1 Juvenile Alosine Downstream Passage Assessment

1.1 Study Requests

Essex filed a PAD with the Commission on June 16, 2023 and a PSP on November 28, 2023. The Commission's August 15, 2023 SD1 and November 28, 2023 SD2 identified a variety of aquatic resource issues to be analyzed in the EA for the Project relicensing. The resource agencies requested a two-part approach to assess downstream passage of juvenile alosines using radio telemetry and balloon tag methods. Essex filed an RSP on April 10, 2024 that did not include a juvenile alosine downstream passage study but instead proposed a desktop assessment of downstream passage through the project turbines. FERC issued a Study Plan Determination on May 10, 2024 that included an assessment of downstream passage of juvenile alosines through the Project spillway and downstream fish bypass using balloon tags. Essex is proposing this study in response to this Study Plan Determination.

1.2 Goals and Objectives

The goal of this study is to determine if the Project operations negatively affect juvenile alosine survival. Specifically, direct survival of juvenile alosines passed downstream through the spillway and fish bypass will be estimated using a HI-Z Tag (i.e., balloon tag) mark-recapture method.

1.3 Study Area

The study area will include the section of the Merrimack River located immediately upstream and downstream of the Essex Dam near the spillway and fish bypass.

1.4 Background and Existing Information

A listing of fish passage studies specific to the Lawrence Project and highlighting the objectives and key findings of each is presented as Table 5.4-3 of the PAD. Evaluation of the downstream passage of juvenile alosines was limited to a single 1993 study which evaluated the timing and proportional use of the downstream bypass facility. It was estimated that between 43 and 67% of juvenile alosines in the forebay were passing downstream via the bypass. The 1993 study did not assess route passage survival.

1.5 Project Nexus

Adult alosines (river herring and American Shad) are known to migrate within the Merrimack River to points upstream of Lawrence and as a result, juvenile alosines must migrate downstream through the project. Direct survival estimates derived from this study will inform whether the Project negatively affects juvenile alosine passage.

1.6 Methodology

The specific objectives of this study are to estimate immediate and latent survival (1- and 48-hour, respectively) and malady-free estimates of juvenile alosines with a precision of ±10% with 90% confidence for fish passed downstream via the Project spillway and downstream fish bypass. Additionally, this study will determine injury rates, types, severity, and probable causes.

1.6.1 Sample Size Determination

One of the primary considerations associated with HI-Z Tag evaluations of direct injury and relative survival of downstream-passed fish is to release an adequate number of individuals such that the resulting survival estimates are within a pre-specified precision (ε) level (Mathur et al. 1996). The required sample sizes are a function of the recapture rate (P), expected passage survival ($\hat{\tau}$) or mortality ($1-\hat{\tau}$), survival of control fish (S), and the desired precision (ε) at a given probability of significance (α). In general, sample size requirements decrease with an increase in control survival and recapture rates. Only precision (ε) and α level can be strictly controlled by the investigator. For the purposes of this study, target releases of 60 treatment fish released for all experimental groups (spillway, bypass, control) were selected to obtain survival estimates with a precision (ε) of ±10% with 90% confidence. This sample size assumed 95% control survival, a recapture rate of ≥99%, and an expected passage survival rate between 85-90% (Table 1). During these HI-Z evaluations, the sample sizes can be adjusted in the field to obtain survival estimates that meet the study-specific precision goal.

1.6.2 Source and Collection of Test Fish

If available, wild fish from the Merrimack River basin will be collected via seining or electrofishing. In the event that fish are collected within the Merrimack Basin, no effort will be made to identify individuals to species and the collected individuals will be assumed to be representative of juvenile American shad, Alewife, and Blueback Herring. If collecting fish locally is not possible, then juvenile American shad may be able to be sourced from the North Attleboro National Fish Hatchery. Fish collection and/or transport to the Project will occur a minimum of two days prior to tagging. Fish will be transported in a circular tank filled with 7.5 ppt brackish saltwater with aeration. Once onsite, fish will be maintained in 8-foot diameter, 600-gallon circular holding tanks with a redundant, flow-through water supply. Water will be supplied by two submersible electric pumps.

