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Maritimes Region

River Herring Assessment for the Tusket River, Nova Scotia

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

This document provides information related to escapement, biological characteristics, commercial fisheries landings, estimated exploitation rates and total mortality of Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*), as well as status of Alewife relative to reference points for the Tusket River, Yarmouth County, Nova Scotia. It is the first comprehensive assessment completed by Fisheries and Oceans Canada for river herring in any river in Southwest Nova Scotia.

Similar to sympatric populations in other rivers, Alewife in the Tusket River are larger for a given sex, length or age than Blueback Herring. Both populations predominantly matured at age 4 and contained a relatively large proportion of repeat spawners. Alewife made up the majority of the returns, with escapement estimates in the vicinity of 1.7 million fish in 2014 and 2.2 million fish in 2015, while Blueback Herring escapement estimates were in the vicinity of 0.5 million in 2014 and 0.2 million in 2015. In terms of commercial landings, approximately equal proportions were taken by the dip net and set gill net components of the fishery in 2014, but not in 2015. After accounting for reporting rates, total landings of Alewife were estimated to range from 2.7 to 2.9 million fish in 2014 and 2.5 to 2.6 million in 2015. Blueback landing estimates were sensitive to assumed transit times from the estuary to the fishway at Lake Vaughan. Catch curve analyses in both years indicated total instantaneous mortality rates of > 1.1 for Alewife and < 1 for Blueback Herring. This is consistent with reduced exploitation on blueback due to run timing relative to the commercial fishing season. Status of Alewife relative to the reference points derived in the assessment framework indicated that spawning escapement was low (critical or cautious zones) and fishing exploitation rates were either in the fully exploited category or above the removal reference level (overexploited). The escapement reference points were sensitive to the amount of habitat assumed to be accessible above the Vaughan Dam. The removal reference points remain unchanged regardless of the river being assessed. Several sources of uncertainty and their effect on conclusions were evaluated, and short-term as well as long-term research and monitoring goals were identified that would improve the assessment if it continued in future years.

Évaluation du gaspareau de la rivière Tusket en Nouvelle-Écosse

RÉSUMÉ

Ce document fournit des renseignements concernant les échappées, les caractéristiques biologiques, les débarquements de la pêche commerciale, les taux d'exploitation estimés et la mortalité totale du gaspareau (*Alosa psuedoharengus*) et de l'alose d'été (*Alosa aestivalis*), ainsi que le statut du gaspareau par rapport aux points de référence de la rivière Tusket, dans le comté de Yarmouth en Nouvelle-Écosse. Il s'agit de la première évaluation exhaustive du gaspareau effectuée par Pêches et Océans Canada dans toutes les rivières du sud-ouest de la Nouvelle-Écosse.

Comme c'est le cas des populations sympatriques d'autres rivières, les gaspareaux de la rivière Tusket sont plus grands que les aloses d'été pour chaque sexe, longueur et âge donnés. Les deux populations sont, en grande partie, devenus matures à 4 ans et comptaient une grande proportion de reproducteurs multifrais. Le gaspareau représentait la majorité des retours, avec des estimations des échappées aux environs de 1,7 million de poissons en 2014 et de 2,2 millions de poissons en 2015; alors que les estimations d'échappées de l'alose d'été étaient d'environ 0,5 million en 2014 et 0,2 million en 2015. En ce qui concerne les débarquements commerciaux, des proportions presque égales ont été prises par épuisette et éléments de filet maillant installés pour la pêche en 2014, mais pas en 2015. Après avoir tenu compte des taux de déclaration, les débarquements totaux pour le gaspareau ont été estimés entre 2,7 et 2,9 millions de poissons en 2014 et entre 2,5 et 2,6 millions en 2015. Les estimations des débarquements de l'alose d'été étaient sensibles au moment de transit présumé entre l'estuaire et la passe migratoire du lac Vaughan. Au cours des deux années, les analyses de la courbe des prises ont indiqué des taux instantanés de mortalité de > 1,1 pour le gaspareau et de < 1 pour l'alose d'été. Ces taux sont cohérents avec l'exploitation réduite de l'alose d'été en raison de la période de montaison liée à la saison de la pêche commerciale. Le statut du gaspareau, par rapport aux points de références établis dans le cadre d'évaluation, a indiqué que l'échappée de géniteurs était basse (zones critiques ou zones de prudence) et que les taux d'exploitation de la pêche se trouvaient soit au maximum, soit supérieurs au niveau d'exploitation de référence (surexploités). Les points de référence concernant l'échappée étaient sensibles à la quantité d'habitats supposés accessibles en aval du barrage Vaughan. Les points de référence de prélèvement demeurent les mêmes, peu importe la rivière évaluée. De nombreuses sources d'incertitude et leurs répercussions sur les conclusions ont été évaluées et des objectifs de recherche et de surveillance à court et à long terme ont été déterminés. Ils permettraient d'améliorer l'évaluation si elle persiste dans les années à venir.

INTRODUCTION

Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*) are diadromous species that are collectively referred to as river herring and are indigenous to the majority of rivers in Atlantic Canada to the southeastern United States. Although the marine distributions of the two species overlap, Blueback Herring have a larger and more southerly range (Nova Scotia to Florida) than Alewife (Labrador to South Carolina) (Loesch 1978, Bozeman and Van Den Avyle 1989). Adults exhibit homing behaviour similar to Atlantic salmon when returning to spawn, so each river is thought to contain a distinct population (McBride et al. 2014, Palkovacs et al. 2013). Adult river herring migrate up coastal rivers in the spring (late March to mid-June) for spawning. In general, Alewife will start returning several weeks before Blueback Herring in rivers with sympatric populations. Both species are iteroparous and recruit to the spawning stock over multiple years, with some returning for the first time at age 3 and virtually all having returned by age 5 (DFO 2001). Spawning runs are thought to be structured by age, with older and larger individuals returning first and smaller first-time spawners coming later in the run.

The river herring fishery is relatively unique in terms of the number of participants, the diversity of licenced gears and its geographic extent. Due to the difficulties in distinguishing between Alewife and Blueback Herring, they are harvested together in rivers or estuarine fisheries where sympatric populations exist. Colloquially, both species are called gaspereau, razorbacks, or kiacks. Most river herring are sold fresh for bait, or are salted for human consumption. In rivers within the Yarmouth and Shelburne counties of Nova Scotia, two types of gear are predominantly fished: set gill nets in estuaries and dip nets in shallower running water.

The river herring fishery is managed through effort controls, with general restrictions on gear deployment and types, seasons and daily open/close times. Variations from the general closures or restrictions are instituted on a river-by-river basis. As such, season length as well as daily open/close times varies among river systems. Beginning in the late-1980s, logbooks have been issued to fishers in rivers located throughout the Bay of Fundy and the Atlantic coast of Nova Scotia to record catch and effort information on a river-specific basis (DFO 2001).

There has been very little previous assessment of river herring populations throughout the Atlantic coast of Nova Scotia. The historical objective for rivers or regions in which there was no specific biological or fisheries information, was to maintain harvests at or above long-term mean levels (DFO 2001). Relative to the Tusket River, harvests by Fishery Statistical District (FSD; Figure 1) were reported from 1960 to 1999 in DFO (2001) for FSD 33 and 34. The long-term mean harvest was 331 t. It is unknown what proportion of that would have come from the Tusket River.

An advisory process, entitled ‘Maritimes Region River Herring Framework and Case Study Application to the Tusket River Fishery’ was held February 10-11, 2016. Of the five Terms of Reference developed for the meeting, this document addresses the following one:

- Evaluate the data collection and assessment methods as applied to the Alewife and Blueback Herring populations in the Tusket River and the resulting determination of their status.

The other four TORs are addressed in an associated Research Document, entitled ‘A Framework for the Assessment of the Status of River Herring Populations and Fisheries in DFO’s Maritimes Region’ by Gibson et al. (2016).

This document represents the first assessment by Fisheries and Oceans Canada for river herring in the Tusket River. It includes landings information, escapement and biological characteristics for Alewife and Blueback Herring, and applies the assessment framework developed in the associated Research Document to determine the status of its Alewife population.

ESCAPEMENT

Video data, collected at the top of the Vaughan fish ladder by Nova Scotia Power Inc., was used to estimate escapement. This ladder is located immediately upstream of all commercial fishing activity in the river and opens directly into Lake Vaughan reservoir (Figure 2). In 2014, the camera was recording from 5:00 until 21:00. In response to accounts from commercial fishermen that a substantial proportion of their catches arrive from early afternoon until approximately 2:00 am, video was captured 24 hours per day in 2015. Similar to other monitoring programs in Nova Scotia, video was captured in 15-minute blocks (e.g. Davies et al. 2007).

To estimate total escapement, video was sub-sampled using a two-way stratified design (e.g. Nelson 2006), rather than a one-way stratification that has been used previously on other rivers in the Maritimes (e.g. Davies et al. 2007). Each day was divided into 4 (2014) or 6 (2015) strata corresponding to the morning, early afternoon, late afternoon, and evening (2014 and 2015), as well as late evening and early morning (2015 only; Table 1). Within each stratum, 5-minute blocks of video were counted in order to increase temporal coverage, as opposed to counting the 15-minute blocks captured. Between 4 (2015 only) and 8 blocks of video could be counted per strata, giving a total of 100 to 240 minutes of video watched from each day of the run. This is a high level of daily coverage relative to other sampling designs (Nelson 2006, Davies et al. 2007). The specific 5-minute time blocks counted in each stratum (for each day and year) were chosen randomly from the total number of 15-minute increments available to count.

From the sampling design, total escapement becomes the sum of the estimated daily escapements, weighted by sampling effort in each strata (Nelson 2006). The mean number of river herring per time unit in each strata (*s*) of each day (*k*) is:

$$\hat{\bar{y}}_{k,s} = \frac{\sum_{i=1}^{n_{k,s}} y_{k,s,i}}{n_{k,s}}$$

Where $\hat{\bar{y}}_{k,s}$ is the mean, $y_{k,s,i}$ is the i^{th} count during strata (s) and $n_{k,s}$ is the number of time blocks sampled during strata *s* on day *k*. The total run size ($\hat{Y}$) becomes:

$$\hat{Y} = \sum_{k=1}^{L} \sum_{s=1}^{S} N_{k,s} \hat{\bar{y}}_{k,s}$$

Where *L* is the number of days of the run, *S* is the total number of strata during each day *k* and $N_{k,s}$ is the total number of time blocks during each strata *s*.

The variance on the total is estimated as:

$$var(\hat{Y}) = \sum_{k=1}^{L} \sum_{s=1}^{S} N_{k,s} \left(N_{k,s} - n_{k,s}\right) \frac{\hat{s}_{k,s}^2}{n_{k,s}}$$

Where:

$$\hat{s}_{k,s}^2 = \frac{\sum_{i=1}^{n_{k,s}} (y_{k,s,i} - \hat{\bar{y}}_{k,s})^2}{n_{k,s} - 1}$$

This is a weighted estimate of the within-stratum variance. Because the number of blocks in each strata as well as the number counted in each were not the same, calculating the degrees of freedom for the confidence intervals is done as:

$$\widehat{df} = \frac{(\sum_{s=1}^{L} a_s\, \hat{s}_s^2)^2}{\left(\sum_{s=1}^{L} \frac{(a_s \hat{s}_s^2)^2}{n_s - 1}\right)}$$

Where *a* is:

$$a_s = \frac{N_s(N_s - n_s)}{n_s}$$

The confidence intervals on the total estimate become:

$$\hat{Y} \pm t_{\alpha/2}\sqrt{var(\hat{Y})}$$

Where 0.05 was used as the critical value of α and the corresponding value for *t* was from the two-tailed *t*-distribution at the estimated degrees of freedom. On the total estimate of the run size, the *df* = 504 in 2014 and *df* = 333 in 2015. On the daily estimates for both years, the degrees of freedom varied and gave slightly larger confidence intervals around daily estimates when low (Figure 3).

ESTIMATES FOR 2014 AND 2015

In 2014, non-zero counts of river herring were observed in at least one of the sampled blocks beginning on April 13th and ending on June 28th. This gives an estimate of 72 days for the length of the run. Although quite variable, appreciable numbers of river herring arrived at the Vaughan ladder in the last week of April, increased to a peak on May 18th, sharply declined on May 29th and remained relatively high until June 11th (Figure 3). This later increase was associated with appreciable numbers of Blueback Herring entering the river (see below). The total escapement estimate was 2,122,525 individuals (95% CI = 2,063,268; 2,181,782), 75% of which were Alewife (see below; Table 2).

In 2015, the river herring run was later to arrive, with non-zero counts beginning on April 30th. The run was essentially over by June 18th (49 days), with extremely low numbers of fish being estimated from June 19th to June 24th (Figure 3). High daily counts began on the 5th of May, peaked on May 14th and the gradually declined until the end of the run. Blueback Herring were also slightly later to arrive in 2015 than 2014 (see below) and did not lead to a distinct second pulse in daily escapements as in 2014. The total escapement estimate was higher in 2015 than 2014, at 2,517,215 (95% CI = 2,450,471; 2,583,960), 92% of which were Alewife (see below; Table 2).

SOURCES OF UNCERTAINTY

Video Counting

The location for video monitoring at the Vaughan fishway is at the outflow of the last bucket that fish ascend prior to entering Lake Vaughan. The water along the bottom of the image is turbulent and the potential for dark spaces in the image increases with the amount of water flow through the fishway. This placement also means that fish are enumerated as they are burst swimming and fighting the current, which leads to a relatively large number of fish moving down as opposed to up on the image, as well as multiple unsuccessful attempts to ascend into the final bucket (where fish only move half-way up the image before falling back down). While watching a 5-minute block of video, counters kept track of the number of fish ascending, as well as the number descending. For some days, as well as some times in days, the number of fish descending was substantial, and in some cases led to negative counts for a block (H. Bowlby, personal observation). For example, a count of 12 could represent a block where only 12 fish were seen or could represent 87 individuals ascending and 75 descending for a net gain of 12.

The dates during which the fallback was observed on the video (occuring throughout the entire run), the relatively small amount of flow through the fishway as compared to that spilled over Vaughan dam (where fish are attracted to the dominant flow), as well as the placement of the camera in the last bucket of the fishway (as opposed to in a location with laminar flow), all suggest that the fish moving downstream in the video are fatigued yet actively attempting to ascend the ladder, as opposed to being post-spawning fish moving downstream on their outward migration.

It would be expected that fallback, as well as extremely large numbers of fish moving within a 5-minute time block would lead to imprecision in the counts. This source of variability was estimated by comparing counts between two individual people observing identical time blocks of video collected in 2015. Overall agreement between counts of individual blocks was high, and there did not seem to be the tendency for one person to report systematically lower (or higher) numbers as compared to the other (Figure 4). A linear regression explained 98% of the variability in the data, with a very low estimated standard error (0.00359) on the relationship.

The escapement estimates reported above had narrow confidence intervals, which were somewhat expected given how the two-way random stratification scheme reduces estimated total variance relative to simple random sampling (Nelson 2006). However, the small discrepancies between individual people counting a given block of video suggest that this variance is slightly underestimated. Either redesigning the video monitoring system or developing a method by which to incorporate counting imprecision the escapement estimates would be a topic for future research.

Diel Patterns

When estimating escapement in 2014, counts in strata 4 (16:30 to 21:00) remained consistently high, indicating that the daily run had not declined by 21:00 hours (i.e. substantial numbers of fish were still ascending the ladder). This meant that a proportion of the population was ascending the ladder after the camera stopped recording for the day. Therefore, it was likely that the escapement estimate in 2014 represented a partial rather than a total population estimate. Discussion with the commercial fishermen at the Zonal Management Advisory Committee (ZMAC) meeting in 2015 indicated that a non-negligible proportion of their daily catches occurred after 21:00 until approximately 2:00 the next morning, so it was plausible that fish would also take the ladder in substantial numbers at night.

To estimate the proportion of the run in 2015 that returned at night, we calculated the daily proportion of the weighted escapement estimates that occurred in strata 1 and 6 (i.e. the 2 new strata) and then multiplied this by the total daily escapement estimate. Overall, 11.1% of the run in 2015 (314,103 individuals; 95% CI = 236,250; 391,956) ascended the ladder in the 2 new strata. If this proportion is representative, it would increase the escapement estimate from 2014 to 2,358,125 (95% CI = 2,292,291; 2,423,960) fish (Table 2).

BIOLOGICAL CHARACTERISTICS

Sampling for biological characteristics took place at the Vaughan fish ladder on the Tusket River, at the same site used to estimate escapement. Site access was granted through a collaborative agreement with Nova Scotia Power Inc. for a field crew of 2. Sampling took place over 3 hours (typically from 16:15 to 19:15) on each consecutive day throughout the run, ending when there were too few fish in the ladder to sample. Sampling was done during the peak of the daily run, since comparison with the video indicated that late afternoon and early evening was when most fish ascended the ladder. For a daily sample of 100, fish were captured from the fish ladder using a commercial dip net, measured for fork length, identified to species and sex, and had a scale sample taken. The first 10 fish of each species captured each day were also weighed prior to release into Lake Vaughan. Extremely low mortality rates were associated with sampling, < 10 fish for each of the 2 years. In 2014, sampling began on of April 22nd and ended on June 21st. The run was later to arrive in 2015, with sufficient numbers arriving on May 4th, but sampling ended at a similar time, on June 24th.

