2022 Columbia Basin Research Report

A Bayesian multidirectional, multistate model to resolve the migration pathways of adult Steelhead within the Columbia River Basin

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# Introduction

Steelhead (anadromous *Oncorhynchus mykiss*) in the Columbia River Basin, including all those found above Bonneville Dam, are listed under the Endangered Species Act. The five Columbia River Basin distinct population segments (DPSs) were first listed in the late 1990s, and are all currently listed as threatened. Despite their protected status and continued recovery efforts, counts of returning Steelhead to Bonneville Dam have been lower in the last five years than they were at the time of listing, and recently completed 5-year reviews for Columbia River Steelhead reaffirmed their status as threatened (**NMFS2022d?**).

One element of the life history of Columbia River Basin Steelhead that may make them more vulnerable to anthropogenic modifications of the Columbia River is their adult migration. Relative to other salmonids, Steelhead from the Columbia River Basin spend longer in freshwater as adults. Essentially all populations of Steelhead in the Columbia River Basin are stream-maturing (Busby *et al.* 1996), meaning that these fish enter freshwater in a sexually immature state and then spend up to a year in freshwater prior to spawning. Also known as summer Steelhead, these fish enter freshwater between May and October and spawn the following spring, typically between March and May (Busby *et al.* 1996). Between their entry into freshwater and arrival at spawning grounds, Columbia River Steelhead exhibit considerable variability in their migration patterns. Virtually all interior Columbia River Steelhead overwinter in freshwater; the majority of individuals are known to overwinter in tributaries, but up to 20% of individuals in a given year have been observed to overwinter in the hydrosystem, which comprises of the mainstem habitat between the 10 hydroelectric dams in the federal Columbia River power system (Keefer *et al.* 2008). Additionally, as individuals migrate upstream toward natal tributaries, the majority of individuals have been observed to temporarily stage in nonnatal tributaries downstream of their natal tributary (High *et al.* 2006). This behavior increases with increasing mainstem river temperature, indicating the use of these colder waters as coldwater refugia (High *et al.* 2006). These highly variable movement patterns and increased duration in freshwater make Steelhead more vulnerable to the hazards faced in freshwater.

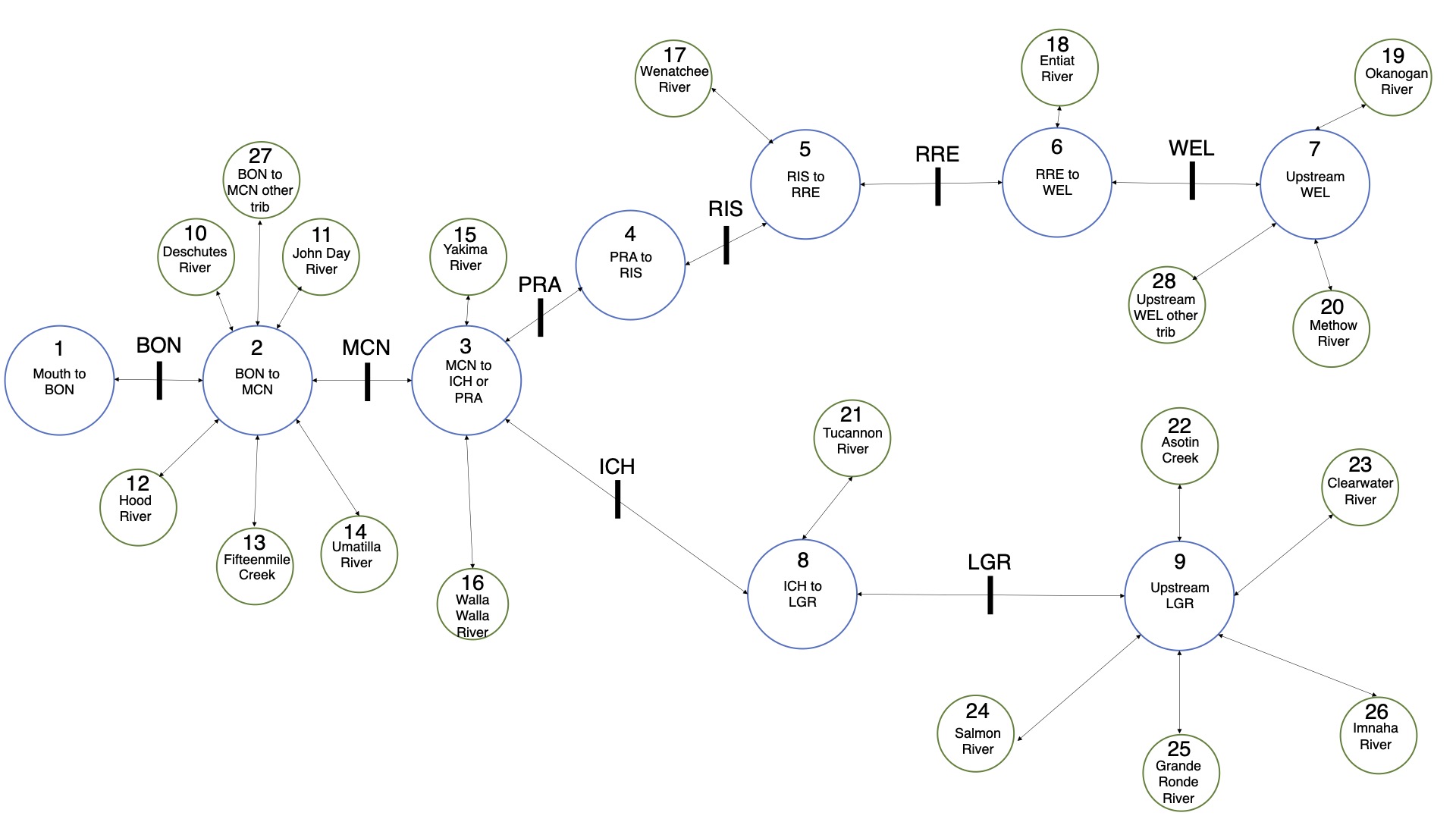
Descending dams, also known as fallback (Boggs *et al.* 2004), is another common behavior observed in Steelhead, with about 20% of Steelhead observed to fall back over at at least one mainstem dam (Boggs *et al.* 2004). This behavior can occur as individuals are migrating upstream to natal tributaries, but can also occur once individuals have ascended mainstem dams upstream of natal tributaries (a behavior known as overshoot), in which case this fallback is called post-overshoot fallback and is necessary for individuals to return to natal tributaries. Overshoot and fallback affect the ability of individuals to successfully spawn, and therefore are consequential for the persistence of ESA-listed populations. Individuals that fall back during their upstream migration (prior to reaching or overshooting their natal tributary) are less likely to return to their natal tributaries or hatcheries (Bjornn *et al.* 2000; Keefer *et al.* 2005). Furthermore, migration success to natal tributaries decreases with overshooting rates (Richins and Skalski 2018), and many overshooting fish are observed to stray to tributaries upstream of the overshoot dam.

The decreased migration success associated with overshoot and fallback is likely due to the hazardous nature of downstream passage for adults, which is often limited to the powerhouse during the primary months that Steelhead are overwintering (Khan *et al.* 2013). Mortality rates for adult Steelhead passing downstream at dams are highly variable, but recent estimates of 48-hour survival at McNary Dam indicate around 90% survival for individuals passing through turbines and 97% survival for individuals passing through the spillway (**Normandeau2014?**). Mortality in downstream passage routes is implicated by low survival rates of Steelhead kelts, which decrease with increasing number of dams that must be navigated as they move downstream to the ocean, with mortality rates of 84-96% for kelts released at Lower Granite Dam, 38-40% at McNary Dam, and 20-37% at John Day Dam (**Westrheim2005?**).

Because of the association between overshoot and fallback and decreased migration success, previous studies have investigated the influence of various factors on these rates. Rates of overshoot have been shown to vary considerably among populations, but have a positive relationship with increasing mainstem water temperature and hatchery rearing upstream of the natal tributary (Richins and Skalski 2018). In spring-summer Chinook, fallback rates have a positive relationship with river discharge (Boggs *et al.* 2004). However, these previous studies have looked at these various factors only in isolation and for specific movements. In this study, we developed a multistate model that is capable of modeling the entire adult Steelhead migration, from first detection at Bonneville Dam to arrival in natal tributaries. This model, which does not constrain movement to only be upstream, allows the complexity of multidirectional movement to be modeled and allows many movements of interest, including fallback, overshoot, and homing, to be estimated in a single framework. The data used in this model were passive integrated transponder (PIT) tag detection histories. This modeling framework accommodates the effect of multiple categorical and continuous covariates at movement probabilities at each step within the migration. By examining how Steelhead movement probabilities, particularly those of conservation concern, such as overshoot, fallback, homing, and straying, vary by population and are influenced by various factors, this modeling framework will improve our understanding of how both environmental and anthropogenically influenced conditions affect how Steelhead move within the Columbia River and its tributaries.

# Methods

## Modeling overview



The model schematic.

In our model, the Columbia River and its tributaries are modeled as a series of connected states, with states defined as either reaches of the mainstem Columbia or Snake River between dams with PIT tag detection capabilities in the adult ladders or tributaries with PIT tag detectors. Fig. 1 shows all of the states in our model; movements over some dams (e.g., The Dalles or John Day Dams) were not explicitly modeled due to these dams not having PIT tag detection capabilities for the duration of our study period. Future iterations of the model could be configured to include these dams for part of the time series by splitting state 2 (mainstem, Bonneville Dam to McNary Dam) into three states: 1) mainstem, Bonneville Dam to The Dalles Dam; 2) mainstem, The Dalles Dam to John Day Dam; and 3) mainstem, John Day Dam to McNary Dam. This would allow the estimation of fallback and overshoot at The Dalles Dam and John Day Dam (which would be of particular interest to populations near these dams, such as the Deschutes River or Fifteenmile Creek), but would require a temporally-varying state configuration.

Description of loss

## Accessing PIT tag data

PIT tag data were obtained from the Columbia Basin PIT Tag Information System (PTAGIS). Only known-origin individuals (based on known release sites) were included in this dataset. To ensure that only individuals marked as juveniles were kept in the dataset, all individuals that were greater than 350 mm at time of marking were removed. To select returning adults, only individuals that were seen in the adult fishways at Bonneville Dam were selected. To ensure that there were enough data for each population included in this dataset, only populations (defined as tributaries in which PIT-tagged juveniles were released) that had at least 250 individuals distributed across 8 run years were kept. Additionally, only populations with instream PIT tag detections sites in their natal tributaries were kept; if sufficient instream detection sites only became available during the later part of our study period, only individuals from those years were kept. Run years were separated by June 1 of each year, and run year 2005/2006 (beginning on June 1, 2005) was selected as the first year in our dataset. In total, populations from 17 natal tributaries met this criteria: 11 tributaries of the Columbia (Deschutes River, John Day River, Hood River, Fifteenmile Creek, Umatilla River, Yakima River, Walla Walla River, Wenatchee River, Entiat River, Okanogan River, and Methow River) and six tributaries of the Snake (Tucannon River, Asotin Creek, Clearwater River, Salmon River, Grande Ronde River, and Imnaha River). Once the tag codes were identified for each of these tributary populations, a complete tag history report was run in PTAGIS for all of the tag codes in our dataset.

