Supplemental Material

Modeling climate and hydropower influences on the movement decisions of an anadromous species

Markus A. Min, Rebecca A. Buchanan, and Mark D. Scheuerell

2025-05-30

Contents

Supplemental Methods

1 Tributary detection efficiency

Detection efficiency at the in-stream PIT tag array closest to the mouth of the tributary (the confluence of the tributary with the mainstem Columbia or Snake River) was estimated for each tributary state. However, detection efficiency was not modeled for three tributaries of the Snake River (the Salmon River, the Grande Ronde River, and the Clearwater River), as these tributaries did not have a detection site on the mainstem of the tributary within 100 km of the confluence.

We modeled detection efficiency in tributaries using logistic regression based on two predictors: 1) changes in antenna configurations over time, and 2) the discharge in the tributary. Changes in antenna configurations were identified from the operational history of the site, based on antennas being installed, decommissioned, upgraded, or moved. Changes in antenna configurations are identified in Table S1. Discharge was included as a predictor based on our hypothesis that river stage would influence the antenna coverage of the river channel. Discharge data were queried from USGS by finding the station on the interactive USGS dashboard closest the river mouth array and navigating to the data page for the specific site. Discharge data were available for all tributaries except Fifteenmile Creek and the Imnaha River; detection efficiency in these tributaries was therefore only modeled as a function of antenna configurations.

Table S1: Tributary PIT tag antenna configurations used in detection efficiency estimation. Years refer to the Steelhead run years in which the site was active in a specific configuration. Site refers to the PIT tag detection site chosen for the detection efficiency estimation, based on its proximity to the mouth of the tributary. Configuration refers to the configuration of antennas at the site, where Initial is the name given to the antenna configuration at the site at the start of the time series, and any subsequent changes from the initial configuration at the site are noted in this column.

Tributary	Years	Site	Configuration
Hood River	12/13-21/22	Hood River Mouth (HRM)	Initial
Fifteenmile Creek	11/12-18/19	Fifteenmile Ck at Eighmile Ck (158)	Initial
Deschutes River	13/14-18/19	Deschutes River Mouth (DRM)	Initial
John Day River	12/13-21/22	John Day River, McDonald Ferry (JD1)	Initial
Umatilla River	06/07-13/14	Three Mile Falls Dam (TMF)	Initial
Umatilla River	14/15-21/22	Three Mile Falls Dam (TMF)	Antenna installation at entrance to adult ladder
Walla Walla River	05/06-11/12	Oasis Road Bridge (ORB)	Initial
Walla Walla River	12/13-14/15	Oasis Road Bridge (ORB) and Walla Walla R at Pierce RV Pk (PRV)	Initial configuration where two mouth sites were operational simultaneously and their joint detection efficiency was estimated
Walla Walla River	15/16-18/19	Walla Walla R at Pierce RV Pk (PRV)	Initial
Walla Walla River	19/20-21/22	Walla Walla River Barge Array (WWB)	Initial
Yakima River	05/06-21/22	Prosser Diversion Dam (PRO)	Initial
Wenatchee River	10/11-21/22	Lower Wenatchee River (LWE)	Initial
Entiat River	07/08-21/22	Lower Entiat River (ENL)	Initial
Methow River	09/10-16/17	Lower Methow River at Pateros (LMR)	Initial
Methow River	17/18-21/22	Lower Methow River at Pateros (LMR)	Site was moved 5 km upstream and transceivers replaced
Okanogan River	13/14-21/22	Lower Okanogan Instream Array (OKL)	Initial
Tucannon River	10/11-19/20	Lower Tucannon River (LTR)	Initial
Tucannon River	20/21-21/22	Lower Tucannon River (LTR)	All antennas replaced, additional antenna installed
Asotin Creek	11/12-17/18	Asotin Creek Mouth (ACM)	Initial
Asotin Creek	18/19-21/22	Asotin Creek Mouth (ACM)	All components replaced and upgraded
Imnaha River	10/11-21/22	Lower Imnaha River ISA @ km 7 (IR1)	Initial

For our model of detection efficiency, we denote z_i as the detection of fish i, p_det as the probability of detection for fish i, $\alpha_{j,k}$ as the antenna configuration for tributary j under configuration k, β_j as the slope for the effect of discharge, and $x_{j,t}$ as the mean discharge for tributary j in year t. The model for detection efficiency was as follows:

$$z_i \sim Bernoulli(p_{det,i})logit(p_{det,i}) = \alpha_{j,k} + \beta_j x_{j,t}$$

The above model was implemented in Stan (Carpenter et al., 2017), with 3 chains run for 5,000 warmup and 5,000 sampling iterations each. Discharge values were Z-scored prior to the model being fit. The posteriors from this model for each of the α (site configuration intercepts) and β (effect of discharge) terms were used as priors in the primary Stan model that was used to estimate movement. The resulting detection efficiency correction for each run year can be found in Fig. S1.

