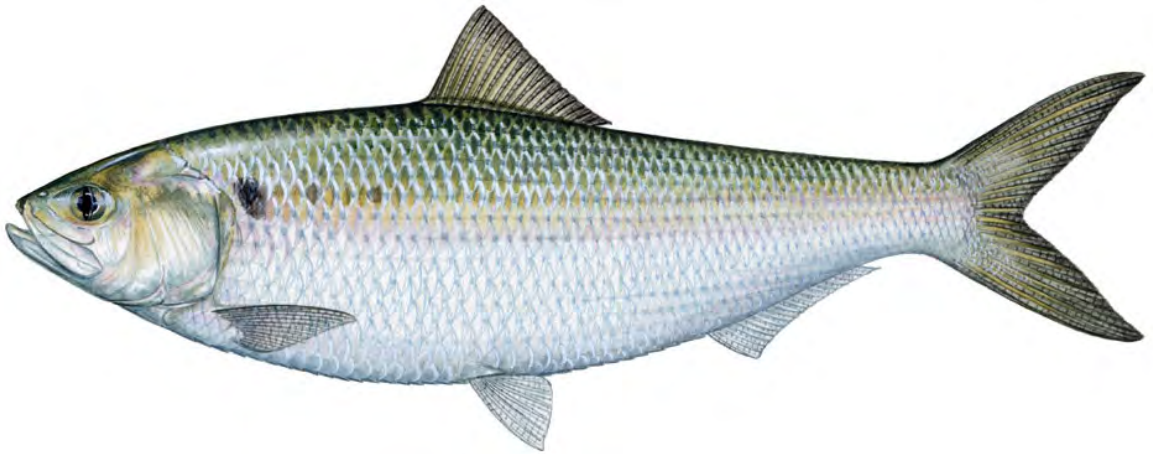
Turners Falls Hydroelectric Project (FERC No. 1889)
Northfield Mountain Pumped Storage Project
(FERC No. 2485)

Data Analysis Workshop

March 8, 2016

Study Overview

Proposed Analysis of Telemetry and PIT Data for Study Report 3.3.2 Evaluate Upstream and Downstream Passage of Adult American Shad



Study Overview

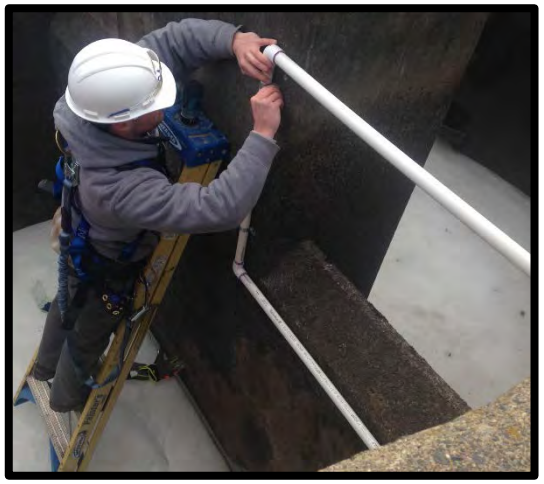
Objectives…

- Describe the effectiveness of the Cabot fish ladder;
- Evaluate attraction, entrance efficiency and internal efficiency of the gatehouse ladder;
- Identify migration delays resulting from continued operation of the Turners Falls Project;
- Determine route selection and behavior of upstream migrating shad at the Turners Falls Project under various spill flow levels;
- Evaluate attraction, entrance efficiency and internal efficiency of the spillway ladder for shad reaching the dam spillway, under a range of spill conditions;

Study Overview

Objectives Continued

- Evaluate migration through the Turners Falls Impoundment;
- Identify impacts of Northfield Mountain, Cabot Station and Station No. 1 operations on upstream and downstream adult shad migration, including delays, entrainment, behavioral changes and migration direction shifts.
- Determine downstream passage route selection, timing/delay, and survival at Turners Falls Dam; and
- Determine passage rates and routes taken by shad migrating downstream through the canal, and evaluate Cabot Station fish bypass effectiveness.



Study Overview

Study Area

- Fix Monitoring – Lower Holyoke Impoundment to Shearer Farms Area (~0.5 miles upstream of the NMPS Intake)
- Mobile Tracking – Holyoke Dam to Northfield Mount Hermon (once per week) Hatfield S-curves to Northfield Mount Hermon School (once per week)

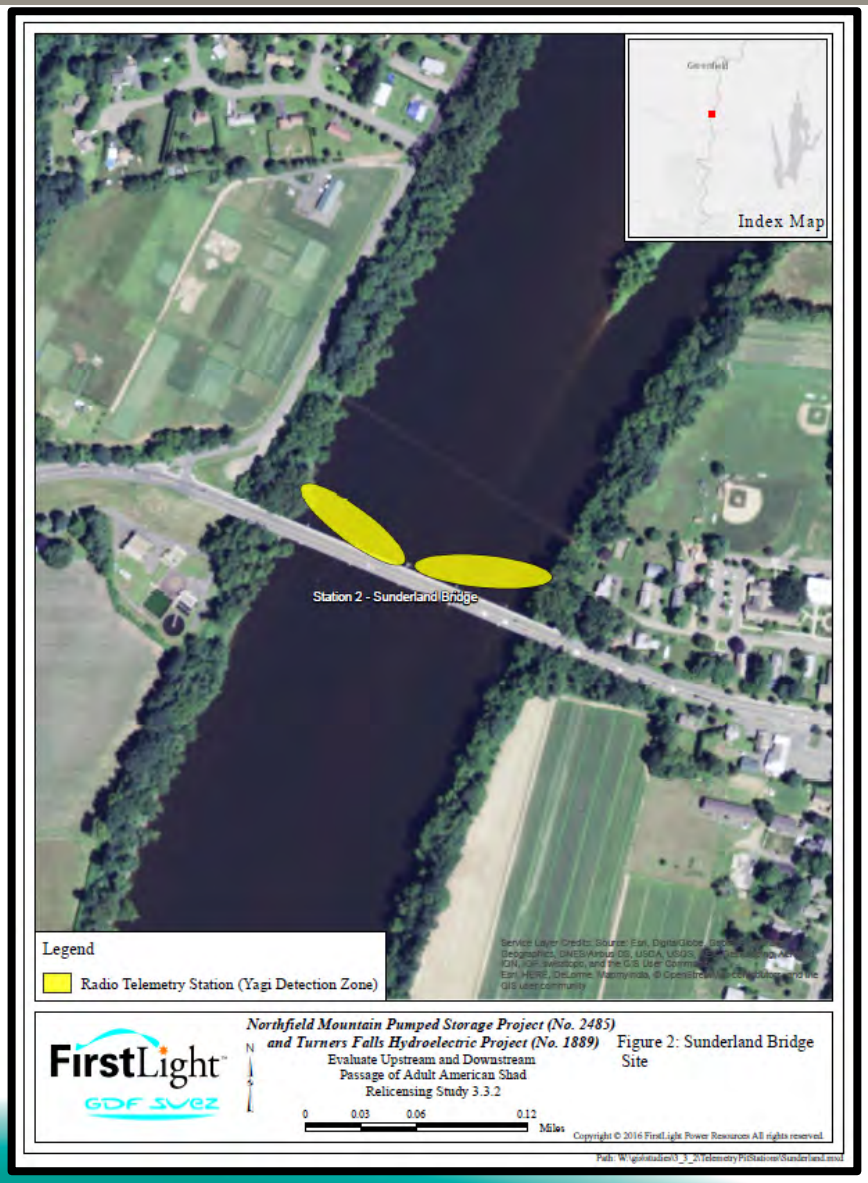
Study Overview

Deployment

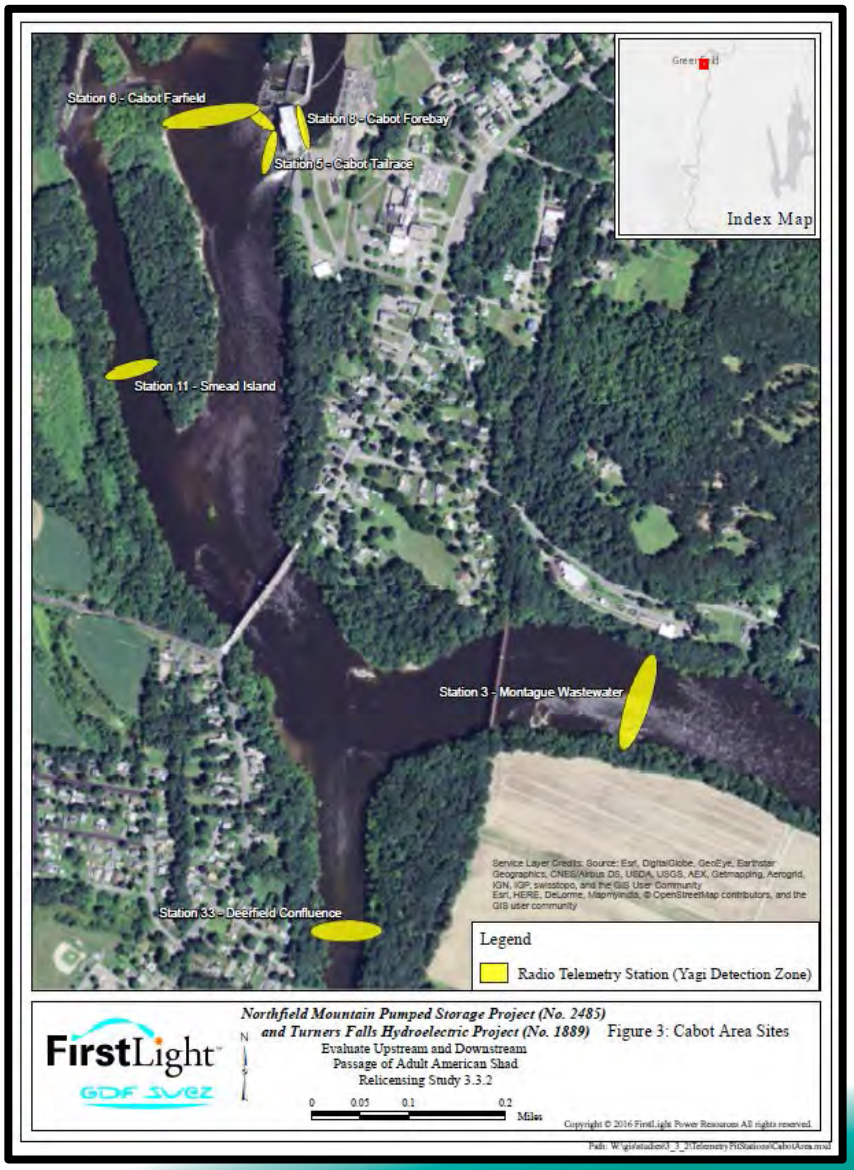
A total of 20 radio telemetry monitoring station using 29 receivers and 13 RFID station were deployed within the study area.