## Processing PIT tag data into detections at various sites

In order to convert detections of fish at individual PIT tag antennas into a history of movements between different reaches of the Columbia, Snake, and their tributaries, the first step with the PIT tag data from PTAGIS was to interpret detections at different PIT tag antennas. For instream tributary detection sites, as well as mainstem sites in between dams, no processing was required, and these detections were interpreted as the fish being in that associated state. For detection sites at dams, additional processing was required to interpret detections.

The first step in interpreting detections at dams was to identify the multiple passage routes associated with each dam. In many cases, multiple passage routes were grouped together into a single interrogation site, and assigning antennas to these different passage routes was necessary to interpret how fish were utilizing these passage routes. For example, antennas at Ice Harbor Dam are all grouped together in PTAGIS as “Ice Harbor Dam (combined)”, when these antennas are actually in three different passage routes: the North Shore Ladder, the South Shore Ladder, and the Juvenile Bypass System.

The second step was to identify, when possible, entrance and exit antennas within each upstream passage route. Entrance and exit antennas were only distinguished when either two distinct groupings of antennas existed in separate parts of the same passage route, or in the case of Bonneville Dam, when there are enough consecutive weirs with PIT tag detection antennas to separate these weirs into entrance and exit antennas. By distinguishing entrance and exit antennas, we were able to identify when fish detections in adult fishways were not ascents, but were rather aborted ascent attempts or descents. When fish were only seen at entrance antennas, this was noted to be an aborted ascension attempt. When fish were first seen at the exit antennas at an adult fish ladder and last seen at the entrance antennas of the same fish ladder, this was noted to be a descent through the ladder. If a fish was first seen at the entrance antennas and last seen at the exit antennas, this was noted to be an ascent. Entrance and exit antennas were identified at all adult fishways except for McNary Dam Washington Shore Ladder (prior to March 2006), Priest Rapids Dam, Rock Island Dam, Rocky Reach Dam, Wells Dam (prior to 2013), and Ice Harbor Dam.

An additional step was to identify antennas in adult fish facilities/traps at ladders. For most dams, detections in the adult fish facility were treated the same as detections in other parts of the adult ladder, as adults were not removed (e.g., Ice Harbor Dam, Priest Rapids Dam, or Lower Granite Dam, where traps were operated but adults were returned after processing). However, in the case of Wells Dam, fish that were trapped were removed and either moved to the hatchery or trucked off-site. As such, any terminal detections in the trap at Wells Dam were classified as terminal trapping events, and were classified as fish moving to the absorbing “loss” state.

Once the antennas had been appropriately assigned, a 48 hour threshold was utilized to distinguish separate visits to a site. However, in some passage routes, due to fish being observed in the same route for days at a time, no time threshold was utilized, and instead the sequence of antennas was used to distinguish separate visits to a site. For example, because individual fish were observed not exiting the Washington shore passage route at Bonneville Dam for upwards of 100 days, new visits to this site were only distinguished by new visits to the entrance antennas, regardless of time between detections at other antennas in the passage route.

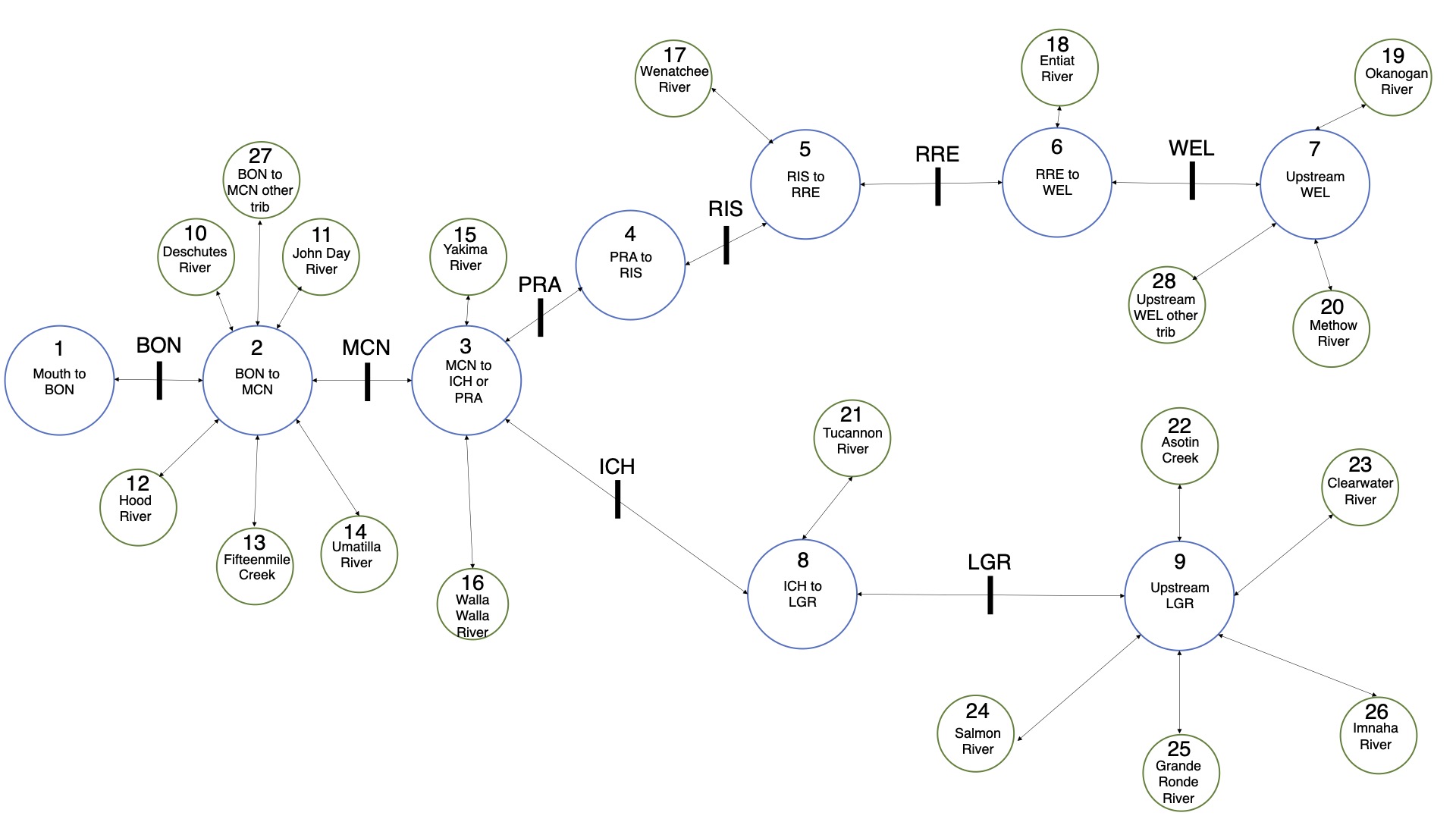
## Turning detections at different sites into state visits

With antennas appropriately assigned to different passage routes and the sequence of antenna detections used at the adult fishways to interpret directionality, the output from the previous script was used as input into the next script, which converted a history of detections at sites into a history of movements between states, as defined in Figure 1. For detections at sites in the fish passage routes at dams, the directionality of movement, as assigned in the previous script, was used to inform transitions between states. Ascents at dams indicated a transition from the downstream state to the upstream state; descents at dams (either through the juvenile bypass system or through descents through the ladder) indicated a transition from the upstream state to the downstream state. Aborted ascension attempts were noted, but interpreted as no transition from the current state. Detections in tributary sites were interpreted as transitions from the mainstem state into the tributary. Once a fish transitioned into a given state, any subsequent detections in that state were ignored, as they did represent transitions between states. Therefore, if fish were detected at sites within the same tributary consecutively, or if fish were detected at instream sites in the mainstem following transition into that mainstem state, these detections were ignored.

With the exception of a few downstream routes, such as the spillway at Lower Granite Dam following the installation of the PIT tag antennas in 2020, or the Bonneville Corner Collector, PIT tag detection capabilities were limited to the adult fish ladders and the juvenile bypass system at each dam. As such, PIT tag antennas have historically been unable to directly monitor fallback at dams, unless an individual subsequently reascends the dam (Boggs *et al.* 2004). With the installation of instream antennas in natal tributaries, fallback to home has been monitored (Richins and Skalski 2018), by noting when individuals entered natal tributaries downstream of a dam that was previously ascended. In this study, we monitored fallback to the greatest extent possible with the current configuration of PIT tag antennas by using our knowledge of the connections between states in our model to note when downstream movements must have occurred. In this way, we included fallback that occurred on the mainstem downstream of the natal tributary (similar to (Boggs *et al.* 2004)), fallback to home (similar to (Richins and Skalski 2018)), and other fallback movements, such as fallback upstream of the natal tributary that did not end in homing.

Once we determined a history of movement between states, we then subset this movement history to eliminate any movement that occurred as a juvenile or as a kelt in order to isolate only the portion of the adult migration prior to reaching spawning areas. Based on manual inspection of detection histories, juvenile movements were identified using the following criteria: 1) any detections within 90 days of juvenile release; 2) any detections on or before June 15 of the the same year that an individual was released, or detections on or before June 15 in a given year if individual was released on or after July 1 of the previous year. The June 15 cutoff date was chosen based on the timing of juvenile outmigration at Bonneville Dam, 95% of which occurs before this date in nearly every run year (data from CBR DART). Kelt movement was identified as any downstream movement occurring between March and July (following spawning). Repeat spawners were also identified in the dataset based on detections at the Bonneville adult ladders occurring at least 180 days after they were initially seen at Bonneville. For the purposes of our analysis, repeat spawners were treated as new fish when they returned to Bonneville.

## The model in stan



The model schematic.

The history of state transitions for each individual PIT-tagged fish, as well as the information on that fish’s natal origin, were the inputs for the multistate model. The multistate model was implemented in a Bayesian framework using the Stan programming language (Carpenter *et al.* 2017). The multistate model is constructed as a series of states, defined as either reaches of the mainstem Columbia or Snake Rivers between dams with active PIT tag antennas for the duration of our study period or tributaries that flow into the Columbia or Snake Rivers (Figure 1). All fish in our model begin when they are first detected as adults in the fish ladders at Bonneville Dam. At each state in our model, each fish is assigned a probability of moving to any of the states connected to the current states. This probability is evaluated through a multinomial logit.

(*MDS: This would be a good place to add/introduce the actual equations.*)

Due to the computational requirements of evaluating the detection histories of over 60,000 individual fish, the model was fit to three different datasets, corresponding to the three Steelhead DPSs found exclusively upstream of Bonneville Dam: the Middle Columbia DPS, the Upper Columbia DPS, and the Snake River Basin DPS. To reduce the number of parameters in the model,

The history of state transitions for each individual PIT-tagged fish, as well as the information on that fish’s natal origin, were the inputs for the multistate model. The multistate model was implemented in a Bayesian framework in Stan (Carpenter *et al.* 2017). The multistate model is constructed as a series of states, defined as either reaches of the mainstem Columbia or Snake Rivers between dams with active PIT tag antennas for the duration of our study period or tributaries that flow into the Columbia or Snake Rivers (Fig. 1). All fish in our model begin when they are first detected as adults in the fish ladders at Bonneville Dam. At each state in our model, each fish is assigned a probability of moving to any of the states connected to the current states, or into the absorbing loss category, which a fish enters once the detection history ends. Each of these probabilities is evaluated through a multinomial logit, with the loss probability calculated as 1 - the sum of the other probabilities, enforcing a constraint that all movement probabilities have to sum to 1.