SPECIES IDENTIFICATION

The majority of species identification was done visually, and were based on eye diameter relative to snout length. At the beginning of the Blueback Herring run each year, several fish were sacrificed to ensure that the visual identification matched the species identification based on peritoneal colour (where it is light for Alewife and dark in Blueback Herring; Scott and Crossman 1973). For visual identification, several additional characteristics were considered, such as the ease of scale removal (greater for Blueback Herring), overall size, depth of the median notch in the upper jaw (greater for Blueback Herring) (Scott and Crossman 1973) and scales patterns on the caudal peduncle (where Blueback Herring in this population seemed to have scales extending onto the tail, while Alewife did not). Based on the estimated daily proportion of each species, the Alewife population arrived at the Vaughan fish ladder 4-5 weeks before the blueback population (Figure 5) and made up 75% of the total returns in 2014 and 92% in 2015 (Figure 5; Table 2).

LENGTH AND WEIGHT

To ensure that biological characteristics were representative of the population, daily biological samples were weighted by daily escapement estimates prior to: (1) calculating mean lengths and weights, and (2) sub-sampling for age determination (see below).

Females of both species were slightly larger than males, and alewives were slightly larger than Blueback Herring. For Alewife, females averaged 25.3 and 25.2 cm fork length and 235 and 205 grams in 2014 and 2015, respectively, while males averaged 24.3 and 24.1 cm fork length and 199 and 180 grams in 2014 and 2015, respectively (Table 3; Figure 6; Figure 7). Blueback Herring were substantially smaller on average than Alewife in 2014 and 2015, with females being 22.9 cm in both years and 158 and 147 grams, respectively, and males measuring 21.9 and 22.2 cm and weighing 137 and 132 grams, respectively (Table 3; Figure 6; Figure 7). Given the consistency of the length distribution among years, it was surprising that the weight estimates differed with 2015 being consistently lower than 2014. In 2015, there were problems with the balance used in 2014, leading to missing data as well as a different and less accurate balance being used. It is likely that the difference in weights is a sampling artifact, and thus, values from 2014 are considered to be more representative of the mean weights of the populations.

Combining all data collected from 2014 and 2015, there was evidence that larger individuals (in terms of length) tended to return at the beginning of their respective runs. Based on linear regression of length predicted by Julian day (where values were weighted by the daily escapement estimate), all slope estimates were negative for both sexes and species (Figure 8). Estimated growth from a linear regression of log(weight) predicted by log(fork length) using data collected in 2014 gave slope estimates of approximately 3 (Figure 9). This conforms well to the established expectations of a cubic relationship between length and weight (Ricker 1975) and suggests that river herring do not substantially change in body shape as they grow.

AGE DISTRIBUTION

Age determination was done from the scale samples (e.g. Macy 1969, O'Neil 1980) taken during biological sampling, with a goal of aging approximately 350 samples per year from Alewife and 200 from blueback. These samples were chosen assuming a fixed proportion in 2014 (i.e. taking 0.4% of the daily run size as the number of samples from a given day), but were chosen randomly in 2015 (i.e. sampling without replacement where the probability of choosing a sample from a specific day was weighted in proportion to the species-specific run size in that day).

The total age was determined by counting the number of annuli (also called winter rings) and adding one year for the scale edge for virgin fish, or counting annuli plus the number of spawning marks (indicated by distinct erosion along the exposed margin of the scale) and adding one year for repeat-spawning fish (Macy 1969, O'Neil 1980). Scale erosion can occur from entry into freshwater environments or as a response to other environmental stressors, which would affect the interpretation of indices of previous spawning as determined from scale samples. Here, we were primarily concerned with the number of times an individual may have been exposed to the fishery, rather than its reproductive output *per se*. Therefore, even if immature or mature fish entered freshwater and did not spawn, any scale erosion would indicate that the fish had been exposed to the fishery in that year.

For Alewife, approximately half of the returning individuals were virgin 4 year-old fish (55% in 2014 and 43% in 2015, with lower proportions of virgin 3 year-olds and 5 year-olds in each year. Overall, first-time spawners made up 78% and 64% of the Alewife populations in 2014 and 2015 (Table 4). Individuals spawning for a second time made up 18% (2014) and 29% (2015) of the returns, while multiple repeat-spawners were a relatively small component (Table 4). However, in both years, the oldest individual observed was age 8 and had spawned 4 times.

Compared to Alewife, there was a larger proportion of virgin 3 year-olds in the Blueback Herring returns, estimated at 29% and 20% in 2014 and 2015, respectively, and a smaller proportion of virgin 5 year-olds, estimated at 4% in both years (Table 4). Overall, the proportion of first-time spawners in the population was lower than for Alewife (60% and 49% in 2014 and 2015, respectively), which is consistent with the population experiencing lower exploitation rates. The estimated proportions of second-time spawners were marginally higher than for Alewife (24% and 30% in 2014 and 2015, respectively). The maximum observed age was 7 as compared to 8 for Alewife, but the maximum number of repeat-spawnings was the same at 4 (Table 4).

Length and Weight at Age

Average fork length and weight of individual fish by age and previous spawning history are summarized in Table 5. In general, fish that had spawned multiple times were smaller for a given age, particularly in terms of weight. For example, the average weight of Alewife at age 4 was 213 grams for virgin fish and 199 grams for fish that had previously spawned. This likely represents an evolutionary trade-off between early maturation vs. overall body size and condition relative to reproductive output (Stearns and Koella 1986). Based on average lengths at age, river herring exhibited relatively little growth between spawning events, Blueback Herring in particular. This means that for a given length, fish of either species can be a variety of ages and previous spawning histories.

SOURCES OF UNCERTAINTY

Missing Days

In 2015, there was one day in June (June 18th) where escapement was not estimated as well as 3 days in the middle of June (June 11-13th) where biological sampling did not take place. The missing day for the video count was not expected to have much influence on the escapement estimate because it occurred at the very end of the run. The previous day's escapement estimate was 4650 fish, and the following day's escapement estimate was 169 fish. Conversely, the missed days for the biological sampling did have the potential to substantially change the proportion of the run composed of Blueback Herring, given that they occurred when the Blueback Herring run would have been expected to be strong. Given the differences in run timing among the two years, it was not possible to apply the previous year's proportions to the missing days.

The manner in which missing data are accounted for in assessments is largely subjective (Campbell 2015). Here we give one example of how the escapement estimates by species change when an attempt is made to account for missing information. Based on the data from 2014, the estimated proportion of Blueback Herring in the run reached a maximum of 0.91 and averaged 0.81 when the blueback run was the strongest. If these values are representative of the three days that were not sampled in 2015 (i.e. proportions of 0.81, 0.91 and 0.81 for June 11, 12 and 13, respectively), the estimated escapement of Blueback Herring increases by 101,552 fish. This has a relatively small effect on the total percentage of Alewife in the run (decreasing to 90% from 92%), but a much greater effect on the escapement estimate of Blueback Herring, increasing it by approximately 1/3 (Table 2).

Species Identification

In rivers that contain both Alewife and Blueback Herring populations, it is generally expected that the proportion of Alewife in the run will peak and then gradually drop off, such that the end of the run will be composed predominantly of bluebacks. On the Tusket River, the run did not seem to follow this pattern, in that it was composed of a large proportion of Alewife at the end in both 2014 and 2015 (Figure 10). Post-spawning fish moving back through the fishway would be one scenario that could cause such a pattern. However, as previously discussed relative to the escapement estimates, this is unlikely on the Tusket River and none of the biological data (lengths or ages) suggested that it was occurring. An alternate explanation could be errors in species identification; in particular, alewives being consistently mis-identified as bluebacks. We used two methods to evaluate potential errors in species identification: (1) a comparison of visual vs. scale sample identification for the Tusket River and (2) a comparison of visual vs. lethal species identification for the Saint John River at Mactaquac. Although from a different river, the program at Mactaquac relies on lethal sampling to determine species composition relative to escapement targets, thus the comparison with visual sampling could be done without the need to sacrifice additional fish.

Blueback scales have been found to be visually distinct from Alewife scales for sympatric populations (e.g. containing pigment below the baseline of the scale and having a more boxy shape; O'Neil 1980). On the Tusket River, very few animals that were visually identified as Alewife were later identified as bluebacks based on scale samples; 1% in 2014 and 5% in 2015 (Table 6). It is worth noting that apparent discrepancies in either size or age of individual fish tended to be resolved using the species identification from the scale sample. For example, two fish that were extremely large for male Blueback Herring (outside the range of the rest of the data) were well within the size range for male Alewife; they had been identified visually as bluebacks and as Alewife from scale samples.

In the first year of monitoring (2014), the higher rate of misidentification of Blueback Herring as Alewife (10%) resulted from the field crew being trained to identify Blueback Herring visually 5 days after their run had started (anecdotal information from life-long commercial fisherman Mil Nickerson). If samples collected only after the training were included, the misidentification rate of Blueback Herring as Alewife dropped to 7%. In 2015, misidentification rates of Blueback Herring as Alewife were substantially lower (2%; Table 6), likely owing to previous experience in species identification by the field crew.

Approximately 50 lethal samples are taken up to 3 times daily over the duration of the river herring run at Mactaquac dam on the Saint John River to estimate species composition (R. Beaumaster, pers. comm.). From these data, average misidentification rates of Alewife as Blueback Herring were 2% in 2014 and 7% in 2015, while average misidentification rates of blueback as Alewife were 7% in 2014 and 10% in 2015.

Overall, errors in species identification are relatively low and both methods indicated a general tendency to misidentify Blueback Herring as Alewife rather than the reverse. Although mis-identification contributes to the proportion of Alewife in the end of the run, the overall magnitude of misidentification biases would be small. Thus, it is likely that Alewife make up a sizeable component of the river herring run for its entire duration on the Tusket River.

COMMERCIAL FISHERY

On the Tusket River, the gill net component of the commercial fishery opens on the first Sunday of April and the dip net component opens 1 week later on the second Sunday of April. Both close on May 31st. Both types of gear may be fished for 24 hours for 4 days per week, but have different daily closed times. Presently, dip netters can be active from 8:00 Sunday to 8:00 Tuesday and again from 8:00 Wednesday to 8:00 Friday each week. Gill nets can be set from 8:00 Sunday to 8:00 Thursday. This means that 8:00 Friday until 8:00 Sunday are the two 24-hour periods in which no commercial fishing activity is permitted. There are currently no trap nets or drift gill nets fished on the Tusket River, although these gears have been reported sporadically prior to 2005. Relative to daily landings, the differences in management would provide an opportunity to compare gear efficiencies relative to the weekly close times for each component of the fishery. This remains a topic for future research.

LANDINGS

Annual landings were estimated from logbooks submitted by licence holders. These are designed for fishermen to record their location, gear type, gear amount as well as daily landings (in number or weight) and number of hours fished. On the Tusket River, the majority of the landings are sold piecemeal rather than by weight, so the majority of fishermen record their landings in numbers of fish. Throughout the Maritimes Region for the duration of the logbook program (1986 to 2015), landings have been archived by weight using an assumed conversion factor of 240 grams/fish.

From 1986 to 2008, logbook data were collected, managed and archived by personnel involved in the annual assessment. Beginning in 2009, data input has been carried out by dockside monitoring companies and logbook records have been archived by the Commercial Data Division at DFO. This switch created several issues when trying to develop a time series of commercial landings (Gibson et al. 2016), and estimates from the transition years between the two logbook programs, 2008 and 2009, are considered to be inaccurate and were excluded. The earliest years of logbook data collection (prior to 1993) represent a time when relatively few licences had been created and very few fishermen were reporting. Therefore, data from 1986 to 1992 were also excluded.

Time Series of Reported Landings

The previous regional assessment (DFO 2001) reported a time series of commercial landings by Statistical District for FSD 33 and 34 (representing landings primarily from the Tusket and Annis rivers), which was assessed relative to the average annual landings in FSD 33 and 34 from 1960 to 1999 (331 t). We did not extend the time series of landings by Statistical District to the present. Instead, we have included a time series of commercial landings developed from the logbook program for the Tusket and Annis rivers combined, as well as separate for each river. Reported annual landings in the Tusket and Annis rivers peaked in 1996 at 931 mt and has remained above 200 mt since 1992 with the exception of 2015 (Figure 11). Reported annual landings tend to be much larger on the Tusket River as compared to the Annis River (Table 7), with the exception of 2015 where they are nearly equivalent (Figure 12). Of the reported landings, approximately half comes from the dip net fishery and half from the gill net fishery on the Tusket River each year (Table 7).

Catch-Per-Unit-Effort

Fishing effort can be thought of relative to the number of participants (i.e. licence-holders) in the fishery, the amount of gear deployed, as well as the number of hours fished each day. Thus catch-per-unit-effort (CPUE) can be represented multiple ways. Here we have shown median total landings by license-holder from 1993 to 2015 (Figure 13) as well as CPUE in the units of kg/hour for dip nets and gill nets separately for the fishery in the Tusket River (Figure 14). These time series demonstrate relatively high variability and do not show evidence of marked changes over time.

Reported Landings in Numbers

For the purposes of calculating exploitation rates and population status, it was necessary to estimate commercial landings for 2014 and 2015 in numbers of fish rather than weight. Landings in weight by gear type in 2014 were 104.3 mt for set gill nets and 146.1 mt for dip nets for both species combined. Landings in weight by gear type in 2015 were 10.5 mt for set gill nets and 85.4 mt for dip nets for both species combined. The species composition data from the biological sampling at the Vaughan fish ladder (detailed above) was used to partition the landings into daily proportions of Alewife and Blueback Herring. The individual logbook records that were originally reported as numbers of fish (and would have been converted to kg upon data entry) were transformed back to numbers using the 240 grams/fish conversion factor. The records that were originally reported as weights (one record in 2014, two records in 2015) were transformed into numbers using the population-level mean weights estimated from the biological data for Alewife and Blueback Herring (methods detailed above). These values were 213 grams/fish for Alewife and 144 grams/fish for Blueback Herring.

Summing the landings by gear type for 2014 gave an estimated value in numbers of 585,419 alewives by dip nets and 424,723 by set gill nets. Estimated landings of Blueback Herring were much lower, at 23,369 individuals from dip nets and 19,000 from set gill nets (Table 8). Overall, Blueback Herring were estimated to be 3.8% of the total landings by dip nets and 4.3% of the total landings by set gill nets (average 4%). In 2015, total landings were much lower and consisted almost entirely of Alewife due to the run timing of Blueback Herring (see above). The estimated total landings were 361,538 alewives in dip nets and 40,108 alewives by set gill nets

(Table 8). Landings of Blueback Herring were negligible, estimated at 74 fish by dip nets. All of these values represent partial estimates because reporting rates in the logbook program are not 100%.

Reporting Rate

Submitting logbooks upon completion of the commercial fishing season was voluntary when the logbook program was originally developed. Reporting rates varied among years, regions, and individuals (DFO 2001). Although mandatory reporting was initiated in 2009 as a condition of license, compliance was not enforced. Therefore, total landings and effort estimated from logbook returns (1986 to 2007 and 2009 onwards) represent a proportion of the annual fishing activity taking place in the Tusket River. Ignoring the issue of non-reporting would lead to an underestimate of total landings by the fishery (e.g. Zeller et al. 2008). However, calculating annual reporting rates is not straightforward for this fishery because licenses that have no associated logbook records cannot be unambiguously assigned to a particular river or gear type.

There were a total of 115 unique license numbers reported as being fished in the Tusket River in at least one year from 1986 to 2015. For each individual fishing each license, we identified the location that was most commonly reported and used it to fill in the location for years with no logbook records. These assumptions were independently verified using lists submitted by the Tusket River Gaspereau Dip Netters Association and Tusket River Gaspereau Gill Netters Association to the Fisheries Protection Area Office which detailed the names of dip netters and gill netters who were fishing in a given year. These records were incomplete (2001, 2002, 2003, 2004, 2005 and 2009 for the gill netters; and 1994, 1998, 2000 and 2004-2015 for the dip netters) as they were never intended to be used or archived as data. However, they were invaluable in identifying individuals who were not fishing in a given year and thus helped prevent overestimation of unreported landings.

The number of license-holders that were assumed to fish predominantly in the Tusket River peaked at 87 in 1998 and slowly declined to 72 in 2015 (Figure 15). Note that these values would include individuals that were not actively fishing but who still maintained a valid license. Coincident with the decline in estimated licenses was a greater decline in the number of fishermen reporting, from more than 60 to fewer than 20 (at the time of the analysis) from 1995 to 2015 (Figure 15). It is likely that reporting rates are underestimated prior to 2007 given that information on inactive licenses (i.e. individuals who returned a logbook record and checked the 'did not fish' box) was lost due to the present structure of the electronic database and could only be partially recovered from the Association lists. It is also likely that the reporting rate is underestimated in 2015 given that some license-holders may send in their logbook records immediately prior to the 2016 season. For this assessment, the logbook records were evaluated in September to December of 2015, so it is possible that more have been submitted in the interim that are not included.

Estimating Unreported Landings

For 2014 and 2015, all of the participants from the dip net fishery were identified using the Tusket River Gaspereau Dip Netters Association lists. All other active licenses that did not have associated logbook records were assumed to be participating in the set gill net component of the fishery. In 2014, this gave 37 dip netters, 26 set gill netters and 10 license holders that did not fish. There were logbook records from 13 of the individuals identified as dip netters (35%), and 9 from the individuals identified as set gill netters (also 35%). In 2015, there were 37 dip netters, 28 set gill netters and 7 license holders that did not fish, with catch records from 6 dip netters (16%) and 3 gill netters (11%).