- Receivers included: Orion, SRX 800 and SRX 400
  - SRX models were programed for frequency switching 2.2 second
- Antennae included: 3 element yagi, dipole and stripped coax cable

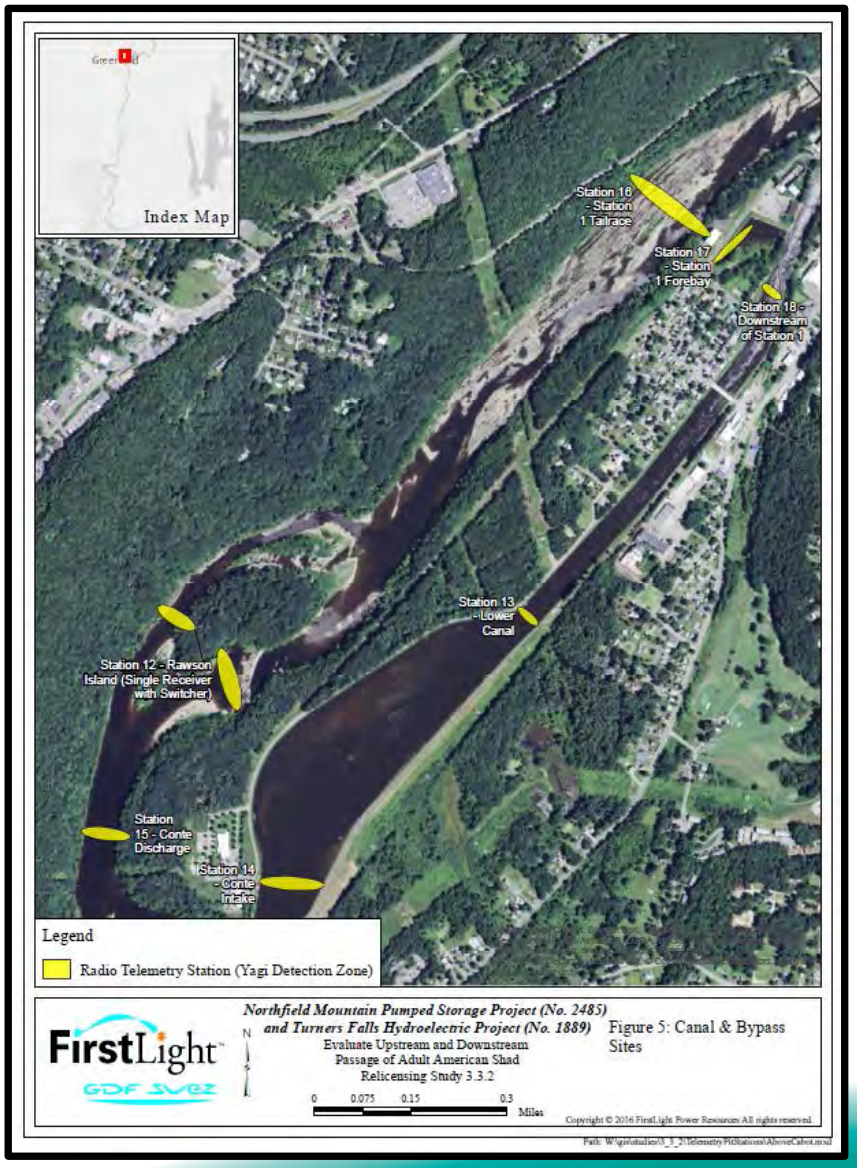
Study Overview



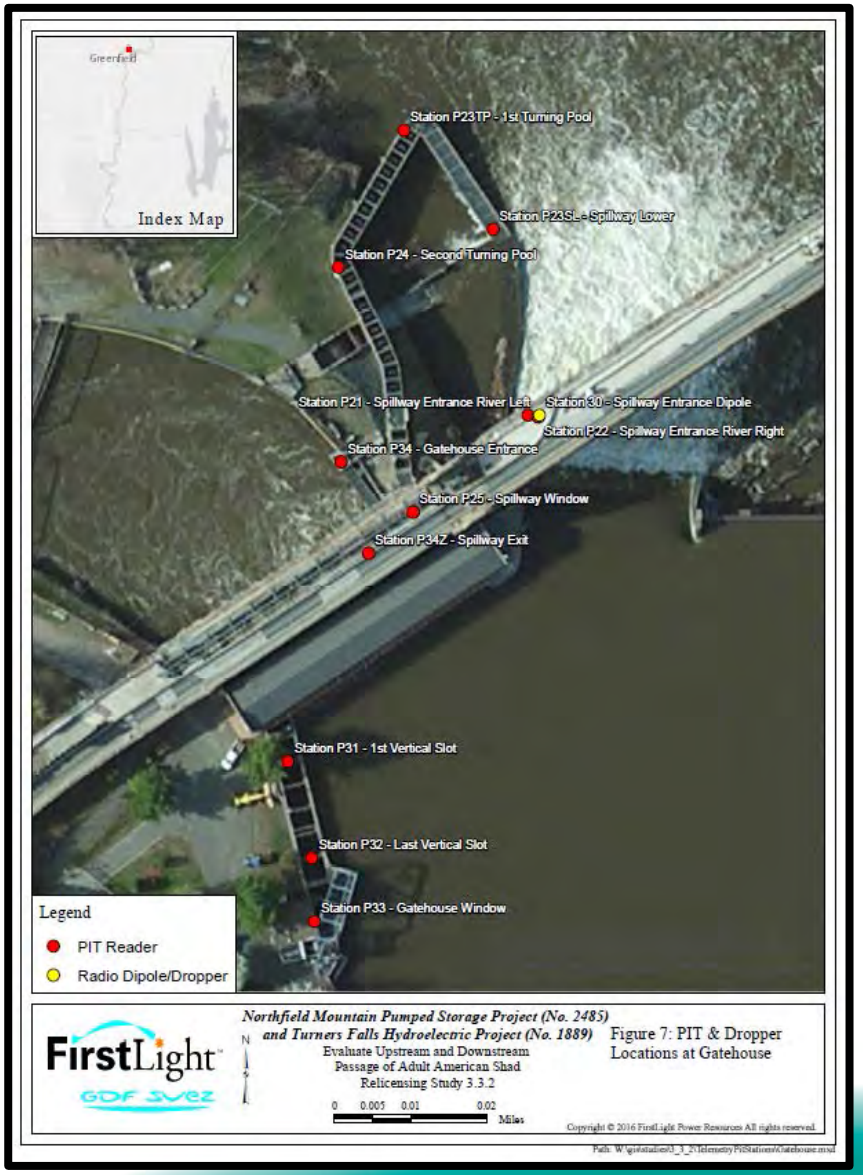
Study Overview

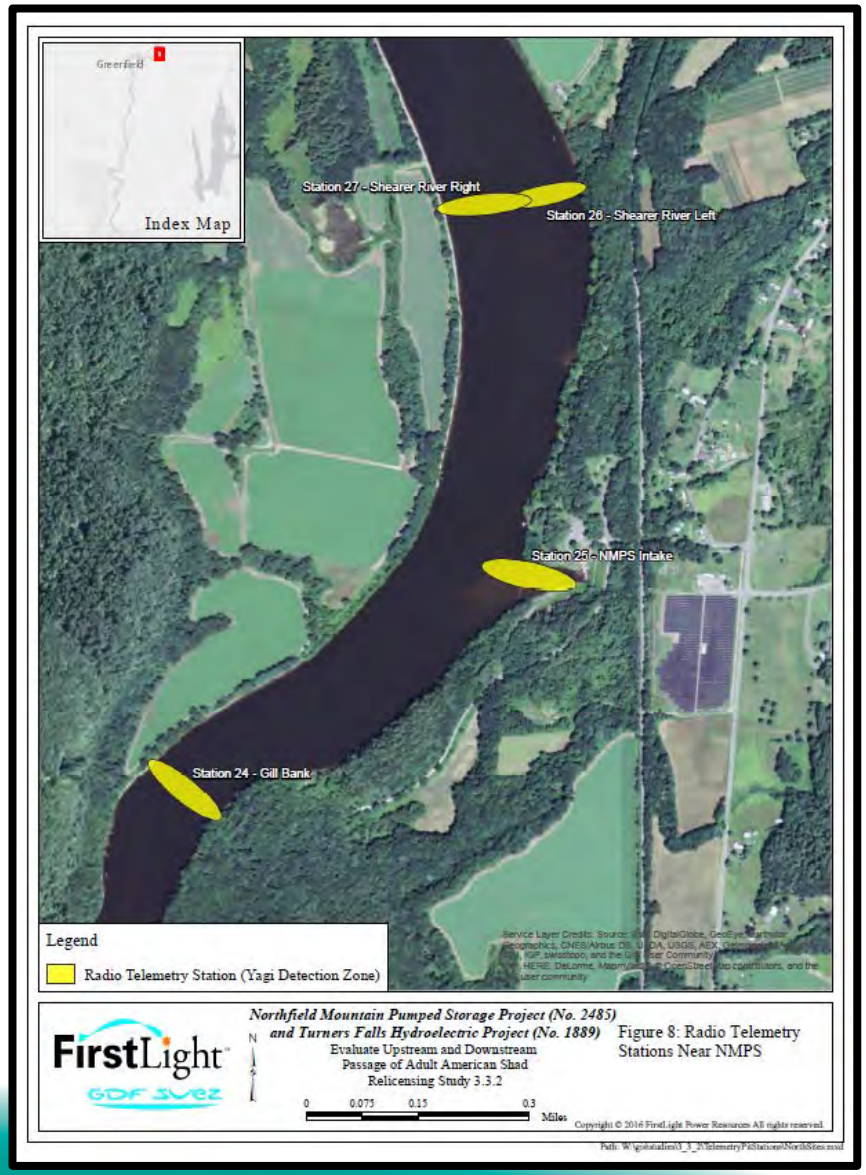


Study Overview



Study Overview





Study Overview

Study Overview

Tags

Sigma Eight (TX-PSC-I-80-M)

- 80mAh 10mm x 28mm
- 2 second burst
- 11 second mortality bust
  - First release -125 contacts/second for 24hrs
  - All others – 125 contacts/second for 6hrs

Oregon RFID

- Read-only tags with a 64 bit unique ID. ISO 11784/11785 compatible. The diameter is 3.65 mm and weighs 0.6g.