Table 1. Required Sample Sizes for HI-Z Tag Studies for a Range of Control Survival, Recapture Rates, and Passage Survival

Control Survival (S)	Recapture Rate (P_A)	Passage Survival ($1-\hat{\tau}$)	Sample Size
1.00	0.99	0.95	18
		0.90	29
		0.85	39
	0.95	0.95	39
		0.90	49
		0.85	57
	0.90	0.95	69
		0.90	76
		0.85	82
0.95	0.99	0.95	45
		0.90	54
		0.85	61
	0.95	0.95	67
		0.90	74
		0.85	80
	0.90	0.95	98
		0.90	103
		0.85	107

1.6.3 Fish Tagging and Release

Fish tagging, release, and recapture techniques will be similar to those used in other HI-Z studies on juvenile alosines at other hydroelectric stations on the east coast (Heisey *et al*. 1992; RMC 1994; Normandeau Associates 1996, 2016; Normandeau Associates, Inc. and Gomez and Sullivan Engineers, P.C. 2012). Differing from those previous evaluations, the juvenile alosines will be anesthetized in a solution of MS-222 in 7.5 ppt brackish saltwater (Deters et al. 2024). Each fish will be fitted with a neutrally buoyant miniature radio transmitter and one HI-Z Tag. The tagged fish will be released by an induction system (Figure 1) either into the passage routes (treatment) or tailrace of the facility (control). Just prior to release into the induction system, the tags will be activated by injecting 1-1.5 ml of catalyst. Details of the tag and release technique are given in Heisey *et al*. (1992).

For this study, Essex will evaluate juvenile alosine passage through the existing downstream bypass facility which provides surface spill from the forebay and via spill flow passed over Essex Dam. Essex Dam. The spillway crest is topped by an Obermeyer pneumatic crest gate system with three independently controllable zones, each 300 feet in length. Essex will consult with the Merrimack River Technical Committee on an appropriate release location which is representative of the spillway and also provides project staff with safe working conditions under which to release and recover test fish.

Figure 1. A juvenile American Shad with a HI-Z Tag attached being released into an induction system.

1.6.4 Recapture

Two recapture boats will be used to retrieve fish downstream of the Project throughout the study. The post-passage dispersal of fish will be determined via radio transmitter signals received on Advanced Telemetry Systems R2000 receivers coupled to loop antennas. Fish will be tracked and recaptured after the HI-Z Tags buoy them to the surface (Figure 2). Boat teams will be notified of the radio transmitter frequency and ID of each fish upon release. To eliminate crew bias, boat crews will not be assigned to recapture specific groups of fish (treatment or control).

Recaptured fish will be placed into onboard holding buckets filled with 7.5 ppt saltwater and the HI-Z Tags and radio transmitters will be removed. The immediate post-passage status of individual recaptured fish will be designated as alive, dead, unknown, or predation. These criteria will used to make these designations:

1. alive: recaptured alive and remained so for 1 hour;

2. alive: the fish is not physically recaptured, but radio signals indicate movement patterns typical of emigrating juveniles;

3. dead: recaptured dead or dead within 1 hour of release;

4. dead: the fish is not physically recaptured, but a dislodged inflated tag was recovered and/or telemetric tracking indicates a stationary signal, and the manner in which inflated tag surfaces is not indicative of predation;

5. unknown: neither dislodged tags nor fish are recovered and/or radio signals are received only briefly, and the subsequent status cannot be ascertained; and

6. predation: fish are either visually observed being preyed upon, the predator is buoyed to the surface, distinctive bite marks are present on a recaptured fish, or subsequent radio telemetric tracking and/or tag dislodgment indicates predation (i.e., rapid movements of tagged fish in and out of turbulent waters or sudden appearance of fully inflated tags more than 5 minutes after release).