A ratio method was used to estimate non-reported landings (e.g. Zeller et al. 2008), where the total reported catch is simply multiplied by the ratio of the total number of fishermen to the number of fishermen reporting. For 2014, the multiplier would be 2.85 (37 licenses/13 reporting) for dip nets and 2.89 (26 licenses / 9 reporting) for set gill nets. This would give estimated landings of 1,668,444 alewives by dip nets and 1,227,449 by set gill nets for an overall total of 2,895,893 individuals. Estimated landings of Blueback Herring would be 66,602 fish by dip nets and 54,909 by set gill nets for an overall total of 121,512 individuals in 2014 (Table 8). For 2015, the multipliers would be 6.17 (37/6) for dip nets and 9.33 (28/3) for set gill nets giving total estimates of 2,230,688 and 374,203 alewives, respectively. Landings of Blueback Herring remained negligible at less than 500 fish (Table 8).

It seems unlikely that the relative proportion of the total landings taken by the dip net component of the fishery would go from 58% in 2014 to 86% in 2015 in the absence of changes in the distribution of fishing effort. It seems more likely that waiting until the start of the 2016 fishery to assess the logbook records associated with the 2015 fishery would have led to higher reporting rate estimates and potentially greater confidence in the 2015 estimate of total landings.

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Time Lags

On the Tusket River, there is a 1 week time lag from when the set gill net component of the commercial fishery begins relative to the dip net component. This reflects when Alewife become available; in that they are expected to be present in large numbers in the estuary approximately 1 week prior to ascending the river to the fish ladder at Lake Vaughan. This gives some idea of the speed at which fish move through the estuary and up the river, even though no quantitative estimates of species-specific transit times exist for the Tusket River. For Blueback Herring, any time lag between when they become vulnerable to the fishery relative to when they are enumerated at Vaughan Dam could substantially influence their estimated landings. To demonstrate the effect that a time lag could have, we assumed lags of 7 days for the set gill net component of the fishery and 3 days for the dip net component. Daily landings were multiplied by the proportion of Blueback Herring in the run 7 days later for set gill nets and 3 days later for dip nets. Stated another way, we assumed: (1) that Blueback Herring were available to the gill net component of the fishery 7 days before they arrived at Vaughan Dam, (2) that they were available to the dip net component of the fishery 3 days before they arrived at Vaughan Dam, and (3) that there were no differences in catchability between the two species.

The estimated numbers of Blueback Herring taken by the commercial fishery in 2014 and 2015 were markedly different by incorporating time lags. From the total reported landings in the dip net fishery in 2014 (608,788 individuals), 47,226 would have been Blueback Herring as compared to the estimate of 23,369 without incorporating time lags. Similarly, the estimate of Blueback Herring in the set gill net component of the catch went from 19,000 fish to 78,105 fish (Table 8). The effect of a time lag was much more dramatic in 2015, where the total number of Blueback Herring estimated to be in the reported landings changed from 74 fish to 14,671 fish. After accounting for the reporting rate, an estimated 104,386 Blueback Herring were taken in the commercial fishery in 2015 (Table 8). This example demonstrates how important it is to have accurate estimates of the species composition of the commercial catches relative to the placement of the gear in the river in order to have more accurate estimates of Blueback Herring landings.

Population Separation

In addition to the need to account for the species composition of the landings when calculating mortality rates, exploitation rates, or status, there is also the need to be able to assign the landings to a specific population. Although both Alewife and Blueback Herring are expected to home to natal rivers for spawning (McBride et al. 2014, Palkovacs et al. 2013), landings in the set gill net component of the fishery are not necessarily population-specific given that the Tusket and Annis rivers share an estuary (Figure 2). Even though individual fishermen may identify their location as the Tusket River when fishing set gill nets, the locations given in latitude and longitude in logbook returns are both above and below the outflow of the Annis River. This means that the set gill net component of the commercial fishery in this estuary would represent a mixed-species and mixed-stock fishery.

If reporting rates are assumed to be similar for both the Tusket and Annis rivers, the magnitude of the dip net landings can be used to infer the relative sizes of each fishery. In 2014, total landings of river herring in the Annis River were estimated to be 12,346 kg by dip nets. This is an order of magnitude smaller compared to the 104,307 kg taken by dip nets in the Tusket River. This order of magnitude difference corresponds well with the overall sizes (1,456 km^2 vs. 158 km^2) and estimated lake areas (92 km^2 vs. 12.5 km^2) of the Tusket and Annis rivers.

Using data from 2014, 58% of the total commercial landings were estimated to have been taken by the dip net component of the fishery in the Tusket River, while only 26% was taken by the dip net component in the Annis River. Although it is possible that capture efficiency at the dip stands in the Annis River is low compared to capture efficiency of gill nets, or that reporting rates vary markedly among individuals fishing the two gear types in the Annis River, it is also possible that a portion of the set gill net catches attributed to the Annis River are comprised of fish destined for the Tusket River. Thus, it is possible that the set gill net component of the total catch is underestimated for the Tusket River, albeit by a relatively small amount.

Other Sources of River Herring Catch

Marine bait licenses exist in Nova Scotia, and are valid for the commercial harvest of mackerel and herring to use as bait. Landings do not have to be partitioned by species and are thought to contain Mackerel, Atlantic Herring and river herring depending on the time of year and fishing location. Because the majority of landings from the Tusket River are sold as bait for the local lobster fishery, the timing of river herring returns overlaps with active lobster fishing. Thus the marine bait licenses would be expected to be targeting river herring to some extent. There is no estimate of river herring landings from these licenses that is available for this assessment. River herring are also captured in marine groundfish, Atlantic Herring, Mackerel and Shrimp fisheries; both in the USA and Canada. By-catch estimates from Canada are < 30 mt annually from all these fisheries combined (Gavaris et al. 2010), although the authors caution that estimates should not be construed as definitive. It would be expected that many populations would contribute to these landings, and that river herring from the Tusket River would be a relatively small component.

River herring are fished throughout Nova Scotia under commercial communal licenses as well as Food Social and Ceremonial (FSC) licenses issued to multiple First Nations and Aboriginal Organizations. There is no estimate of annual landings of river herring from these licenses incorporated into this assessment.

Anecdotal reports of illegal fishing are commonly discussed during the Regional Advisory Committee meetings for river herring, including the one in Yarmouth-Shelburne counties. No estimate of poaching or illegal harvest from the Tusket River was available for this assessment.

STATUS

The status of the Alewife population in the Tusket River was assessed by comparing the estimated exploitation rates and escapement with reference points derived in Gibson et al. (2016). No information is available to derive similar reference points for Blueback Herring, so status of the Tusket River blueback population cannot be assessed. However, we do present estimates of exploitation rates as well as total instantaneous mortality rates for blueback in 2014 and 2015. Two sets of reference points were derived, the upper stock reference (USR) and limit reference point (LRP) relative to biomass, as well as the fishing removal reference (RRL) and lower fishing removal reference (LRRL) values relative to exploitation rates. This approach allows distinction between whether or not a population is in an overfished state (i.e. critically low biomass) from whether or not overfishing is currently occurring (i.e. high exploitation rates). The USR was the spawning stock biomass at the maximum sustainable yield (SSB_{msy}) and the LRP was 10% of the unfished equilibrium biomass ($SSB_{10\%}$). The RRL was an exploitation rate of 0.53 and the LRRL was 0.35; these exploitation rates define the boundaries between the overexploited, fully exploited and underexploited states, respectively.

To calculate the unfished equilibrium spawner biomass (SSB_0) for the Tusket River population, we multiplied the median carrying capacity estimate of 51mt/km^2 (Gibson et al. 2016) by the amount of accessible spawning habitat in the Tusket River. The total area represented by lakes and stillwaters in the Tusket watershed was calculated using the landscape database in ArcGIS© developed for Nova Scotia by Bowlby et al. (2014). Areas upstream of the two impassable impoundment dams were not included, but those upstream of the fishway at Carlton were (Figure 2). This gave an area estimate of 92 km^2 and a river-specific estimate of carrying capacity of 4692 mt. As detailed in Gibson et al. (2016), the unfished equilibrium biomass represents 94.7% of carrying capacity so SSB_0 = 4443 mt for the Tusket River.

Given that abundance in this fishery is calculated as escapement (numbers) rather than biomass (weight), SSB_0 was transformed back into numbers of Alewife using the population-level mean weight per fish of 213 grams (reported above). The unfished equilibrium escapement estimate was 20,860,676 alewives (i.e. 4,443,324 kg/0.213 kg/fish), giving an Esc_{LRP} of 2,086,068 fish. From the meta-analysis done by Gibson (2004), SSB_{msy} averaged 14.85% of SSB_0. Applying this ratio here gives an escapement estimate at MSY (Esc_{USR}) of 3,098,547 alewives.

Annual exploitation rates (μ), fishing mortality rates (F), total mortality rates (Z) and status relative to the above reference points were calculated multiple ways to evaluate the effect of sources of uncertainty in this assessment. From 2014, two escapement estimates have been brought forward: (1) the estimated totals by species from the two-way stratified random counts (4 daily strata), partitioned by the biological sampling data (Scenario 1a), and (2) these estimated totals increased by the estimated proportion of the run that ascended the fish ladder at night in 2015 (Scenario 1b; Table 2). From 2015, the two escapement estimates represent: (1) the estimated totals from two-way stratified random counts (6 daily strata), partitioned by species biological sampling data at Vaughan Dam (Scenario 1a) and (2) the estimated totals from two-way stratified random counts (6 daily strata), partitioned by species using assumed values for the missing days in the biological sampling (Scenario 1b; Table 2). For the commercial fisheries in 2014 and 2015, two estimates of total landings by species have been brought forward: (1) the sum the reported daily landings multiplied by the reporting ratio, partitioned by species using the same-day biological sampling from Vaughan Dam (Scenario 2a) and (2) the sum the reported daily landings multiplied by the reporting ratio, but partitioned by species using the biological sampling data from 7 days later for set gill nets and 3 days later for dip nets (Scenario 2b). As such, these 4 scenarios evaluate the effect of missing biological data or partial counts from video monitoring on escapement estimates, as well as the effect of variation in the species composition of the landings relative to biological sampling at Vaughan Dam.

EXPLOITATION RATE

The annual exploitation rate can be calculated as: $\mu_t = C_t/(C_t + Esc_t)$ (Ricker 1975) where C_t represents total annual landings by the fishery and Esc_t represents the annual escapement estimate above the Vaughan fish ladder. The escapement and landings estimates by species for the different scenarios are summarized in Table 9 for 2014 and Table 10 for 2015. For Alewife, annual exploitation rate estimates ranged from 0.60 to 0.65 and 0.52 to 0.54 in 2014 and 2015, respectively. For Blueback Herring, annual exploitation rate estimates ranged from 0.17 to 0.40 and 0 to 0.35, respectively. Lower values for Blueback Herring were expected given that the fishing season closed prior to the end of the river herring run in both years, when Blueback Herring are predominant.

River herring are exposed to commercial fishing gear for a relatively short duration and are enumerated immediately after they are no longer vulnerable to capture. Although there would be some natural mortality occurring as they migrate upstream (e.g. cormorant predation; DeBruyne et al. 2012), it would represent a small component of total annual mortality. Therefore, fishing mortality and natural mortality are largely separated in time, making the river herring fishery approximate a Type 1 fishery (Ricker 1975). For a Type 1 fishery, the exploitation rate is related to the instantaneous fishing mortality rate (*F*) by: $\mu = 1 - e^{-F}$. Given the estimated exploitation rates above, *F* for Alewife ranges from 0.97 to 1.04 (Table 9) and 0.73 to 0.78 (Table 10) in 2014 and 2015, respectively. For Blueback Herring, estimates are 0.19 to 0.52 (Table 9) and <0.01 to 0.44 (Table 10), respectively.

TOTAL MORTALITY

Catch curve analysis (Millar 2012) can be used to estimate instantaneous total mortality (*Z*). This is related to fishing mortality by $Z = M + F$, where *M* represents the instantaneous rate of natural mortality (Ricker 1975). Here we applied the Poisson generalized linear model (GLM) using previous spawning history and age at maturity as predictors, as described by Gibson et al. (2016). Total mortality (*Z*) for Alewife was estimated to be 1.58 in 2014 and 1.18 in 2015; for Blueback Herring, estimates were 0.99 in 2014 and 0.87 in 2015 (Table 11). The estimated relationships fit the data better for Alewife (Figure 16) than for Blueback Herring (Figure 17). Based on the simulation results in Gibson et al. (2016), these values are likely underestimates (i.e. total mortality is higher than predicted), particularly given the number of scale samples used to develop the age distribution for both species.

Gibson and Myers (2003) provided estimates of adult natural mortality rates for 3 populations of Alewife against which the estimates of *M* from the Tusket River can be compared. For the 3 populations included in their analysis, the annual natural mortality rate (*A*) averaged 0.487, corresponding to a value of *M* of 0.67. To get estimates for *M* for the Tusket River population, the range of *F* values in Tables 9 and 10 were subtracted from the annual estimates of *Z* for Alewife and Blueback Herring. Instantaneous values were 0.543 and 0.662 in 2014, and 0.405 and 0.45 in 2015 (Table 11). Transforming these into annual mortality rates (*A*) following: $1 - exp^{-M}$, gives a range of 0.419 to 0.484 in 2014, which is only marginally below the estimate of 0.487 by Gibson and Myers (2003). Values for 2015 are somewhat below the estimate of *A* by Gibson and Myers (2003), which would be consistent with *Z* being underestimated from the catch curve analyses (see discussion in Gibson et al. 2016).

There are no independent estimates of natural mortality for Blueback Herring populations in the Atlantic region. Here, the two higher estimates for *M* (0.803 and 0.868) would represent annual mortality rates of 0.552 and 0.58 for 2014 and 2015, respectively. The two lower estimates (0.472 and 0.435) would represent annual natural mortality rates of 0.376 and 0.357 (Table 11). If a natural mortality rate similar to that of Alewife characterizes Blueback Herring, these results would suggest that the escapement scenarios considered here bracket the true fishing mortality rate experienced by Blueback Herring. This implies (1) that missing biological data needs to be accounted for in assessments and (2) that estimating the species composition of landings from the commercial fishery is an important area for future research. It also suggests that exploitation on the Blueback Herring component of the run is not negligible even though they arrive at the Vaughan fishway very close to the end of the fishing season.

STATUS OF ALEWIFE

The values derived above were assessed in the reference point framework (Gibson et al. 2016) to determine the status of the Alewife population in the Tusket River. Plotting the 4 escapement/exploitation rate scenarios for each year relative to the population-specific values for the USR, LRP, RRL and LRRL suggests that spawning escapement is near the LRP and that exploitation rates are at or just above the RRL (Figure 18). All 4 values from 2014 plot in the left upper quadrant, indicating overexploitation by the fishery (i.e. $\mu > 0.53$) coupled with escapement in the critical zone for abundance (i.e. $Esc < Esc_{LRP}$). Values from 2015 are better in terms of status, bringing escapement just into the cautious zone (i.e. $Esc_{LRP} < Esc < Esc_{USR}$) and having exploitation rates clustered around the μ_{RRL} (i.e. $\mu \sim 0.53$).

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Other Human Activities

The effects of other human activities on river herring in the Tusket River were not evaluated as part of this assessment. The river has been developed for hydropower generation, with fishways providing upstream passage at Vaughan as well as at Carlton (Figure 2). There is the potential for downstream passage mortality for juveniles and adults through turbines as well as reduced upstream passage efficiency for adults at one or both fish ladders; the effects of which relative to reference points and expected yields are discussed in Gibson et al. (2016). Relative to the estimated carrying capacity (> 20 million alewives), reduced upstream passage efficiency would lower the amount of habitat area that individuals could access, which would reduce the total estimate of spawning area below 92 km^2. If this reduction was substantial, it would lower Esc_{URP}, possibly moving the escapement estimates from 2014 and 2015 into the cautious or healthy zones. However, it would not affect status relative to the removal reference points. This hypothetical scenario is shown in Figure 19 to demonstrate the effect of the 30% change in accessible area.

RESEARCH AND DATA NEEDS

To address the potential for imprecision in the counts due to fish moving downstream in the video data as well as low image quality, it would be necessary to revisit the placement of the camera system as well as the technology used to capture the images at Vaughan Dam. Designing the system so that the fish pass under the camera as they exit the fishway (i.e. in laminar flow, not as they attempt to ascend into the last bucket) is expected to dramatically reduce fallback as well as water turbulence and the potential for dark spaces on the images. These upgrades would be necessary if video data collected at Vaughan Dam becomes part of an annual assessment.

Other monitoring and data collection needs identified in this assessment were: (1) to sample the fisheries landings to determine species composition, (2) to design and implement a tagging study to determine the proportion of the landings in the Tusket/Annis estuary destined for the Tusket, and (3) to evaluate upstream passage efficiency as well as downstream passage mortality for juveniles and adults. Furthermore, if the assessment on the Tusket River was to move away from using catch curve analysis to estimate Z to using statistical catch-at-age models, a continuous time series of species-specific escapement estimates and biological characteristics would need to be developed. At a minimum, if catch curve analyses were continued, the number of scale samples read annually would need to be increased to 500 or more, in order to reduce potential bias in the estimate of *Z* (Gibson et al. 2016). Incorporating such changes to the assessment for the Tusket River would address the main sources of uncertainty identified in this document.

Historical escapement estimates, video data, as well as biological samples exist for river herring in the Tusket River. There are multiple considerations related to the interpretation of these data: (1) they often represent partial counts for the duration of the fishery as opposed to escapement estimates as presented here, (2) they use a different stratification scheme for the video counts, and (3) they do not have associated biological samples collected in proportion to run size and/or for the entire duration of the run. Assessing current status and developing a time series of commercial landings was the priority for this framework, however, these historical data sources could be revisited in the future.

Although this assessment does provide estimates of abundance, biological characteristics and exploitation rates for Blueback Herring in the Tusket River, it does not provide an assessment of status because references points are not currently available. For Blueback Herring in general, biologically-based reference points need to be developed, as identified by Gibson et al. (2016).