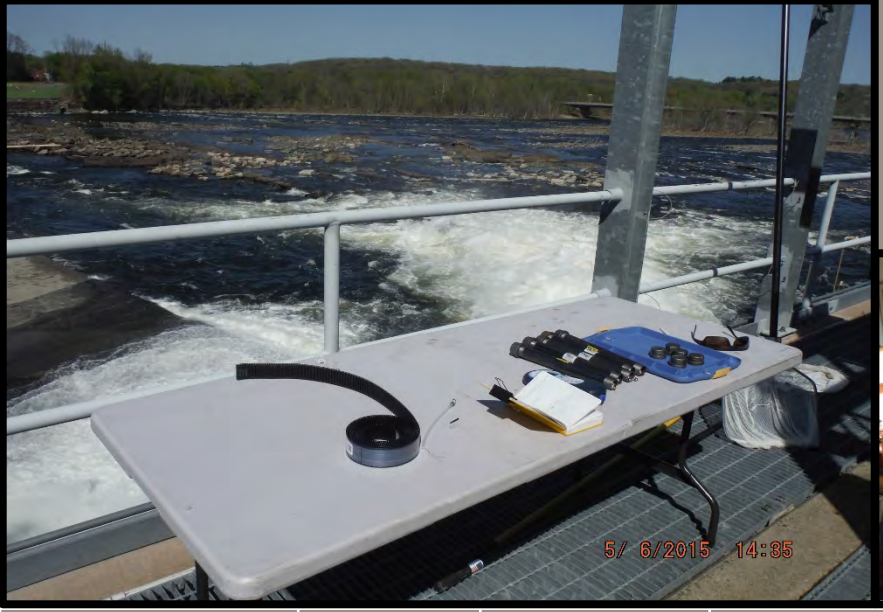
Study Overview

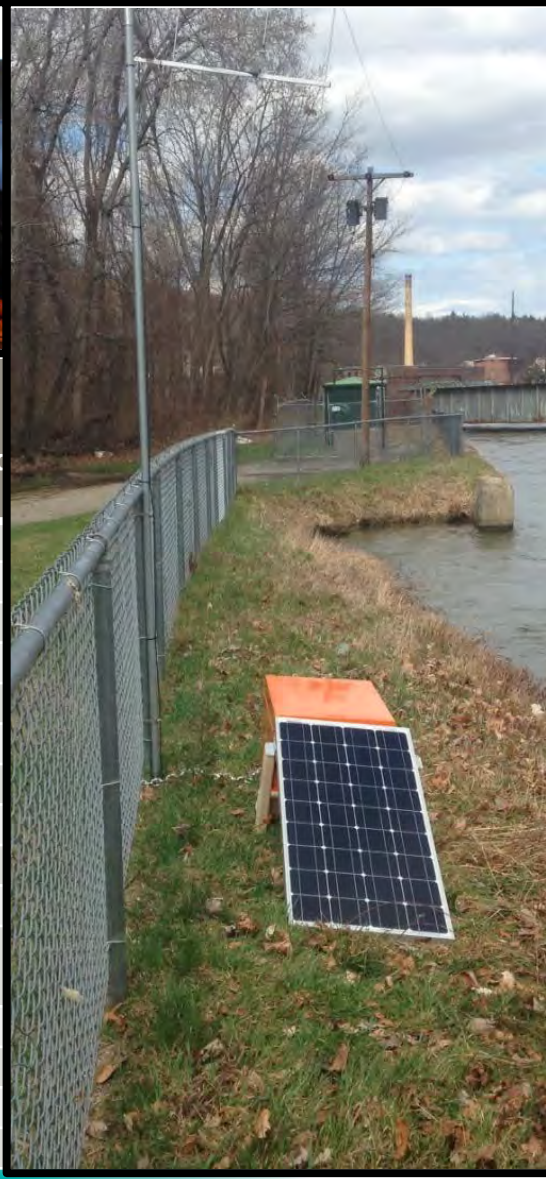
Test Shad Collection and Tagging

A total of 793 adult shad were collected, tagged and released

- Collection and tagging occurred at the Holyoke Lift and the Cabot Ladder over 12 days nonconsecutive days between May 6, and June 8, 2015.
- 397 Shad were double tagged with PIT and radio tags
- 396 Shad were tagged with PIT only

Study Overview





Date of Collection/Release	Collection Location	Release Location	Number of Double Tagged Shad	Number of PIT only Shad	Total Tagged and Released
5/6/15	Holyoke	Holyoke	72	1	73
5/7/15	Holyoke	Holyoke	0	72	72
5/12/15	Holyoke	Holyoke	48	1	49
5/13/15	Holyoke	Holyoke	0	47	47
	Cabot	Canal	25	25	50
5/15/15	Holyoke	TFI	33	29	62
5/16/15	Cabot	TFI	33	33	66
5/18/15	Cabot	Canal	0	25	25
5/19/15	Holyoke	Holyoke	48	48	96
	Cabot	Canal	25	0	25
5/22/15	Holyoke	Impoundment	33	33	66
5/23/15	Cabot	TFI	33	33	66
5/26/15	Holyoke	Holyoke	24	24	48
6/8/15	Holyoke	Holyoke	23	25	48
Totals			397	396	793

Study Overview

Fish were transported using a shad transport truck leased from the USFWS

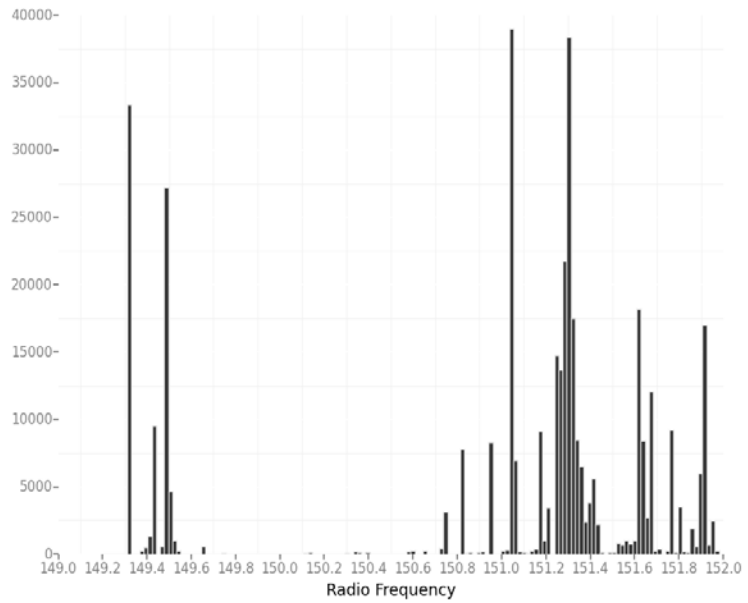
Study Overview

Data Collection

Shad Tagging
- Total length
- Sex
- Condition
- PIT ID
- Radio ID (when applicable)
- Water quality

Radio/PIT data
- Downloaded twice weekly
  - Site ID
  - System voltage (solar stations)
- PIT stations tested weekly

Radio Tag Frequencies Used
- 149.720149.780
- 149.800
- 150.440
- 150.540
  - Codes 20-155