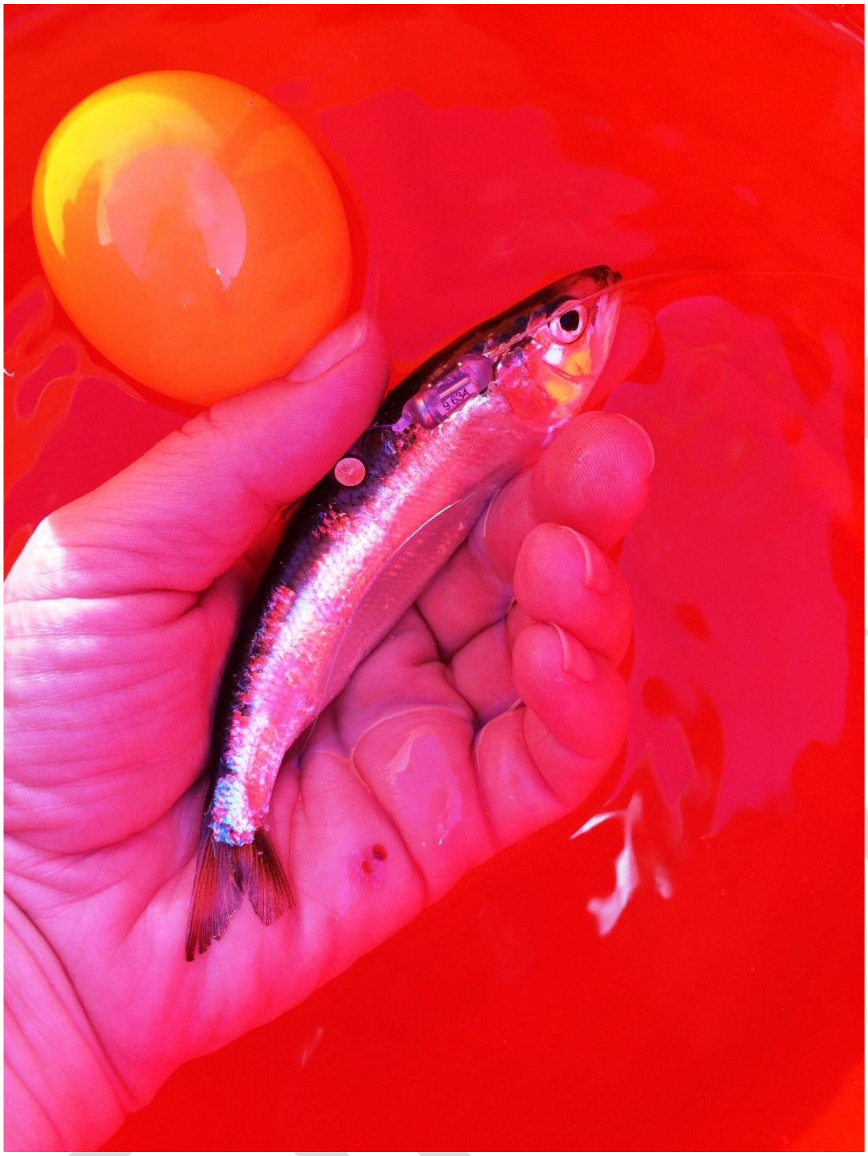

Figure 2. A juvenile American Shad after recapture during a HI-Z study.

1.6.5 Classification of Recaptured Fish

Each fish will be immediately examined for descaling, injuries, and abnormal swimming behavior and injury codes will be assigned to describe their status (Table 2). Injury and descaling will be categorized by type, extent, and area of body. A fish will be classified descaled if ≥20% of the scales were missing on a side. Fish without any visible injuries but not actively swimming or swimming erratically at recapture will be classified as having “loss of equilibrium” (LOE). This condition has been noted in past studies and often disappears within 10 to 15 minutes after recapture if the fish has no other apparent injuries (Normandeau et al. 2008).

Active radio transmitters that fail to surface will be tracked for the remainder of each day to determine whether those transmitters are suspected of being dislodged from the fish, continuing to display downstream movement patterns typical of emigrating alosines, or show rapid movement within the tailrace into and out of turbulent areas (typical of predation). Assumptions regarding the status of these fish can be made based on these designations, and each fish will be assigned an appropriate status code (Table 3). Fish that become trapped within unrecoverable or unsafe areas will be recorded and removed from the analysis.