SUMMARY

Alewife return to the Tusket River more than 4 weeks sooner than Blueback Herring and remain a sizeable proportion of daily returns for the duration of the river herring run. Both species exhibit similar variability in age at maturity, with the majority of fish returning to spawn for the first time as four year-olds. There is evidence of size structure in the run, suggesting that older, larger individuals return earlier in both species. Alewife make up the majority of returns, estimated to be 75% of the total in 2014 and >90% in 2015. Escapement estimates for Alewife were in the vicinity of 1.7 million fish in 2014 and 2.2 million fish in 2015, while Blueback Herring escapement estimates were in the vicinity of 0.5 million in 2014 and 0.2 million in 2015.

The Tusket River populations of Alewife and Blueback Herring support a large commercial fishery, both in terms of annual landings as well as numbers of participants. After accounting for reporting rates (which were very low in 2015), estimated landings in numbers of fish were > 2.5 million for all scenarios in both years. Approximately equal proportions were taken by the dip net and set gill net components of the fishery in 2014, but not in 2015. Partitioning these catches by species depended on the assumed time lags between when Blueback Herring first become vulnerable to the fishery relative to the estimated daily proportions of Alewife and blueback at Vaughan fishway.

Catch curve analyses indicated total instantaneous mortality rates > 1.1 for Alewife in both years, and < 1 for blueback in both years. Similarly, instantaneous fishing mortality and exploitation rate estimates were higher for Alewife than for blueback. This is consistent with reduced exploitation on blueback due to run timing relative to the commercial fishing season. Status of Alewife relative to the reference points derived in the assessment framework indicated that escapement is low (critical or cautious zones) and fishing exploitation rates are at (fully exploited) or above (overexploited) the removal reference. However, the escapement reference points were sensitive to the amount of accessible habitat above Vaughan dam, which can be influenced by fish passage at fishways.

For future assessments, the sources of uncertainty identified in this document could be largely addressed by re-designing the video monitoring set-up, by implementing geographically widespread sampling of the commercial catches for species composition, and by estimating the river of origin for estuarine catches. More long-term goals would be the development of a time series of escapement and landings (proportioned by age and species) that could be used in a similar modeling framework as Gibson (2004) to calculate life history parameters, carrying capacity and maximum reproductive rates for both Alewife and Blueback Herring specific to the Tusket River. These could be used to assess sources of mortality as well as to refine (or develop in the case of blueback) reference points that better represent the productive potential of the Tusket River.

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TABLES

Table 1. Summary of the strata used in the 2-way random stratified sampling scheme for estimating escapement from the video data collected at the Lake Vaughan fish ladder on the Tusket River. The 'blocks' represents a count of the number of 5-minute increments in each strata.

Year	Strata	Start	End	Blocks
2014	1	NA	NA	NA
2014	2	5:00	10:30	69
2014	3	10:45	13:30	36
2014	4	13:45	16:30	36
2014	5	16:45	20:45	51
2014	6	NA	NA	NA
2015	1	0:00	4:45	60
2015	2	5:00	10:30	69
2015	3	10:45	13:30	36
2015	4	13:45	16:30	36
2015	5	16:45	20:45	51
2015	6	21:00	23:45	36

Table 2. Total escapement estimates plus 95% CI (Lower, Upper), as well as total escapement by species for 2014 and 2015. The 2 scenarios for 2014 represent: the escapement estimate from the two-way stratified sampling design assuming 4 strata per day (1a), and increasing this estimate by 11% to account for the proportion of individuals returning at night (strata 1 and 6 in 2015; 1b). The two scenarios in 2015 represent: the escapement estimate from the two-way stratified sampling design assuming 6 strata per day, partitioned to species from the available biological data (1a), and this same escapement estimate, partitioned to species assuming proportions of Alewife relative to blueback for the days in which biological data were missing (1b).

Year	Scenario	Description	Escapement	Lower	Upper	% Alewife	Alewife	Blueback
2014	1a	two-way stratification; 4 strata	2,122,525	2,063,268	2,181,782	75	1,591,597	530,928
2014	1b	plus proportion at night	2,358,125	2,292,291	2,423,960	75	1,767,745	590,380
2015	1a	two-way stratification; 6 strata	2,517,215	2,450,471	2,583,960	92	2,325,787	191,428
2015	1b	estimate missing biological data	2,517,215	2,450,471	2,583,959	90	2,224,235	292,980

Table 3. Summary of population characteristics for river herring in the Tusket River, calculated from daily biological samples weighted by daily escapement estimates. Mean lengths and weights plus standard deviation (s.d.) for Alewife and blueback males (M) and females (F) are shown.

Species	Year	Sex	Length	Length s.d.	Weight	Weight s.d.
Alewife	2014	F	25.3	1.3	235	37
Alewife	2014	M	24.3	1.2	199	33
Alewife	2015	F	25.2	1.5	205	38
Alewife	2015	M	24.1	1.4	180	40
Blueback	2014	F	22.9	1.3	158	36
Blueback	2014	M	21.9	1.4	137	33
Blueback	2015	F	22.9	0.9	147	28
Blueback	2015	M	22.2	0.7	132	13

Table 4. A comparison of the age distribution for Alewife and blueback from 2014 and 2015. Age is the total age of the animal, Ps is the total number of previous spawnings, Count is the number of scale samples that were determined to be a specific age and % is the percentage of each age relative to the total number of scale samples that were aged. The number of samples taken that were not aged (NA) as well as the number that could not be aged from the available scale sample (Regen) are also given.

Year	Species	Age	Ps	Count	%	Year	Species	Age	Ps	Count	%
2014	Alewife	3	0	57	16.62	2015	Alewife	3	0	34	10.15
2014	Alewife	4	0	190	55.39	2015	Alewife	4	0	143	42.69
2014	Alewife	4	1	14	4.08	2015	Alewife	4	1	12	3.58
2014	Alewife	5	0	22	6.41	2015	Alewife	5	0	39	11.64
2014	Alewife	5	1	41	11.95	2015	Alewife	5	1	81	24.18
2014	Alewife	5	2	0	0.00	2015	Alewife	5	2	5	1.49
2014	Alewife	6	1	6	1.75	2015	Alewife	6	1	4	1.19
2014	Alewife	6	2	8	2.33	2015	Alewife	6	2	9	2.69
2014	Alewife	6	3	0	0.00	2015	Alewife	6	3	2	0.60
2014	Alewife	7	2	3	0.87	2015	Alewife	7	2	1	0.30
2014	Alewife	7	3	1	0.29	2015	Alewife	7	3	4	1.19
2014	Alewife	8	4	1	0.29	2015	Alewife	8	4	1	0.30
2014	Alewife	Regenerated		11		2015	Alewife	Regenerated		13	
2014	Alewife	NA		4310		2015	Alewife	NA		3198	
2014	Blueback	3	0	51	28.98	2015	Blueback	3	0	41	20.30
2014	Blueback	4	0	48	27.27	2015	Blueback	4	0	50	24.75
2014	Blueback	4	1	27	15.34	2015	Blueback	4	1	34	16.83
2014	Blueback	5	0	7	3.98	2015	Blueback	5	0	8	3.96
2014	Blueback	5	1	14	7.95	2015	Blueback	5	1	26	12.87
2014	Blueback	5	2	5	2.84	2015	Blueback	5	2	25	12.38
2014	Blueback	6	1	1	0.57	2015	Blueback	6	1	1	0.50
2014	Blueback	6	2	17	9.66	2015	Blueback	6	2	13	6.44
2014	Blueback	6	3	6	3.41	2015	Blueback	6	3	1	0.50
2014	Blueback	7	2	0	0.00	2015	Blueback	7	2	1	0.50
2014	Blueback	7	3	0	0.00	2015	Blueback	7	3	1	0.50
2014	Blueback	7	4	0	0.00	2015	Blueback	7	4	1	0.50

Year	Species	Age	Ps	Count	%	Year	Species	Age	Ps	Count	%
2014	Blueback	Regenerated		3		2015	Blueback	Regenerated		4	
2014	Blueback	NA		1200		2015	Blueback	NA		510	

Table 5. Mean fork length in cm and weight in grams plus standard deviations for individuals of each species, age and previous spawning history (Ps), based on data collected in 2014 for river herring in the Tusket River.

Species	Total Age	Ps	Length (cm)	Length s.d.	Weight (grams)	Weight s.d.
Alewife	3	0	22.8	1.12	171	25.8
Alewife	4	0	24.8	0.93	213	29.8
Alewife	5	0	25.7	1.08	240	33.2
Alewife	4	1	24.3	0.93	199	24.7
Alewife	5	1	25.7	0.97	235	32.4
Alewife	6	1	26.6	0.68	263	27.8
Alewife	6	2	27.0	0.98	284	38.1
Alewife	7	2	25.9	2.71	237	60.1
Alewife	7	3	26.9	NA	276	NA
Alewife	8	4	28.4	NA	350	NA
Blueback	3	0	21.4	1.26	130	32.3
Blueback	4	0	22.6	1.20	155	36.7
Blueback	5	0	24.2	2.16	192	54.9
Blueback	4	1	21.8	0.68	126	12.2
Blueback	5	1	22.8	0.53	154	12.3
Blueback	6	1	23.2	NA	NA	NA
Blueback	5	2	23.1	1.40	142	21.9
Blueback	6	2	23.4	1.15	171	40.7
Blueback	6	3	22.6	0.33	145	10.0

Table 6. A two-way contingency table comparing species identification from visual characteristics (rows) and from scale sample characteristics (columns) for river herring in the Tusket River in 2014 and 2015. As an example for Alewife in 2014, 99% of samples were identified as Alewife from both methods while 1% of animals that were visually identified as Alewife were Blueback Herring based on scale characteristics.

Year	Visual ID	Alewife	Blueback
2014	Alewife	0.99	0.01
2014	Blueback	0.10	0.90
2015	Alewife	0.95	0.05
2015	Blueback	0.02	0.98

Table 7. Reported annual commercial landings in kilograms by year and gear type on the Annis and Tusket Rivers. Values represent the sum of all daily logbook records.

River	Year	Dip Net	Gill Net	Total	River	Year	Dip Net	Gill Net	Total
Annis	1993	17,528	51,707	69,235	Tusket	1993	200,749	112,003	312,753
Annis	1994	20,635	35,253	55,888	Tusket	1994	263,192	149,271	412,463
Annis	1995	76,553	74,999	151,552	Tusket	1995	333,579	286,370	619,949
Annis	1996	68,507	55,686	124,193	Tusket	1996	456,482	345,362	801,844
Annis	1997	29,013	61,446	90,459	Tusket	1997	149,742	154,399	304,141
Annis	1998	17,285	38,770	56,056	Tusket	1998	216,825	127,022	343,847
Annis	1999	1,113	17,152	18,265	Tusket	1999	246,864	29,403	276,268
Annis	2000	12,780	18,995	31,775	Tusket	2000	215,728	109,611	325,338
Annis	2001	23,087	19,100	42,186	Tusket	2001	130,085	74,679	204,764
Annis	2002	48,270	95,560	143,829	Tusket	2002	287,966	179,713	467,679
Annis	2003	105,540	113,315	218,855	Tusket	2003	348,731	186,805	535,536
Annis	2004	15,610	54,209	69,819	Tusket	2004	150,910	107,658	258,567
Annis	2005	7,265	79,368	86,633	Tusket	2005	93,682	47,373	141,055
Annis	2006	25,649	107,895	133,544	Tusket	2006	147,819	109,488	257,307
Annis	2007	14,041	58,756	72,797	Tusket	2007	128,697	69,230	197,928
Annis	2008	809	31,411	32,220	Tusket	2008	4,432	32,799	37,231
Annis	2009	5,207	16,099	21,306	Tusket	2009	92,084	146,432	238,516
Annis	2010	9,949	27,000	36,949	Tusket	2010	73,285	123,391	196,676
Annis	2011	15,510	22,490	37,999	Tusket	2011	156,816	45,913	202,728
Annis	2012	16,003	29,522	45,525	Tusket	2012	118,302	38,482	156,783
Annis	2013	12,573	14,293	26,866	Tusket	2013	113,621	58,815	172,436
Annis	2014	12,346	34,751	47,097	Tusket	2014	146,109	104,307	250,416
Annis	2015	40,812	30,955	71,767	Tusket	2015	85,376	10,538	95,914

Table 8. Total landings (in numbers) of Alewife and Blueback Herring by gear type for 2014 and 2015. Values with grey shading represent totals from logbook reports and values with no grey shading are total estimates after accounting for reporting rates. Two types of scenarios are presented: one in which the daily landings are multiplied by the same-day estimates for the proportion of Alewife in the run from the biological sampling at Vaughan Dam (no lag; 2a), and one in which set gill net landings were multiplied by the proportion of Alewife from the biological sampling 7 days later and the dip net catches were multiplied by the proportion of Alewife from the biological sampling 3 days later (time lag; 2b).

Year	Scenario	Type	Species	Dip Net	Set Gill Net	Total
2014	no lag	Reported	Alewife	585,419	424,723	1,010,142
2014	no lag	Reported	Blueback	23,369	19,000	42,369
2015	no lag	Reported	Alewife	361,538	40,108	401,645
2015	no lag	Reported	Blueback	74	0	74
2014	2a	Total	Alewife	1,668,444	1,227,449	2,895,893
2014	2a	Total	Blueback	66,602	54,910	121,512
2015	2a	Total	Alewife	2,230,688	374,203	2,604,891
2015	2a	Total	Blueback	457	0	457
2014	time lag	Reported	Alewife	561,562	365,618	927,180
2014	time lag	Reported	Blueback	47,226	78,105	125,331
2015	time lag	Reported	Alewife	351,329	35,720	387,048
2015	time lag	Reported	Blueback	10,283	4,388	14,671
2014	2b	Total	Alewife	1,600,451	1,056,636	2,657,087
2014	2b	Total	Blueback	134,594	225,723	360,318
2015	2b	Total	Alewife	2,167,698	333,263	2,500,961
2015	2b	Total	Blueback	63,446	40,940	104,386

Table 9. Estimates of exploitation rate (μ) and the instantaneous rate of fishing mortality (F) for Alewife and Blueback Herring in 2014 from 4 combinations of the escapement and catch scenarios for the Tusket River.

Scenario	Estimate	Total	Alewife	Blueback
1a	Escapement	2,122,525	1,591,597	530,928
1b	Escapement + proportion at night	2,358,125	1,767,745	590,380
	Reported catch	1,052,511	1,010,142	42,369
2a	Catch*reporting ratio	3,017,405	2,895,893	121,512
2b	Catch*reporting ratio +time lag	3,017,405	2,657,087	360,318
	u (Scenario 1a,2a)		0.65	0.19
	u (Scenario 1a,2b)		0.63	0.40
	u (Scenario 1b,2a)		0.62	0.17
	u (Scenario 1b,2b)		0.60	0.38
	F (Scenario 1a,2a)		1.037	0.206
	F (Scenario 1a,2b)		0.982	0.518
	F (Scenario 1b,2a)		0.970	0.187
	F (Scenario 1b,2b)		0.918	0.476

Table 10. Estimates of exploitation rate (μ) and the instantaneous rate of fishing mortality (F) for Alewife and Blueback Herring in 2015 from 4 combinations of the escapement and catch scenarios for the Tusket River.

Scenario	Estimate	Total	Alewife	Blueback
1a	Escapement	2,517,215	2,325,787	191,428
1b	Escapement + estimate missing biological data	2,517,215	2,224,235	292,980
	Reported catch	401,719	387,048	14,671
2a	Catch*reporting ratio	2,605,348	2,604,891	457
2b	Catch*reporting ratio +time lag	2,605,347	2,500,961	104,386
	u (Scenario 1a,2a)		0.53	0.00
	u (Scenario 1a,2b)		0.52	0.35
	u (Scenario 1b,2a)		0.54	0.00
	u (Scenario 1b,2b)		0.53	0.26
	F (Scenario 1a,2a)		0.751	0.002
	F (Scenario 1a,2b)		0.730	0.435
	F (Scenario 1b,2a)		0.775	0.002
	F (Scenario 1b,2b)		0.753	0.305

Table 11. Estimates of total instantaneous mortality (Z) from catch-curve analyses of the age distribution for Alewife and Blueback Herring in 2014 and 2015, as well as a comparison of the resulting instantaneous natural mortality rates (M) given estimates of F from the exploitation rate scenarios. The annual natural mortality rate (A) is also given.