Due to the computational requirements of evaluating the detection histories of over 60,000 individual fish, the model was fit to three different datasets, corresponding to the three Steelhead DPSs found exclusively upstream of Bonneville Dam: the Middle Columbia DPS, the Upper Columbia DPS, and the Snake River Basin DPS. To reduce the number of parameters in the model, an effect of natal origin was only included for state transitions into or out of states within the DPS boundaries, whereas for states outside of the DPS, all origins shared a common movement probability. This model structure allowed different natal origins to differentiate as they neared natal tributaries.

All code is available at <https://github.com/markusmin/steelhead>.

# Results

A total of 662 different movement probabilities, based on the combination of state transition and origin/DPS, were estimated by the model (Tables 1-6). The model schematic in Fig. 1 is necessary to interpret the ecological significance of these movement probabilities, in terms of which movements constitute the probabilities of certain movements, such as overshoot, fallback, homing, or straying. Furthermore, each movement probability represents only the probability of an individual making that movement conditional on it already being in the “from” state. Due to poor detection probabilities in tributaries and in downstream passage routes, only overshoot probabilities (which have near 100% detection probability) are discussed in the Results; see [Current Limitations](#current-limitations) for a discussion of these issues and future directions to address them. Overshoot probabilities, or the probability of ascending the dam upstream of the natal tributary in the model schematic (Fig. 1), varied considerably by natal origin.

## Middle Columbia River Steelhead

Of the natal tributaries downstream of McNary Dam, John Day River and Umatilla River Steelhead each had a high mean probability of overshooting McNary Dam (46.4% and 33.8%, respectively; Table 2), while Deschutes River and Fifteenmile Creek Steelhead had a low mean probability (0.7% and 9%, respectively; Table 2). Conditional on overshooting McNary Dam, John Day River and Umatilla River Steelhead had an approximately 20% chance of additionally overshooting Ice Harbor Dam on the Snake River, but only a very low probability of overshooting Priest Rapids Dam on the Columbia River (Table 2). For Yakima River and Walla Walla River Steelhead, whose natal tributaries are upstream of McNary Dam, Yakima River Steelhead were more likely to overshoot Priest Rapids Dam (13.8% mean probability) than Ice Harbor Dam (3.5% mean probabiltiy) whereas Wallla Walla River Steelhead were much more likely to overshoot Ice Harbor Dam (57.4% mean probability) than Priest Rapids Dam (2% mean probability) (Table 2).

Movement probabilities for Middle Columbia Steelhead, outside of the DPS boundaries.

from

to

mean

q5

q95

mainstem, RIS to RRE

mainstem, PRA to RIS

0.384

0.328

0.443

mainstem, RIS to RRE

mainstem, RRE to WEL

0.390

0.330

0.446

mainstem, RIS to RRE

Wenatchee River

0.041

0.013

0.080

mainstem, RIS to RRE

loss

0.185

0.133

0.252

mainstem, RRE to WEL

mainstem, RIS to RRE

0.304

0.189

0.426

mainstem, RRE to WEL

mainstem, upstream of WEL

0.428

0.319

0.551

mainstem, RRE to WEL

Entiat River

0.021

0.001

0.067

mainstem, RRE to WEL

loss

0.247

0.136

0.373

mainstem, upstream of WEL

mainstem, RRE to WEL

0.437

0.272

0.581

mainstem, upstream of WEL

Okanogan River

0.044

0.003

0.152

mainstem, upstream of WEL

Methow River

0.130

0.034

0.260

mainstem, upstream of WEL

loss

0.388

0.232

0.545

mainstem, upstream of LGR

mainstem, ICH to LGR

0.380

0.359

0.403

mainstem, upstream of LGR

Asotin Creek

0.012

0.007

0.018

mainstem, upstream of LGR

Clearwater River

0.018

0.011

0.026

mainstem, upstream of LGR

Salmon River

0.002

0.000

0.005

mainstem, upstream of LGR

Grande Ronde River

0.016

0.010

0.023

mainstem, upstream of LGR

Imnaha River

0.003

0.001

0.007

mainstem, upstream of LGR

loss

0.569

0.543

0.590

Wenatchee River

mainstem, RIS to RRE

0.511

0.168

0.864

Wenatchee River

loss

0.489

0.136

0.832

Entiat River

mainstem, RRE to WEL

0.069

0.000

0.522

Entiat River

loss

0.931

0.478

1.000

Okanogan River

mainstem, upstream of WEL

0.087

0.000

0.618

Okanogan River

loss

0.913

0.382

1.000

Methow River

mainstem, upstream of WEL

0.661

0.240

0.962

Methow River

loss

0.339

0.038

0.760

Tucannon River

mainstem, ICH to LGR

0.096

0.067

0.127

Tucannon River

loss

0.904

0.873

0.933

Asotin Creek

mainstem, upstream of LGR

0.010

0.000

0.049

Asotin Creek

loss

0.990

0.951

1.000

Clearwater River

mainstem, upstream of LGR

0.068

0.002

0.224

Clearwater River

loss

0.932

0.776

0.998

Salmon River

mainstem, upstream of LGR

0.039

0.000

0.287

Salmon River

loss

0.961

0.713

1.000

Grande Ronde River

mainstem, upstream of LGR

0.007

0.000

0.037

Grande Ronde River

loss

0.993

0.963

1.000

Imnaha River

mainstem, upstream of LGR

0.028

0.000

0.180

Imnaha River

loss

0.972

0.820

1.000

Movement probabilities for Middle Columbia Steelhead by natal origin, inside the DPS boundaries.