2 Covariate data processing

Temperature data Due to the noise and gaps inherent to the temperature data, a series of steps were performed to clean this data. First, plots of temperature were manually inspected and sequential runs of temperature points that were outside of the range of possible values for that time of year were removed. Next, a filtering algorithm was applied to remove any temperature values that were more than four degrees outside of the interannual average temperature value for that day of the year, as well as any values that were more than two degrees outside of the 7-day moving average. To address the incomplete temporal resolution for temperature at each dam in our modeling framework, a state-space model was fit using the MARSS package (Holmes et al., 2014). The inputs for this model were the cleaned temperature data at the forebay and tailrace for the eight dams (a total of 16 temperature time series). The model was structured with only a single process (the basin-scale temperature) and 16 observations of that process. Each dam had a different offset/bias term (8 total). Model-estimated temperatures on each day for each dam were then exported by using the estimate of the basin-scale temperature plus the dam-specific offset.

To estimate the temperatures experienced by fish, the median residence time in each state in our model was first calculated. To do so, we calculated the difference between the date on which a fish was observed exiting a state and the date on which a fish was observed entering a state, and then computed the state-specific median across all fish. However, for the two furthest upstream states (upstream of Lower Granite Dam and upstream of Wells Dam), residence times were significantly longer and were found to be bimodal. Based on our hypothesis that movement decisions are made soon after a fish enters a state, we fit a two-component mixture model using the mixtools package in R (Benaglia et al., 2010) to residence times in these states and used the median residence time for fish in the first mode. The mean temperature experienced by the fish while in a state was estimated as the mean temperature across a window of time defined as the date a fish was observed entering a state plus the median residence time for all fish in that state.

Spill data Daily average spill (in thousands of cubic feet per second) was queried from the Columbia Basin Conditions portal from the DART page for the eight dams that were modeled as the boundaries of states (Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, and Lower Granite). Spill data were processed in two different ways to facilitate the inclusion of two hypothesized relationships between spill and fish fallback over dams. For en-route fallback, spill volume was processed in the same way as temperature: by taking the mean volume of spill across the residence time window. For post-overshoot fallback, spill volume was converted into days of winter spill, by counting the number of days that had nonzero spill in the months of January, February, and March for each year.

Supplemental Results

1 Sample sizes

Table 2: The number of fish per run year from each combination of natal tributary and rearing type (natural or hatchery origin).

Population	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16
Fifteenmile Creek (N)	0	0	0	11	47	89	95	33	32	37	24
Deschutes River (N)	0	0	38	68	117	113	109	81	180	97	49
John Day River (N)	68	119	114	247	347	279	287	151	261	243	217
Umatilla River (H)	9	12	59	80	115	77	64	24	13	36	42
Umatilla River (N)	2	10	17	21	14	13	81	65	68	171	278
Walla Walla River (H)	33	32	25	301	415	222	261	120	111	163	114
Walla Walla River (N)	11	11	10	8	61	95	115	90	57	75	72
Yakima River (N)	15	12	18	16	33	23	40	18	45	78	93
Wenatchee River (H)	399	400	350	450	818	523	427	380	183	189	173
Wenatchee River (N)	0	0	2	8	71	73	53	32	31	39	44
Entiat River (N)	0	3	8	7	75	74	55	26	43	66	56
Methow River (H)	1866	3088	478	35	128	58	319	324	292	286	289
Methow River (N)	0	0	6	13	42	24	33	18	43	44	51
Okanogan River (H)	172	36	8	17	9	9	117	134	100	141	115
Tucannon River (H)	58	83	549	423	639	259	166	83	121	141	133
Tucannon River (N)	35	24	40	15	50	44	50	55	45	59	59
Clearwater River (H)	36	34	48	176	95	679	721	650	315	368	317
Clearwater River (N)	37	29	50	79	138	200	140	111	88	285	177
Asotin Creek (N)	0	1	12	23	30	27	42	45	79	107	57
Grande Ronde River (H)	19	102	163	149	1135	619	654	414	382	571	549
Grande Ronde River (N)	35	15	35	37	65	83	86	64	63	62	68
Salmon River (H)	36	20	67	78	1650	1233	1471	949	965	1137	710
Salmon River (N)	17	21	19	49	158	104	126	70	116	148	90
Imnaha River (H)	31	36	33	33	734	442	392	161	337	408	407
Imnaha River (N)	38	14	35	124	151	124	143	70	93	129	162
Total	2917	4102	2184	2468	7137	5486	6047	4168	4063	5080	4346