Recaptured fish will be transferred to onsite 8-ft-diameter circular holding tanks equipped with a redundant water supply via electric, submersible pumps. Fish will be held for 48-h to monitor delayed mortality. Fish released and recaptured on each day will be held in the same tank. A final thorough injury examination will occur at the end of the 48-h holding period to detect injuries that may not have been apparent or were overlooked during the initial evaluation at recapture. Photographs of dead and injured fish will be taken after the 48-h holding period.

Mortality of recaptured fish after 1 h post-passage will be considered 48-h mortality. However, the condition of fish will be evaluated at intervals of approximately 12 hours. Dead fish will be examined for descaling and injury and will be necropsied to determine the probable cause of mortality.

Probable causes of injury (e.g., mechanical, shear, or pressure-related) will be ascribed to each injured fish depending on the observed injury characteristics. In the case of some injuries, probable causes cannot be attributed directly to one source. However, in other instances the unique characteristics of the observed injuries will be used to delineate specific causes of injury.

Injuries likely to be associated with direct contact with structural components will be classified as mechanical and include bruising, lacerations, and severance of the fish body. Injuries likely to be attributed to shear forces are decapitation (with the isthmus attached to the body and a slanted wound), torn or flared opercula, and inverted or broken gill arches. The probable pressure-related effects are manifested as bloody eyes, ruptured/bulging eyes, air bladder rupture, hemorrhaged internal organs, and embolism; however, shear forces can also inflict hemorrhaged/ruptured eyes, and most eye injuries resulting from turbine and spillway passage have been attributed to shear forces (Pflugrath et al. 2021).

Injuries will be categorized as minor or major following the same procedures as previous evaluations (Table 4).

Table 2. Injury Codes Assigned to Each Recaptured Fish

Injury Code	Description
A	No visible injuries on fish and is not displaying LOE (malady-free)
B	Damaged gill(s): hemorrhaged, torn, or inverted
C	Damaged operculum: torn, bent, removed
D	Major scale loss (>50%)
E	Minor scale loss (>20% but <50%)
F	Damaged eye(s): hemorrhaged, bulged, ruptured, or removed
G	Severed or nearly severed body
H	Decapitated or nearly decapitated
I	Laceration(s): tear(s) on body or head (not severed)
J	Torn isthmus
K	Hemorrhaged or bruised head or body
L	Fins damaged: displaced, hemorrhaged, ripped/torn, or removed
M	Abrasion/scrape
N	LOE and remaining so for >20 minutes
O	Tear at the tag site (HI-Z Tag dislodged)
P	Predation injuries/marks
Q	Substantial bleeding at tag site
R	Bleeding from gills or mouth
1	Swim bladder ruptured
2	Damaged kidneys
3	Broken bones obvious
4	Internal hemorrhaging
5	Organ displacement
6	Heart damage (ruptured, hemorrhaged)
7	Liver damage (ruptured, hemorrhaged)
8	Necropsied; no internal injuries observed
9	Spine damage (broken vertebrae, hemorrhaged)

Table 3. Status Codes Assigned to Each Released Fish

Status Code	Description
1	Fish recaptured without passage-related maladies
2	Fish recaptured with passage-related visible injury
3	Fish recaptured with loss of equilibrium only (LOE) and remaining so for >20 minutes
4	Fish recaptured with a tear at the tag site only (HI-Z Tag dislodged)
5	Fish not recaptured; stationary radio signal
6	Fish not recaptured; mobile radio signal
7	Fish not recaptured and a single, detached HI-Z Tag is recaptured
8	Fish not recaptured and likely preyed on based on telemetry or other info
9	Replaced; unrecoverable conditions
10	Replaced; trapped
11	Replaced; failed to enter system
12	Other information
13	No information

