North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

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North American Journal of Fisheries Management 35:1144–1151, 2015

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2015.1084407

ARTICLE

Utility of Single-Channel Electronic Resistivity Counters for Monitoring River Herring Populations

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Abstract
Automated electronic counting systems are used to estimate river herring populations throughout New England. Measuring the accuracy of these counting systems is essential to understanding the limitations of counter-derived estimates, which comprise a vital component of river herring stock assessments. Our objective was to conduct a direct visual–electronic comparison of passage to evaluate the accuracy and biases of using single-channel electronic resistivity counting systems to monitor river herring. From 1999 to 2012, we conducted 1,189 direct comparisons. Of these, 555 occurred when river herring were actively migrating through the system. The counting system consistently underestimated passage, with 34–87% of seasonal observations recording fewer fish than were known to pass. Mixed-effects logistic regression indicated that the probability of an inexact count increased with increasing passage rate, which we attribute to simultaneous passage. We explored two techniques to correct for the biases observed during our sampling period and produce corrected estimates of run size. Although our results have limitations, the consistency of observed bias provides evidence that single-channel counters yield the resolution needed to infer population trend. Future monitoring should endeavor to correct the biases in single-channel counters and to explore alternative technologies that provide greater accuracy.

River herring (Alewife *Alosa pseudoharengus* and Blueback Herring *A. aestivalis*) formerly supported important commercial and recreational fisheries along the east coast of North America. Commercial landings peaked in the late 1950s at nearly 34,000 metric tons before declining to less than 4,000 metric tons by the late 1970s (Haas-Castro 2006). River herring were listed as a Species of Concern by the National Marine Fisheries Service in 2011 (National Oceanic and Atmospheric Administration 2013), and the most recent stock assessment demonstrated the need for improved stock indices (Atlantic States Marine Fisheries Commission 2012). In response to declining stocks and these recent management events, the assessment of river herring stocks has become a high priority for federal and state management agencies.

Automatic fish counting systems are an important tool for monitoring migratory fish populations and can provide estimates of abundance and escapement. Electronic resistivity counters (ERCs) operate by monitoring changes in water conductivity caused by fish passing through a counting array (Forbes et al. 1999a; Eatherley et al. 2005). The information they provide is used to assess long-term trends in stock abundance (Moores and Ash 1984), investigate environmental influences on migration (Hellawell et al. 1974; Jensen et al. 1986; Alabaster 1990), and evaluate fishway utilization (Saila et al. 1972) and performance (Pon et al. 2006). However, ERCs have several disadvantages, including missed, false, and multiple counts (Dunkley and Shearer 1982; Smith et al. 1996; Forbes et al. 1999a, 1999b). Specifically, because ERCs may count tightly bunched schools as a single fish, they may underestimate abundance (Dunkley and Shearer 1982). These biases may limit the utility of ERCs for deriving accurate estimates of population size and identifying trends over time.

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Received April 3, 2015; accepted August 10, 2015

Electronic resistivity counters are widely deployed throughout New England to gather data on river herring populations. In several states (New Hampshire, Massachusetts, Rhode Island, and Connecticut), single-channel ERCs (SCERCs; typically Models SR 1100 and 1101; Smith-Root, Vancouver, Washington) are used to produce river herring spawning run counts ranging from hundreds to over 672,000 fish (Reback et al. 2005). Although directed studies are lacking, anecdotal information suggests that count accuracy varies considerably among rivers and at different run sizes (Massachusetts Division of Marine Fisheries [Marine Fisheries], unpublished data). Moreover, studies using single- and multi-channel ERCs conducted in the United Kingdom (Dunkley and Shearer 1982; Simpson 1997; Forbes et al. 1999a, 1999b, 2000; Eatherley et al. 2005) and on the West Coast of the United States (McCubbing et al. 2000; Coyle and Reed 2012) indicate that counter accuracy decreases as passage activity increases when counting migrating salmonids. The strong negative nonlinear relationship found between the number of fish migrating per hour and counter efficiency (Forbes et al. 1999b; McCubbing et al. 2000) suggests that the main factor affecting counter performance is simultaneous ascents (Dunkley and Shearer 1982; Shardlow and Hyatt 2004).

