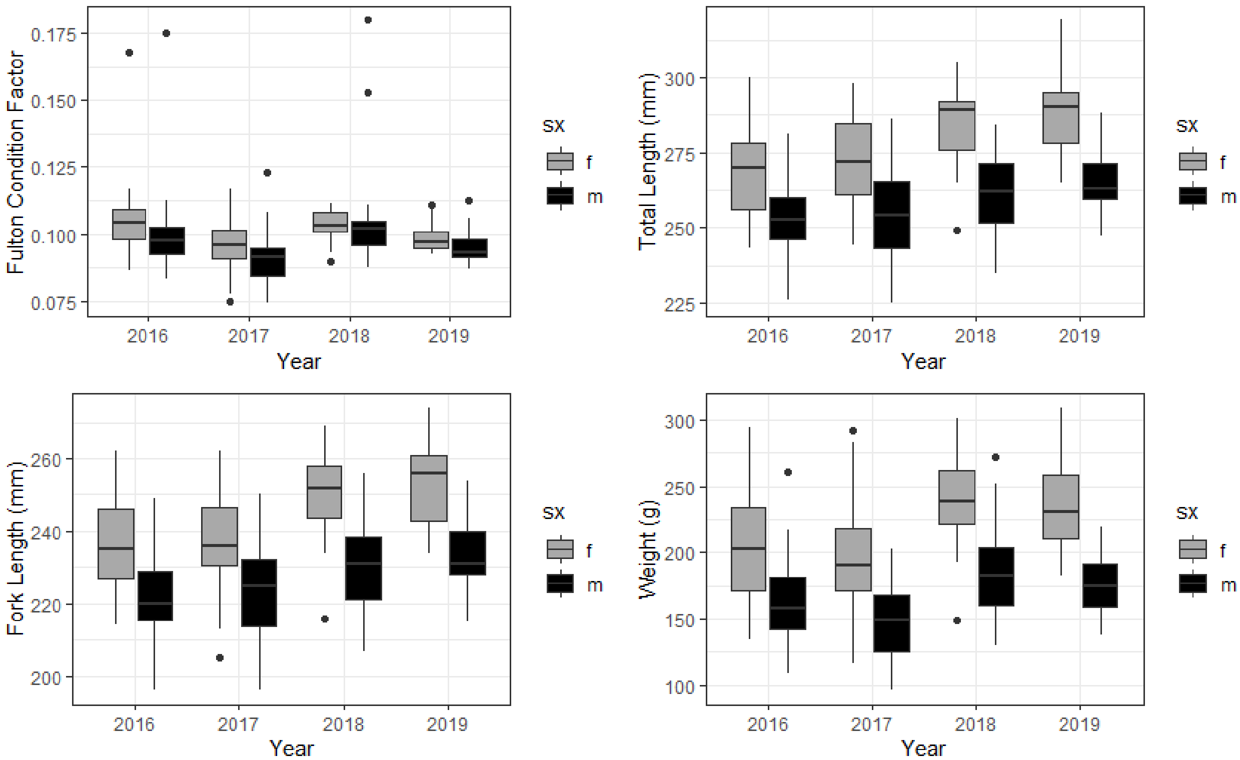

Figure 7 Biological characteristics (Condition Factor, Total Length, Fork Length and Weight) by year from 2016 to 2019, for both sexes (n =5608), values are recorded as mean and standard deviation

There was an interaction between sample year and sex on condition factor (two-way ANOVA, $F_{2,328}$=3.209, p= 0.04). There was no interaction between sample year and sex on total length (two-way ANOVA, $F_{2,328}$=1.148, p= 0.319) but total length did increase with time (two-way ANOVA, $F_{2,328}$=56.2, p<0.0001) and females grew to have a longer total length than males (two-way ANOVA, $F_{2,328}$=76.0, p<0.0001). Similarly, there was no interaction between sample year and sex on fork length (two-way ANOVA, $F_{2,328}$=1.044, p= 0.353) but fork length increased with time (two-way ANOVA, $F_{2,328}$=52.4, p<0.0001) and females grew to have longer fork length compared to males (two-way ANOVA, $F_{2,328}$=69.8, p<0.0001). Lastly, there was no interaction between sample year and sex on weight (two-way ANOVA, $F_{2,328}$=1.05, p= 0.351) however similar to total length and total length, weight did increase each year (two-way ANOVA, $F_{2,328}$=34.79, p<0.0001) and females grew to be heavier than males (two-way ANOVA, $F_{2,328}$=81.49, p<0.0001).