Table 4. Major and Minor Injury Classifications

Injury/Condition	Classification	
	Major	Minor
Loss of equilibrium (LOE) only	Fish dies within 1 h	Fish survives beyond 1 h
No visible external or internal injuries	Fish dies within 1 h	Fish survives beyond 1 h
Any minor injury	Fish dies within 1 h	Fish survives beyond 1 h
Hemorrhaged eye(s)	>50% hemorrhaged	<50% hemorrhaged
Deformed pupil(s)	Always considered major	
Bulged eyes	1 or both eyes entirely bulged	Only 1 eye slightly bulged
Bruises	>10% of body per side	<10% of body per side
Operculum tear	>5% of operculum	<5% of operculum
Operculum folded under or torn off	Always considered major	
Scale loss	≥50% per side	>20% and <50%
Scrape (damage to epidermis)	>10% per side	<10% per side
Cut/laceration	Generally, any cut/laceration	Small flap of skin cut/torn
Internal hemorrhage or ruptured organ	Fish dies within 96 h	Fish survives beyond 96 h
Broken backbone	Always considered major	
Multiple injuries	Dependent upon worst injury	

1.6.6 Survival and Malady-Free Estimation

Survival and malady-free (MF) estimates will be calculated for the spillway and bypass, and the data collected over multiple days (trials) will be pooled if the results were not significantly different. The MF metric provides a standardized way to depict a specific passage route's effect on the condition of entrained fish and was based solely on fish recaptured and examined. The MF metric will not include fish that were assumed to be either dead or alive based on telemetric information or the recovery of inflated HI-Z Tags only.

Passage survival or MF rates will be estimated relative to the respective control rates using the likelihood model given in Mathur et al. 1996.

The estimators associated with the likelihood model are:

For estimating survival ($\hat{\tau}$):

$$\hat{\tau} = \frac{a_T R_c}{R_T a_c}$$

where:

R_T = number of fish released for the treatment condition;

a_T = number of fish alive for the treatment condition;

R_c = number of control fish released; and

a_c = number of control fish alive.

For malady-free (MF):

$$MF = \frac{m_T E_c}{E_T m_c}$$

where:

E_T = number of treatment fish examined for maladies;

m_T = number of treatment fish without maladies;

E_c = number of control fish examined for maladies; and

m_c = number of control fish without maladies.

MF rates will be based on the proportion of recaptured fish without passage-related visible injuries, LOE, and/or scale loss (>20%) or fish with injuries that are not attributable to passage.

1.6.7 Derivation of Precision and Maximum Likelihood Parameters

The statistical description below is an excerpt from Normandeau and Skalski (2000).

The estimation for the likelihood model parameters is given herein. Additionally, the results of statistical analyses for evaluating homogeneity in recapture and survival probabilities and in testing hypotheses of equality in parameter estimates under the simplified (H_O: P_A=P_D) versus the most generalized model (H_A:$P_A \neq P_D$) are given.

The following terms are defined for the equations and likelihood functions that follow:

R_C = Number of control fish released

R_T = Number of treatment fish released

$R = R_C = R_T$

N = Number of replicate estimates $\hat{\tau}_i$ (i=1,…,n)

a_C = Number of control fish recaptured alive

d_C = Number of control fish recaptured dead

a_T = Number of treatment fish recaptured alive

d_T = Number of treatment fish recaptured dead

S = Probability fish survive from the release point of the controls to recapture

P_A = Probability an alive fish is recaptured

P_D = Probability a dead fish is recaptured

$\hat{\tau}$ = Probability a treatment fish survives to the point of the control releases (i.e., passage survival)

1- $\hat{\tau}$ = Passage-related mortality.

The precision of the estimate is defined as:

$$P(-\varepsilon < \hat{\tau} - \tau < \varepsilon) = 1 - \alpha$$

or equivalently:

$$P(-\varepsilon <| \hat{\tau} - \tau |< \varepsilon) = 1 - \alpha$$

where the absolute errors in estimation (i.e., $|\hat{\tau} - \tau|$) is $<\varepsilon$ $(1-\alpha)$ 100% of the time, $\hat{\tau}$ is the estimated passage survival, and ε is the half-width of a $(1-\alpha)$ 100% confidence interval for $\hat{\tau}$ or 1- $\hat{\tau}$. A precision of 10%, with 90% confidence is shown as $P(|\hat{\tau} - \tau|<0.10) = 0.90$.