2 Covariate correlations

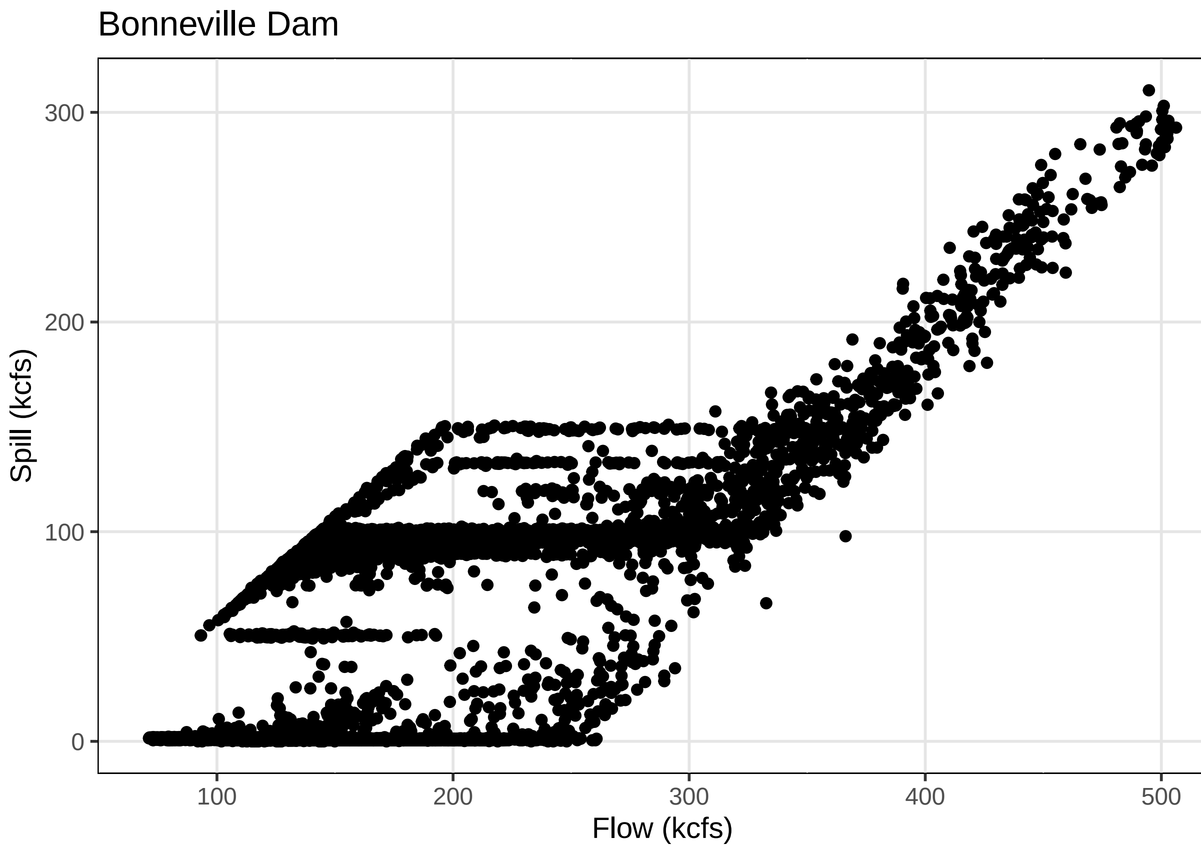
Table 3: Correlation between spill and flow across all run years in the dataset, by dam.

Dam	Mean Flow	Mean Spill	R-squared
Bonneville Dam	177.04	46.73	0.61
McNary Dam	168.59	52.07	0.80
Priest Rapids Dam	117.07	20.84	0.72
Rock Island Dam	113.00	12.22	0.60
Rocky Reach Dam	109.27	8.12	0.61
Wells Dam	109.43	8.80	0.65
Ice Harbor Dam	45.87	18.17	0.82
Lower Granite Dam	45.33	12.23	0.71

Table 4: Correlation between spill and temperature across all run years in the dataset, by dam.

Dam	Mean temp	Mean Spill	R-squared
Bonneville Dam	13.11	46.73	0.08
McNary Dam	12.32	52.07	0.04
Priest Rapids Dam	11.45	20.84	0.03
Rock Island Dam	11.07	12.22	0.04
Rocky Reach Dam	11.06	8.12	0.01
Wells Dam	10.87	8.80	0.01
Ice Harbor Dam	12.42	18.17	0.00
Lower Granite Dam	11.52	12.23	0.02