Study Overview

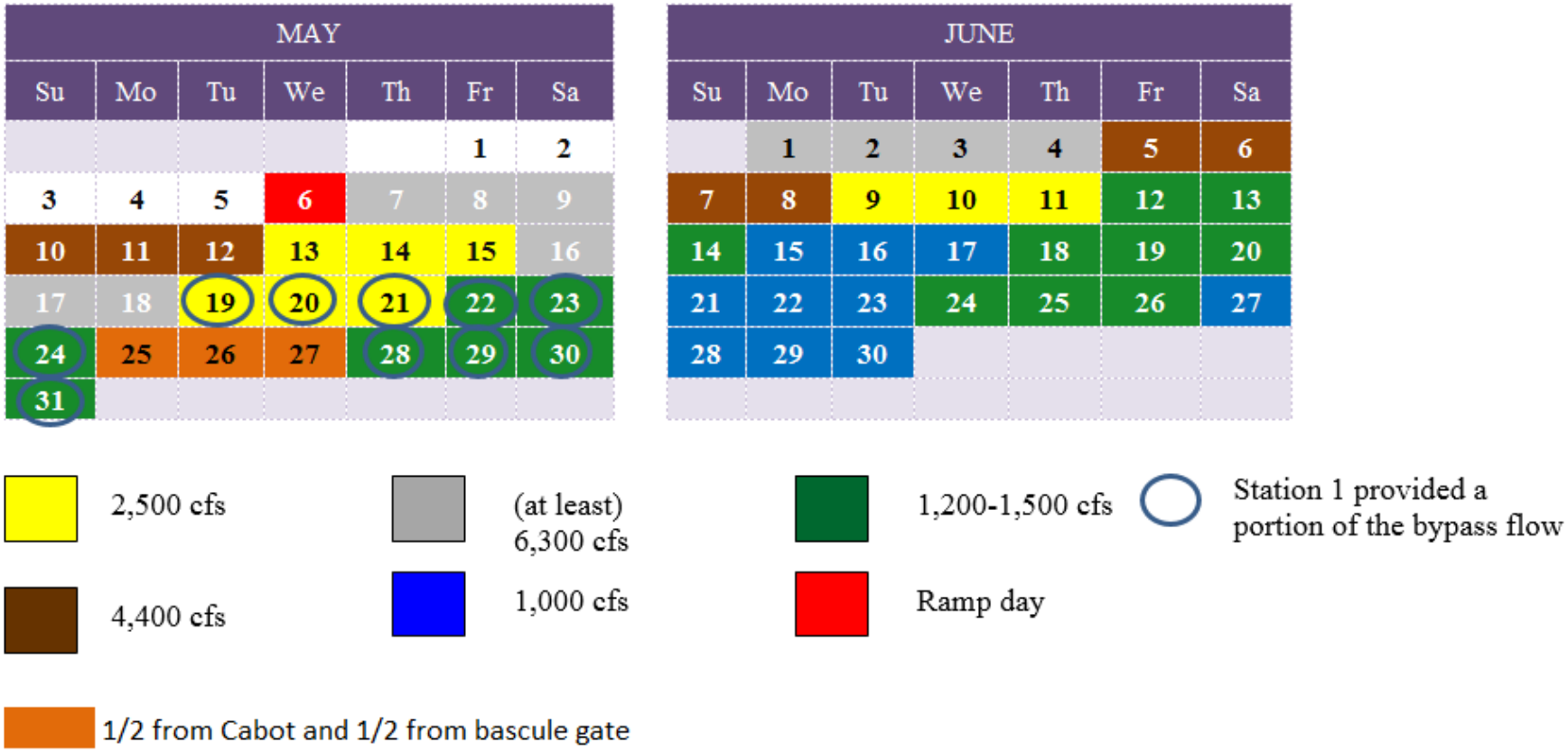
Mobile Tracking

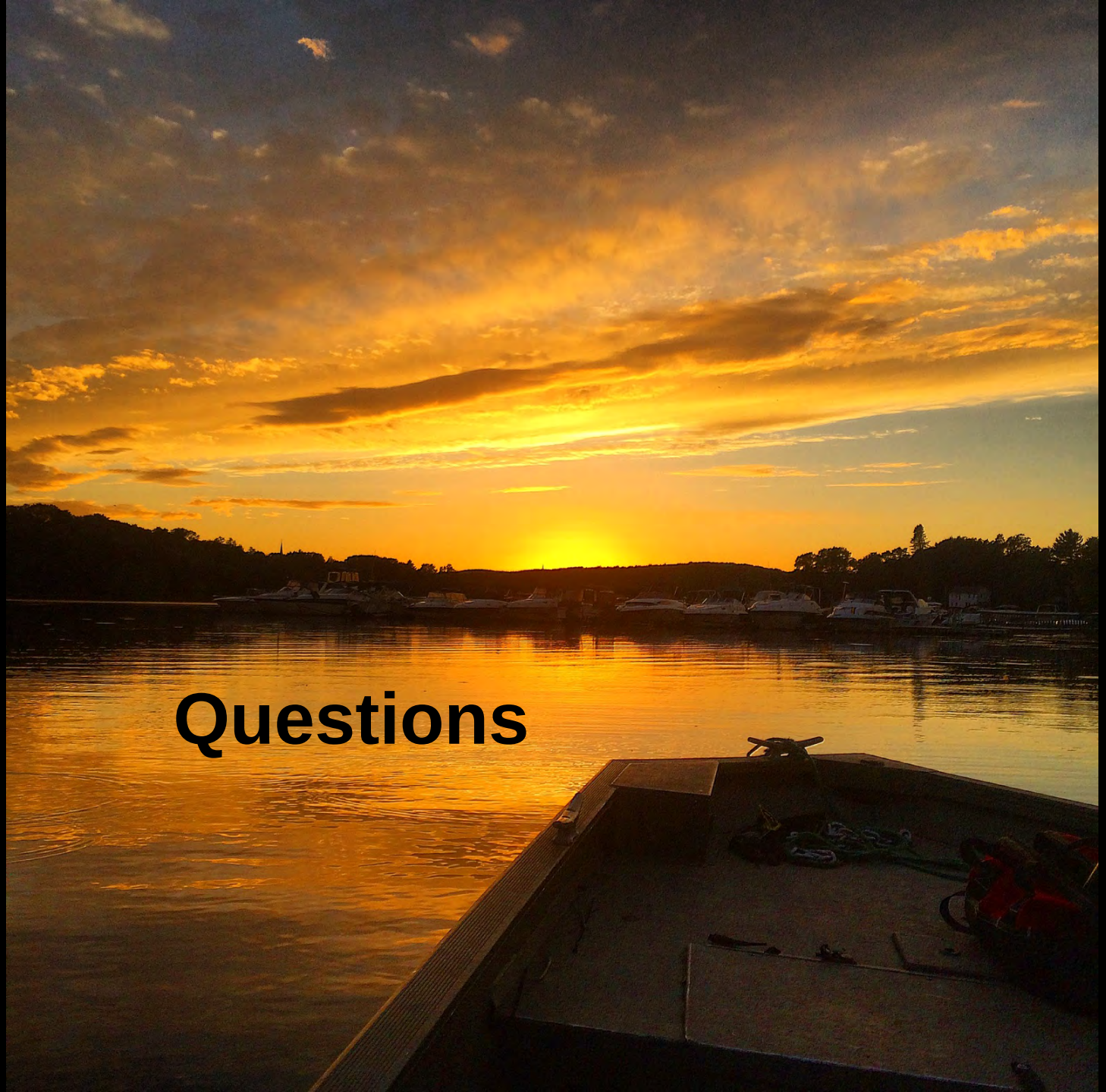
Four Zones

- Holyoke Dam – RT 116 Bridge in Sunderland
- RT 116 Bridge in Sunderland – Cabot Station
- Turners Falls Dam – NMPS Intake
- NMPS Intake – Shearer Farms

Study Overview

A dynamic flow release schedule was maintained throughout the study and was determined in real time with input from the US Fish and Wildlife Service




Questions

Analysis Overview

- False Positive Data Reduction
- Introduction to Analysis Techniques
  - Mark Recapture
  - Time To Event
  - Multi State
- Visualizations
- Objective Overview

False Positive Removal

- An algorithm identified false positive detections using a Naïve Bayes Classifier
- Compares the properties of the present detection with those of known true and false positive detections
- Predictors:
  - detection history,
  - power,
  - misread ratio
- Derived Predictors:
  - Hit ratio
  - Consecutive Record Length

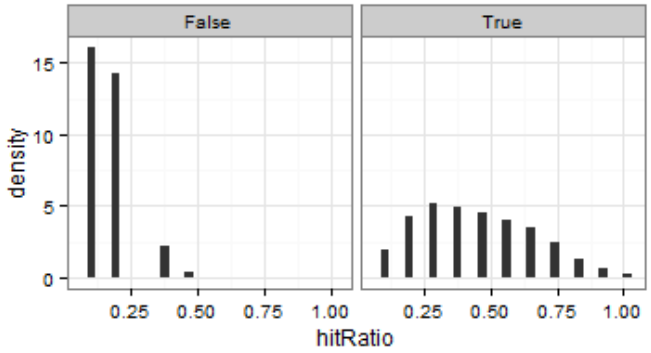
Example of a +/- 4 Detection History

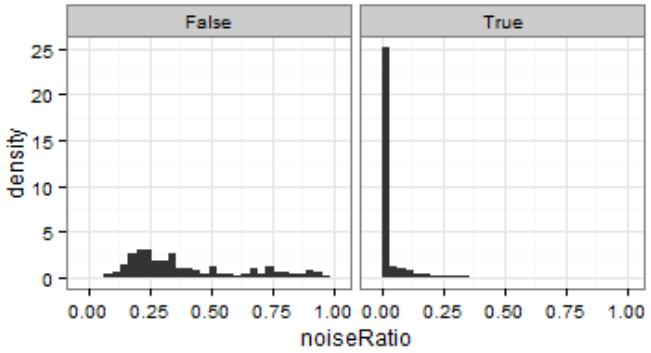
Event	-4	-3	-2	-1	0	1	2	3	4
1	1	0	1	0	1	0	1	0	1
2	1	1	1	1	1	0	0	0	0
3	1	1	1	1	1	1	1	1	1

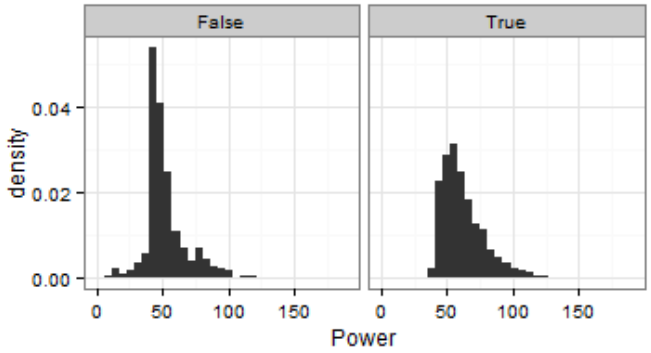
Event	Hit Ratio	Cons Rec Length
1	5/9	1
2	5/9	5
3	9/9	9

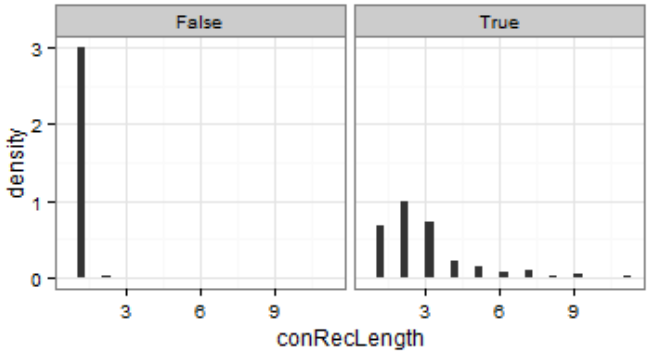
False Positive Removal

Site 24 (TF Impoundment)









Classification	Avg Lag (Back)	Avg Lag (Forward)
True	444	439
False	14,571	14,801

Analysis

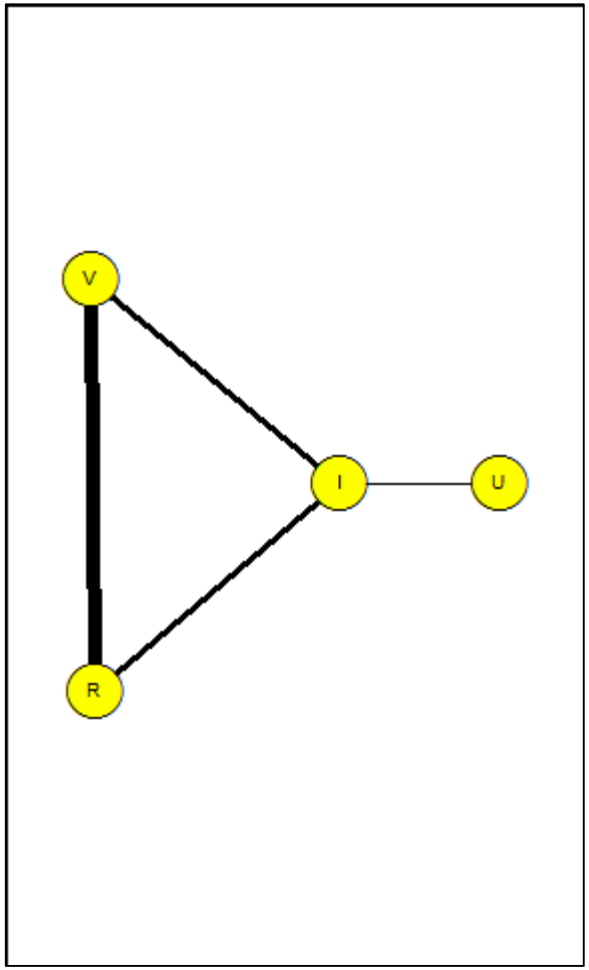
- Effective fish passage requires that animals are passed in timely and safe manner
  - Minimal delay with maximum survivability
- Intent of the analysis is to generalize study results to the population of migrating shad
- Survival and movement assessed with Mark Recapture theory
- Delay assessed with Time-to-Event / Survival Analysis