Precision is defined as:

$$P(| \bar{\hat{\tau}} - \bar{\tau} |< \varepsilon) = 1 - \alpha$$

$$P(-\varepsilon < \bar{\hat{\tau}} - \bar{\tau} |< \varepsilon) = 1 - \alpha$$

$$P\left(\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} < t_{n-1} < \frac{\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} \right) = 1 - \alpha$$

$$P\left(t_{n-1} < \frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} \right) = \alpha / 2$$

$$\Phi\left(\frac{-\varepsilon}{Var(\bar{\hat{\tau}})} \right) = \alpha / 2$$

$$\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} = t_{\alpha/2,n-1}$$

$$Var(\bar{\hat{\tau}}) = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1 - S\tau P_A)}{R_T} + \frac{(1 - SP_A)\tau}{R_C} \right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

where σ_τ^2=natural variation in passage-related mortality.

Now letting R_T=R_C

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1 - S\tau P_A)}{R} + \frac{(1 - SP_A)\tau}{R} \right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

which must be iteratively solved for n given R. Or R given n where:

$$R = \frac{\frac{\tau}{SP_A}\left[(1 - S\tau P_A) + (1 - SP_A)\tau \right]}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2,n-1}} - \sigma_\tau^2 \right]}$$

$$R = \frac{\frac{\tau(1+\tau)}{SP_A}}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2,n-1}} - \sigma_\tau^2 \right]}$$

$$R = \frac{\tau(1+\tau)}{SP_A}\left[\frac{t^2_{1-\alpha/2,n-1}}{n\varepsilon^2 - \sigma_\tau^2 t^2_{1-\alpha/2,n-1}} \right].$$

The joint likelihood for the passage-related mortality is:

$L\ (S,\ \tau,\ P_A,\ P_D \mid R_C,\ R_T,\ a_C,\ a_T,\ d_C,\ d_T)=$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_T}{a_T d_T}(S\tau P_A)^{a_T}((1-S\tau)P_D)^{d_T}(1-S\tau P_A-(1-S\tau)P_D)^{R_T-a_T-d_T}\ .$$

The likelihood model was based on the following assumptions: (1) the fate of each fish is independent, (2) the control and treatment fish come from the same population of inference and share that same survival probability, (3) all alive fish have the same probability, P_A, of recapture, (4) all dead fish have the same probability, P_D, of recapture, and (5) passage survival (τ) and survival (S) to the recapture point are conditionally independent. The likelihood model has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_C, d_C, a_T, d_T).

Because two treatment releases (spillway and bypass) will be made concurrently with a single shared control group, we used the likelihood model that considered dependencies within the study design (Normandeau et al. 1995). For any two treatment groups (denoted τ_1 and τ_2), the likelihood model is as follows:

$$L(S,\tau_1,\tau_2,P_A,P_D \mid R_C,R_{T_1},R_{T_2},a_C,d_c,a_{T_1},d_{T_1},a_{T_2},d_{T_2})=$$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_{T_1}}{a_{T_1} d_{T_1}}(S\tau_1 P_A)^{a_{T_1}}((1-S\tau_1)P_D)^{d_{T_1}}(1-S\tau_1 P_A-(1-S\tau_1)P_D)^{R_{T_1}-a_{T_1}-d_{T_1}}$$

$$\times\binom{R_{T_2}}{a_{T_2} d_{T_2}}(S\tau_2 P_A)^{a_{T_2}}((1-S\tau_2)P_D)^{d_{T_2}}(1-S\tau_2 P_A-(1-S\tau_2)P_D)^{R_{T_2}-a_{T_2}-d_{T_2}}\ .$$

This likelihood model has the same assumptions as stated in Normandeau and Skalski (2000) but has five estimable parameters (S, τ_1, τ_2, P_A, and P_D). The survival rate for treatment T_1 is estimated by τ_1 and for treatment T_2, by τ_2. A likelihood ratio test with 1 degree of freedom will be used to test the hypotheses of equality in parameter estimates under the simplified (H_O: $P_A=P_D$) versus the most generalized model (H_A:$P_A \neq P_D$).