Year	Species	Z	s.e.	F_{lower}	F_{upper}	M_{upper}	M_{lower}	A_{upper}	A_{lower}
2014	Alewife	1.58	0.041	0.918	1.037	0.662	0.543	0.484	0.419
2015	Alewife	1.18	0.026	0.730	0.775	0.45	0.405	0.362	0.333
2014	Blueback	0.99	0.042	0.187	0.518	0.803	0.472	0.552	0.376
2015	Blueback	0.87	0.053	0.002	0.435	0.868	0.435	0.580	0.357

FIGURES

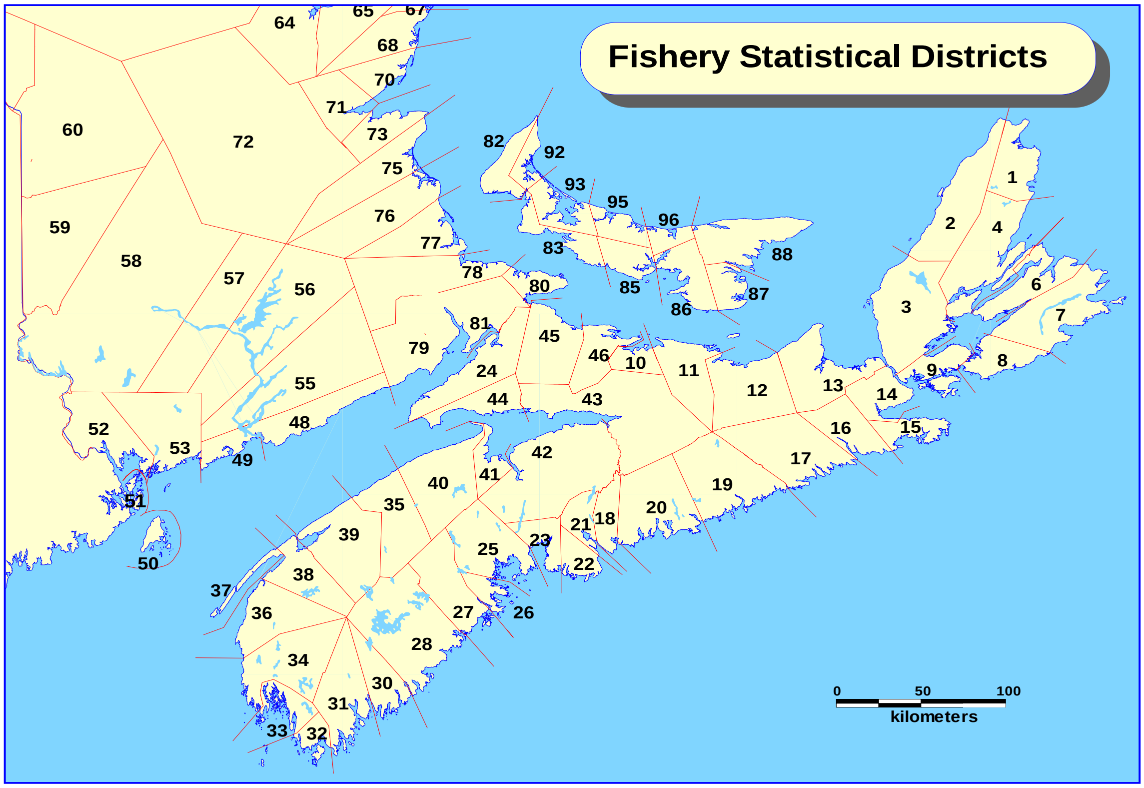

Figure 1. Fishery Statistical Districts (FSD) for river herring in Nova Scotia and New Brunswick.

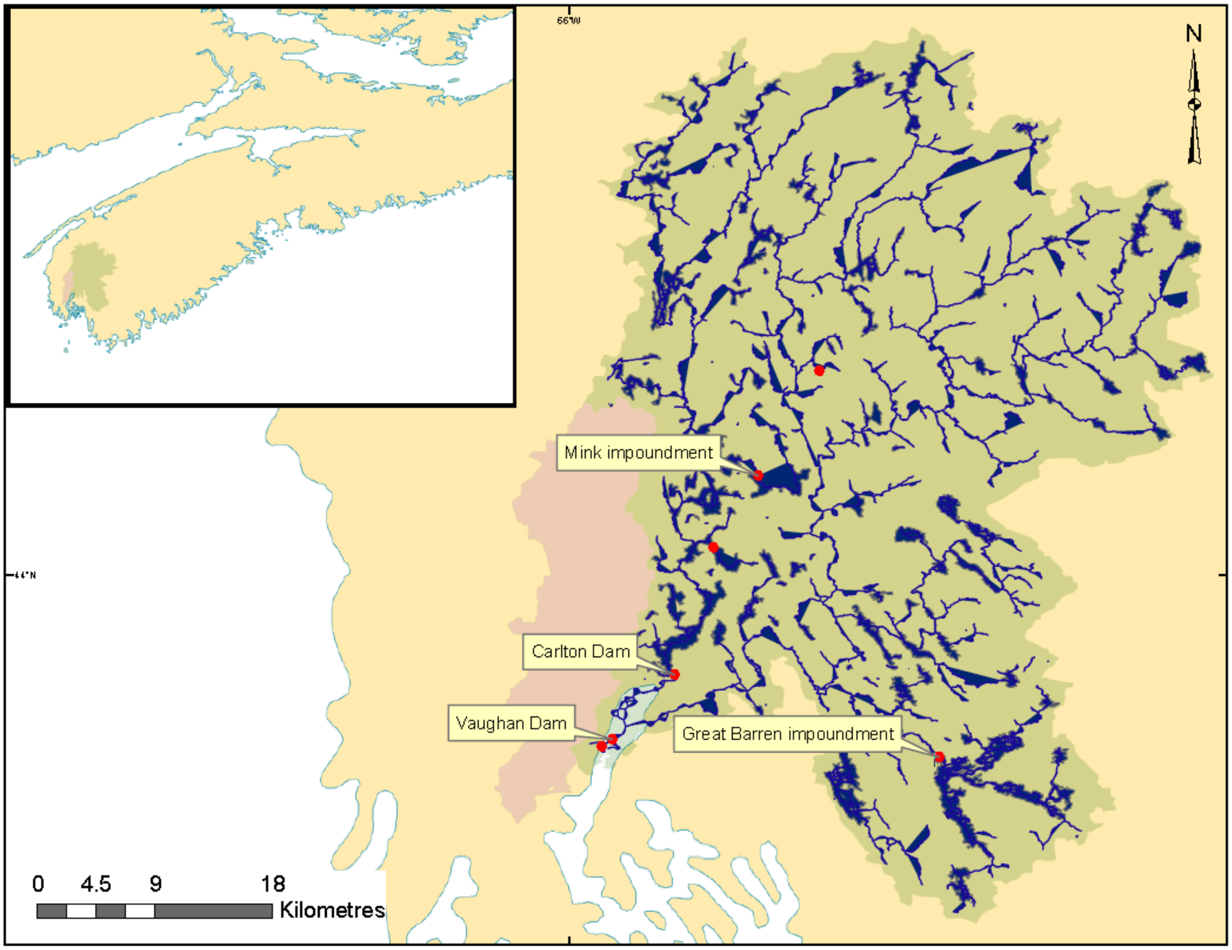

Figure 2. Map of the Tusket watershed (green shading) in Yarmouth County, Nova Scotia, showing the stream network, the major waterbodies as well as the locations of the identified dams on the system (red dots). The two fish ladders on the river are at the Vaughan Dam and the Carlton Dam. The Annis watershed (pink shading) is also shown because it shares an estuary with the Tusket River.

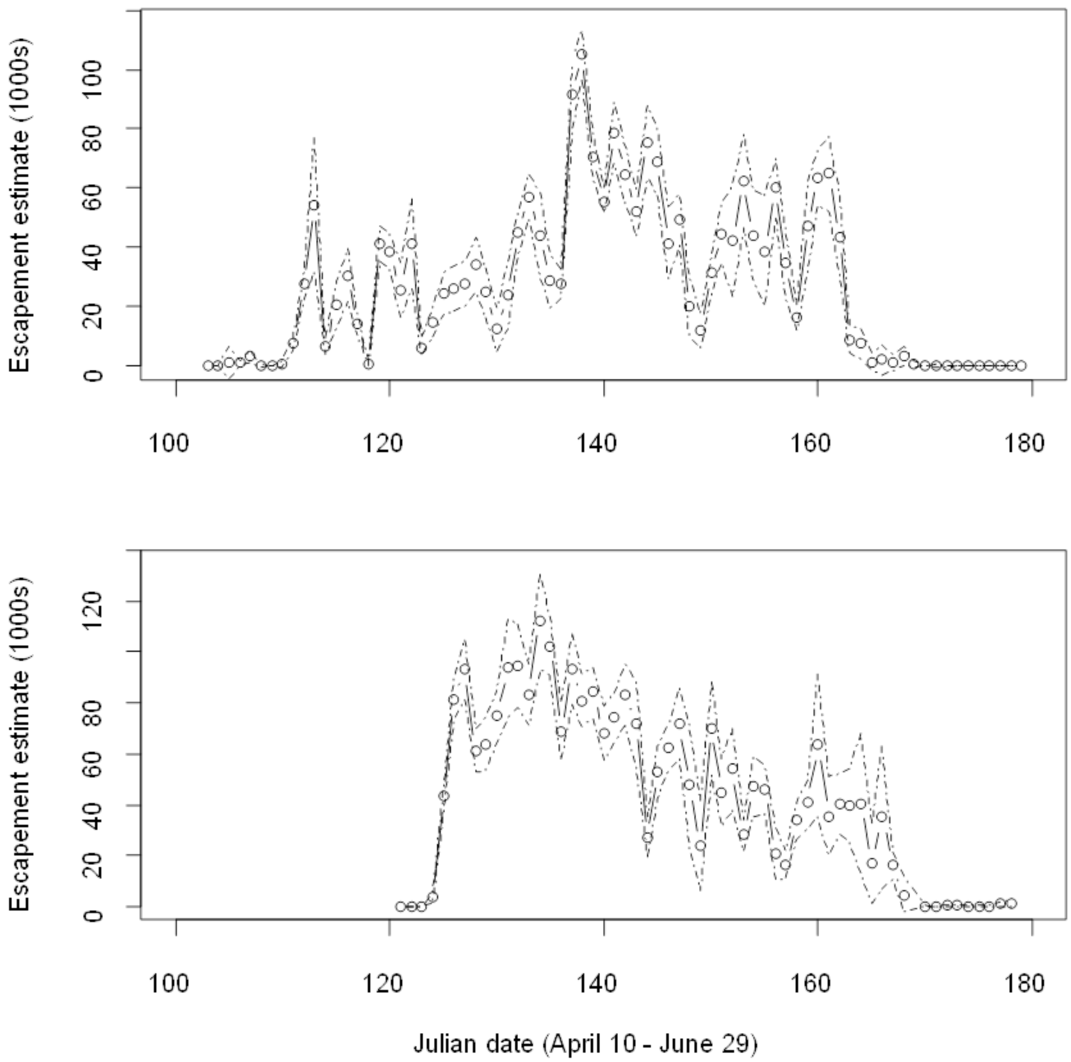

Figure 3. Estimated total daily escapement and 95% CI from 2014 (top panel) and 2015 (bottom panel) for river herring in the Tusket River. Daily confidence intervals are corrected by the estimated degrees of freedom.

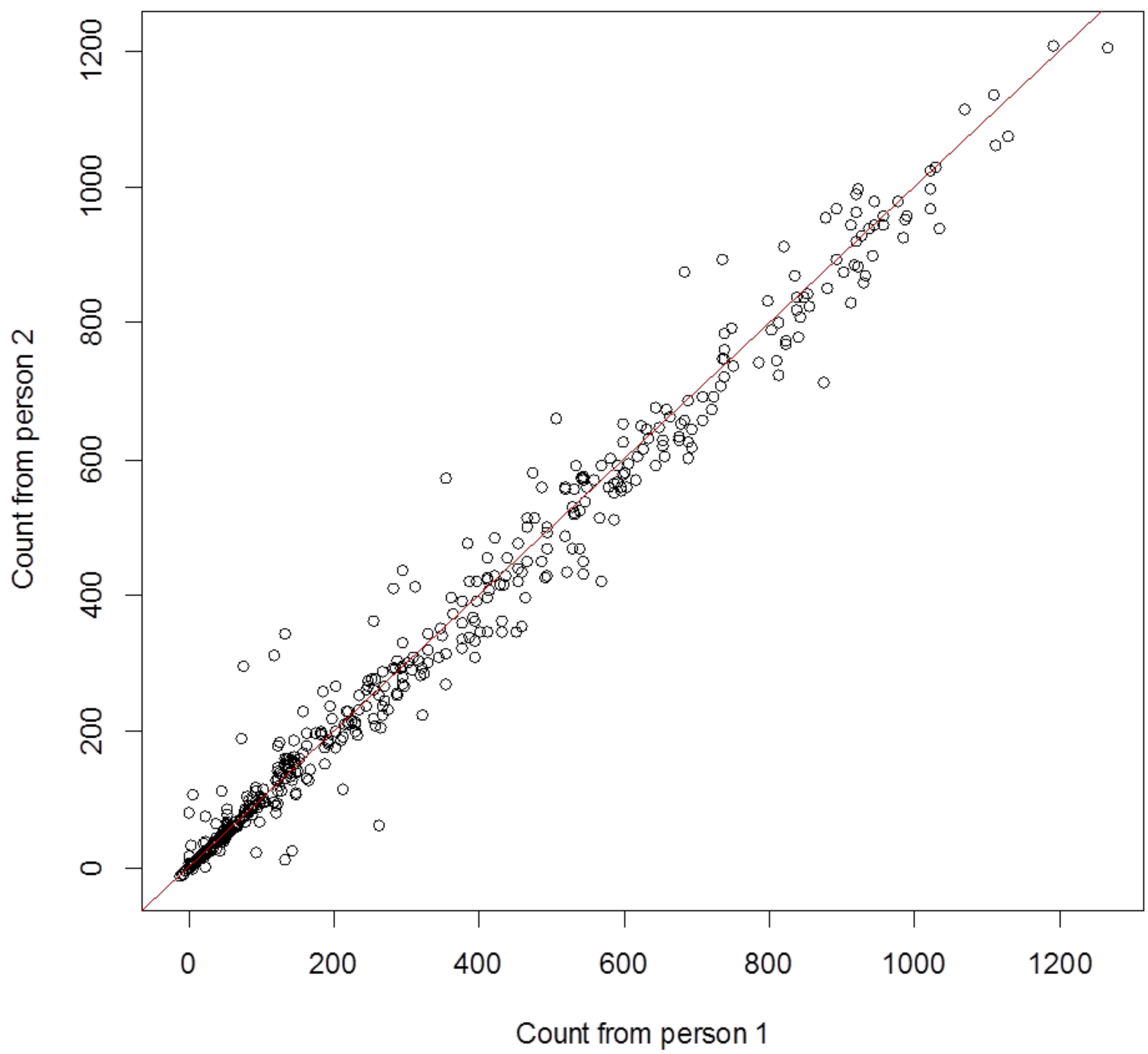

Figure 4. A comparison of counts from two people for the same 5-minute blocks of video collected at Vaughan fishway in 2015. The red line represents the 1:1 line.

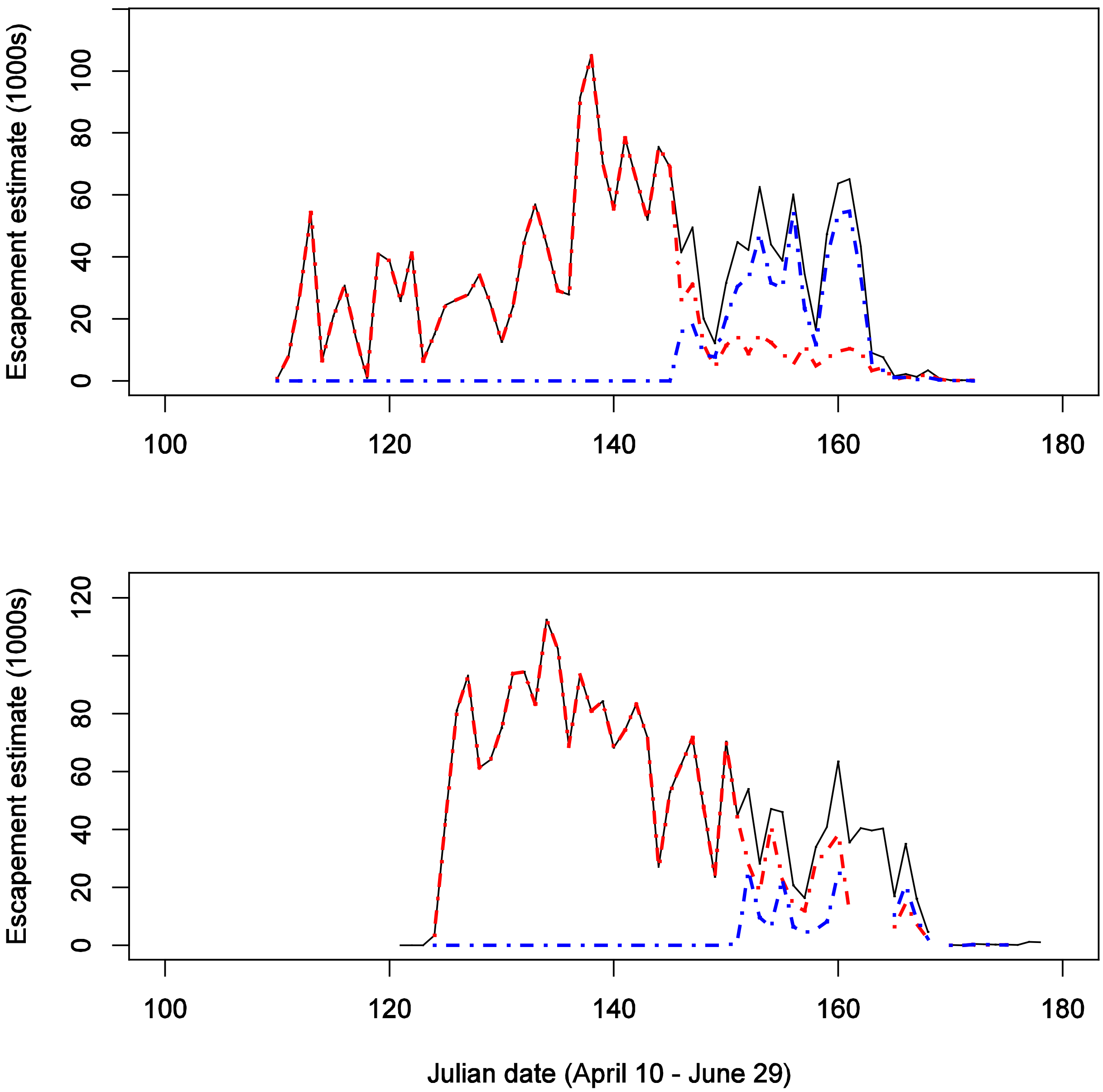

Figure 5. Daily escapement by species for 2014 (top panel) and 2015 (bottom panel), showing total daily run size (black line), alewife (red dashed line) and Blueback Herring (blue dashed line). Note the missing days in the middle of the blueback run in 2015.