In concert with these findings, preliminary studies (Marine Fisheries, unpublished data) indicate that count accuracy decreases as river herring passage rates increase, particularly when multiple fish pass through the counting array simultaneously. However, salmonid studies have focused on counts of $<$20,000 individuals; river herring runs often contain $>$100,000 individuals. Hence, simultaneous ascents are likely to occur more often for river herring populations. Accordingly, biases in the accuracy of these systems may be more pronounced, ultimately limiting the utility of ERCs for assessing river herring populations.

Further assessments of these biases are needed to better determine how to interpret counter-derived data for river herring and, ultimately, to assess the utility of such data for stock assessment purposes. The objectives of this study are to (1) identify and quantify the biases associated with using a single-channel electronic resistivity counter to count river herring in the Monument River, Massachusetts; (2) determine if these systems provide an acceptable level of accuracy; and (3) investigate the possibility of correcting count data collected in past seasons to produce more accurate time series of population estimates.

STUDY SITE

The Monument River, also known as the Herring River, is a 6-km-long, first-order stream located in Plymouth County, Massachusetts. River herring enter the Monument River from the Cape Cod Canal and pass up three fish ladders before reaching their upstream nursery habitats, which consist of Great Herring (167 ha) and Little Herring (33 ha) ponds (Figure 1). Based on anecdotal information and historical harvest records (Belding 1921), the Monument River is considered one of the most productive river herring runs in Massachusetts.

METHODS

Field data collection.—We placed an SCERC (Model 1100; Smith-Root) at the upstream side of the second fish ladder (weir–pool: nine weirs, eight pools) in the Monument River (Benoit's Pond Dam) during the spring months from 1999 to 2012. The counting apparatus consisted of a white PVC circular counting tunnel (121.92-cm length, 20.3-cm diameter) outfitted with three stainless steel electrodes with centers placed at a distance equal to the tunnel diameter (Liscom and Volz 1975). Each season, we installed and calibrated the SCERC and counting tunnel prior to the onset of migration (around April 1) in accordance with manufacturer protocol. The counter was monitored and the number of fish passing upstream was recorded on a daily basis throughout the spring spawning migration. When necessary, we adjusted tunnel depth and counter sensitivity to improve flow rates and counting resolution. We monitored water velocity using a flow probe (Model FP201; Global Water Instrumentation, College Station, Texas) and observed velocities between 1.0 and 1.5 m/s, which is within the acceptable velocity range for river herring passage (Haro et al. 2004; Castro-Santos 2005).

During each SCERC check, we performed at least two visual counts for comparison. To perform these checks, one person positioned directly upstream of the array looked directly into the water and counted all fish that passed through the outlet of the counter within a 5-min period. The color contrast of the dorsal surface of fish and the white interior of the tunnel created a silhouette, enabling detection. A second person monitored the counter and recorded the number of fish that were logged during the visual counting period. When possible, a third person counted at the same time as the first person to verify the visual count.

Data analysis.—We used discrete visual counts to validate and correct SCERC records. To validate visual counts, we calculated the level of agreement, based on percent difference, between concurrent visual counts. When concurrent visual counts occurred, we only used one of the visual counts to correct the SCERC record.

We employed various methods of data exploration to understand the accuracy of SCERCs relative to various passage rates of river herring. Within each season, we calculated the proportion of observations during which the SCERC recorded perfect accuracy to those when the SCERC recorded positively or negatively biased data. When positive or negative bias was observed within a season, we calculated the median difference per observation from observed passage.

To explore how accuracy changed relative to passage rates, which we hypothesized a priori to be the major factor influencing the accuracy of the SCERC, we employed a mixed-effects logistic regression model (Bates et al. 2014). This model included a random effect for season and a fixed effect for passage rate. Passage rate was included as the observed passage