Mark Recapture

- Mark-recapture theory provides the researcher with an analytical framework that can estimate demographic parameters of interest (survival and movement) that are unbiased with respect to imperfect detection (Perry, Castro-Santos, Holbrook, & Sandford, 2012).
- Data analyzed here representative of an open population
  - Model allows for births/deaths/immigration/emigration
  - We will use the live recapture CJS model to analyze data with MARK
- CJS model estimates two parameters:
  - ϕ: probability of surviving from telemetry station i to $i+1$
  - p: probability of being detected at station i conditional on surviving to station i
- MARK uses Maximum Likelihood Estimation (MLE) to estimate survival and recapture probabilities

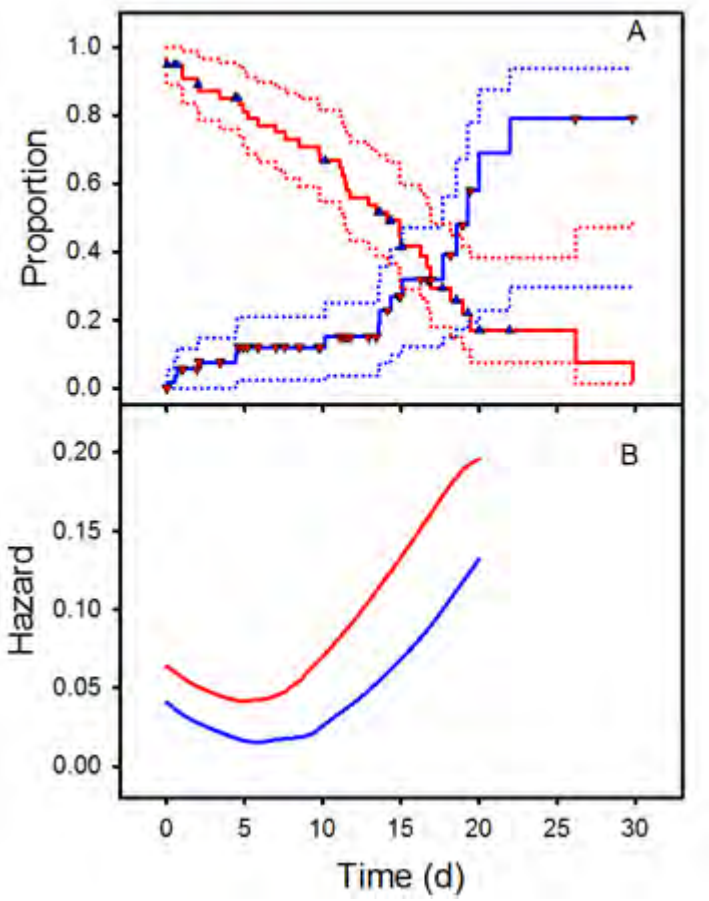
Multi-State Mark Recapture

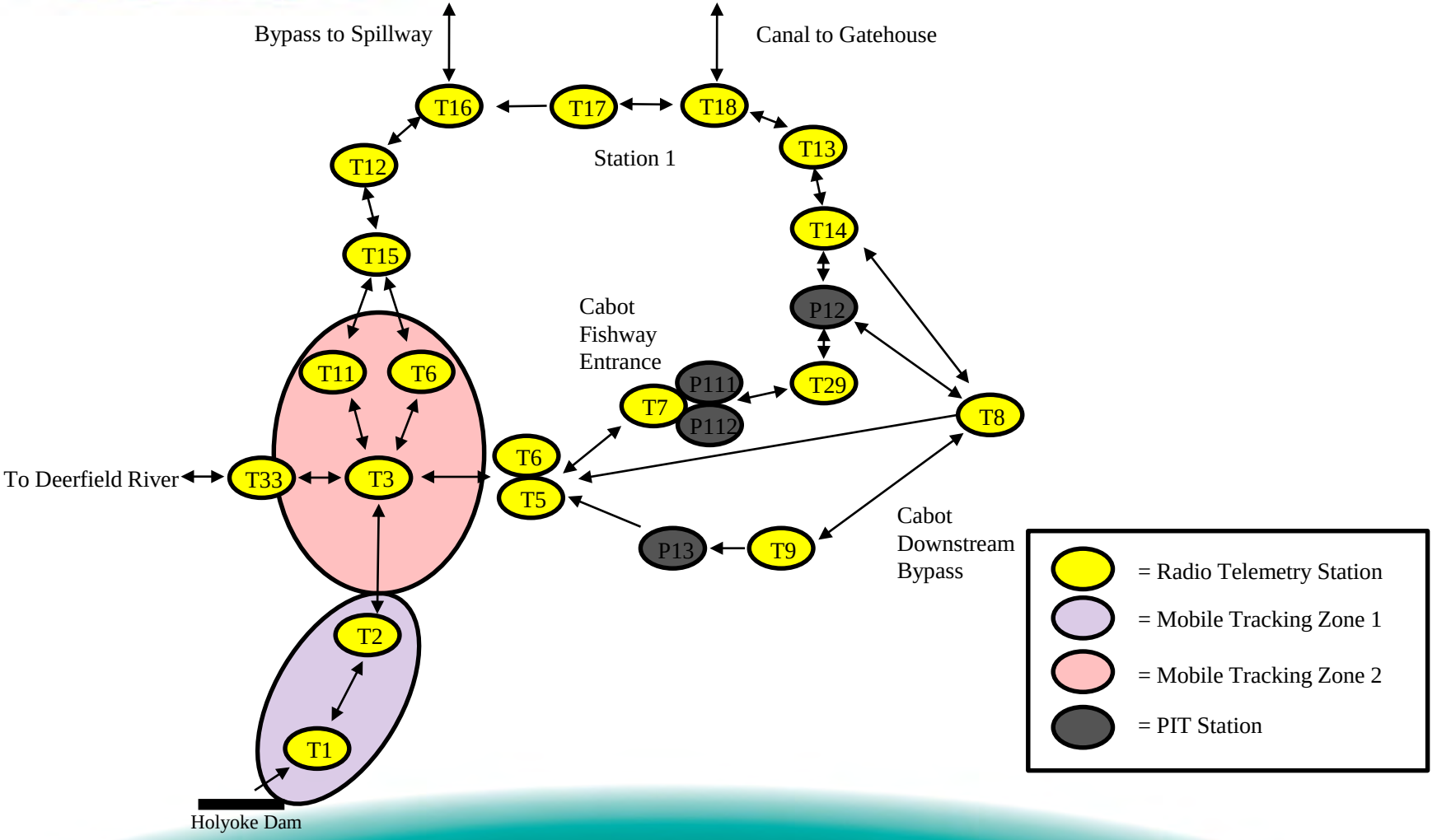
- Multi-state models are an extension of the CJS live recapture model in MARK
- Aside from traditional estimates of survival and recapture, multi-state models estimate the transition probability (Ψ) that a marked animal will move from one state into another
  - State = location
- When all states are sampled at every occasion, and all animals move among all states at all operating levels, all parameters are estimable