4 Discussion

4.1 Length-Weight Relationship

Both fork length and weight are reliable indicators of growth patterns and were closely correlated with total length with the exception of outliers. The outliers (fish that had a difference between fork length and total length of less than 15 mm or more than 50 mm) can be attributed to inaccurate measurements in the field and were excluded in determining the mean and range of the data above. To determine growth patterns, length-weight relationships are generally more biologically relevant than age, because several ecological and physiological factors are more size-dependent than age-dependent (Rosli & Isa, 2012). As one of the most common parameters in fisheries research, the length-weight relationship is typically used in conjunction with Fulton's condition factor to validate results of length-weight relationships and growth rates.

Comparisons between sex and biological characteristics revealed that female Alewife are bigger than male Alewife when considering the parameters of length and weight. The gaps of mean weight and length between males and females increased over time between the ages of 3 to 6; this information is consistent to the results found in Lake Michigan (Madenjian, Holuszko, & Desorcie, 2003)

4.2 Age

The mean age of both males and females was four ± two, this is also the mode of all samples collected. This is comparable to other studies that have reviewed age for Alewife populations, those sampled within the border region and regions of Connecticut had the same mean age of four (Davis & Schultz, 2009; Marcy, 1961). As age increases, female Alewife reached a larger size than males at a consistent growth rate per year (Figure 6), despite female Alewife requiring a higher energy input per offspring (Pauly, 2019). This confirms previous anecdotal observations that females are generally larger than males when controlling for age. Though both males and females spend most of their energy on movement and other activities, some authors believe that females are less likely to interact with other males compared to their male counterparts (Carbonara & Follesa, 2019). Similarly, male fish are found to exert energy during the process of courtship while females do not, allowing females to conserve energy and resources and grow bigger than males (Barneche, Robertson, White, & Marshall, 2018; Koch & Wieser, 1983).

4.3 Ageing Accuracy

The method for aging described by Marcy (1961) was used for processing the Alewife scales. As mentioned above, this method involved counting annuli and spawning marks for each scale and adding a year for the scale edge to account for the current year. While this method is useful for short -lived fish such as Alewife, it becomes increasingly difficult for long-lived fish species because the distance between the markings becomes increasingly smaller, resulting in indistinguishable annuli. Methods to age long-lived fish species include age determination by otoliths, spines and vertebrae (Carbonara & Follesa, 2019).

Issues with accurate age estimations have been reported by researchers in studies such as (Carbonara & Follesa, 2019) however there have also been multiple studies that validate this process (Davis & Schultz, 2009; Judy, 1961; Marcy, 1961; Stewart et al., 2015). Scales are also subject to regeneration or loss which would result in a scale that cannot be used for age determination. Spawning marks are often difficult to interpret when the scale has been eroded or the mark occurred in close proximity to the annuli, in which case the absorption could take place over the previous marking (Marcy, 1961).

Though the reader was confident during the age assessment using the scales, it is essential to include a coefficient of variance of age determination between the first reader and a second reader. Due to the current circumstances of the COVID-19 pandemic, this data was unavailable for this study but must be included in future studies to increase validity of the results.

4.4 Growth

Fulton's Condition Factor was used for the determination of health of Alewife. When this factor was compared for the four river systems, each year there were only slight differences for the total of each year, with no significant differences based on overlap of values (Table 2). The mean condition calculated for Alewife within the Inner Bay of Fundy for fish ages 3 to 6, are smaller, yet comparable to those calculated within Lake Michigan from 1984 to 2001, where the mean condition factors per year ranged from 0.70 to 0.87 (Madenjian et al., 2003). Several years of data are missing for the Tantramar River because this river system was not included for four consecutive years of the study. Between 2013 and 2019, there has been the most significant increase between the value at Tantramar River to the value obtained in 2018 however with missing data, there is no method to evaluate the change further. While observing the Tantramar river system, illegal fishing activity using gill nets was recorded each year, removing thousands of Alewife from this system each day during the spawning run. The impact of the illegal fishery lead to the anecdotal observation that fish size is smaller due to the fish selectivity that takes places at the mouth of the Inner Bay of Fundy. This observation is confirmed by comparing the condition factor of the fish within this system to the next. To confirm the impact on fishing selectivity, future research should review the limits of fishing selectivity and how this can be restricted by fisheries management. Overall, the mechanisms that could be influencing the slight increase in condition factor for all samples could include the changes in growth patterns and the portion of the spawning run being sampled.