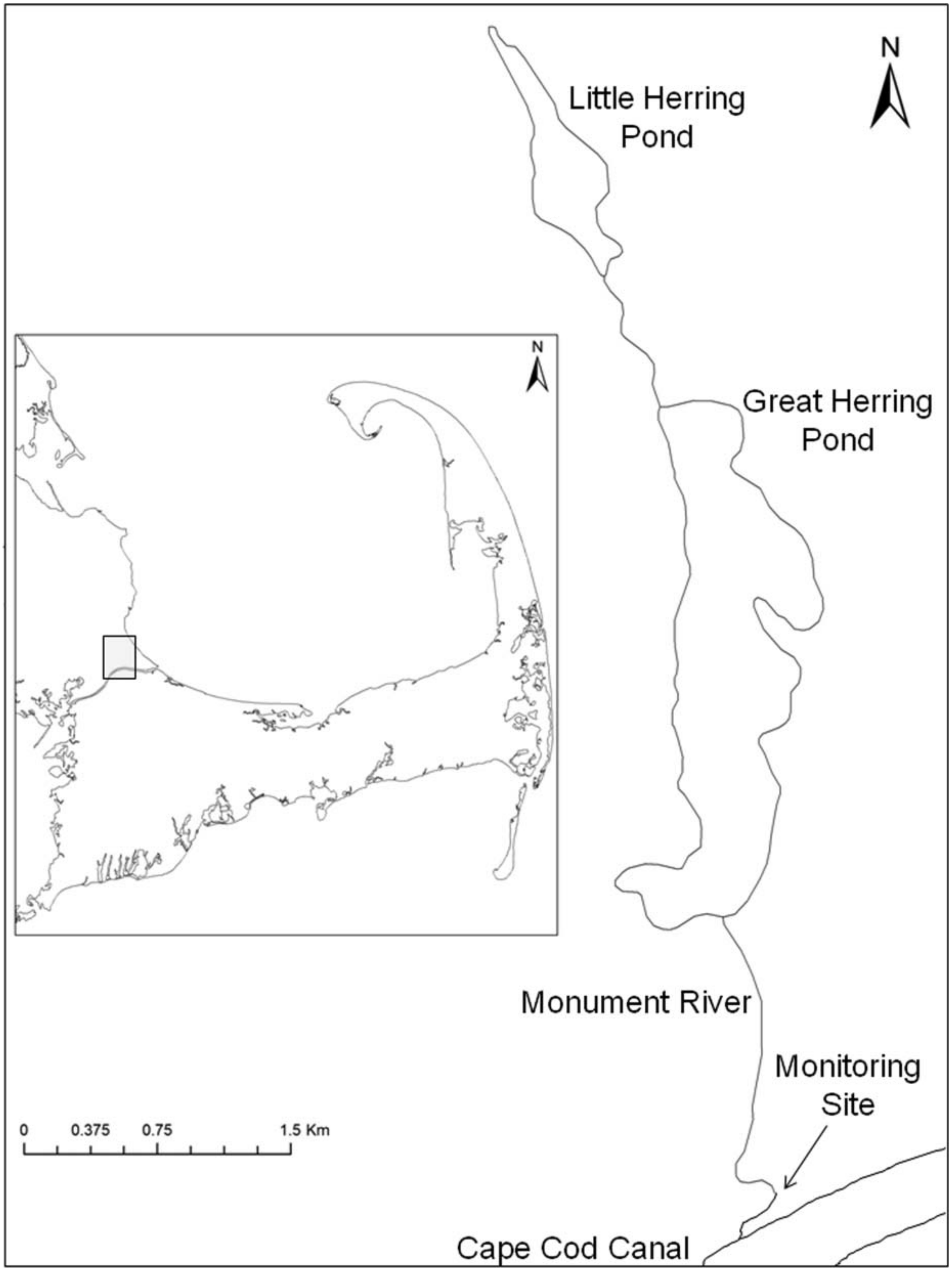

FIGURE 1. The Monument River watershed located in Plymouth County, Massachusetts (inset). Area map includes locations of spawning impoundments and the monitoring site (lower watershed).

rate for a given visual comparison. This approach allowed us to predict the probability of observing an exact count as a function of passage rate, with the random season effect allowing us to account for within-season dependence. The directionality and precision of the passage rate parameter will allow us to quantify what change, if any, appears to occur in the probability of the SCERC recording an exact count relative to differences in actual passage rate.