The estimators associated with the likelihood model are:

$$\hat{\tau}=\frac{a_T R_C}{R_T a_C}$$

$$\hat{S}=\frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C} \; .$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1-\hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau}) = Var(\hat{\tau}) = \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau}) = SE(\hat{\tau}) = \sqrt{Var(1-\hat{\tau})}$$

1.7 Schedule, Level of Effort, and Estimated Cost

The Juvenile Alosine Downstream Passage Study will be conducted during the 2025 passage season. The cost for this study is estimated at approximately $150,000.

1.8 Discussion of Alternative Approaches

The proposed methods for this study are consistent with accepted professional practices. The overall approach is commonly used in relicensing proceedings and is consistent with generally accepted methods for and analytical techniques used by federal and state agencies. In addition, the proposed methods for this study are consistent with FERC study requirements under the ILP. No alternative approaches to this study are necessary.

1.9 Literature Cited

Deters, K. A., R. P. Mueller, S. A. Liss, J. M. H. Li. J. J. Martinez, R. A. Harnish, J. Lu, and Z. D. Deng. 2024. Development of optimal methods for collection, transportation, holding, handling, and tagging of juvenile American shad. Reviews in Fish Biology and Fisheries. 34, 731-751 (2024). https://doi.org/10.1007/s11160-024-09835-5

Heisey, P. G., D. Mathur, and T. Rineer. 1992. A reliable tag-recapture technique for estimating turbine passage survival: application to young-of-the-year American Shad (*Alosa sapidissima*). Can. Jour. Fish. Aquat. Sci. 49:1826-1834.

Mathur, D., P. G. Heisey, E. T. Euston, J. R. Skalski, and S. Hays. 1996. Turbine passage survival estimation for Chinook salmon smolts (*Oncorhynchus tshawytscha*) at a large dam on the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 53:542-549.

Normandeau Associates, Inc. 1996. Estimation of survival and injuries of juvenile American Shad in passage through a Francis turbine at the Vernon Hydroelectric Station, Connecticut River. Draft Report prepared for New England Power Co., Westborough, MA.

Normandeau Associates, Inc. 2016. TransCanada Hydro Northeast Inc. ILP Study 22: Downstream Migration of Juvenile American Shad at Vernon. Report prepared for TransCanada Hydro Northeast Inc., Concord, NH.

Normandeau and Skalski, J. R. 2000. Evaluation of prototype shallow-flat flow deflector at Wanapum Dam spillbay 5 relative to Chinook salmon smolt passage survival, 1999. Report prepared for Grant County Public Utility District No. 2. Ephrata, WA.

Normandeau Associates, Inc., J.R. Skalski, and R.L. Townsend. 2008. Turbine operational effects on survival/condition of juvenile Chinook Salmon, *Oncorhynchus tshawytscha*, at Ice Harbor Dam, March 2007. Report prepared for U.S. Army Corps of Engineers Walla Walla District.

Normandeau Associates, Inc., and Gomez and Sullivan Engineers, P.C. 2012 Estimation of survival of juvenile American Shad passed through Francis turbines, RSP 3.2, Conowingo Hydroelectric Project. Report prepared for Exelon, Kennett Square, PA.

Pflugrath, B .D., R. K. Saylor, K. Engbrecht, R. P. Mueller, J. R. Stephenson, M. Bevelhimer, B. M. Pracheil, and A. H. Colotelo. 2021. Biological response models: predicting injury and mortality of fish during downstream passage through hydropower facilities. U.S. Department of Energy Report. PNNL-30893.

RMC. 1994. Turbine passage survival of juvenile American Shad (*Alosa sapidissima*) at Conowingo Hydroelectric Station (FERC Project No. 405), Susquehanna River, Maryland. Prepared for Susquehanna Electric Company, Darlington, MD.