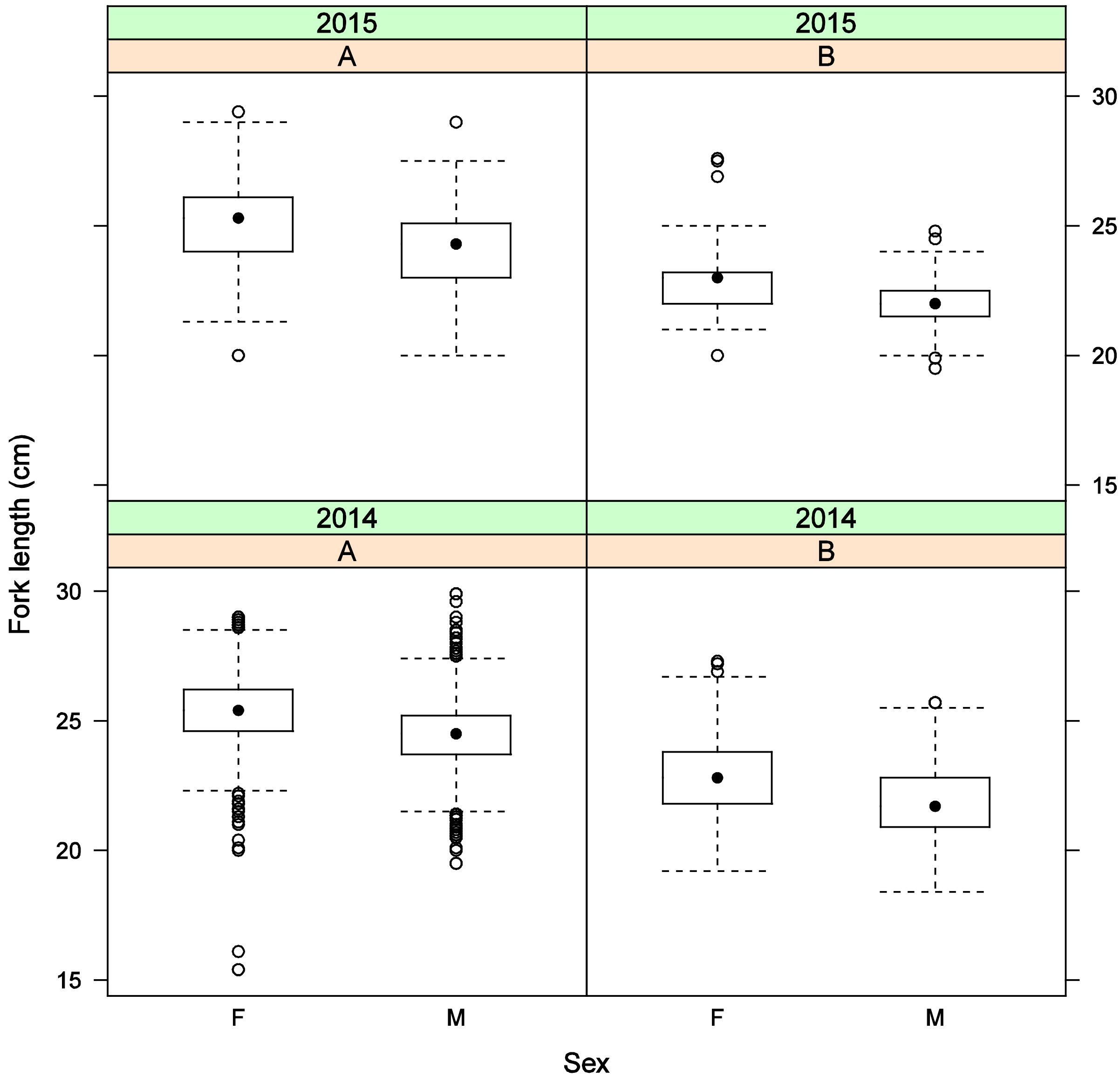

Figure 6. Boxplots of fork length for male (M) and female (F) Alewife (A) and Blueback Herring (B) estimated from biological samples collected at Vaughan fishway on the Tusket River in 2014 and 2015.

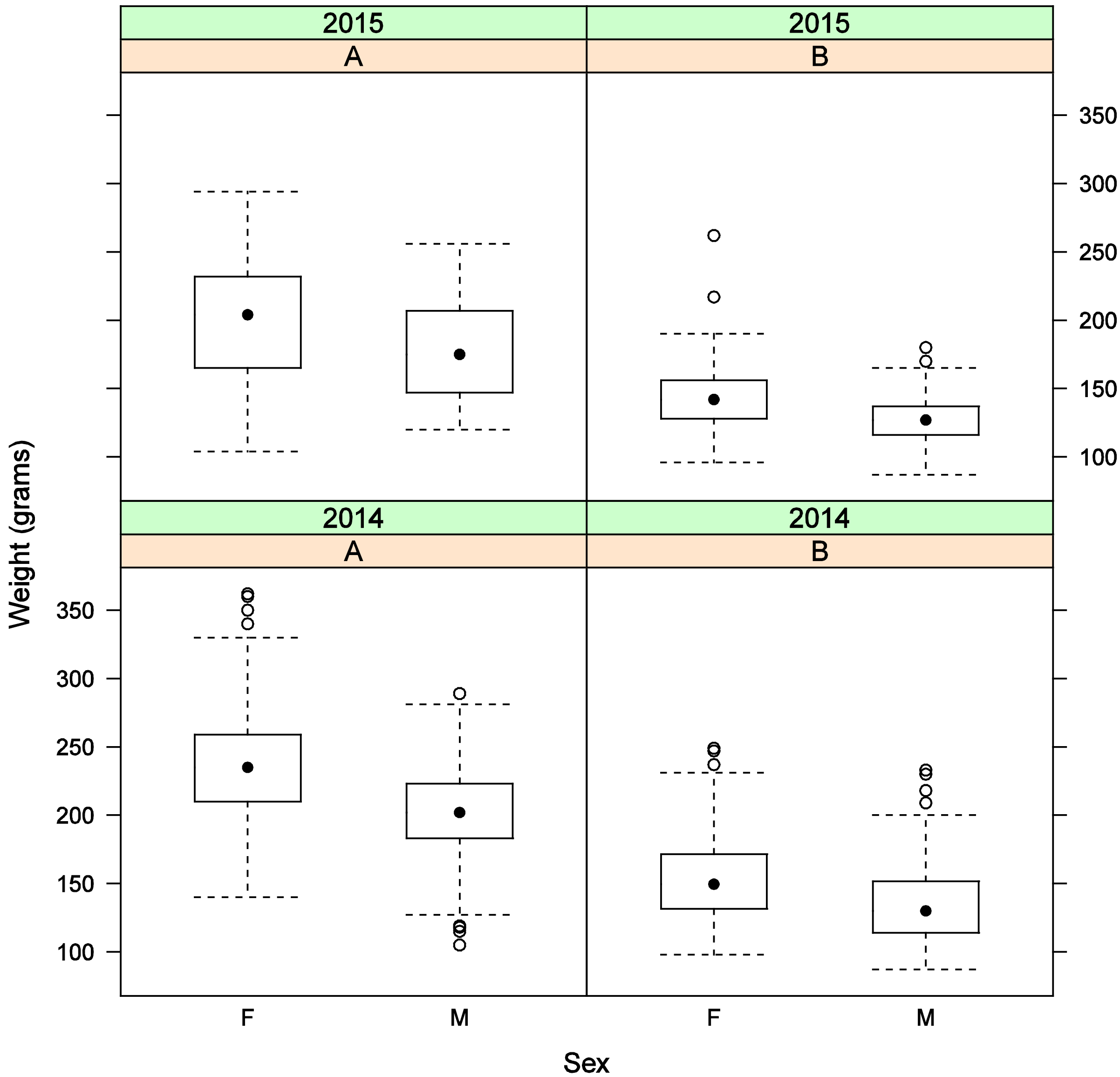

Figure 7. Boxplots of weight for male (M) and female (F) Alewife (A) and Blueback Herring (B) estimated from biological samples collected at Vaughan fishway on the Tusket River in 2014 and 2015.

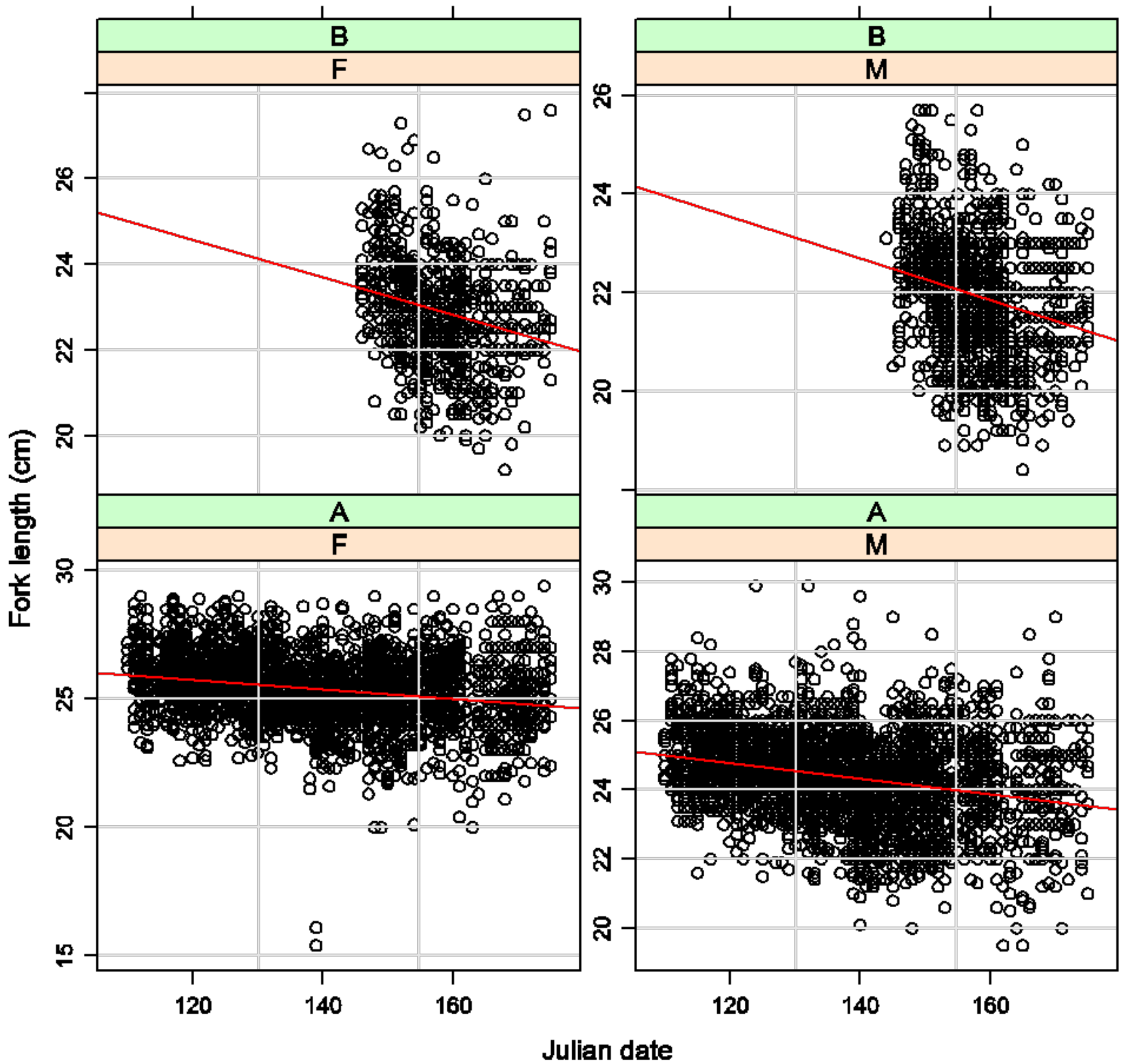

Figure 8. Length by Julian date for Alewife (A) and Blueback Herring (B) males (M) and females (F) from all biological samples collected in 2014 and 2015 as well as a linear regression fit to the data (red lines), where individual points were weighted by the estimated daily escapement.

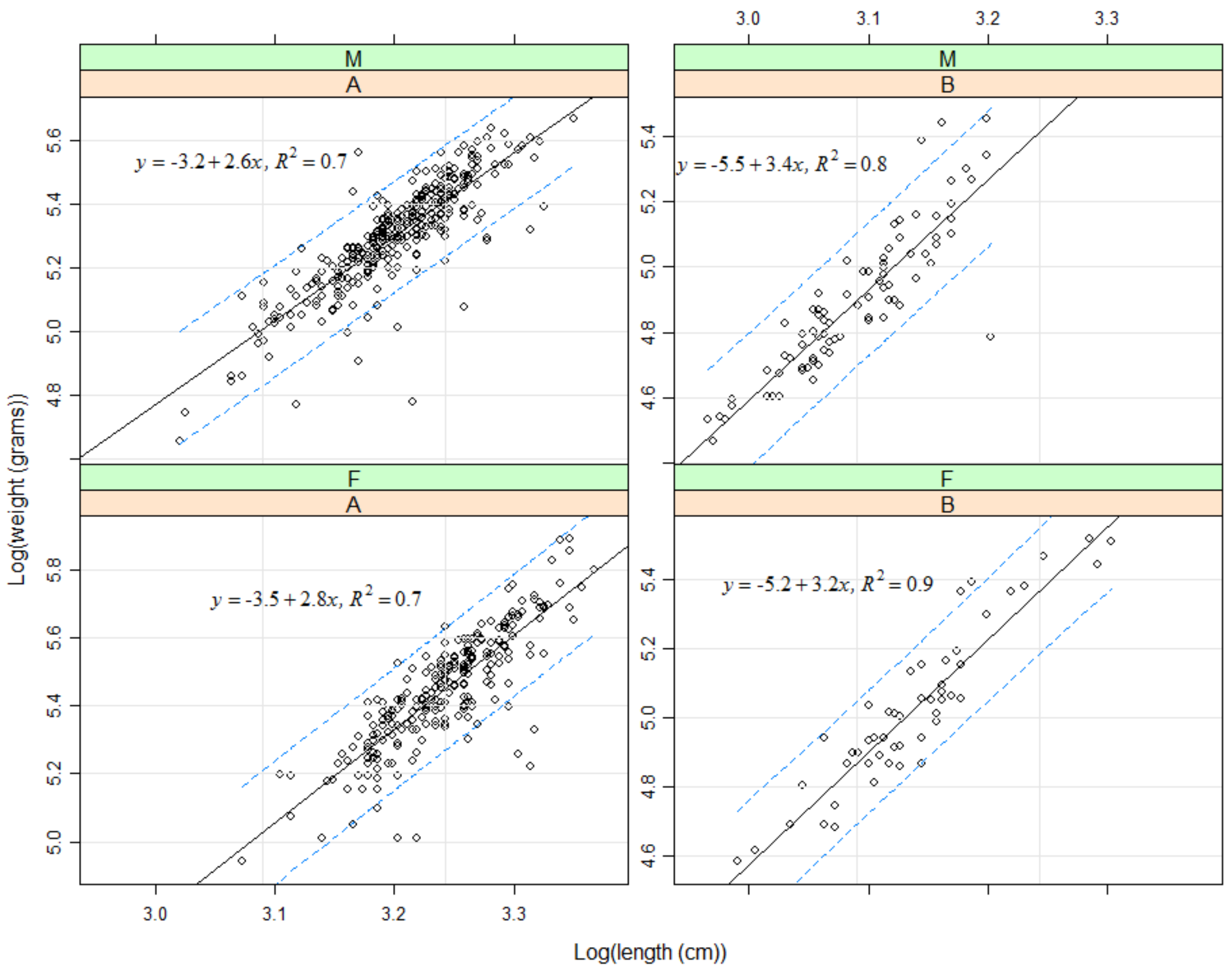

Figure 9. A log-log relationship of weight at length plus the linear regression equation estimates and R-square values for Alewife (A) and Blueback Herring (B) males (M) and females (F) in the Tusket River. Given the uncertainty of the weight data collected in 2015, only 2014 data are used here.