We then used two methods to correct for potential biases in the total season count caused by the SCERC. Our baseline for season SCERC count was based on the cumulative total of all daily counter counts. The first correction method (hereafter, "the traditional method") is the method used by Marine Fisheries in previous seasons (Nelson et al. 2011) and is similar to the correction method used by Coyle and Reed (2012). The traditional method utilizes daily comparisons to construct a correction factor, which is applied to a total daily SCERC count to correct the day's passage. We derived daily correction factors (μ_d) using equation (1), expressed as

$$\mu_d = \sum\ [v_1/c_1 + v_2/d_2 + \ldots v_i/d_i]/n, \tag{1}$$

where v is the estimate from the visual count, c is the estimate from the SCERC, and n is the number of counts per day. The daily correction factor was applied to daily total upstream counts (n_{uc}) to generate corrected daily counts (N_{cd}) using equation (2), expressed as

$$N_{cd} = n_{uc}/\mu_d. \tag{2}$$

Corrected daily counts were tallied, and the cumulative sum (equation 3) provides the estimate of total passage (T_p), given as

$$T_p = \sum(N_{cd}). \tag{3}$$

The traditional method assumed that counter checks were conducted randomly and that the correction factor was constant during a particular day.

The second method of correction (hereafter, "the reconstruction method") used each counter check as a representative "snapshot" of run activity. Within a season, all counter checks were pooled together and then sampled randomly with replacement until their total cumulative sum was within 1% of the total season count. Thus, we were able to simulate the activity that comprised the river herring run in a given season. This method assumed that counter checks were conducted randomly and that the observations comprised a representative sample of the passage activity that occurred during the run. All simulations were performed 10,000 times. The corrected count was based on the median estimate from the simulations.

RESULTS

We conducted 1,189 SCERC checks between 1999 and 2012. Of these observations, 555 occurred when fish were present. In all cases where no fish were observed, the SCERC also registered zero passage. Thus, zero points were excluded from further analysis. We performed 45 visual validation comparisons and found a high level of agreement, with a median percent difference of 1.9 (range, 0.0–14.4%). Total season passage, as registered by the SCERC, ranged from a low of 55,047 in 2011 to a high of 256,382 in 2000.

The SCERC recorded exact passage (i.e., 100% accuracy when compared with visual counts) between 11% and 66% of the time, depending on year (Table 1). Negative bias, which indicated undercounting, was present in all seasons, with the seasonal proportion of negatively biased observations ranging from 34% to 87% of all observations. The median difference associated with these observations ranged from 1.5 to 48.0 fish, depending on season. Positive biases, which would indicate overcounting, were rare, occurring only during five seasons of the study. In most seasons when positive biases occurred, they occurred <3% of the time. We note that 2009 was an exception, with 29% of all SCERC counts being positively biased. We attribute this anomaly to a brief period of high flow which appeared to influence the effectiveness of both the visual count and the SCERC.

The mixed-effects logistic regression model indicated that the probability of the SCERC providing an exact reading of passage (i.e., count accuracy) declined rapidly as passage rate increased (Figure 2). For example, the probability of providing an exact reading declined from 78% at 1 river herring/5-min interval to <10% at a passage rate of 27 river herring/5-min interval. Our estimates for the intercept parameter and the effect of passage rate from the mixed-effects logistic regression models were 1.43 (95% CI, 0.99–1.87; P < 0.01) and −0.14 (95% CI, −0.17 to −0.11; P < 0.01), respectively. The passage rate effect indicates that for every one fish increase in passage rate, the odds of the SCERC recording exact passage over a 5-min interval decreases by a factor of 0.87.

Figures 3 and 4 show run size estimates derived from the SCERC in comparison with corrected run size estimates. Our corrections of run size based on the traditional method indicated that in each season of the study, the SCERC counted 50.6–98.6% (mean, 78.6%) of the river herring that passed through (Figure 3). As run size increased, the percentage of river herring counted appeared to decrease. The largest disparity between SCERC count and estimated total passage—250,704—occurred in 2000, the most abundant run in the time series (Figure 4).