All dams



Bonneville Dam

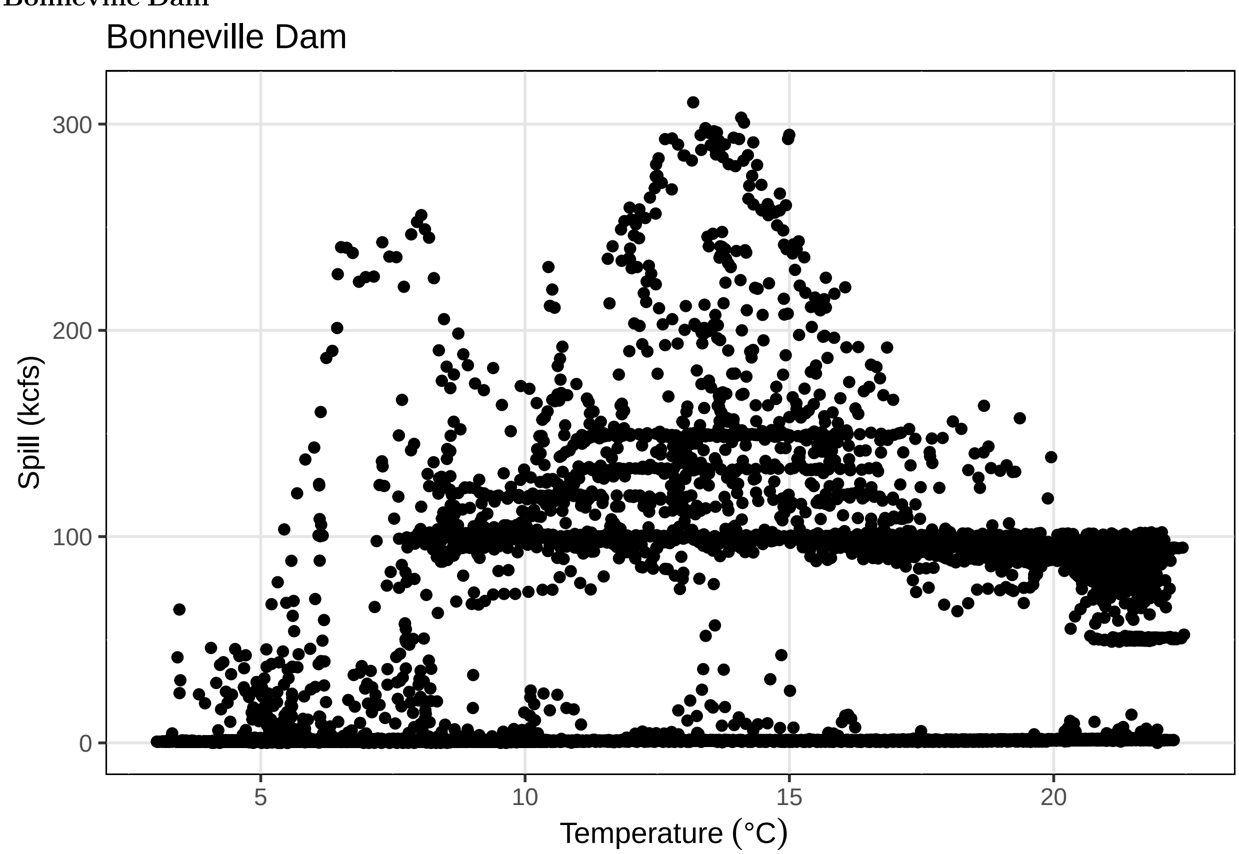
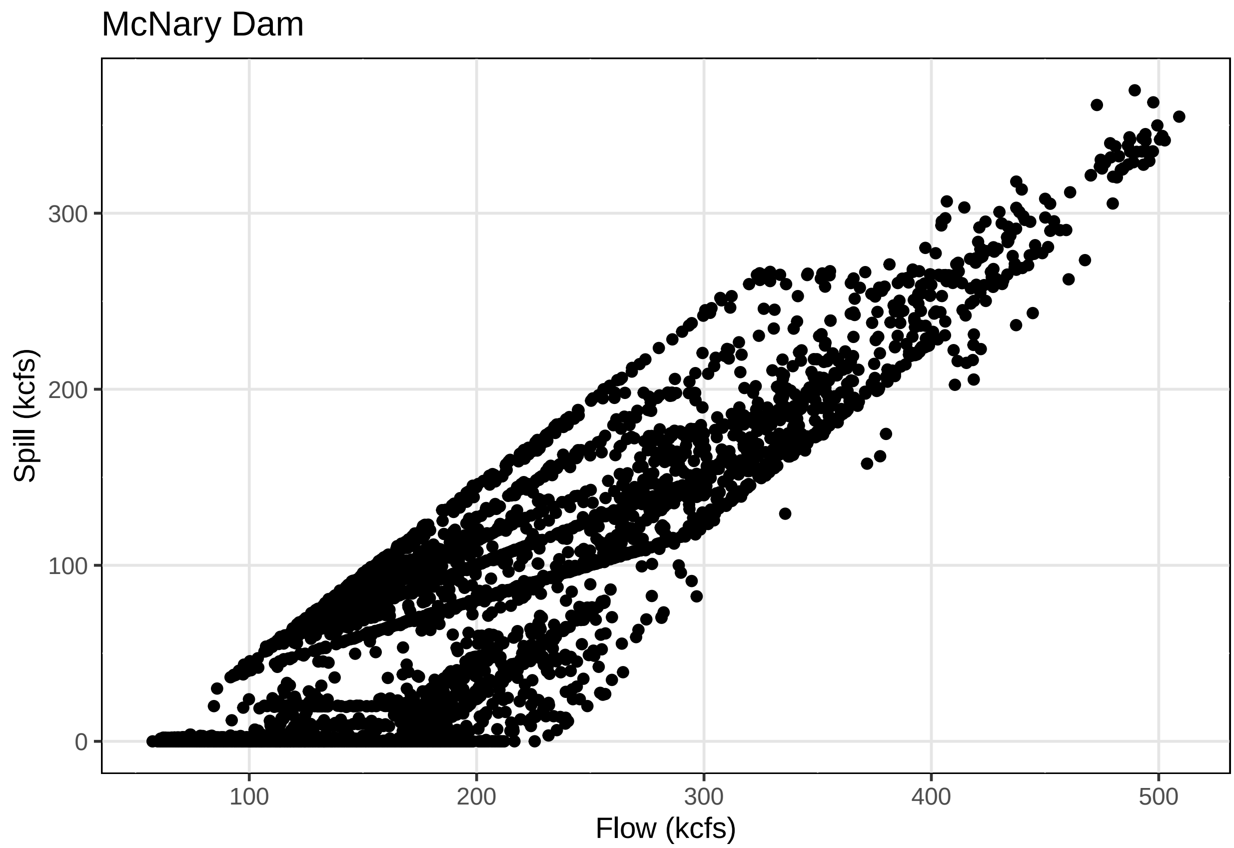