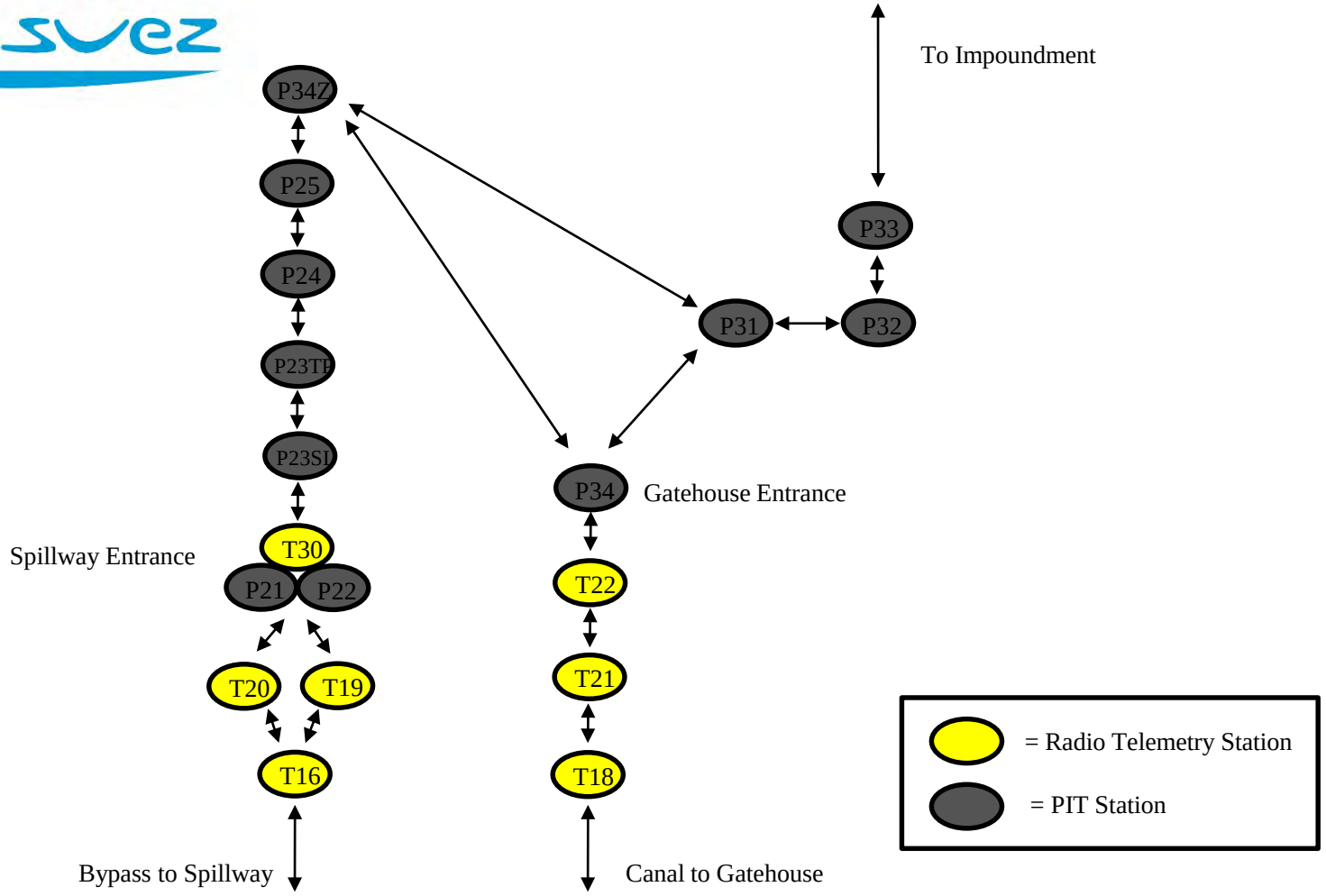


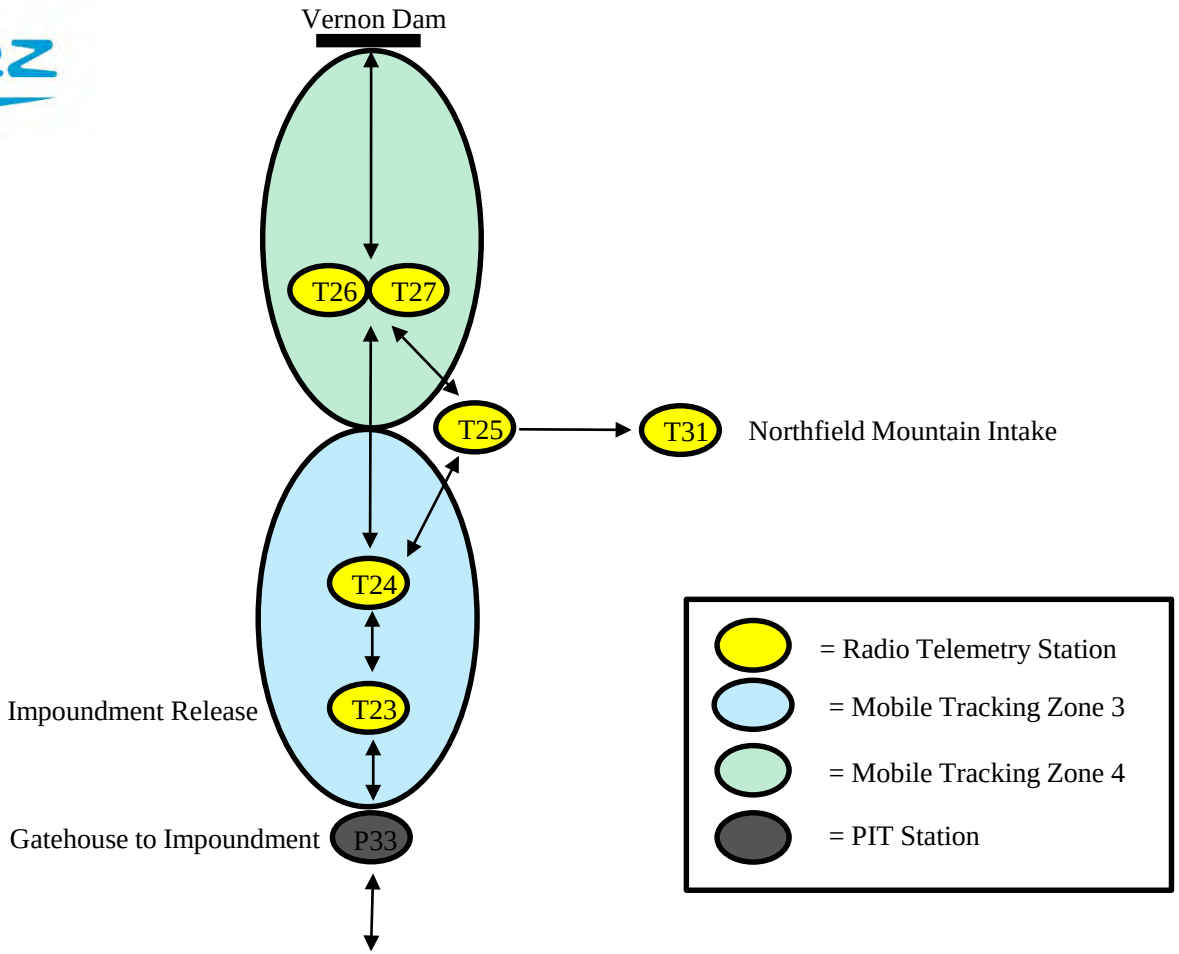
Time-To-Event

- Survival analysis – typically used in biomedical research – is an appropriate method to describe the timing of passage events
- Time-to-event analysis allows for a more complete investigation of passage and can help diagnose fishway delay problems
- We estimate time to event (passage or fallback) with the survival function
  - Proportion of animals remaining in the population at time *t* that have yet to pass
  - Kaplan-Meier (KM) curve
- Hazard function: probability that an event occurs at time t conditional on the subject surviving to time (t)



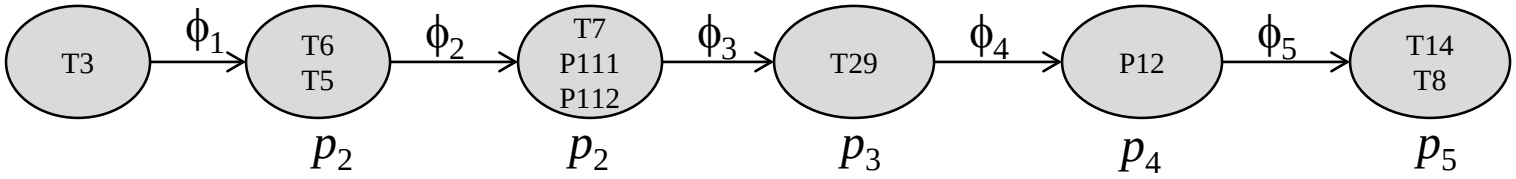

Bypass to Spillway
Canal to Gatehouse
T16
T17
T18
Station 1
T12
T13
T15
T14
Cabot
Fishway
Entrance
P12
T11
T6
P111
T29
T7
P112
T8
To Deerfield River
T33
T3
T6
T5
P13
T9
Cabot
Downstream
Bypass
T2
T1
Holyoke Dam
= Radio Telemetry Station
= Mobile Tracking Zone 1
= Mobile Tracking Zone 2
= PIT Station


To Impoundment
P34Z
P25
P24
P23TP
P23SL
P33
P31
P32
P34
Gatehouse Entrance
Spillway Entrance
T30
P21
P22
T20
T19
T16
T22
T21
T18
Bypass to Spillway
Canal to Gatehouse
= Radio Telemetry Station
= PIT Station

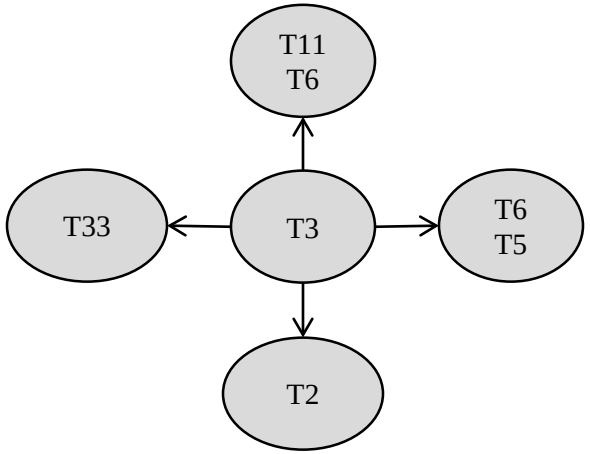

Vernon Dam
T26
T27
T25
T31
Northfield Mountain Intake
T24
T23
Impoundment Release
Gatehouse to Impoundment
P33
= Radio Telemetry Station
= Mobile Tracking Zone 3
= Mobile Tracking Zone 4
= PIT Station

Cabot Fish Passage Effectiveness

Evaluate attraction, entrance efficiency and internal efficiency of the Cabot ladder



- Top model – internal efficiency of Cabot Fishway Ladder
- Right model – Cabot Fishway Attraction
- Time to Event – assessed between each recapture occasion



Gatehouse Ladder Attraction – Analysis 1

Multi State Mark Recapture

- Estimates:

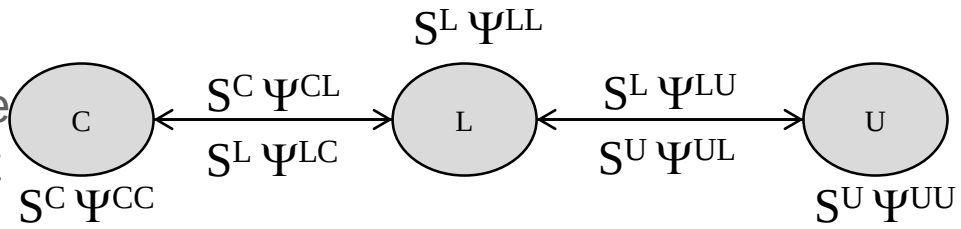
S
- probability that an animal alive in state *r* (C,L,U) at time *i* is alive in state *s* at time *i+1*
  - *C = canal, L = ladder, U = upstream*

p
- Probability that an animal alive in state *s* at time *i* is recaptured at time *i*

Ψ
- Probability that an animal in state *r* at time *i* in state *s* at time *i+1*, given that animal is alive at *i+1*

What will this give us?

- Transition probabilities must sum to 1, therefore Ψ is the relative proportion of fish at time *i* choosing a particular passage route
- Fish may not transition over a time step

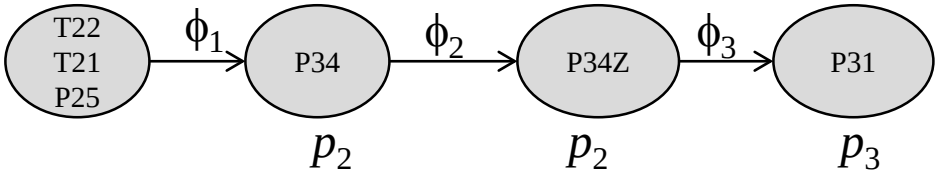


Gatehouse Entrance Efficiency Analysis 2

- Model 1 Mark Recapture
  - Model will assess survival (ratio of animals who pass via gatehouse to number of animals that attempt gatehouse)
  - Includes fish from canal and spillway ladder