Similarly, the reconstruction method indicated that the counter recorded 37.2–96.2% (mean, 70.4%) of the river herring estimated to pass through the SCERC (Figure 3). Similar to the results of the traditional method, the reconstruction method indicated that the percentage of river herring counted decreased as

TABLE 1. Table illustrating the results of SCERC monitoring of the Monument River, Massachusetts, river herring spawning migration from 1998 to 2012. Observed passage is the raw count determined from the SCERC. Number of observations represents the number of visual-to-SCERC comparisons where river herring were observed to pass. The percent of exact measures as well as of positively and negatively biased observations are included. Median difference represents the median negative and median positive difference associated with positively and negatively biased observations.

			Exact	Negative		Positive	
Year	Raw count	Observations	Percent (%)	Percent (%)	Median difference	Percent (%)	Median difference
1999	139,387	26	15	85	11.5	0	
2000	256,382	54	11	87	48.0	2	−2.0
2001	200,294	39	26	74	37.0	0	
2002	124,303	43	44	56	11.5	0	
2003	137,595	18	50	50	7.0	0	
2004	110,197	39	36	62	8.5	3	−4.0
2005	92,621	40	55	43	2.0	3	−2.0
2006	64,267	44	32	68	2.0	0	
2007	68,152	27	37	63	4.0	0	
2008	86,741	26	35	65	3.0	0	
2009	183,374	28	38	40	2.0	23	−3.0
2010	77,541	36	53	44	6.0	3	−1.0
2011	55,047	47	66	34	1.5	0	
2012	125,611	68	32	68	6.0	0	

run size increased. We note large disparities at high rates of passage, with a difference in SCERC count and estimated total passage of 433,540 individuals in 2000 (Figure 4).

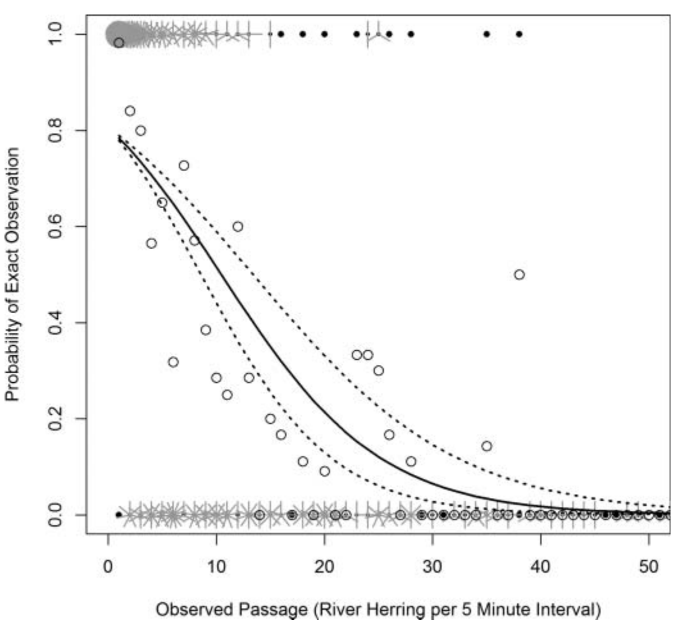

FIGURE 2. Sunflower plot illustrating the results of our mixed-effects logistic regression model relating the probability of the SCERC recording an exact measure of passage relative to observed passage rate in the Monument River, Massachusetts. Actual observations are displayed, with 1 indicating a measure of exact passage and 0 indicating a measure of nonexact passage. Each petal represents a single observation. Open circles represent observed percent accuracy, pooled among years. Dashed line represents limits of 95% CI of the fixed effect for observed passage rate.

DISCUSSION

Based on our findings, we found that the SCERC in the Monument River consistently undercounted river herring. Our mixed-effects logistic regression model supports the conclusion that SCERC accuracy is greater at lower rates of river herring passage. These results agree with those of Forbes et al. (1999b), who observed that the counting accuracy of a SCERC