origin

from

to

mean

q5

q95

Deschutes River

mainstem, mouth to BON

mainstem, BON to MCN

0.916

0.795

0.989

Fifteenmile Creek

mainstem, mouth to BON

mainstem, BON to MCN

0.994

0.957

1.000

John Day River

mainstem, mouth to BON

mainstem, BON to MCN

0.962

0.914

0.994

Umatilla River

mainstem, mouth to BON

mainstem, BON to MCN

0.958

0.900

0.994

Yakima River

mainstem, mouth to BON

mainstem, BON to MCN

0.996

0.985

1.000

Walla Walla River

mainstem, mouth to BON

mainstem, BON to MCN

0.972

0.943

0.994

Deschutes River

mainstem, mouth to BON

loss

0.084

0.011

0.205

Fifteenmile Creek

mainstem, mouth to BON

loss

0.006

0.000

0.043

John Day River

mainstem, mouth to BON

loss

0.038

0.006

0.086

Umatilla River

mainstem, mouth to BON

loss

0.042

0.006

0.100

Yakima River

mainstem, mouth to BON

loss

0.004

0.000

0.015

Walla Walla River

mainstem, mouth to BON

loss

0.028

0.006

0.057

Deschutes River

mainstem, BON to MCN

mainstem, mouth to BON

0.016

0.010

0.023

Fifteenmile Creek

mainstem, BON to MCN

mainstem, mouth to BON

0.011

0.005

0.020

John Day River

mainstem, BON to MCN

mainstem, mouth to BON

0.008

0.006

0.012

Umatilla River

mainstem, BON to MCN

mainstem, mouth to BON

0.008

0.006

0.011

Yakima River

mainstem, BON to MCN

mainstem, mouth to BON

0.007

0.003

0.011

Walla Walla River

mainstem, BON to MCN

mainstem, mouth to BON

0.016

0.013

0.019

Deschutes River

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.007

0.003

0.012

Fifteenmile Creek

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.090

0.075

0.109

John Day River

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.464

0.452

0.476

Umatilla River

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.338

0.323

0.352

Yakima River

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.759

0.731

0.787

Walla Walla River

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.781

0.768

0.793

Deschutes River

mainstem, BON to MCN

Deschutes River

0.366

0.342

0.389

Fifteenmile Creek

mainstem, BON to MCN

Deschutes River

0.136

0.112

0.167

John Day River

mainstem, BON to MCN

Deschutes River

0.041

0.036

0.045

Umatilla River

mainstem, BON to MCN

Deschutes River

0.062

0.055

0.070

Yakima River

mainstem, BON to MCN

Deschutes River

0.059

0.045

0.073

Walla Walla River

mainstem, BON to MCN

Deschutes River

0.027

0.024

0.032

Deschutes River

mainstem, BON to MCN

John Day River

0.001

0.000

0.003

Fifteenmile Creek

mainstem, BON to MCN

John Day River

0.006

0.002

0.012

John Day River

mainstem, BON to MCN

John Day River

0.238

0.227

0.248

Umatilla River

mainstem, BON to MCN

John Day River

0.000

0.000

0.001

Yakima River

mainstem, BON to MCN

John Day River

0.000

0.000

0.001

Walla Walla River

mainstem, BON to MCN

John Day River

0.000

0.000

0.000

Deschutes River

mainstem, BON to MCN

Hood River

0.003

0.001

0.006

Fifteenmile Creek

mainstem, BON to MCN

Hood River

0.000

0.000

0.001

John Day River

mainstem, BON to MCN

Hood River

0.001

0.000

0.001

Umatilla River

mainstem, BON to MCN

Hood River

0.003

0.001

0.005

Yakima River

mainstem, BON to MCN

Hood River

0.000

0.000

0.001

Walla Walla River

mainstem, BON to MCN

Hood River

0.000

0.000

0.000

Deschutes River

mainstem, BON to MCN

Fifteenmile Creek

0.000

0.000

0.000

Fifteenmile Creek

mainstem, BON to MCN

Fifteenmile Creek

0.218

0.190

0.248

John Day River

mainstem, BON to MCN

Fifteenmile Creek

0.000

0.000

0.000

Umatilla River

mainstem, BON to MCN

Fifteenmile Creek

0.000

0.000

0.000

Yakima River

mainstem, BON to MCN

Fifteenmile Creek

0.000

0.000

0.000

Walla Walla River

mainstem, BON to MCN

Fifteenmile Creek

0.000

0.000

0.000

Deschutes River

mainstem, BON to MCN

Umatilla River

0.000

0.000

0.000

Fifteenmile Creek

mainstem, BON to MCN

Umatilla River

0.002

0.000

0.005

John Day River

mainstem, BON to MCN

Umatilla River

0.018

0.014

0.022

Umatilla River

mainstem, BON to MCN

Umatilla River

0.307

0.294

0.321

Yakima River

mainstem, BON to MCN

Umatilla River

0.000

0.000

0.001

Walla Walla River

mainstem, BON to MCN

Umatilla River

0.000

0.000

0.000

Deschutes River

mainstem, BON to MCN

BON to MCN other tributaries

0.001

0.000

0.002

Fifteenmile Creek

mainstem, BON to MCN

BON to MCN other tributaries

0.026

0.017

0.037

John Day River

mainstem, BON to MCN

BON to MCN other tributaries

0.001

0.001

0.002

Umatilla River

mainstem, BON to MCN

BON to MCN other tributaries

0.003

0.002

0.005

Yakima River

mainstem, BON to MCN

BON to MCN other tributaries

0.001

0.000

0.004

Walla Walla River

mainstem, BON to MCN

BON to MCN other tributaries

0.000

0.000

0.001

Deschutes River

mainstem, BON to MCN

loss

0.607

0.582

0.629

Fifteenmile Creek

mainstem, BON to MCN

loss

0.511

0.477

0.541

John Day River

mainstem, BON to MCN

loss

0.228

0.219

0.238

Umatilla River

mainstem, BON to MCN

loss

0.279

0.265

0.295

Yakima River

mainstem, BON to MCN

loss

0.173

0.149

0.194

Walla Walla River

mainstem, BON to MCN

loss

0.176

0.165

0.188

Deschutes River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.394

0.145

0.671

Fifteenmile Creek

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.472

0.347

0.599

John Day River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.508

0.489

0.528

Umatilla River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.478

0.453

0.501

Yakima River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.010

0.005

0.017

Walla Walla River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.045

0.039

0.051

Deschutes River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.008

0.000

0.034

Fifteenmile Creek

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.001

0.000

0.008

John Day River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.014

0.010

0.019

Umatilla River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.021

0.014

0.029

Yakima River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.138

0.116

0.162

Walla Walla River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.020

0.017

0.024

Deschutes River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.236

0.055

0.478

Fifteenmile Creek

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.120

0.059

0.199

John Day River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.212

0.199

0.225

Umatilla River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.192

0.168

0.212

Yakima River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.035

0.025

0.048

Walla Walla River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.574

0.558

0.590

Deschutes River

mainstem, MCN to ICH or PRA

Yakima River

0.007

0.000

0.039

Fifteenmile Creek

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.007

John Day River

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.002

Umatilla River

mainstem, MCN to ICH or PRA

Yakima River

0.002

0.000

0.005

Yakima River

mainstem, MCN to ICH or PRA

Yakima River

0.761

0.735

0.791

Walla Walla River

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.001

Deschutes River

mainstem, MCN to ICH or PRA

Walla Walla River

0.010

0.000

0.052

Fifteenmile Creek

mainstem, MCN to ICH or PRA

Walla Walla River

0.020

0.002

0.053

John Day River

mainstem, MCN to ICH or PRA

Walla Walla River

0.005

0.003

0.008

Umatilla River

mainstem, MCN to ICH or PRA

Walla Walla River

0.008

0.004

0.013

Yakima River

mainstem, MCN to ICH or PRA

Walla Walla River

0.000

0.000

0.001

Walla Walla River

mainstem, MCN to ICH or PRA

Walla Walla River

0.279

0.264

0.293

Deschutes River

mainstem, MCN to ICH or PRA

loss

0.344

0.107

0.608

Fifteenmile Creek

mainstem, MCN to ICH or PRA

loss

0.384

0.262

0.492

John Day River

mainstem, MCN to ICH or PRA

loss

0.259

0.242

0.274

Umatilla River

mainstem, MCN to ICH or PRA

loss

0.300

0.277

0.324

Yakima River

mainstem, MCN to ICH or PRA

loss

0.055

0.041

0.071

Walla Walla River

mainstem, MCN to ICH or PRA

loss

0.081

0.073

0.089

Deschutes River

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.517

0.000

1.000

Fifteenmile Creek

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.508

0.000

1.000

John Day River

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.509

0.365

0.656

Umatilla River

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.552

0.342

0.713

Yakima River

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.603

0.523

0.684

Walla Walla River

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.525

0.443

0.603

Deschutes River

mainstem, PRA to RIS

mainstem, RIS to RRE

0.380

0.000

0.829

Fifteenmile Creek

mainstem, PRA to RIS

mainstem, RIS to RRE

0.388

0.000

0.832

John Day River

mainstem, PRA to RIS

mainstem, RIS to RRE

0.387

0.264

0.498

Umatilla River

mainstem, PRA to RIS

mainstem, RIS to RRE

0.352

0.228

0.519

Yakima River

mainstem, PRA to RIS

mainstem, RIS to RRE

0.312

0.242

0.383

Walla Walla River

mainstem, PRA to RIS

mainstem, RIS to RRE

0.374

0.307

0.449

Deschutes River

mainstem, PRA to RIS

loss

0.103

0.000

0.262

Fifteenmile Creek

mainstem, PRA to RIS

loss

0.105

0.000

0.261

John Day River

mainstem, PRA to RIS

loss

0.104

0.066

0.145

Umatilla River

mainstem, PRA to RIS

loss

0.095

0.057

0.146

Yakima River

mainstem, PRA to RIS

loss

0.084

0.057

0.112

Walla Walla River

mainstem, PRA to RIS

loss

0.101

0.071

0.141

Deschutes River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.236

0.010

0.544

Fifteenmile Creek

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.306

0.102

0.560

John Day River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.277

0.243

0.314

Umatilla River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.325

0.273

0.376

Yakima River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.556

0.390

0.735

Walla Walla River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.259

0.244

0.276

Deschutes River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.357

0.212

0.461

Fifteenmile Creek

mainstem, ICH to LGR

mainstem, upstream of LGR

0.325

0.205

0.416

John Day River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.338

0.317

0.362

Umatilla River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.316

0.288

0.342