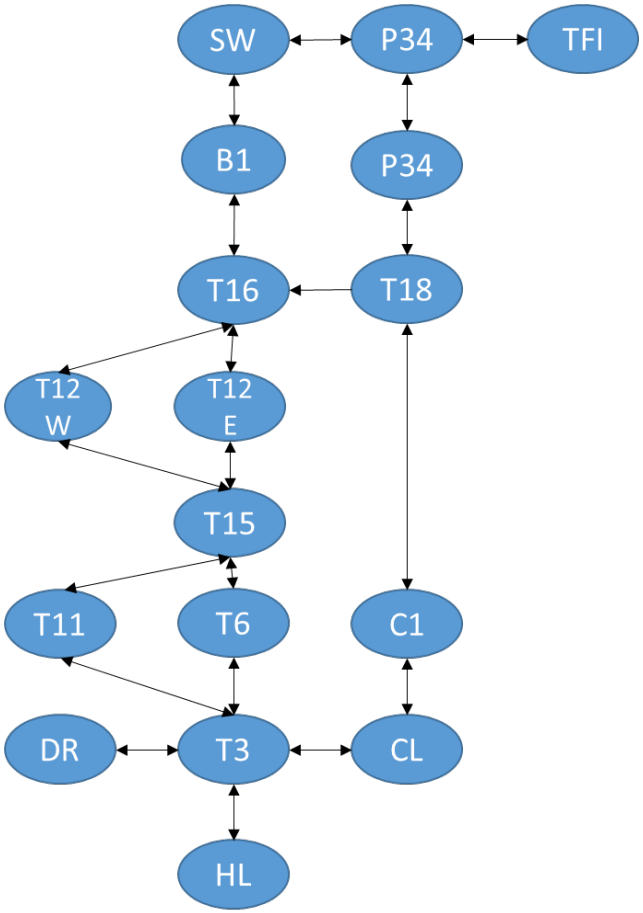
Model 2 Time to Event

- Model will assess delay and competing events as fish fall back and make multiple passage attempts

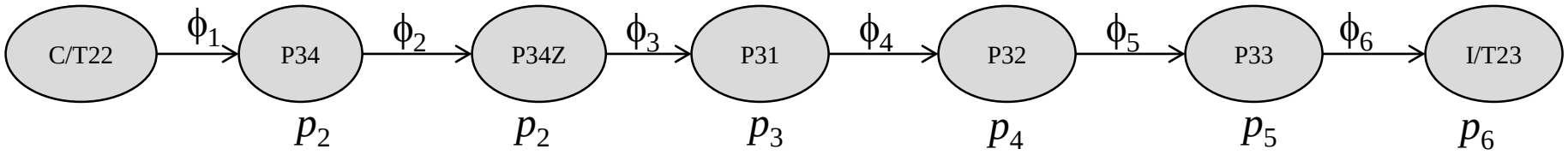


Migration Delays Resulting From Flows through Turners Falls

- Aggregated stations below Turners Falls meant to assess migratory delay through critical reaches
- HL = Holyoke
- DR = Deerfield River
- CL = Cabot Ladder
- B1 = Bypass Reach 1
- C1 = Canal Reach 1
- SW = Spillway Ladder
- GL = Gatehouse Ladder
- TFI = Turners Falls Impoundment



Gatehouse Ladder Internal Efficiency Analysis 3



- Model 1 Mark Recapture
  - Model will assess survival (ratio of animals who pass via gatehouse ladder)

Model 2 Time to Event

- Model will assess delay and competing events as fish fall back and make multiple passage attempts

Spillway Ladder Attraction – Analysis 1

Multi State Mark Recapture

- Estimates:

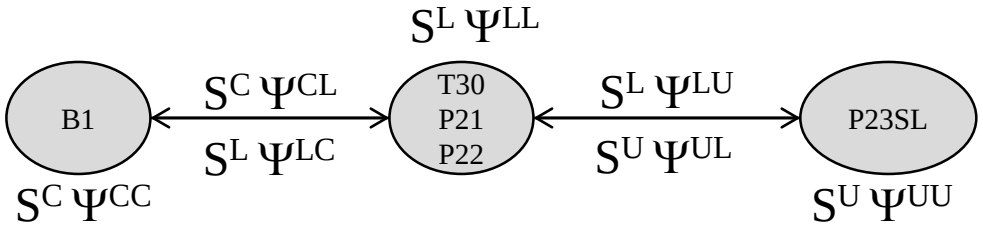
S
- probability that an animal alive in state *r* (C,L,U) at time *i* is alive in state *s* at time *i+1*

p
- Probability that an animal alive in state *s* at time *i* is recaptured at time *i*

Ψ
- Probability that an animal in state *r* at time *i* in state *s* at time *i+1*, given that animal is alive at *i+1*

What will this give us?

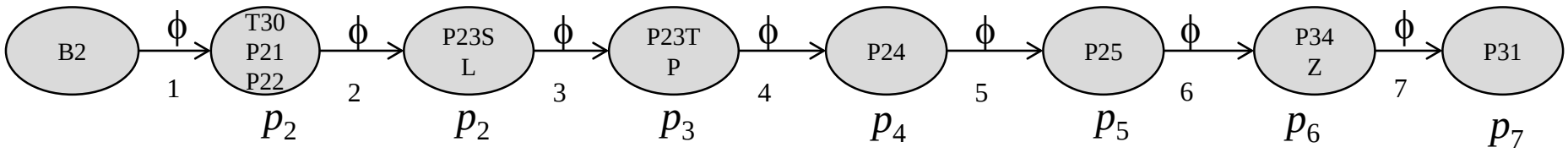
- Transition probabilities must sum to 1, therefore Ψ is the relative proportion of fish at time *i* choosing a particular passage route
- Fish may not transition over a time step



Spillway Entrance & Internal Efficiency – Analysis 2

Model 1 Mark Recapture
- Model will assess survival (ratio of animals who pass via spillway to number of animals that attempt spillway ladder)

Model 2 Time to Event
- Model will assess delay and competing events as fish fall back and make multiple passage attempts



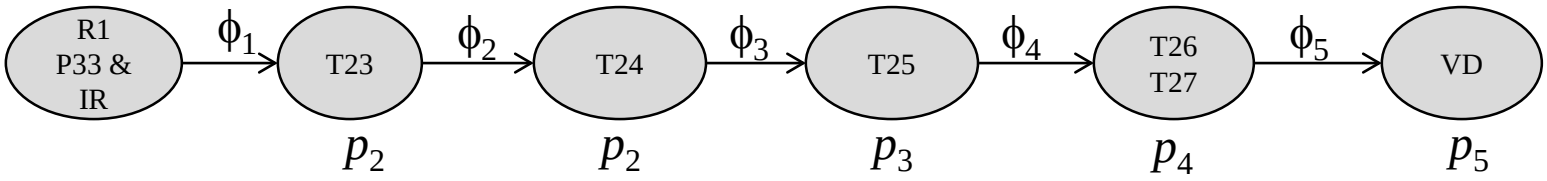
Migration Through Turners Falls Impoundment

Model 1 Mark Recapture

- Model will assess survival of those animals migrating up through the impoundment (# animals who pass via gatehouse and that are released into the impoundment)

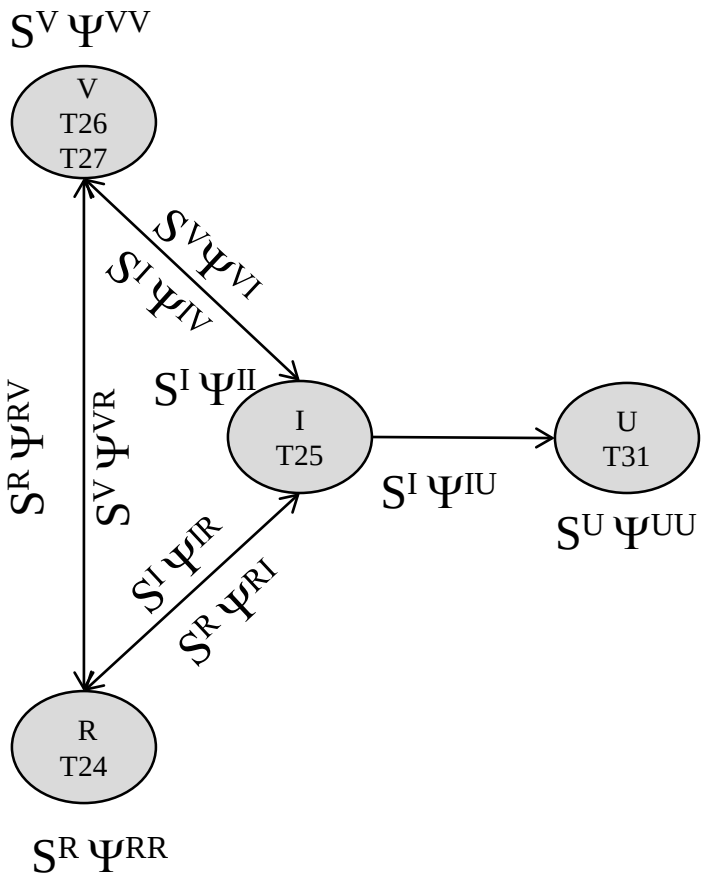
Model 2 Time to Event

- Model will assess delay and competing events as fish fall back and make multiple passage attempts