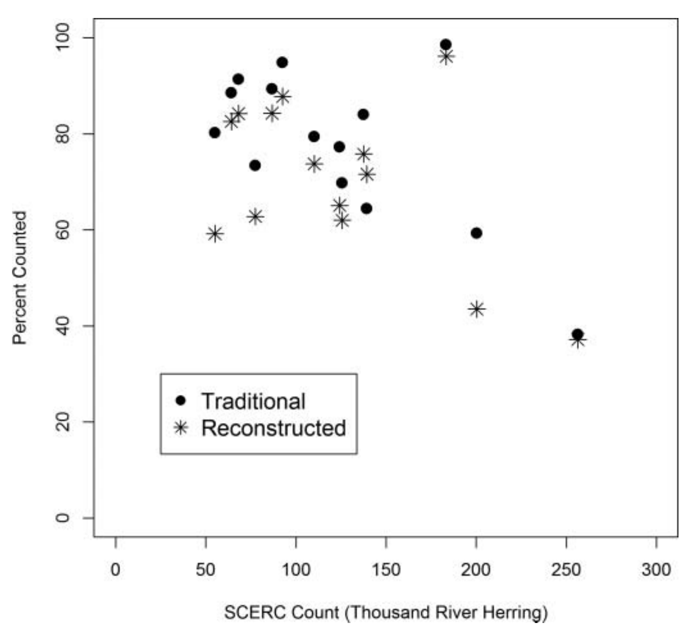

FIGURE 3. Performance of the SCERC placed in the Monument River, Massachusetts. Percent counted represents the percent counted by the SCERC relative to the traditional and reconstructed total passage estimates.

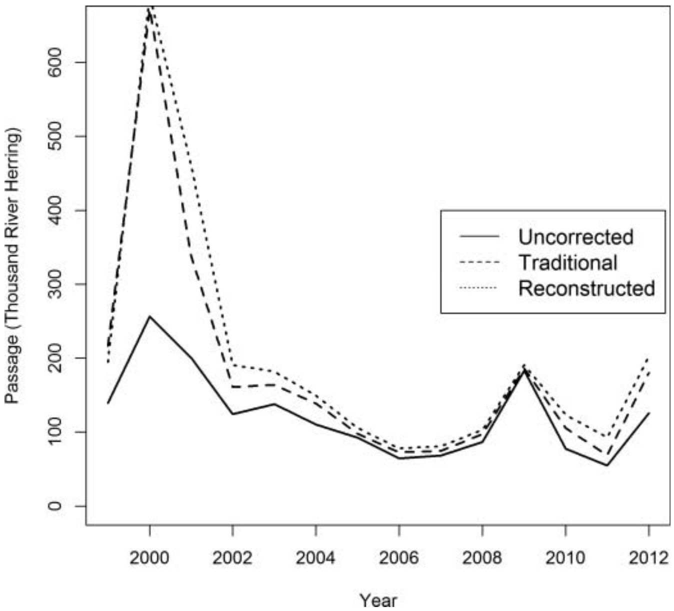

FIGURE 4. Uncorrected and corrected river herring passage counts for the Monument River river herring spawning run 1999–2012. Uncorrected counts represent raw passage estimates obtained from the SCERC. Traditional and reconstructed counts represent corrected counts based on each method.

(Model MK10; Scottish Hydro Electric) decreased as the passage of Atlantic Salmon *Salmo salar* increased. Our field observations indicate that the primary factor affecting counter accuracy was the simultaneous ascent of multiple individuals. This is also consistent with the results of Dunkley and Shearer (1982), who identified simultaneous ascents as a factor affecting the performance of a custom SCERC to count Atlantic Salmon.

The biases identified by our study appear related to the behavior of river herring relative to the counting system. In the Monument River, river herring aggregate at the entrance to the SCERC even at low densities. During the peak of the spawning run, the resting pool where the counting tunnel is located becomes saturated before river herring begin to pass in groups of multiple individuals. However, we note that based on our experience operating weir pool fishways throughout Massachusetts, river herring aggregate in each pool before passing as a group. These aggregations do not appear to be as dense in systems that are not outfitted with a SCERC, indicating that the Monument River SCERC delayed passage and served as a partial obstruction to migration. Thus, we conclude that SCERCs can exacerbate aggregation behavior. We recommend that groups operating SCERCs be aware of how aggregation behavior may be influencing the migratory patterns of river herring and, accordingly, the accuracy of uncorrected SCERC counts.