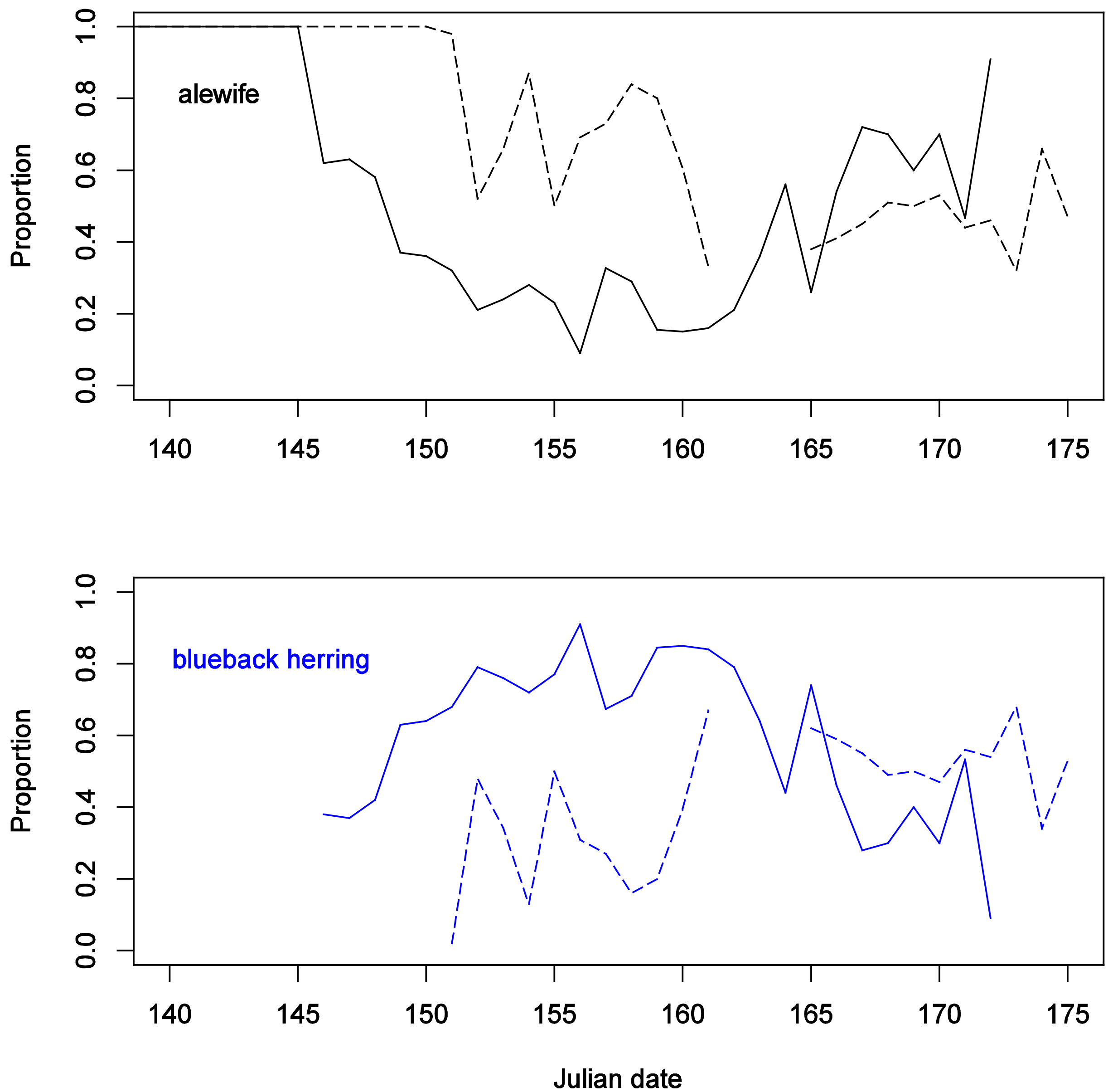

Figure 10. The proportion of Alewife (top panel) and Blueback Herring (bottom panel) in the daily escapement estimates in the Tusket River for 2014 (solid lines) and 2015 (dashed lines), considering only the duration of the river herring run that contained both species. Estimates were not available for three days in 2015.

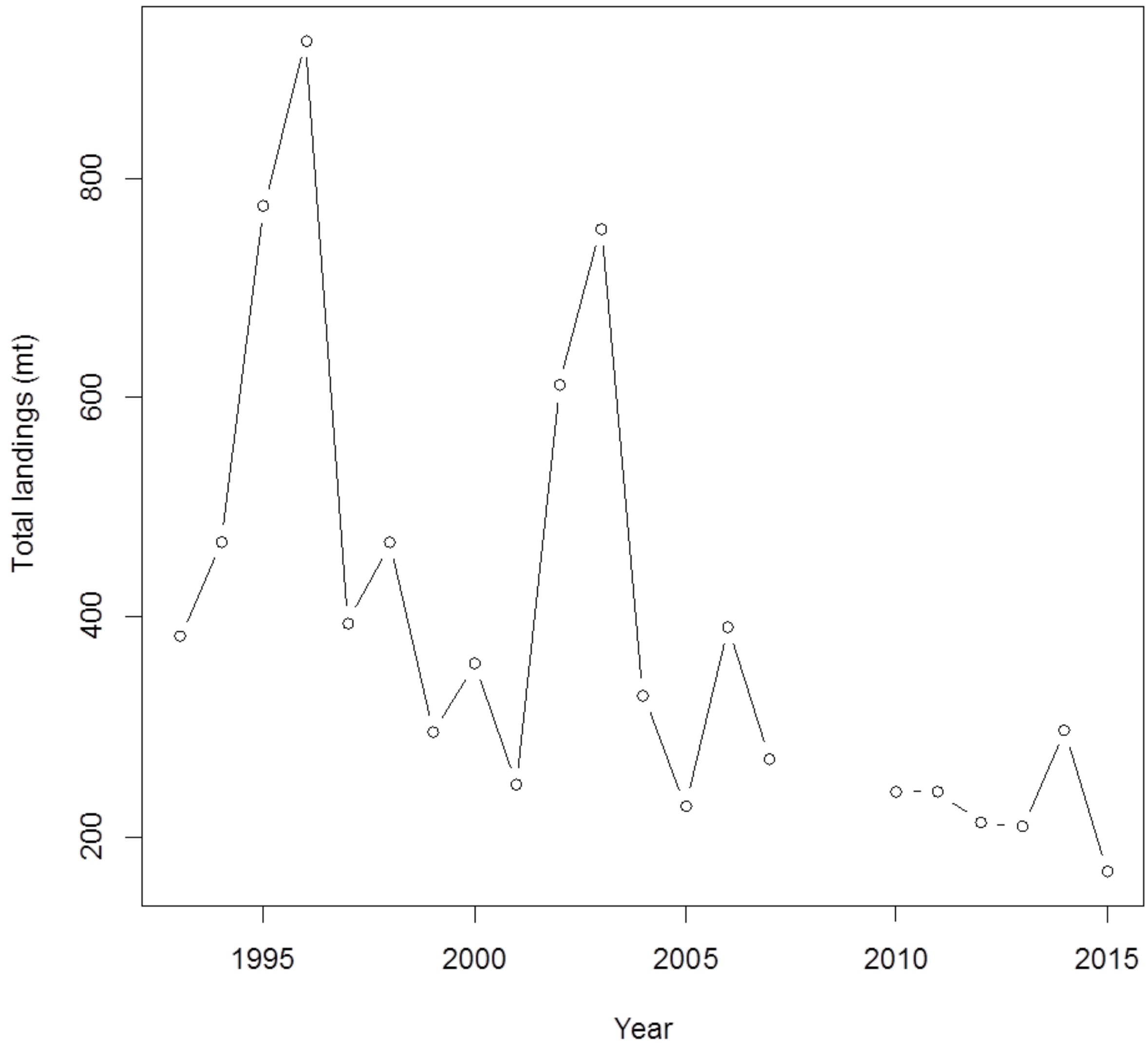

Figure 11. Time series of total commercial landings (mt) reported through logbooks on the Tusket and Annis rivers combined from 1993 to 2015, excluding 2008 and 2009 due to issues with data reliability.

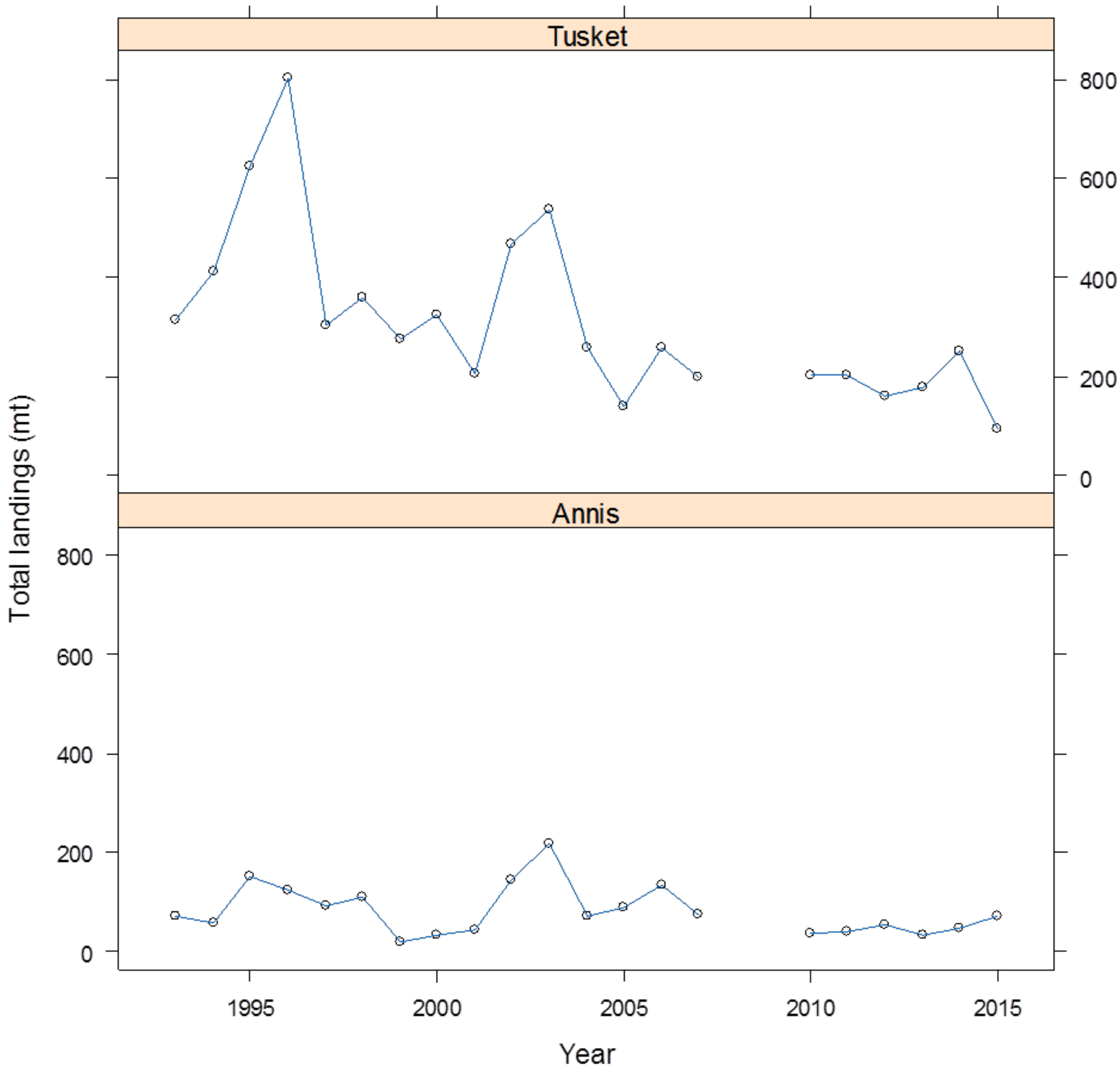

Figure 12. Time series of commercial landings estimated from logbook records for the Tusket and Annis rivers, separately. Values represent the sum of all reported daily landings in each river in each year.

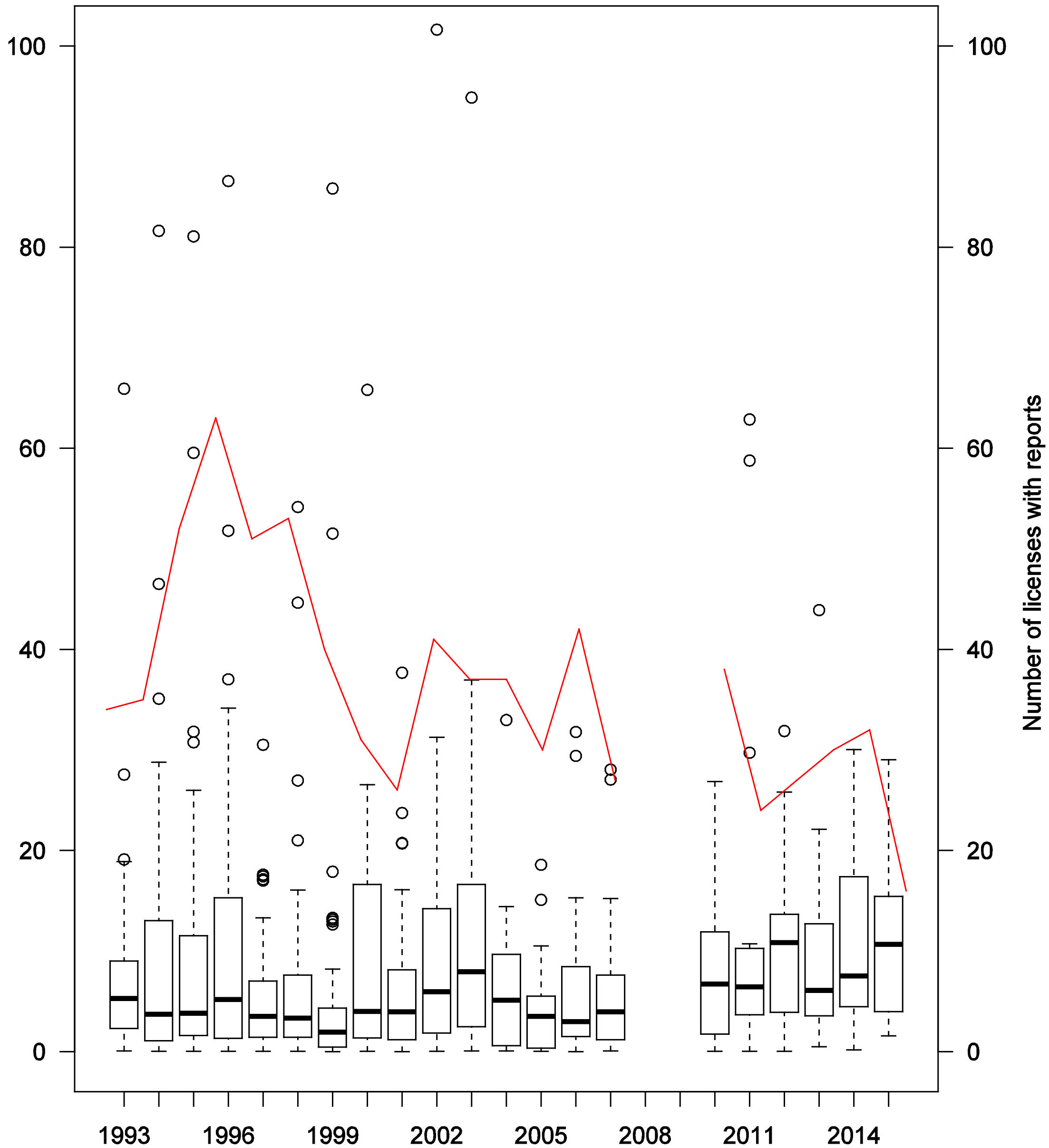

Figure 13. A boxplot of the median reported annual landings of individual license holders from 1993 to 2015, relative to the total number of license holders reporting (red line) in the Tusket River, N.S.

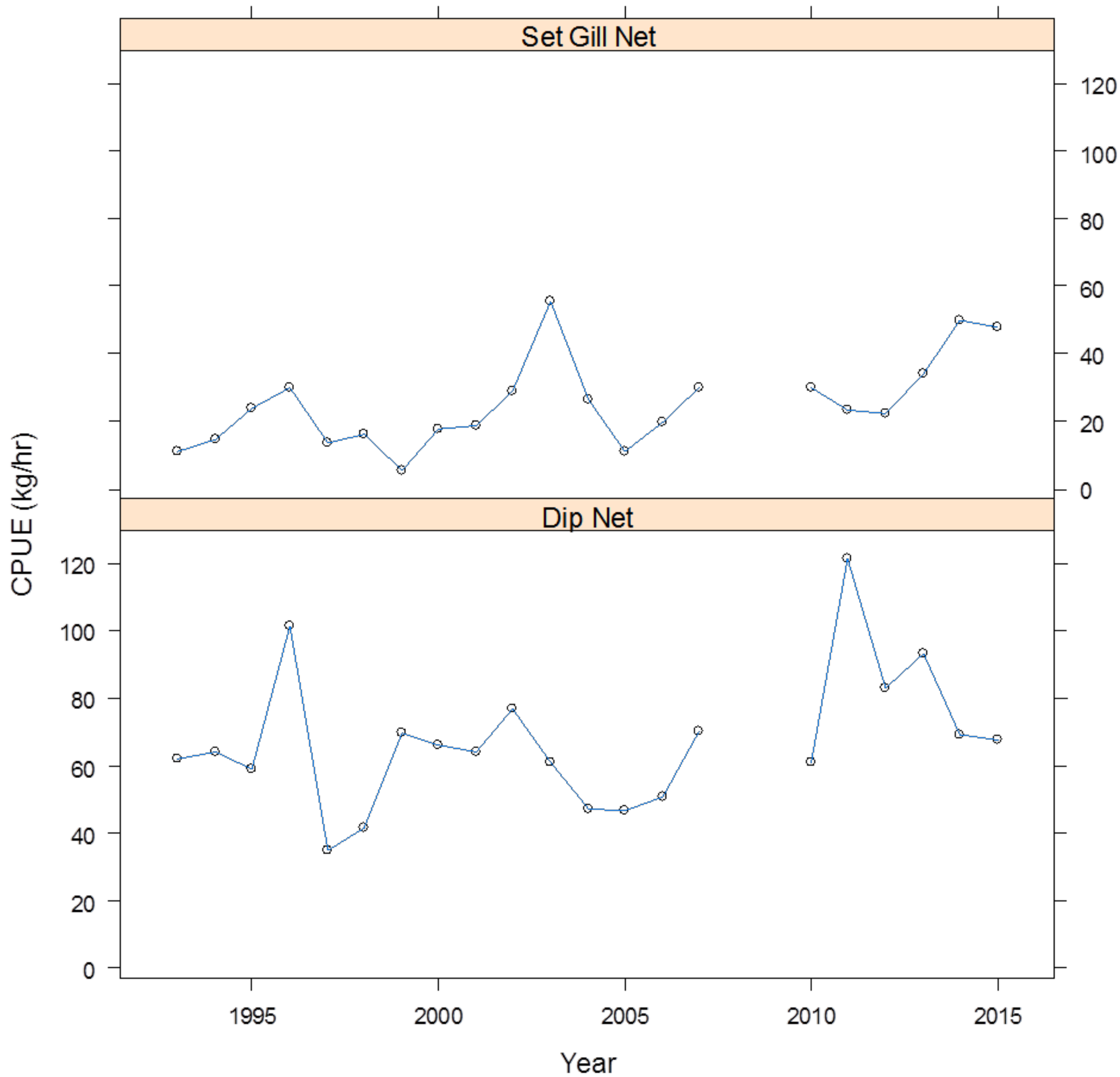

Figure 14. Annual catch-per-unit-effort by gear type for the Tusket River, estimated as total daily landings divided by the number of hours fished from the logbook returns.