Table 5: Correlation between spill and flow for each year, for Bonneville Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	180.17	41.81	0.53
06/07	181.43	41.00	0.50
07/08	158.63	42.10	0.63
08/09	176.30	43.57	0.72
09/10	140.96	36.58	0.61
10/11	202.42	51.84	0.63
11/12	226.12	65.71	0.89
12/13	200.28	47.16	0.80
13/14	179.49	43.32	0.62
14/15	179.59	42.42	0.17
15/16	165.34	39.32	0.23
16/17	213.67	71.28	0.74
17/18	211.81	59.17	0.70
18/19	167.99	42.83	0.63
19/20	157.30	43.00	0.46
20/21	169.73	43.06	0.55
21/22	162.99	42.98	0.27
22/23	180.03	51.71	0.86
23/24	137.09	43.82	0.64

Table 6: Correlation between spill and temperature for each year, for Bonneville Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	12.60	41.81	0.15
06/07	12.70	41.00	0.18
07/08	12.34	42.10	0.16
08/09	12.14	43.57	0.13
09/10	12.80	36.58	0.19
10/11	12.36	51.84	0.05
11/12	12.18	65.71	0.07
12/13	12.81	47.16	0.14
13/14	12.92	43.32	0.12
14/15	13.72	42.42	0.13
15/16	14.02	39.32	0.21
16/17	13.08	71.28	0.00
17/18	13.29	59.17	0.06
18/19	13.24	42.83	0.14
19/20	13.25	43.00	0.14
20/21	13.15	43.06	0.09
21/22	13.18	42.98	0.08
22/23	12.88	51.71	0.05
23/24	13.90	43.82	0.08