Yakima River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.208

0.122

0.290

Walla Walla River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.347

0.329

0.365

Deschutes River

mainstem, ICH to LGR

Tucannon River

0.114

0.067

0.154

Fifteenmile Creek

mainstem, ICH to LGR

Tucannon River

0.104

0.066

0.139

John Day River

mainstem, ICH to LGR

Tucannon River

0.108

0.097

0.120

Umatilla River

mainstem, ICH to LGR

Tucannon River

0.101

0.089

0.115

Yakima River

mainstem, ICH to LGR

Tucannon River

0.066

0.039

0.094

Walla Walla River

mainstem, ICH to LGR

Tucannon River

0.111

0.102

0.120

Deschutes River

mainstem, ICH to LGR

loss

0.292

0.175

0.376

Fifteenmile Creek

mainstem, ICH to LGR

loss

0.265

0.169

0.345

John Day River

mainstem, ICH to LGR

loss

0.276

0.260

0.296

Umatilla River

mainstem, ICH to LGR

loss

0.258

0.235

0.283

Yakima River

mainstem, ICH to LGR

loss

0.169

0.105

0.234

Walla Walla River

mainstem, ICH to LGR

loss

0.283

0.271

0.299

Deschutes River

Deschutes River

mainstem, BON to MCN

0.003

0.000

0.008

Fifteenmile Creek

Deschutes River

mainstem, BON to MCN

0.248

0.173

0.330

John Day River

Deschutes River

mainstem, BON to MCN

0.642

0.582

0.692

Umatilla River

Deschutes River

mainstem, BON to MCN

0.486

0.413

0.549

Yakima River

Deschutes River

mainstem, BON to MCN

0.950

0.889

0.990

Walla Walla River

Deschutes River

mainstem, BON to MCN

0.808

0.744

0.861

Deschutes River

Deschutes River

loss

0.997

0.992

1.000

Fifteenmile Creek

Deschutes River

loss

0.752

0.670

0.827

John Day River

Deschutes River

loss

0.358

0.308

0.418

Umatilla River

Deschutes River

loss

0.514

0.451

0.587

Yakima River

Deschutes River

loss

0.050

0.010

0.111

Walla Walla River

Deschutes River

loss

0.192

0.139

0.256

Deschutes River

John Day River

mainstem, BON to MCN

0.032

0.000

0.157

Fifteenmile Creek

John Day River

mainstem, BON to MCN

0.014

0.000

0.064

John Day River

John Day River

mainstem, BON to MCN

0.001

0.000

0.003

Umatilla River

John Day River

mainstem, BON to MCN

0.031

0.000

0.251

Yakima River

John Day River

mainstem, BON to MCN

0.223

0.000

1.000

Walla Walla River

John Day River

mainstem, BON to MCN

0.520

0.000

1.000

Deschutes River

John Day River

loss

0.968

0.843

1.000

Fifteenmile Creek

John Day River

loss

0.986

0.936

1.000

John Day River

John Day River

loss

0.999

0.997

1.000

Umatilla River

John Day River

loss

0.969

0.749

1.000

Yakima River

John Day River

loss

0.777

0.000

1.000

Walla Walla River

John Day River

loss

0.480

0.000

1.000

Deschutes River

Hood River

mainstem, BON to MCN

0.369

0.026

0.793

Fifteenmile Creek

Hood River

mainstem, BON to MCN

0.652

0.000

1.000

John Day River

Hood River

mainstem, BON to MCN

0.953

0.688

1.000

Umatilla River

Hood River

mainstem, BON to MCN

0.993

0.957

1.000

Yakima River

Hood River

mainstem, BON to MCN

0.665

0.000

1.000

Walla Walla River

Hood River

mainstem, BON to MCN

0.407

0.000

1.000

Deschutes River

Hood River

loss

0.631

0.207

0.974

Fifteenmile Creek

Hood River

loss

0.348

0.000

1.000

John Day River

Hood River

loss

0.047

0.000

0.312

Umatilla River

Hood River

loss

0.007

0.000

0.043

Yakima River

Hood River

loss

0.335

0.000

1.000

Walla Walla River

Hood River

loss

0.593

0.000

1.000

Deschutes River

Fifteenmile Creek

mainstem, BON to MCN

0.278

0.000

1.000

Fifteenmile Creek

Fifteenmile Creek

mainstem, BON to MCN

0.001

0.000

0.005

John Day River

Fifteenmile Creek

mainstem, BON to MCN

0.257

0.000

1.000

Umatilla River

Fifteenmile Creek

mainstem, BON to MCN

0.279

0.000

1.000

Yakima River

Fifteenmile Creek

mainstem, BON to MCN

0.242

0.000

1.000

Walla Walla River

Fifteenmile Creek

mainstem, BON to MCN

0.517

0.000

1.000

Deschutes River

Fifteenmile Creek

loss

0.722

0.000

1.000

Fifteenmile Creek

Fifteenmile Creek

loss

0.999

0.995

1.000

John Day River

Fifteenmile Creek

loss

0.743

0.000

1.000

Umatilla River

Fifteenmile Creek

loss

0.721

0.000

1.000

Yakima River

Fifteenmile Creek

loss

0.758

0.000

1.000

Walla Walla River

Fifteenmile Creek

loss

0.483

0.000

1.000

Deschutes River

Umatilla River

mainstem, BON to MCN

0.354

0.000

1.000

Fifteenmile Creek

Umatilla River

mainstem, BON to MCN

0.047

0.000

0.309

John Day River

Umatilla River

mainstem, BON to MCN

0.068

0.027

0.117

Umatilla River

Umatilla River

mainstem, BON to MCN

0.001

0.000

0.004

Yakima River

Umatilla River

mainstem, BON to MCN

0.332

0.000

1.000

Walla Walla River

Umatilla River

mainstem, BON to MCN

0.460

0.000

1.000

Deschutes River

Umatilla River

loss

0.646

0.000

1.000

Fifteenmile Creek

Umatilla River

loss

0.953

0.691

1.000

John Day River

Umatilla River

loss

0.932

0.883

0.973

Umatilla River

Umatilla River

loss

0.999

0.996

1.000

Yakima River

Umatilla River

loss

0.668

0.000

1.000

Walla Walla River

Umatilla River

loss

0.540

0.000

1.000

Deschutes River

Yakima River

mainstem, MCN to ICH or PRA

0.166

0.000

1.000

Fifteenmile Creek

Yakima River

mainstem, MCN to ICH or PRA

0.190

0.000

1.000

John Day River

Yakima River

mainstem, MCN to ICH or PRA

0.016

0.000

0.060

Umatilla River

Yakima River

mainstem, MCN to ICH or PRA

0.020

0.000

0.085

Yakima River

Yakima River

mainstem, MCN to ICH or PRA

0.004

0.001

0.009

Walla Walla River

Yakima River

mainstem, MCN to ICH or PRA

0.532

0.054

0.973

Deschutes River

Yakima River

loss

0.834

0.000

1.000

Fifteenmile Creek

Yakima River

loss

0.810

0.000

1.000

John Day River

Yakima River

loss

0.984

0.940

1.000

Umatilla River

Yakima River

loss

0.980

0.915

1.000

Yakima River

Yakima River

loss

0.996

0.991

0.999

Walla Walla River

Yakima River

loss

0.468

0.027

0.946

Deschutes River

Walla Walla River

mainstem, MCN to ICH or PRA

0.402

0.000

1.000

Fifteenmile Creek

Walla Walla River

mainstem, MCN to ICH or PRA

0.074

0.000

0.475

John Day River

Walla Walla River

mainstem, MCN to ICH or PRA

0.391

0.152

0.669

Umatilla River

Walla Walla River

mainstem, MCN to ICH or PRA

0.565

0.272

0.852

Yakima River

Walla Walla River

mainstem, MCN to ICH or PRA

0.405

0.000

1.000

Walla Walla River

Walla Walla River

mainstem, MCN to ICH or PRA

0.011

0.006

0.017

Deschutes River

Walla Walla River

loss

0.598

0.000

1.000

Fifteenmile Creek

Walla Walla River

loss

0.926

0.525

1.000

John Day River

Walla Walla River

loss

0.609

0.331

0.848

Umatilla River

Walla Walla River

loss

0.435

0.148

0.728

Yakima River

Walla Walla River

loss

0.595

0.000

1.000

Walla Walla River

Walla Walla River

loss

0.989

0.983

0.994

Deschutes River

BON to MCN other tributaries

mainstem, BON to MCN

0.058

0.000

0.400

Fifteenmile Creek

BON to MCN other tributaries

mainstem, BON to MCN

0.145

0.030

0.319

John Day River

BON to MCN other tributaries

mainstem, BON to MCN

0.215

0.018

0.570

Umatilla River

BON to MCN other tributaries

mainstem, BON to MCN

0.697

0.368

0.927

Yakima River

BON to MCN other tributaries

mainstem, BON to MCN

0.035

0.000

0.179

Walla Walla River

BON to MCN other tributaries

mainstem, BON to MCN

0.977

0.851

1.000

Deschutes River

BON to MCN other tributaries

loss

0.942

0.600

1.000

Fifteenmile Creek

BON to MCN other tributaries

loss

0.855

0.681

0.970

John Day River

BON to MCN other tributaries

loss

0.785

0.430

0.982

Umatilla River

BON to MCN other tributaries

loss

0.303

0.073

0.632

Yakima River

BON to MCN other tributaries

loss

0.965

0.821

1.000

Walla Walla River

BON to MCN other tributaries

loss

0.023

0.000

0.149

## Upper Columbia River Steelhead

Wenatchee River Steelhead, whose natal tributary is between Rock Island Dam and Rocky Reach Dam, had a 58.3% (90% CI 57%-59.6%) probability of overshooting Rocky Reach Dam. Entiat River Steelhead, whose natal tribuatry is between Rocky Reach Dam and Wells Dam, had a 36.3% (90% CI 33%-39.5%) probability of overshooting Wells Dam. Because no dam with PIT tag detectors in the adult fishways exists above Wells Dam, overshoot probabilities on the Columbia River could not be calculated for Okanogan River or Methow River Steelhead. Overshoot probabilities at Ice Harbor Dam for all four Upper Columbia River origins were exceedingly low (0-0.1%).

**Table** : Movement probabilities for Upper Columbia Steelhead, outside of the DPS boundaries.

| from | to | mean | q5 | q95 |
| --- | --- | --- | --- | --- |
| mainstem, mouth to BON | mainstem, BON to MCN | 0.976 | 0.960 | 0.990 |
| mainstem, mouth to BON | loss | 0.024 | 0.010 | 0.040 |
| mainstem, BON to MCN | mainstem, mouth to BON | 0.012 | 0.010 | 0.013 |
| mainstem, BON to MCN | mainstem, MCN to ICH or PRA | 0.749 | 0.744 | 0.754 |
| mainstem, BON to MCN | Deschutes River | 0.013 | 0.012 | 0.014 |
| mainstem, BON to MCN | John Day River | 0.000 | 0.000 | 0.000 |
| mainstem, BON to MCN | Hood River | 0.000 | 0.000 | 0.000 |
| mainstem, BON to MCN | Fifteenmile Creek | 0.000 | 0.000 | 0.000 |
| mainstem, BON to MCN | Umatilla River | 0.000 | 0.000 | 0.000 |
| mainstem, BON to MCN | BON to MCN other tributaries | 0.000 | 0.000 | 0.000 |
| mainstem, BON to MCN | loss | 0.226 | 0.221 | 0.231 |
| mainstem, ICH to LGR | mainstem, MCN to ICH or PRA | 0.096 | 0.003 | 0.248 |
| mainstem, ICH to LGR | mainstem, upstream of LGR | 0.890 | 0.727 | 0.990 |
| mainstem, ICH to LGR | Tucannon River | 0.004 | 0.000 | 0.017 |
| mainstem, ICH to LGR | loss | 0.009 | 0.000 | 0.042 |
| mainstem, upstream of LGR | mainstem, ICH to LGR | 0.330 | 0.124 | 0.558 |
| mainstem, upstream of LGR | Asotin Creek | 0.009 | 0.000 | 0.034 |
| mainstem, upstream of LGR | Clearwater River | 0.109 | 0.007 | 0.340 |
| mainstem, upstream of LGR | Salmon River | 0.009 | 0.000 | 0.047 |
| mainstem, upstream of LGR | Grande Ronde River | 0.009 | 0.000 | 0.062 |
| mainstem, upstream of LGR | Imnaha River | 0.010 | 0.000 | 0.061 |
| mainstem, upstream of LGR | loss | 0.525 | 0.259 | 0.790 |
| Deschutes River | mainstem, BON to MCN | 0.872 | 0.830 | 0.908 |
| Deschutes River | loss | 0.128 | 0.092 | 0.170 |
| Hood River | mainstem, BON to MCN | 0.956 | 0.741 | 1.000 |
| Hood River | loss | 0.044 | 0.000 | 0.259 |
| Clearwater River | mainstem, upstream of LGR | 0.070 | 0.000 | 0.458 |
| Clearwater River | loss | 0.930 | 0.542 | 1.000 |