Figure 15. The estimated total number of licenses being fished on the Tusket River (black line) relative to the number of those licenses that had associated logbook records or were identified as individuals that did not fish (red line) from 1993 to 2015.

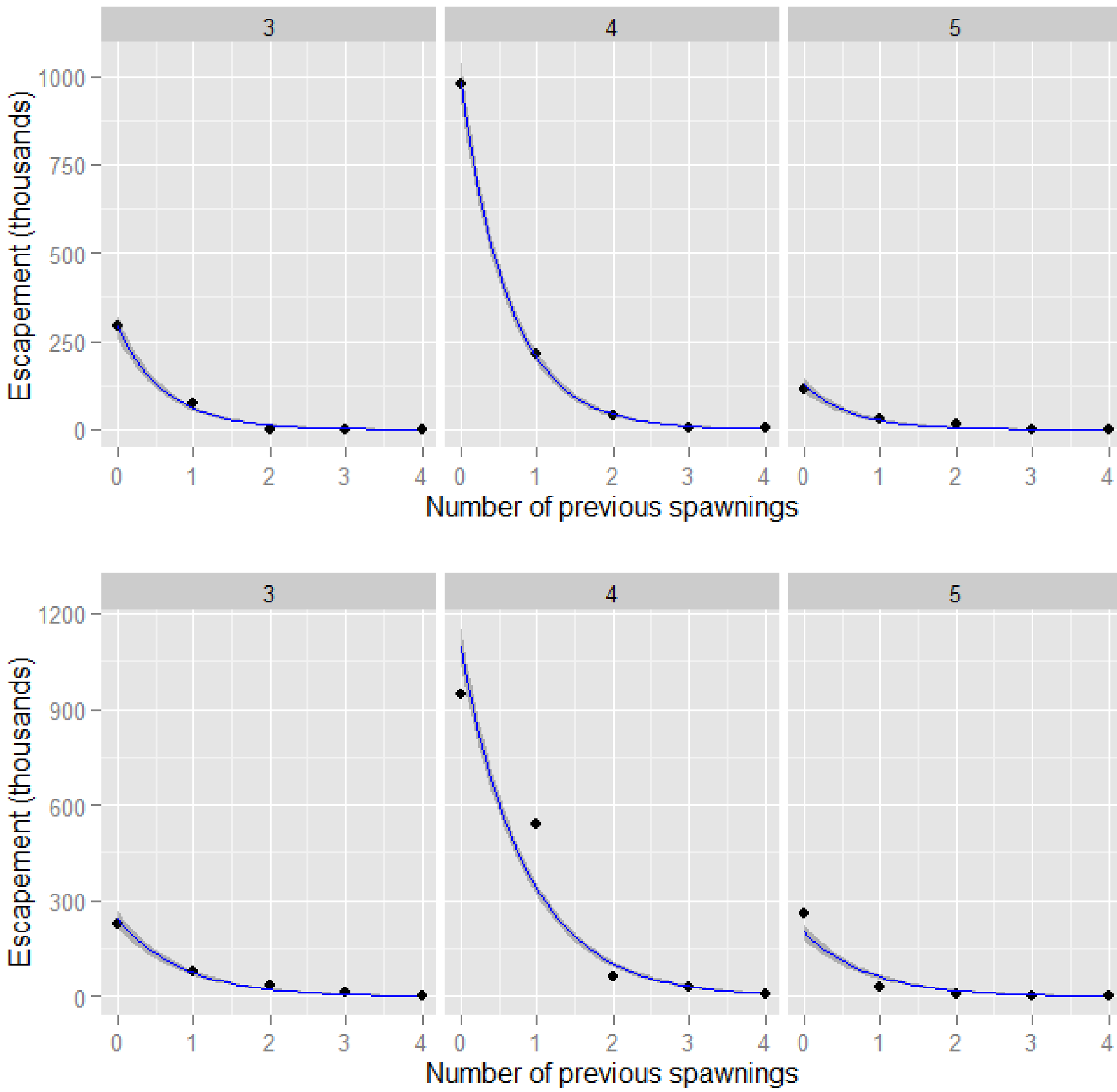

Figure 16. The fit of a Generalized Linear Model (blue lines) assuming a Poisson distribution for the response used to estimate Z for 2014 (top panel) and 2015 (bottom panel) from the estimated numbers at age (points) for each age at maturity (panel headings 3,4,5) for Alewife.

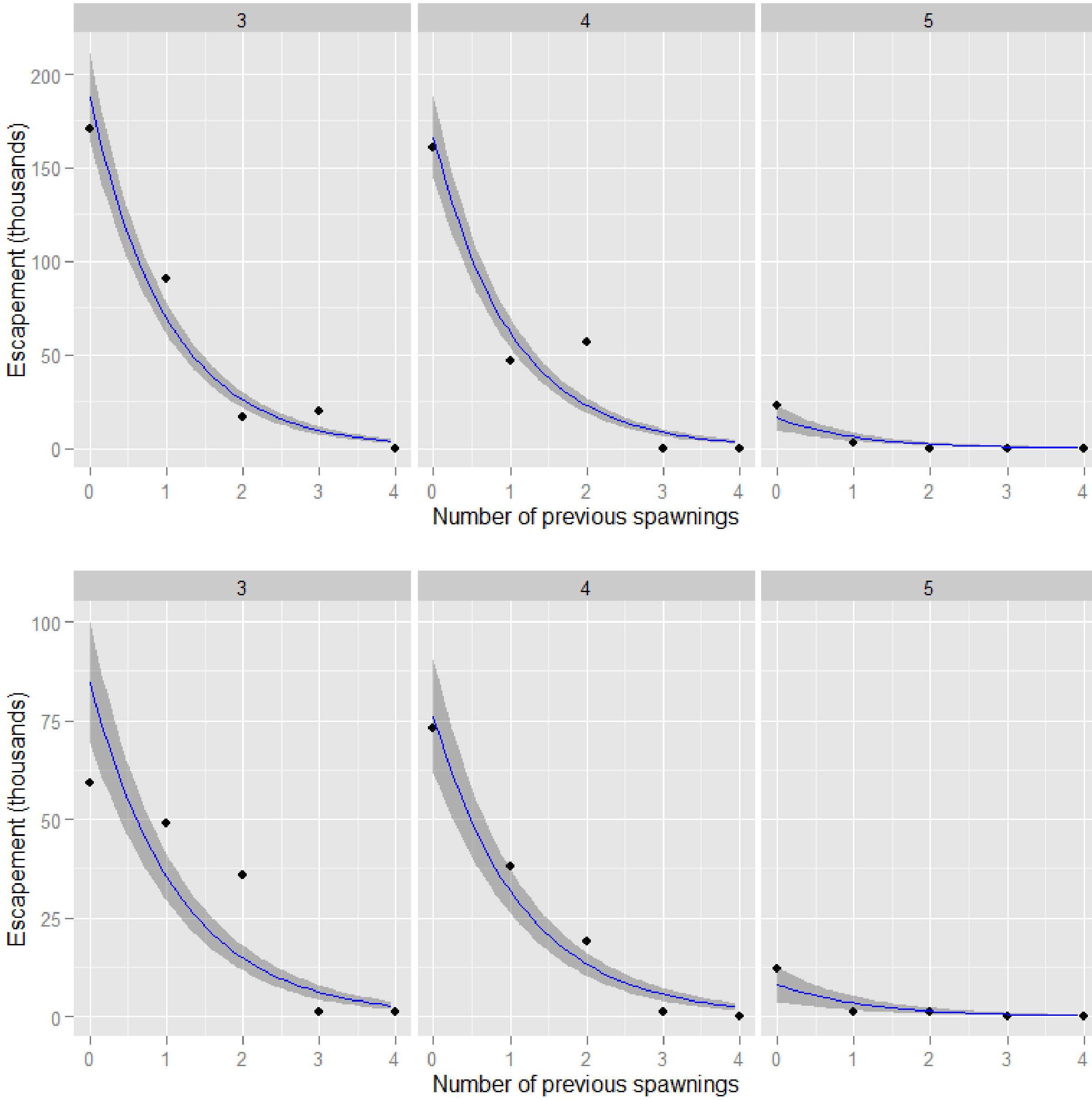

Figure 17. The fit of a Generalized Linear Model (blue lines) assuming a Poisson distribution for the response used to estimate Z for 2014 (top panel) and 2015 (bottom panel) from the estimated numbers at age (points) for each age at maturity (panel headings 3,4,5) for blueback.

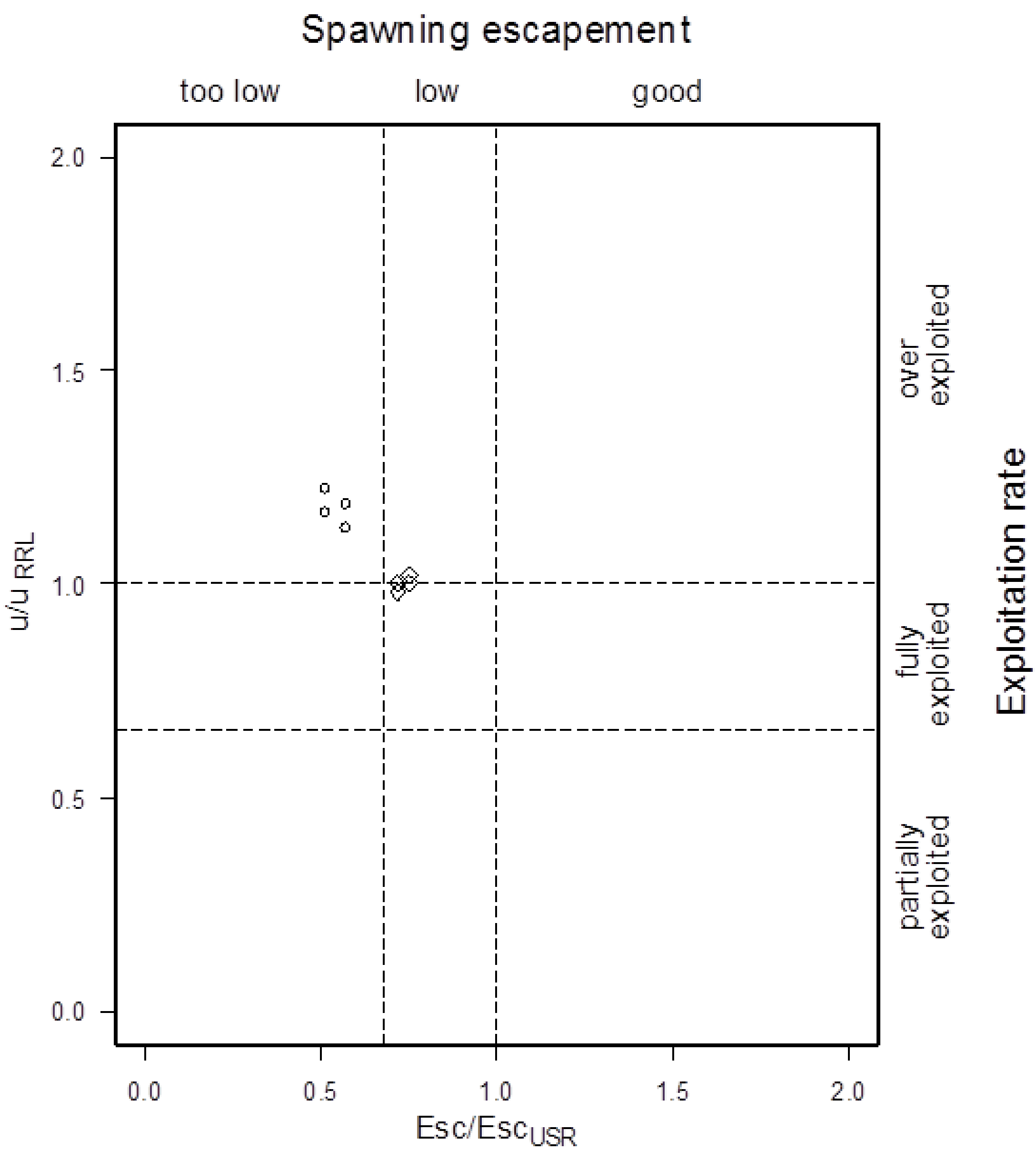

Figure 18. Application of the reference point framework to determine population status for Alewife in the Tusket River relative to the escapement and exploitation rate scenarios for 2014 (circles) and 2015 (diamonds).

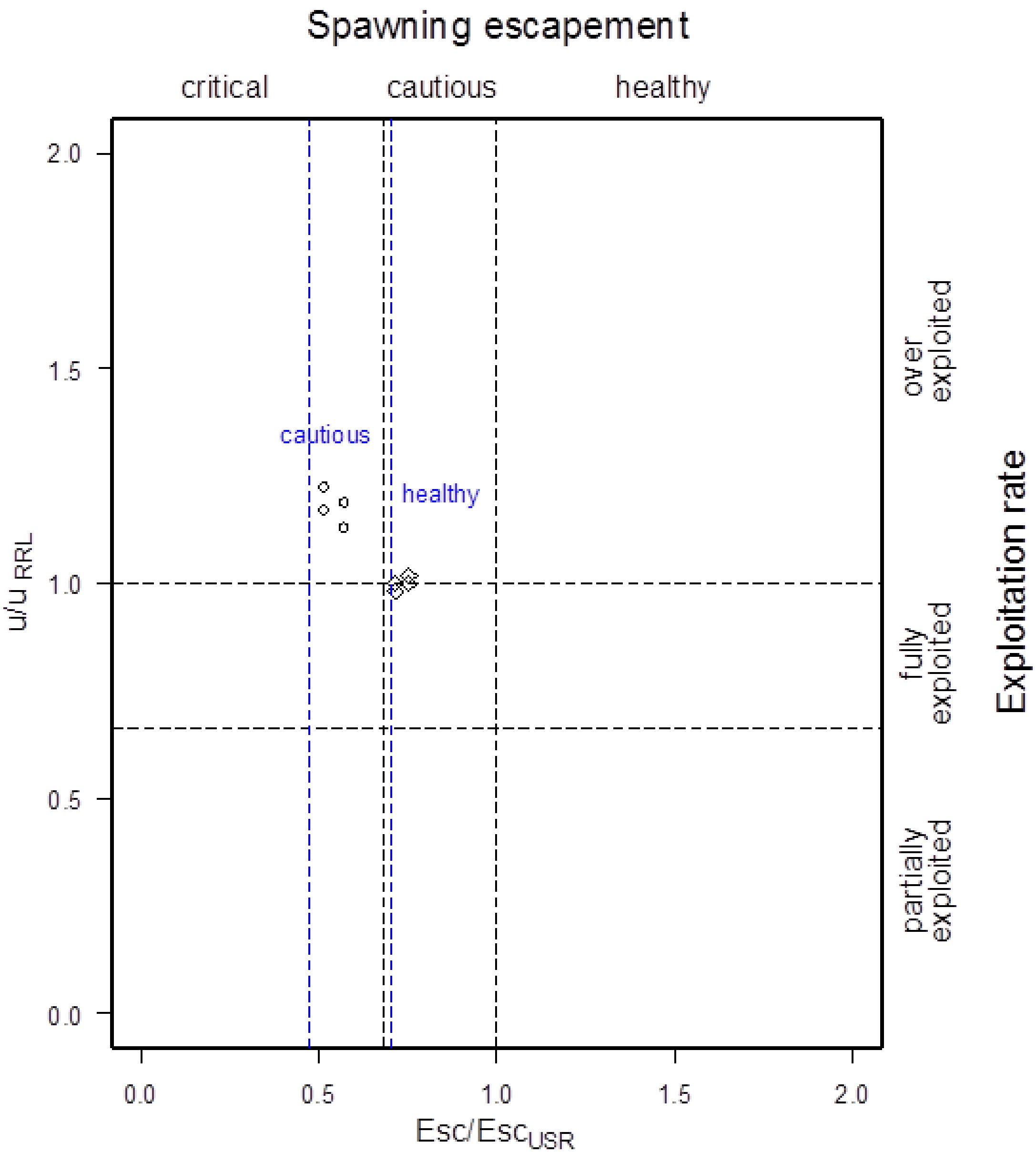

Figure 19. A Hypothetical example (blue lines and text) of how status changes relative to a 30% reduction in accessible area for spawning for Alewife in the Tusket River in 2014 (circles) and 2015 (diamonds).