McNary Dam
Spill (kcfs)
Flow (kcfs)
0
100
200
300
100
200
300
400
500

McNary Dam

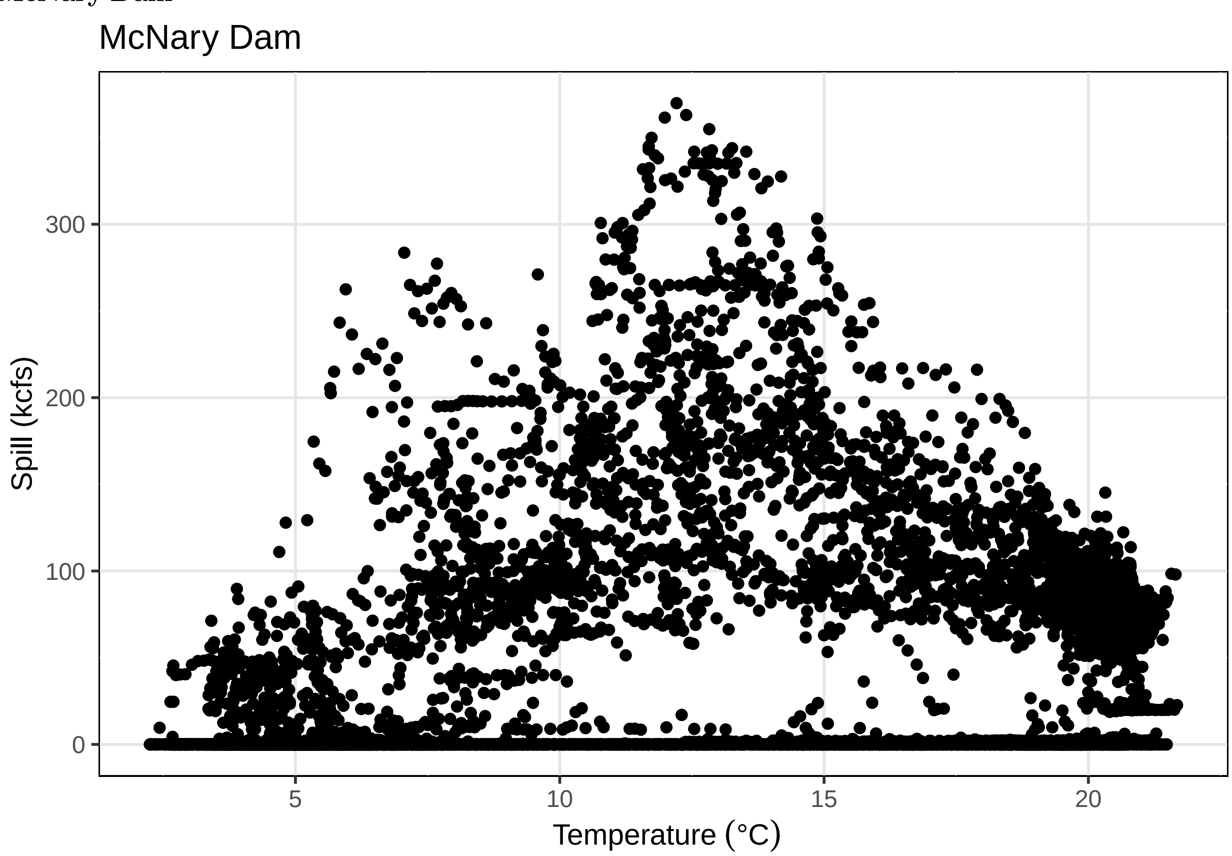
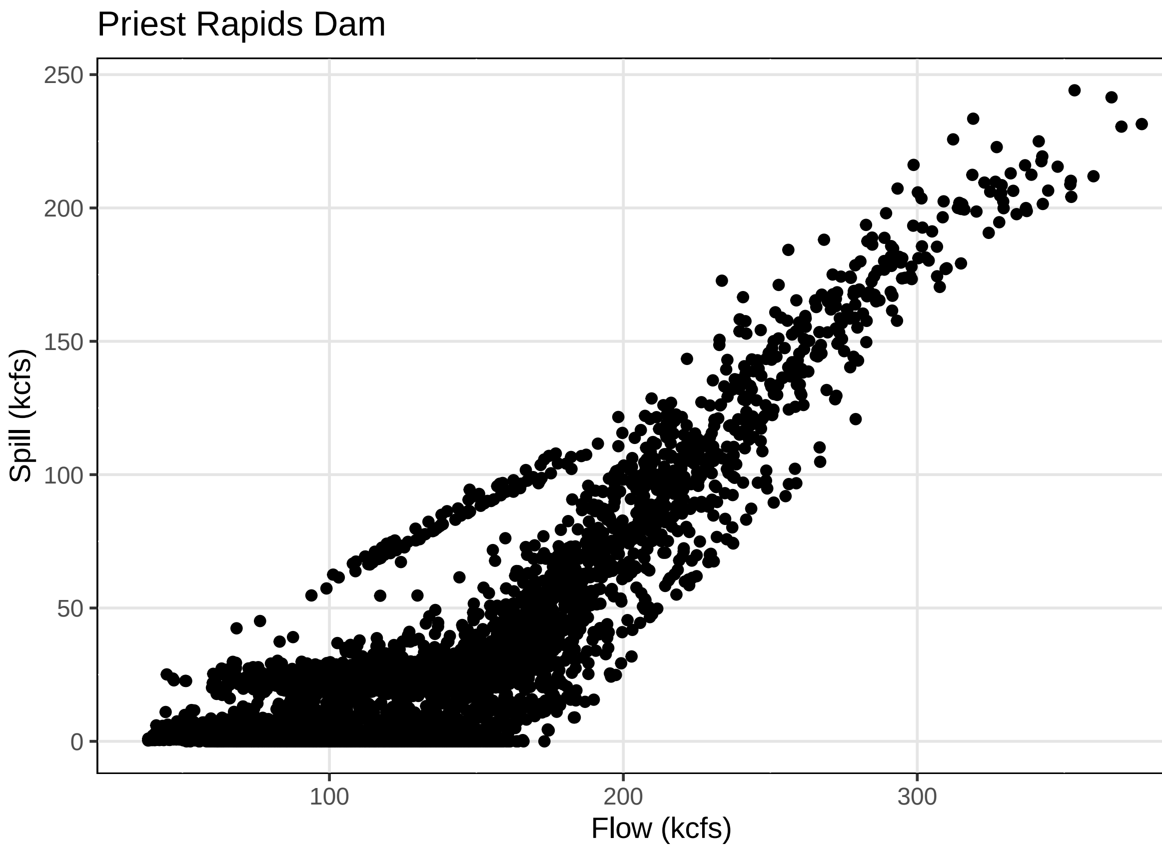