**Table** : Movement probabilities for Upper Columbia Steelhead by natal origin, inside the DPS boundaries.

| origin | from | to | mean | q5 | q95 |
| --- | --- | --- | --- | --- | --- |
| Wenatchee River | mainstem, MCN to ICH or PRA | mainstem, BON to MCN | 0.010 | 0.008 | 0.012 |
| Entiat River | mainstem, MCN to ICH or PRA | mainstem, BON to MCN | 0.007 | 0.004 | 0.011 |
| Okanogan River | mainstem, MCN to ICH or PRA | mainstem, BON to MCN | 0.011 | 0.008 | 0.015 |
| Methow River | mainstem, MCN to ICH or PRA | mainstem, BON to MCN | 0.009 | 0.008 | 0.012 |
| Wenatchee River | mainstem, MCN to ICH or PRA | mainstem, PRA to RIS | 0.980 | 0.977 | 0.984 |
| Entiat River | mainstem, MCN to ICH or PRA | mainstem, PRA to RIS | 0.985 | 0.978 | 0.992 |
| Okanogan River | mainstem, MCN to ICH or PRA | mainstem, PRA to RIS | 0.978 | 0.972 | 0.984 |
| Methow River | mainstem, MCN to ICH or PRA | mainstem, PRA to RIS | 0.981 | 0.978 | 0.984 |
| Wenatchee River | mainstem, MCN to ICH or PRA | mainstem, ICH to LGR | 0.001 | 0.000 | 0.001 |
| Entiat River | mainstem, MCN to ICH or PRA | mainstem, ICH to LGR | 0.000 | 0.000 | 0.001 |
| Okanogan River | mainstem, MCN to ICH or PRA | mainstem, ICH to LGR | 0.001 | 0.000 | 0.001 |
| Methow River | mainstem, MCN to ICH or PRA | mainstem, ICH to LGR | 0.001 | 0.000 | 0.001 |
| Wenatchee River | mainstem, MCN to ICH or PRA | Yakima River | 0.000 | 0.000 | 0.000 |
| Entiat River | mainstem, MCN to ICH or PRA | Yakima River | 0.000 | 0.000 | 0.000 |
| Okanogan River | mainstem, MCN to ICH or PRA | Yakima River | 0.000 | 0.000 | 0.000 |
| Methow River | mainstem, MCN to ICH or PRA | Yakima River | 0.000 | 0.000 | 0.000 |
| Wenatchee River | mainstem, MCN to ICH or PRA | Walla Walla River | 0.000 | 0.000 | 0.000 |
| Entiat River | mainstem, MCN to ICH or PRA | Walla Walla River | 0.000 | 0.000 | 0.000 |
| Okanogan River | mainstem, MCN to ICH or PRA | Walla Walla River | 0.000 | 0.000 | 0.000 |
| Methow River | mainstem, MCN to ICH or PRA | Walla Walla River | 0.000 | 0.000 | 0.000 |
| Wenatchee River | mainstem, MCN to ICH or PRA | loss | 0.009 | 0.007 | 0.011 |
| Entiat River | mainstem, MCN to ICH or PRA | loss | 0.007 | 0.004 | 0.011 |
| Okanogan River | mainstem, MCN to ICH or PRA | loss | 0.010 | 0.007 | 0.013 |
| Methow River | mainstem, MCN to ICH or PRA | loss | 0.009 | 0.007 | 0.010 |
| Wenatchee River | mainstem, PRA to RIS | mainstem, MCN to ICH or PRA | 0.015 | 0.012 | 0.018 |
| Entiat River | mainstem, PRA to RIS | mainstem, MCN to ICH or PRA | 0.020 | 0.010 | 0.033 |
| Okanogan River | mainstem, PRA to RIS | mainstem, MCN to ICH or PRA | 0.016 | 0.011 | 0.023 |
| Methow River | mainstem, PRA to RIS | mainstem, MCN to ICH or PRA | 0.012 | 0.010 | 0.014 |
| Wenatchee River | mainstem, PRA to RIS | mainstem, RIS to RRE | 0.951 | 0.944 | 0.957 |
| Entiat River | mainstem, PRA to RIS | mainstem, RIS to RRE | 0.966 | 0.950 | 0.979 |
| Okanogan River | mainstem, PRA to RIS | mainstem, RIS to RRE | 0.969 | 0.960 | 0.977 |
| Methow River | mainstem, PRA to RIS | mainstem, RIS to RRE | 0.963 | 0.959 | 0.966 |
| Wenatchee River | mainstem, PRA to RIS | loss | 0.035 | 0.030 | 0.040 |
| Entiat River | mainstem, PRA to RIS | loss | 0.014 | 0.006 | 0.024 |
| Okanogan River | mainstem, PRA to RIS | loss | 0.014 | 0.009 | 0.022 |
| Methow River | mainstem, PRA to RIS | loss | 0.026 | 0.023 | 0.029 |
| Wenatchee River | mainstem, RIS to RRE | mainstem, PRA to RIS | 0.013 | 0.010 | 0.016 |
| Entiat River | mainstem, RIS to RRE | mainstem, PRA to RIS | 0.009 | 0.004 | 0.018 |
| Okanogan River | mainstem, RIS to RRE | mainstem, PRA to RIS | 0.004 | 0.001 | 0.008 |
| Methow River | mainstem, RIS to RRE | mainstem, PRA to RIS | 0.010 | 0.008 | 0.012 |
| Wenatchee River | mainstem, RIS to RRE | mainstem, RRE to WEL | 0.583 | 0.570 | 0.596 |
| Entiat River | mainstem, RIS to RRE | mainstem, RRE to WEL | 0.981 | 0.968 | 0.990 |
| Okanogan River | mainstem, RIS to RRE | mainstem, RRE to WEL | 0.973 | 0.964 | 0.982 |
| Methow River | mainstem, RIS to RRE | mainstem, RRE to WEL | 0.954 | 0.949 | 0.958 |
| Wenatchee River | mainstem, RIS to RRE | Wenatchee River | 0.319 | 0.307 | 0.331 |
| Entiat River | mainstem, RIS to RRE | Wenatchee River | 0.007 | 0.002 | 0.015 |
| Okanogan River | mainstem, RIS to RRE | Wenatchee River | 0.002 | 0.000 | 0.005 |
| Methow River | mainstem, RIS to RRE | Wenatchee River | 0.002 | 0.001 | 0.003 |
| Wenatchee River | mainstem, RIS to RRE | loss | 0.085 | 0.078 | 0.092 |
| Entiat River | mainstem, RIS to RRE | loss | 0.003 | 0.000 | 0.008 |
| Okanogan River | mainstem, RIS to RRE | loss | 0.020 | 0.012 | 0.027 |
| Methow River | mainstem, RIS to RRE | loss | 0.034 | 0.030 | 0.038 |
| Wenatchee River | mainstem, RRE to WEL | mainstem, RIS to RRE | 0.228 | 0.213 | 0.243 |
| Entiat River | mainstem, RRE to WEL | mainstem, RIS to RRE | 0.027 | 0.016 | 0.039 |
| Okanogan River | mainstem, RRE to WEL | mainstem, RIS to RRE | 0.002 | 0.001 | 0.005 |
| Methow River | mainstem, RRE to WEL | mainstem, RIS to RRE | 0.006 | 0.004 | 0.008 |
| Wenatchee River | mainstem, RRE to WEL | mainstem, upstream of WEL | 0.564 | 0.548 | 0.579 |
| Entiat River | mainstem, RRE to WEL | mainstem, upstream of WEL | 0.362 | 0.330 | 0.395 |
| Okanogan River | mainstem, RRE to WEL | mainstem, upstream of WEL | 0.978 | 0.969 | 0.985 |
| Methow River | mainstem, RRE to WEL | mainstem, upstream of WEL | 0.930 | 0.924 | 0.935 |
| Wenatchee River | mainstem, RRE to WEL | Entiat River | 0.032 | 0.027 | 0.037 |
| Entiat River | mainstem, RRE to WEL | Entiat River | 0.585 | 0.552 | 0.623 |
| Okanogan River | mainstem, RRE to WEL | Entiat River | 0.000 | 0.000 | 0.001 |
| Methow River | mainstem, RRE to WEL | Entiat River | 0.000 | 0.000 | 0.000 |
| Wenatchee River | mainstem, RRE to WEL | loss | 0.175 | 0.166 | 0.188 |
| Entiat River | mainstem, RRE to WEL | loss | 0.027 | 0.016 | 0.038 |
| Okanogan River | mainstem, RRE to WEL | loss | 0.020 | 0.013 | 0.028 |
| Methow River | mainstem, RRE to WEL | loss | 0.064 | 0.059 | 0.069 |
| Wenatchee River | mainstem, upstream of WEL | mainstem, RRE to WEL | 0.205 | 0.192 | 0.219 |
| Entiat River | mainstem, upstream of WEL | mainstem, RRE to WEL | 0.618 | 0.571 | 0.666 |
| Okanogan River | mainstem, upstream of WEL | mainstem, RRE to WEL | 0.022 | 0.015 | 0.031 |
| Methow River | mainstem, upstream of WEL | mainstem, RRE to WEL | 0.029 | 0.026 | 0.032 |
| Wenatchee River | mainstem, upstream of WEL | Okanogan River | 0.002 | 0.000 | 0.004 |
| Entiat River | mainstem, upstream of WEL | Okanogan River | 0.005 | 0.001 | 0.014 |
| Okanogan River | mainstem, upstream of WEL | Okanogan River | 0.667 | 0.639 | 0.692 |
| Methow River | mainstem, upstream of WEL | Okanogan River | 0.025 | 0.021 | 0.028 |
| Wenatchee River | mainstem, upstream of WEL | Methow River | 0.124 | 0.109 | 0.140 |
| Entiat River | mainstem, upstream of WEL | Methow River | 0.202 | 0.163 | 0.245 |
| Okanogan River | mainstem, upstream of WEL | Methow River | 0.050 | 0.039 | 0.064 |
| Methow River | mainstem, upstream of WEL | Methow River | 0.232 | 0.223 | 0.243 |
| Wenatchee River | mainstem, upstream of WEL | Upstream WEL other tributaries | 0.003 | 0.001 | 0.006 |
| Entiat River | mainstem, upstream of WEL | Upstream WEL other tributaries | 0.004 | 0.000 | 0.014 |
| Okanogan River | mainstem, upstream of WEL | Upstream WEL other tributaries | 0.002 | 0.000 | 0.005 |
| Methow River | mainstem, upstream of WEL | Upstream WEL other tributaries | 0.000 | 0.000 | 0.001 |
| Wenatchee River | mainstem, upstream of WEL | loss | 0.666 | 0.644 | 0.687 |
| Entiat River | mainstem, upstream of WEL | loss | 0.171 | 0.129 | 0.211 |
| Okanogan River | mainstem, upstream of WEL | loss | 0.259 | 0.232 | 0.281 |
| Methow River | mainstem, upstream of WEL | loss | 0.714 | 0.703 | 0.724 |
| Wenatchee River | Wenatchee River | mainstem, RIS to RRE | 0.043 | 0.034 | 0.052 |
| Entiat River | Wenatchee River | mainstem, RIS to RRE | 0.977 | 0.856 | 1.000 |
| Okanogan River | Wenatchee River | mainstem, RIS to RRE | 0.963 | 0.803 | 1.000 |
| Methow River | Wenatchee River | mainstem, RIS to RRE | 0.905 | 0.742 | 0.986 |
| Wenatchee River | Wenatchee River | loss | 0.957 | 0.948 | 0.966 |
| Entiat River | Wenatchee River | loss | 0.023 | 0.000 | 0.144 |
| Okanogan River | Wenatchee River | loss | 0.037 | 0.000 | 0.197 |
| Methow River | Wenatchee River | loss | 0.095 | 0.014 | 0.258 |
| Wenatchee River | Entiat River | mainstem, RRE to WEL | 0.116 | 0.066 | 0.180 |
| Entiat River | Entiat River | mainstem, RRE to WEL | 0.027 | 0.014 | 0.043 |
| Okanogan River | Entiat River | mainstem, RRE to WEL | 0.412 | 0.000 | 1.000 |
| Methow River | Entiat River | mainstem, RRE to WEL | 0.520 | 0.000 | 1.000 |
| Wenatchee River | Entiat River | loss | 0.884 | 0.820 | 0.934 |
| Entiat River | Entiat River | loss | 0.973 | 0.957 | 0.986 |
| Okanogan River | Entiat River | loss | 0.588 | 0.000 | 1.000 |
| Methow River | Entiat River | loss | 0.480 | 0.000 | 1.000 |
| Wenatchee River | Okanogan River | mainstem, upstream of WEL | 0.022 | 0.000 | 0.119 |
| Entiat River | Okanogan River | mainstem, upstream of WEL | 0.887 | 0.337 | 1.000 |
| Okanogan River | Okanogan River | mainstem, upstream of WEL | 0.004 | 0.001 | 0.008 |
| Methow River | Okanogan River | mainstem, upstream of WEL | 0.001 | 0.000 | 0.003 |
| Wenatchee River | Okanogan River | loss | 0.978 | 0.881 | 1.000 |
| Entiat River | Okanogan River | loss | 0.113 | 0.000 | 0.663 |
| Okanogan River | Okanogan River | loss | 0.996 | 0.992 | 0.999 |
| Methow River | Okanogan River | loss | 0.999 | 0.997 | 1.000 |
| Wenatchee River | Methow River | mainstem, upstream of WEL | 0.128 | 0.095 | 0.165 |
| Entiat River | Methow River | mainstem, upstream of WEL | 0.615 | 0.480 | 0.731 |
| Okanogan River | Methow River | mainstem, upstream of WEL | 0.023 | 0.001 | 0.070 |
| Methow River | Methow River | mainstem, upstream of WEL | 0.007 | 0.004 | 0.011 |
| Wenatchee River | Methow River | loss | 0.872 | 0.835 | 0.905 |
| Entiat River | Methow River | loss | 0.385 | 0.269 | 0.520 |
| Okanogan River | Methow River | loss | 0.977 | 0.930 | 0.999 |
| Methow River | Methow River | loss | 0.993 | 0.989 | 0.996 |
| Wenatchee River | Upstream WEL other tributaries | mainstem, upstream of WEL | 0.006 | 0.000 | 0.032 |
| Entiat River | Upstream WEL other tributaries | mainstem, upstream of WEL | 0.032 | 0.000 | 0.210 |
| Okanogan River | Upstream WEL other tributaries | mainstem, upstream of WEL | 0.019 | 0.000 | 0.123 |
| Methow River | Upstream WEL other tributaries | mainstem, upstream of WEL | 0.026 | 0.000 | 0.215 |
| Wenatchee River | Upstream WEL other tributaries | loss | 0.994 | 0.968 | 1.000 |
| Entiat River | Upstream WEL other tributaries | loss | 0.968 | 0.790 | 1.000 |
| Okanogan River | Upstream WEL other tributaries | loss | 0.981 | 0.877 | 1.000 |
| Methow River | Upstream WEL other tributaries | loss | 0.974 | 0.785 | 1.000 |

## Snake River Basin Steelhead

Tucannon River Steelhead are the only Snake River Steelhead population for which overshoot probabiltiies at the upstream dam could be calculated. Tucannon River Steelhead had a 57% (90% CI 55.8%-58.2%) probability of overshooting Lower Granite Dam. All six origins had probabilities of overshooting Priest Rapids Dam on the Columbia River between 1% and 3%.