As with any counting system, SCERCs require daily maintenance to ensure optimum functionality. Thorley et al. (2005) and Dunkley and Shearer (1982) noted that variations in hydraulic conditions, such as flow rates, can affect counter accuracy. Each season, we installed and calibrated our system prior to the start of the spawning run. Our adjustments to counter sensitivity were made to ensure maximum accuracy when passage rates are low. When required, we also made in-season adjustments to counter sensitivity and hydraulic conditions (water depth and velocity). Although these adjustments undoubtedly lead to a variation in the operation of the counter, our procedure followed manufacturer recommendations. Thus, we are confident that our results are representative of the normal day-to-day operation of the counter and that our observations are applicable in other systems where SCERCs operate.

The consistency of observed bias provides guidance on how to interpret data collected from SCERCs. Because the SCERCs consistently undercounted river herring, counts generally represent an underestimate. This has important implications for monitoring and managing river herring. First, if raw counts are used to set catch targets, such targets will be conservative and provide an additional measure of safety against overharvest. Second, because SCERC biases appear consistent, we believe that inter-season count comparisons are appropriate for monitoring relative trends in abundance. However, because the biases appear to be magnified at greater rates of passage, which are likely to be more common when herring are abundant, we recommend that regulators interpret large estimates with caution. Further, we encourage users of SCERCs to explore corrective measures to adjust raw count data to a more accurate representation of the run.

Although visual checks have utility for correcting SCERC counts, this method has several important limitations. Visual validation methods are subject to error because of various environmental conditions such as turbidity, low light intensity or glare, or high flow (Eatherley et al. 2005). Because our site had favorable conditions for visual monitoring (low turbidity, limited glare), our counts were relatively accurate, a fact verified by our visual validations. We do acknowledge that in theory, visual counts may underestimate actual passage as passage rate increases. While this was not evident in our visual-to-counter comparisons, this may be more evident in larger runs, and, therefore, alternative methods for correction may be required.

Although our corrective measures have limitations, they provide insight into the magnitude of bias that can accumulate over the course of a monitoring season. Depending on season and method of correction, we found that the SCERC counted between 37% and 99% of the river herring that passed through the system. If all seasons where raw passage counts of greater than 200,000 are excluded, the SCERC counted >59% of all the river herring that passed through, regardless of method, indicating that SCERCs can provide the accuracy needed to understand the status of small- to moderate-sized river herring runs. For larger run sizes (>200,000 fish), the accuracy of these systems degrades to a level where it becomes difficult to determine accurate estimates of run size. We conclude that below this threshold, SCERCs may provide the resolution needed to infer population trend.

Future monitoring efforts should explore alternative technologies that may provide greater accuracy. For example, optical counters such as the Riverwatcher (Vaki Aquaculture Systems) are used to monitor salmonid populations in Scotland (Eatherley et al. 2005). In Connecticut, several river herring runs are being monitored using multi-channel electronic counters (e.g., Model SR1601; Smith-Root; Dalton et al. 2009; Post and Walters 2009; Walters et al. 2009) equipped with six to eight (10.16-cm) counting tunnels. Field trials using the same system were also conducted to monitor river herring passage on the Sebasticook River, Maine (Maine Department of Marine Resources 2009), using arrays equipped with 16 counting tunnels. In theory, smaller tunnel diameters will reduce simultaneous passage and, therefore, improve accuracy. In other systems, including those in Massachusetts, video monitoring has been explored as an alternative for monitoring river herring runs (Gahagan et al. 2010; Magowan et al. 2012). Because video systems can record all passage activity, the accuracy can approach a census. However, video footage requires extensive review time, which may not justify the improvement in accuracy over SCERCs. Future studies should be conducted to assess accuracy, understand inherent biases, and examine the resources required to operate alternative systems, and to determine if these systems represent a substantial improvement over SCERCs for monitoring river herring spawning runs.

ACKNOWLEDGMENTS

This is Marine Fisheries contribution 57. This research is partially funded by the U.S. Fish and Wildlife Service through the Sport Fish Restoration Program, grant F-67-R, provided to the Marine Fisheries. We thank former Marine Fisheries biologist Philips D. Brady for his many contributions to the development of this study. Additional thanks to Bradford Chase and Gregory Skomal (Marine Fisheries) for reviews at the manuscript stage. We also thank Phillip Edwards, David Ellis, Kevin Sullivan, Michael Dionne, and Nate Gray for providing information regarding the performance of their single- and multi-channel electronic counting systems and the river herring runs they monitor.

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