McNary Dam
Spill (kcfs)
Temperature (°C)
0
100
200
300
5
10
15
20

Table 7: Correlation between spill and flow for each year, for McNary Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	171.49	48.98	0.70
06/07	170.81	44.03	0.74
07/08	149.40	37.95	0.81
08/09	164.91	45.81	0.86
09/10	132.37	32.68	0.82
10/11	190.75	65.60	0.87
11/12	215.33	82.03	0.97
12/13	192.16	64.59	0.92
13/14	171.66	51.86	0.86
14/15	174.30	46.22	0.61
15/16	156.69	35.75	0.55
16/17	204.29	74.21	0.85
17/18	204.60	69.46	0.82
18/19	159.08	49.98	0.86
19/20	150.22	49.63	0.78
20/21	162.52	49.52	0.81
21/22	155.80	47.77	0.55
22/23	173.80	65.12	0.91
23/24	129.43	38.14	0.74

Table 8: Correlation between spill and temperature for each year, for McNary Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	11.81	48.98	0.11
06/07	11.91	44.03	0.14
07/08	11.55	37.95	0.15
08/09	11.35	45.81	0.10
09/10	12.01	32.68	0.18
10/11	11.58	65.60	0.00
11/12	11.39	82.03	0.05
12/13	12.02	64.59	0.14
13/14	12.13	51.86	0.06
14/15	12.93	46.22	0.06
15/16	13.23	35.75	0.13
16/17	12.30	74.21	0.00
17/18	12.50	69.46	0.02
18/19	12.45	49.98	0.06
19/20	12.46	49.63	0.07
20/21	12.36	49.52	0.08
21/22	12.39	47.77	0.02
22/23	12.09	65.12	0.04
23/24	13.11	38.14	0.07