4.5 Temporal Shift in Biological Characteristics

From 2016 to 2019, the temporal shifts in fork length, total length and weight indicated significant variation observed over four years of repeated sampling (two-way ANOVA, $F=38.6_1$, $p>0.481$; $F=37.0_1$, $p<0.695$; $F=23.6_1$, $P<0.0000018$, respectively). These shifts in demography and life history are consistent with those observed in Alewife populations in Connecticut (Davis & Schultz, 2009). The composition and life history traits of fish populations are crucial for management applications. While these results from Alewife in the border region reveal a slight temporal shift, it is important to note that these changes may result from anthropogenic factors such as anthropogenic barriers preventing previous spawning runs, instead of the natural factors indicated in the Connecticut systems. Other mechanisms that could influence the increase of growth rates over time include changes in growth in growth patterns and the portion of the spawning run being sampled, and the portion of males and females sampled.

In addition to the three biological characteristics mentioned above, condition factor was also analyzed over the four years by sex. From 2016 to 2019, there was a slight decrease in the mean condition factor (0.1007 ±0.01 in 2016 to 0.097 9±0.01 in 2019). Interestingly, this analysis revealed that female Alewife have a slightly higher condition factor when compared to male fish which could be attributed to their fork and total length measurements and larger body mass. Female Alewife carry upwards of thousands of eggs, which causes them to have a larger body mass. Females have are less likely to part take in spawning conflicts, typically spawn later than males and use less energy during courtship giving them the ability to reach a larger size compared to males (Carbonara & Follesa, 2019). The sexual dimorphic growth patterns observed suggest that separate growth relationships should be considered for males and females. One other study revealed a similar trend of increasing growth and condition of Alewife which was initially assumed to be connected to the availability of large-bodied invertebrates, which are an important regulator of adult Alewife growth (Madenjian et al., 2003). To understand the mechanisms influencing Alewife growth, studies should include information of food resource availability, including macro-invertebrate surveys and stomach content analysis within the freshwater systems.

4.6 Research Recommendations

Research is one of the most important tools that will highlight the important shifts necessary to improve current Alewife populations within the Maritimes. In regions where information on biological characteristics of the spawning populations is available, determining biological reference points should be one of the main research objectives. Based on biological characteristics and characteristics of the fishery, references points are used to gauge whether or not specific management objectives are being achieved, and to connect stock assessments with management objectives (Gibson & Myers, 2003). Additionally, reference points provide a basis for risk analysis of management actions, which becomes essential information as the abundance of Alewife populations continue to decline(Gibson & Myers, 2003). For these reasons, biological reference point estimations are crucial in determine stock health and fishery status. Estimated carrying-capacity of Alewife populations can also be improved with new information (Gibson et al., 2017; Gibson & Myers, 2004). Existing stock assessments, carrying-capacities, spawning-recruit parameters and the resulting production reference models should be updated to our improve understanding on the population within regions. In addition to growth rates, age and sex ratios, future research should include population abundance estimates and fishing mortality rates. Overall, future work on biological characteristics, growth rates and age can help determine reference points and stock status zones which will influence harvest strategies and harvest decision rules.

5.0 Conclusion

Alewife play a significant role in aquatic ecosystems and Maritime communities, contributing, environmentally, economically and culturally though the status of river herring in this area has not been regularly assessed. When biological characteristics are determined, biological reference points can be created to influence changes in fisheries management and the subsequent conservation efforts. From this study, the relationship between length and weight indicated that females grow at a faster rate and are therefore larger than male Alewife. The determination of age revealed that the distribution of ages per sex during the spawning run was similar, with both sexes having a mean age of four. The average proportion of virgin spawners occurred at the age of four for both sexes, yet some fish spawned for the first time at three years old. The variation in Fulton's condition factor revealed that there is little difference in health for Alewife across the sample years and the four river systems.

This information will lead to the development of an on-going monitoring and assessment program, which will provide an overview of the population framework. With such a framework, monitoring methods, analytical methods as well as research recommendations can be informed. Eventually leading towards the development of stronger legislation and comprehensive stock assessments which will establish a carrying-capacity for this region. Overall, once the goal of stronger legislation and proper stock assessments is achieved, it will work to create a sustainable Alewife fishery while meeting the needs of both recreational and commercial fisheries. From the determination of these biological characteristics, additional changes can be made to mitigate the detrimental effects of selective fisheries and anthropogenic structures. Ultimately, this can help us understand the causal mechanisms of annual spawning runs for Alosids, such as growth rates, age and size at maturity, time of spawning and morphology.

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