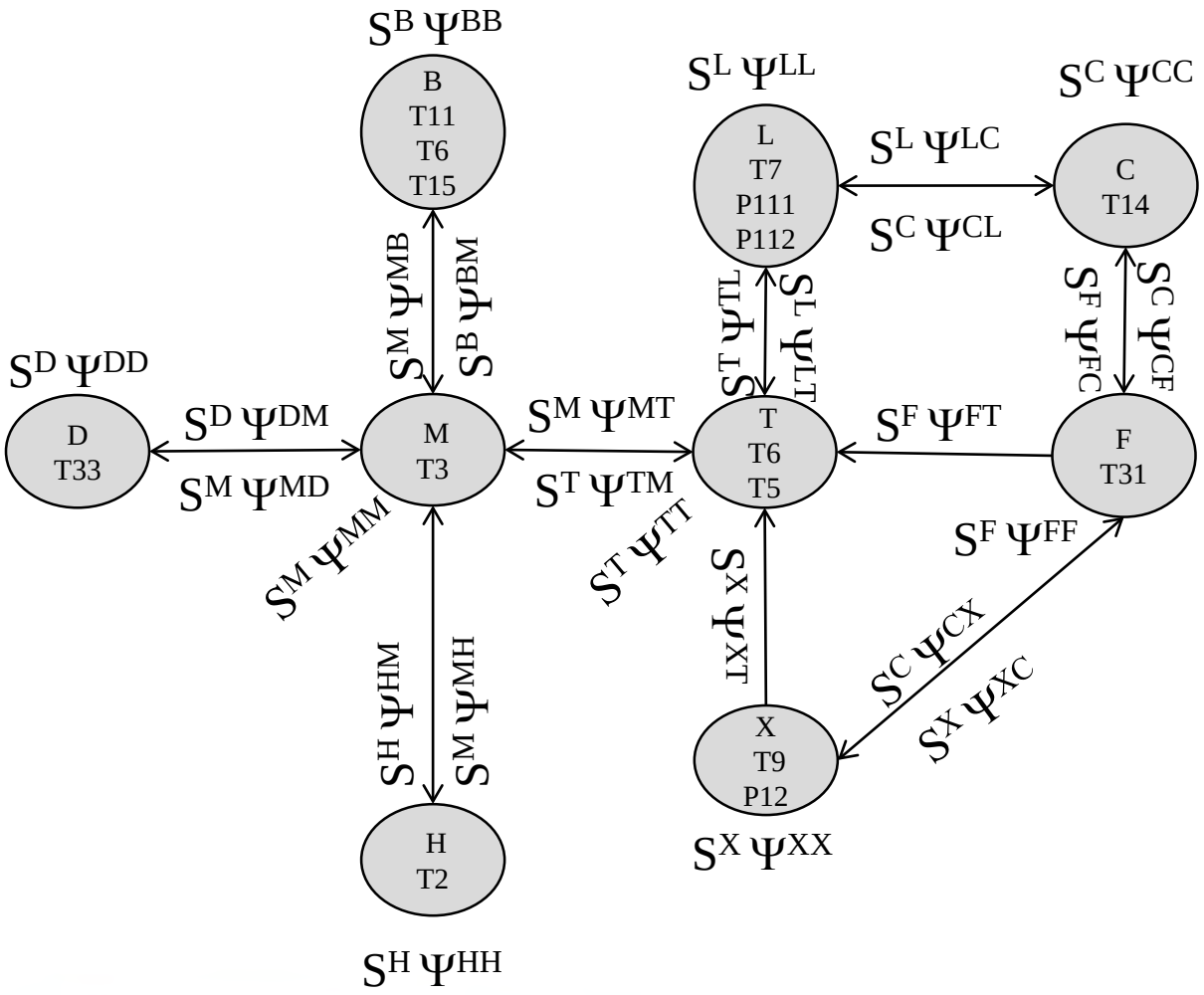
Northfield Mountain Migration Impacts

- Single analysis for upstream & downstream
- Multi-state mark recapture will quantify survival and transition probabilities
- Delay assessed with Time to Event along each passage route
- V = Vernon,
- I = intake,
- U = upper impoundment,
- R = release



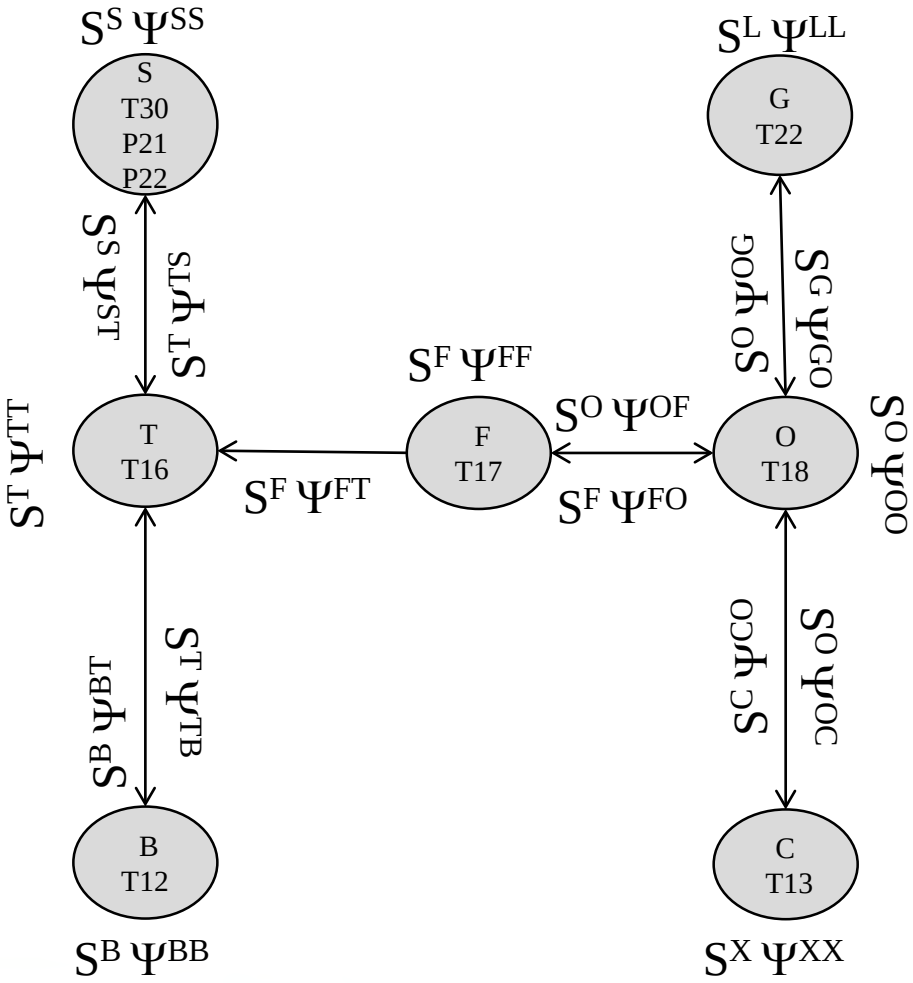
Cabot Station Migration Impacts

- Single analysis for upstream & downstream
- Multi-state mark recapture will quantify survival and transition probabilities
- Delay assessed with Time to Event along each passage route
- H = Holyoke Release,
- M = Montague Wastewater,
- D = Deerfield River,
- B = bypass reach,
- L = Cabot Ladder,
- C = canal,
- X = downstream bypass,
- F = Cabot Forebay,
- T = Cabot Tailrace



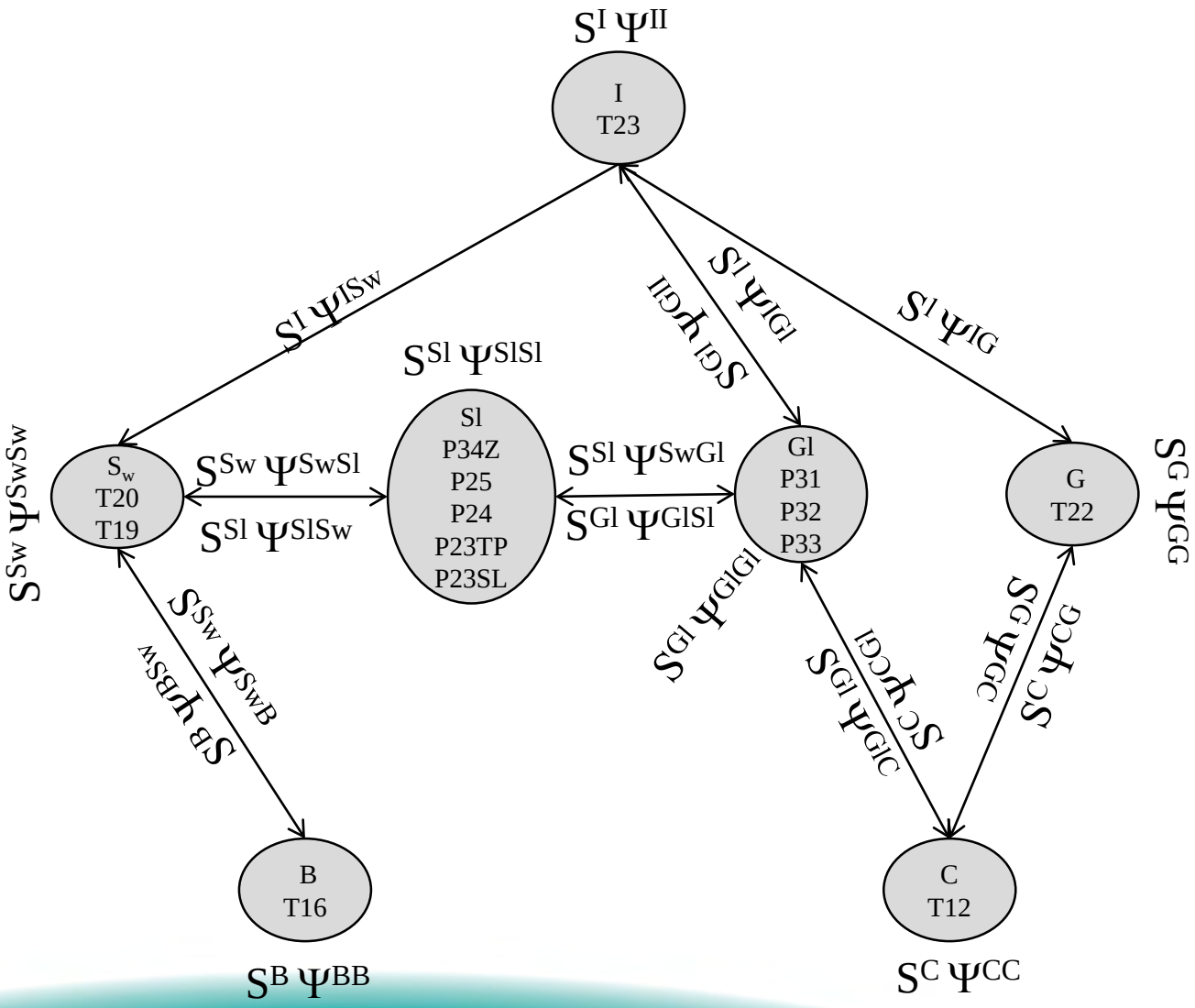
Station No. 1 Migration Impacts

- Single analysis for upstream & downstream
- Multi-state mark recapture will quantify survival and transition probabilities
- Delay assessed with Time to Event along each passage route
- B = bypass reach,
- C = canal,
- O = station 1 canal turn,
- G = gatehouse,
- F = station 1 forebay,
- T = station 1 tailrace,
- S = spillway



Impacts to Downstream Migration Past Turners Falls Dam

- Route of passage and survival assessed with multi-state mark recapture
- Delay assessed with time to event analysis
- I = impoundment,
- G = gatehouse,
- G_l = gatehouse ladder,
- S_l = spillway ladder,
- S_w = spillway,
- B = bypass reach,
- C = canal



Downstream Route of Passage Through Turners Falls Canal

- Multi-state mark recapture will quantify survival and transition probabilities
- Delay assessed with Time to Event along each passage route
- G = gatehouse,
- B = bypass reach,
- C = canal,
- O = station 1 canal turn,
- G = gatehouse,
- F_1 = station 1 forebay,
- F_2 = Cabot forebay,
- Rw = Rawson West
- Re = Rawson East
- T_1 = station 1 tailrace,
- T_c =Cabot Tailrace,
- C = canal,
- X = downstream bypass,
- D = Deerfield River,
- M = Montague wastewater,
- H = Holyoke