Movement probabilities for Snake River Basin Steelhead, outside of the DPS boundaries.

from

to

mean

q5

q95

mainstem, mouth to BON

mainstem, BON to MCN

0.980

0.973

0.986

mainstem, mouth to BON

loss

0.020

0.014

0.027

mainstem, BON to MCN

mainstem, mouth to BON

0.020

0.019

0.021

mainstem, BON to MCN

mainstem, MCN to ICH or PRA

0.746

0.742

0.749

mainstem, BON to MCN

Deschutes River

0.037

0.036

0.039

mainstem, BON to MCN

John Day River

0.004

0.003

0.004

mainstem, BON to MCN

Hood River

0.001

0.000

0.001

mainstem, BON to MCN

Fifteenmile Creek

0.000

0.000

0.000

mainstem, BON to MCN

Umatilla River

0.001

0.001

0.001

mainstem, BON to MCN

BON to MCN other tributaries

0.001

0.001

0.001

mainstem, BON to MCN

loss

0.191

0.187

0.195

mainstem, PRA to RIS

mainstem, MCN to ICH or PRA

0.468

0.437

0.502

mainstem, PRA to RIS

mainstem, RIS to RRE

0.476

0.445

0.507

mainstem, PRA to RIS

loss

0.056

0.039

0.071

mainstem, RIS to RRE

mainstem, PRA to RIS

0.378

0.336

0.413

mainstem, RIS to RRE

mainstem, RRE to WEL

0.569

0.532

0.612

mainstem, RIS to RRE

Wenatchee River

0.006

0.001

0.012

mainstem, RIS to RRE

loss

0.048

0.032

0.068

mainstem, RRE to WEL

mainstem, RIS to RRE

0.261

0.219

0.307

mainstem, RRE to WEL

mainstem, upstream of WEL

0.627

0.573

0.677

mainstem, RRE to WEL

Entiat River

0.013

0.004

0.027

mainstem, RRE to WEL

loss

0.100

0.077

0.126

mainstem, upstream of WEL

mainstem, RRE to WEL

0.306

0.248

0.375

mainstem, upstream of WEL

Okanogan River

0.110

0.071

0.159

mainstem, upstream of WEL

Methow River

0.160

0.117

0.201

mainstem, upstream of WEL

Upstream WEL other tributaries

0.006

0.000

0.017

mainstem, upstream of WEL

loss

0.418

0.362

0.480

Deschutes River

mainstem, BON to MCN

0.797

0.781

0.815

Deschutes River

loss

0.203

0.185

0.219

John Day River

mainstem, BON to MCN

0.262

0.197

0.330

John Day River

loss

0.738

0.670

0.803

Hood River

mainstem, BON to MCN

0.734

0.576

0.874

Hood River

loss

0.266

0.126

0.424

Fifteenmile Creek

mainstem, BON to MCN

0.020

0.000

0.106

Fifteenmile Creek

loss

0.980

0.894

1.000

Umatilla River

mainstem, BON to MCN

0.142

0.061

0.230

Umatilla River

loss

0.858

0.770

0.939

Yakima River

mainstem, MCN to ICH or PRA

0.355

0.152

0.541

Yakima River

loss

0.645

0.459

0.848

Walla Walla River

mainstem, MCN to ICH or PRA

0.213

0.124

0.312

Walla Walla River

loss

0.787

0.688

0.876

Wenatchee River

mainstem, RIS to RRE

0.488

0.055

0.946

Wenatchee River

loss

0.512

0.054

0.945

Entiat River

mainstem, RRE to WEL

0.029

0.000

0.150

Entiat River

loss

0.971

0.850

1.000

Okanogan River

mainstem, upstream of WEL

0.117

0.017

0.278

Okanogan River

loss

0.883

0.722

0.983

Methow River

mainstem, upstream of WEL

0.238

0.128

0.377

Methow River

loss

0.762

0.623

0.872

BON to MCN other tributaries

mainstem, BON to MCN

0.233

0.134

0.357

BON to MCN other tributaries

loss

0.767

0.643

0.866

Upstream WEL other tributaries

mainstem, upstream of WEL

0.083

0.000

0.561

Upstream WEL other tributaries

loss

0.917

0.439

1.000

Movement probabilities for Snake River Basin Steelhead by natal origin, inside the DPS boundaries.

origin

from

to

mean

q5

q95

Tucannon River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.074

0.068

0.079

Asotin Creek

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.058

0.047

0.069

Clearwater River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.031

0.028

0.034

Salmon River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.048

0.045

0.051

Grande Ronde

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.029

0.026

0.032

Imnaha River

mainstem, MCN to ICH or PRA

mainstem, BON to MCN

0.046

0.042

0.049

Tucannon River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.028

0.025

0.030

Asotin Creek

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.022

0.017

0.026

Clearwater River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.012

0.011

0.013

Salmon River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.018

0.016

0.020

Grande Ronde

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.011

0.010

0.012

Imnaha River

mainstem, MCN to ICH or PRA

mainstem, PRA to RIS

0.017

0.016

0.019

Tucannon River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.854

0.844

0.863

Asotin Creek

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.884

0.863

0.907

Clearwater River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.938

0.933

0.943

Salmon River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.905

0.900

0.910

Grande Ronde

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.943

0.938

0.947

Imnaha River

mainstem, MCN to ICH or PRA

mainstem, ICH to LGR

0.909

0.903

0.915

Tucannon River

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.001

Asotin Creek

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.001

Clearwater River

mainstem, MCN to ICH or PRA

Yakima River

0.000

0.000

0.000

Salmon River

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.001

Grande Ronde

mainstem, MCN to ICH or PRA

Yakima River

0.000

0.000

0.000

Imnaha River

mainstem, MCN to ICH or PRA

Yakima River

0.001

0.000

0.001

Tucannon River

mainstem, MCN to ICH or PRA

Walla Walla River

0.003

0.002

0.004

Asotin Creek

mainstem, MCN to ICH or PRA

Walla Walla River

0.002

0.002

0.003

Clearwater River

mainstem, MCN to ICH or PRA

Walla Walla River

0.001

0.001

0.002

Salmon River

mainstem, MCN to ICH or PRA

Walla Walla River

0.002

0.001

0.002

Grande Ronde

mainstem, MCN to ICH or PRA

Walla Walla River

0.001

0.001

0.001

Imnaha River

mainstem, MCN to ICH or PRA

Walla Walla River

0.002

0.001

0.002

Tucannon River

mainstem, MCN to ICH or PRA

loss

0.041

0.038

0.045

Asotin Creek

mainstem, MCN to ICH or PRA

loss

0.033

0.026

0.039

Clearwater River

mainstem, MCN to ICH or PRA

loss

0.017

0.016

0.019

Salmon River

mainstem, MCN to ICH or PRA

loss

0.027

0.025

0.029

Grande Ronde

mainstem, MCN to ICH or PRA

loss

0.016

0.014

0.018

Imnaha River

mainstem, MCN to ICH or PRA

loss

0.025

0.024

0.028

Tucannon River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.032

0.027

0.037

Asotin Creek

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.033

0.022

0.048

Clearwater River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.010

0.008

0.012

Salmon River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.021

0.019

0.024

Grande Ronde

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.019

0.016

0.022

Imnaha River

mainstem, ICH to LGR

mainstem, MCN to ICH or PRA

0.038

0.033

0.043

Tucannon River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.570

0.558

0.582

Asotin Creek

mainstem, ICH to LGR

mainstem, upstream of LGR

0.901

0.877

0.923

Clearwater River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.954

0.949

0.959

Salmon River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.939

0.935

0.942

Grande Ronde

mainstem, ICH to LGR

mainstem, upstream of LGR

0.937

0.931

0.942

Imnaha River

mainstem, ICH to LGR

mainstem, upstream of LGR

0.912

0.905

0.919

Tucannon River

mainstem, ICH to LGR

Tucannon River

0.289

0.278

0.301

Asotin Creek

mainstem, ICH to LGR

Tucannon River

0.018

0.009

0.030

Clearwater River

mainstem, ICH to LGR

Tucannon River

0.001

0.001

0.002

Salmon River

mainstem, ICH to LGR

Tucannon River

0.002

0.002

0.003

Grande Ronde

mainstem, ICH to LGR

Tucannon River

0.003

0.002

0.004

Imnaha River

mainstem, ICH to LGR

Tucannon River

0.002

0.001

0.003

Tucannon River

mainstem, ICH to LGR

loss

0.109

0.100

0.118

Asotin Creek

mainstem, ICH to LGR

loss

0.048

0.033

0.066

Clearwater River

mainstem, ICH to LGR

loss

0.034

0.030

0.039

Salmon River

mainstem, ICH to LGR

loss

0.038

0.035

0.041

Grande Ronde

mainstem, ICH to LGR

loss

0.042

0.038

0.046

Imnaha River

mainstem, ICH to LGR

loss

0.049

0.043

0.055

Tucannon River

mainstem, upstream of LGR

mainstem, ICH to LGR

0.413

0.395

0.433

Asotin Creek

mainstem, upstream of LGR

mainstem, ICH to LGR

0.046

0.028

0.064

Clearwater River

mainstem, upstream of LGR

mainstem, ICH to LGR

0.018

0.015

0.021

Salmon River

mainstem, upstream of LGR

mainstem, ICH to LGR

0.020

0.017

0.022

Grande Ronde

mainstem, upstream of LGR

mainstem, ICH to LGR

0.019

0.016

0.021

Imnaha River

mainstem, upstream of LGR

mainstem, ICH to LGR

0.026

0.022

0.029

Tucannon River

mainstem, upstream of LGR

Asotin Creek

0.033

0.026

0.041

Asotin Creek

mainstem, upstream of LGR

Asotin Creek

0.689

0.644

0.727

Clearwater River

mainstem, upstream of LGR

Asotin Creek

0.000

0.000

0.000

Salmon River

mainstem, upstream of LGR

Asotin Creek

0.000

0.000

0.000

Grande Ronde

mainstem, upstream of LGR

Asotin Creek

0.002

0.001

0.003

Imnaha River

mainstem, upstream of LGR

Asotin Creek

0.000

0.000

0.000

Tucannon River

mainstem, upstream of LGR

Clearwater River

0.024

0.019

0.029

Asotin Creek

mainstem, upstream of LGR

Clearwater River

0.000

0.000

0.001

Clearwater River

mainstem, upstream of LGR

Clearwater River

0.303

0.294

0.313

Salmon River

mainstem, upstream of LGR

Clearwater River

0.000

0.000

0.000

Grande Ronde

mainstem, upstream of LGR

Clearwater River

0.000

0.000

0.000

Imnaha River

mainstem, upstream of LGR

Clearwater River

0.000

0.000

0.000

Tucannon River

mainstem, upstream of LGR

Salmon River

0.002

0.000

0.003

Asotin Creek

mainstem, upstream of LGR

Salmon River

0.000

0.000

0.000

Clearwater River

mainstem, upstream of LGR

Salmon River

0.000

0.000

0.000

Salmon River

mainstem, upstream of LGR

Salmon River

0.279

0.270

0.286

Grande Ronde

mainstem, upstream of LGR

Salmon River

0.000

0.000

0.000

Imnaha River

mainstem, upstream of LGR

Salmon River

0.000

0.000

0.000

Tucannon River

mainstem, upstream of LGR

Grande Ronde River

0.007

0.004

0.010

Asotin Creek

mainstem, upstream of LGR

Grande Ronde River

0.020

0.010

0.032

Clearwater River

mainstem, upstream of LGR

Grande Ronde River

0.000

0.000

0.000

Salmon River

mainstem, upstream of LGR

Grande Ronde River

0.000

0.000

0.000

Grande Ronde

mainstem, upstream of LGR

Grande Ronde River

0.084

0.077

0.092

Imnaha River

mainstem, upstream of LGR

Grande Ronde River

0.000

0.000

0.000

Tucannon River

mainstem, upstream of LGR

Imnaha River

0.002

0.000

0.003

Asotin Creek

mainstem, upstream of LGR

Imnaha River

0.000

0.000

0.001

Clearwater River

mainstem, upstream of LGR

Imnaha River

0.000

0.000

0.000

Salmon River

mainstem, upstream of LGR

Imnaha River

0.000

0.000

0.000

Grande Ronde

mainstem, upstream of LGR

Imnaha River

0.001

0.000

0.002

Imnaha River

mainstem, upstream of LGR

Imnaha River

0.463

0.448

0.477

Tucannon River

mainstem, upstream of LGR

loss

0.520

0.500

0.537

Asotin Creek

mainstem, upstream of LGR

loss

0.245

0.211

0.288

Clearwater River

mainstem, upstream of LGR

loss

0.679

0.668

0.688

Salmon River

mainstem, upstream of LGR

loss

0.701

0.693

0.709

Grande Ronde

mainstem, upstream of LGR

loss

0.894

0.887

0.901

Imnaha River

mainstem, upstream of LGR

loss

0.512

0.497

0.526

Tucannon River

Tucannon River

mainstem, ICH to LGR

0.026

0.018

0.033

Asotin Creek

Tucannon River

mainstem, ICH to LGR

0.236

0.053

0.488

Clearwater River

Tucannon River

mainstem, ICH to LGR

0.167

0.029

0.402

Salmon River

Tucannon River

mainstem, ICH to LGR

0.358

0.195

0.518

Grande Ronde

Tucannon River

mainstem, ICH to LGR

0.142

0.026

0.309

Imnaha River

Tucannon River

mainstem, ICH to LGR

0.493

0.178

0.789

Tucannon River

Tucannon River

loss

0.974

0.967

0.982

Asotin Creek

Tucannon River

loss

0.764

0.512

0.947

Clearwater River

Tucannon River

loss

0.833

0.598

0.971

Salmon River

Tucannon River

loss

0.642

0.482

0.805

Grande Ronde

Tucannon River

loss

0.858

0.691

0.974

Imnaha River

Tucannon River

loss

0.507

0.211

0.822

Tucannon River

Asotin Creek

mainstem, upstream of LGR

0.094

0.045

0.150

Asotin Creek

Asotin Creek

mainstem, upstream of LGR

0.003

0.000

0.009

Clearwater River

Asotin Creek

mainstem, upstream of LGR

0.347

0.000

1.000

Salmon River

Asotin Creek

mainstem, upstream of LGR

0.292

0.000

1.000

Grande Ronde

Asotin Creek

mainstem, upstream of LGR

0.006

0.000

0.037

Imnaha River

Asotin Creek

mainstem, upstream of LGR

0.468

0.000

1.000

Tucannon River

Asotin Creek

loss

0.906

0.850

0.955

Asotin Creek

Asotin Creek

loss

0.997

0.991

1.000

Clearwater River

Asotin Creek

loss

0.653

0.000

1.000

Salmon River

Asotin Creek

loss

0.708

0.000

1.000

Grande Ronde

Asotin Creek

loss

0.994

0.963

1.000

Imnaha River

Asotin Creek

loss

0.532

0.000

1.000

Tucannon River

Clearwater River

mainstem, upstream of LGR

0.002

0.000

0.010

Asotin Creek

Clearwater River

mainstem, upstream of LGR

0.287

0.000

1.000

Clearwater River

Clearwater River

mainstem, upstream of LGR

0.003

0.001

0.006

Salmon River

Clearwater River

mainstem, upstream of LGR

0.245

0.000

1.000

Grande Ronde

Clearwater River

mainstem, upstream of LGR

0.293

0.000

1.000

Imnaha River

Clearwater River

mainstem, upstream of LGR

0.513

0.000

1.000

Tucannon River

Clearwater River

loss

0.998

0.990

1.000

Asotin Creek

Clearwater River

loss

0.713

0.000

1.000

Clearwater River

Clearwater River

loss

0.997

0.994

0.999

Salmon River

Clearwater River

loss

0.755

0.000

1.000

Grande Ronde

Clearwater River

loss

0.707

0.000

1.000

Imnaha River

Clearwater River

loss

0.487

0.000

1.000

Tucannon River

Salmon River

mainstem, upstream of LGR

0.020

0.000

0.085

Asotin Creek

Salmon River

mainstem, upstream of LGR

0.287

0.000

1.000

Clearwater River

Salmon River

mainstem, upstream of LGR

0.342

0.000

1.000

Salmon River

Salmon River

mainstem, upstream of LGR

0.001

0.000

0.002

Grande Ronde

Salmon River

mainstem, upstream of LGR

0.360

0.000

1.000

Imnaha River

Salmon River

mainstem, upstream of LGR

0.584

0.000

1.000

Tucannon River

Salmon River

loss

0.980

0.915

1.000

Asotin Creek

Salmon River

loss

0.713

0.000

1.000

Clearwater River

Salmon River

loss

0.658

0.000

1.000

Salmon River

Salmon River

loss

0.999

0.998

1.000

Grande Ronde

Salmon River

loss

0.640

0.000

1.000

Imnaha River

Salmon River

loss

0.416

0.000

1.000

Tucannon River

Grande Ronde River

mainstem, upstream of LGR

0.001

0.000

0.006

Asotin Creek

Grande Ronde River

mainstem, upstream of LGR

0.007

0.000

0.044

Clearwater River

Grande Ronde River

mainstem, upstream of LGR

0.158

0.000

1.000

Salmon River

Grande Ronde River

mainstem, upstream of LGR

0.131

0.000

0.998

Grande Ronde

Grande Ronde River

mainstem, upstream of LGR

0.000

0.000

0.001

Imnaha River

Grande Ronde River

mainstem, upstream of LGR

0.491

0.000

1.000

Tucannon River

Grande Ronde River

loss

0.999

0.994

1.000

Asotin Creek

Grande Ronde River

loss

0.993

0.956

1.000

Clearwater River

Grande Ronde River

loss

0.842

0.000

1.000

Salmon River

Grande Ronde River

loss

0.869

0.002

1.000

Grande Ronde

Grande Ronde River

loss

1.000

0.999

1.000

Imnaha River

Grande Ronde River

loss

0.509

0.000

1.000

Tucannon River

Imnaha River

mainstem, upstream of LGR

0.020

0.000

0.119

Asotin Creek

Imnaha River

mainstem, upstream of LGR

0.383

0.000

1.000

Clearwater River

Imnaha River

mainstem, upstream of LGR

0.390

0.000

1.000

Salmon River

Imnaha River

mainstem, upstream of LGR

0.882

0.351

1.000

Grande Ronde

Imnaha River

mainstem, upstream of LGR

0.022

0.000

0.113

Imnaha River

Imnaha River

mainstem, upstream of LGR

0.001

0.000

0.002

Tucannon River

Imnaha River

loss

0.980

0.881

1.000

Asotin Creek

Imnaha River

loss

0.617

0.000

1.000

Clearwater River

Imnaha River

loss

0.610

0.000

1.000

Salmon River

Imnaha River

loss

0.118

0.000

0.649

Grande Ronde

Imnaha River

loss

0.978

0.887

1.000

Imnaha River

Imnaha River

loss

0.999

0.998

1.000

# Discussion

## Current limitations and next steps

### Detection probabilties in tributaries

Over the course of our study period, detection efficiencies in tributaries varied wildly as arrays were installed and decommissioned. For example, from 2010 to 2018, the number of tag detection arrays in tributaries almost tripled (Morrisett 2018). In some years of our study, the tributaries in our model had no active antennas at all (Richins 2017). However, our current model configuration does not explicitly account for detection efficiency in any state transition. The consequences of this are that movement probabilities into tributaries will be biased low, whereas loss probabilities both from the mainstem state that is connected to the tributary and any mainstem states that are overshoot states will be biased high, as missed detections in tributaries will be interpreted as loss from the state in which an individual was last detected. As a result, post-overshoot fallback to natal tributaries is also biased low, as this type of fallback is not able to be captured well due to low detection efficiencies in tributaries.

In future iterations of the model, detection probabilities in tributaries, as well as when tributaries had active arrays, will be explicitly modeled. When tributaries had multiple active arrays, detection probabilities will be calculated for the array furthest downstream (closest to the confluence with the mainstem) by examining what percentage of fish that were eventually seen at upstream arrays were also seen at the furthest downstream array. The model will account for years in which tributaries had no active arrays by removing those states from the model for movements occurring in that year.

### Detection probabilities in downstream passage routes

Steelhead fallback is difficult to monitor using PIT tags because of the lack of detection capabilities in the primary downstream passage routes for Steelhead, which include spillways, the Juvenile Bypass System (JBS), navigation locks, ice/trash sluiceways, and turbines. While some passage routes, such as the JBS, the corner collector at Bonneville Dam, and as of 2020, the spillway at Lower Granite Dam, have PIT tag detection capability, the majority of downstream movements are only detected by examining the rest of the detection history. For example, Boggs *et al.* (2004) used consecutive detections in the same adult fish ladder to monitor rates of fallback, whereas Richins and Skalski (2018) calculated fallback to home following overshoot as detections in tributaries following detections in the adult fish ladder at a dam upstream of the tributary. Our modeling framework includes both of these ways of detecting fallback, but this is still an underestimate of total fallback. Fallback such as fallback that leads to mortality cannot be detected using PIT tags, and any time a fish is not seen after fallback (i.e., either due to a fish entering a tributary with PIT tag arrays but not being detected, entering a tributary without PIT tag arrays, spawning in the mainstem, or mortality following fallback), the fallback event will not be observed. While accounting for detection probability in tributaries in future iterations of the model should allow us to achieve a better estimate of post-overshoot fallback, the current network of PIT tag arrays is incapable of monitoring all fallback, and as such all estimates of fallback from this model will be lower bound estimates. However, the current modeling framework will give us the closest estimate of fallback possible using PIT tag data.

### Final fates

The final fate of an individual fish is of central concern to the management and conservation of Steelhead. Whether an individual strayed (and to which tributary), reached its natal tributary, or died before spawning (and where) is one of the core questions that we set out to answer with this model. Final fates are not directly estimated directly as parameters in this model, but can be derived from the stepwise movement probabilities presented in Tables 1-6. This can be done either using a simulation-based approach, where a large number of simulated fish (e.g., 1,000,000) enter the model at Bonneville Dam and subsequently move through the states, with movements governed by random draws from the movement probabilities estimated in the model. It can also be calculated analytically by multiplying out the probabilities of each possible sequence of movements. It is of note that the biases for certain movements mentioned in the preceding sections will be perpetuated in any calculation of final fates, and thus some final fates (primarily associated with entering tributaries) would currently be underestimated due to detection probability issues.

### Adding additional covariates

The model structure and the use of the multinomial logit to evaluate movement probabilities allows for the inclusion of both categorical and continuous covariates in the model. The next covariates that we plan to include in future iterations of the model are rear type (hatchery or wild), temperature (mainstem temperatures from dam tailraces), flow, and spill. We are also considering the addition of covariates related to juvenile experiences (barged vs. not barged, acclimated vs. not acclimated hatchery releases). The inclusion of these covariates will further our understanding of what environmental conditions (e.g., temperature or flow conditions) lead to increased probability of Steelhead choosing more dangerous migration pathways to natal tributaries, such as overshooting natal tributaries, and the inclusion of covariates that can be influenced by hydropower managers (e.g., spill or flow) or fishery managers (e.g., hatchery practices or assisted juvenile migration) would help inform how we can help Steelhead return safely to natal tributaries. Given the increased interest in assisting downstream Steelhead passage, such as via spill practices (Ham *et al.* 2021), the inclusion of these covariates would improve our understanding of how to help recover these populations by informing management practices.

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