Priest Rapids Dam

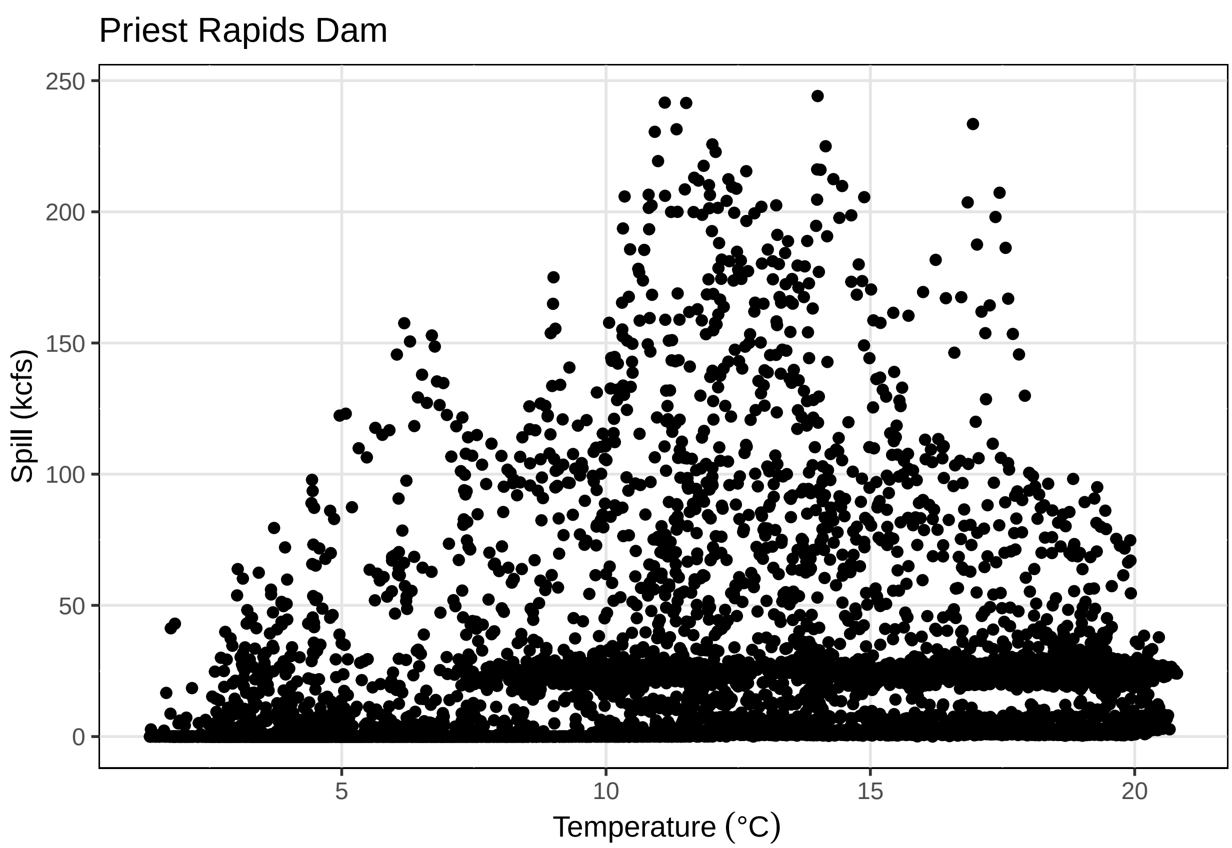
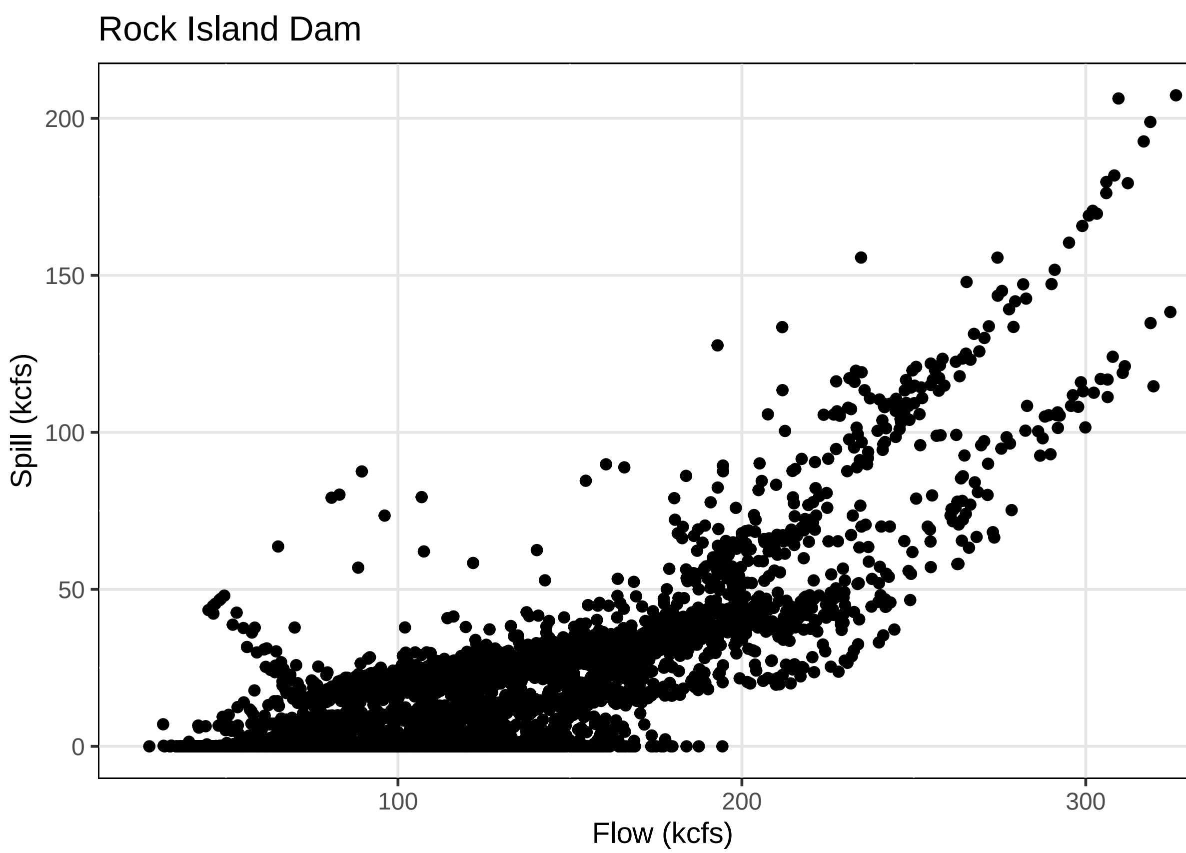


Table 9: Correlation between spill and flow for each year, for Priest Rapids Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	114.99	22.65	0.41
06/07	122.40	13.77	0.51
07/08	106.20	8.24	0.58
08/09	106.28	10.91	0.69
09/10	88.09	8.55	0.50
10/11	125.87	22.67	0.68
11/12	147.35	43.37	0.93
12/13	147.75	41.49	0.86
13/14	123.81	21.70	0.78
14/15	126.11	19.42	0.52
15/16	111.21	14.26	0.49
16/17	138.56	35.89	0.85
17/18	138.43	35.61	0.85
18/19	104.91	14.60	0.75
19/20	101.01	13.27	0.58
20/21	117.17	19.19	0.74
21/22	115.20	15.57	0.34
22/23	120.31	30.36	0.89
23/24	84.08	10.31	0.36

Table 10: Correlation between spill and temperature for each year, for Priest Rapids Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	10.93	22.65	0.15
06/07	11.03	13.77	0.03
07/08	10.67	8.24	0.14
08/09	10.47	10.91	0.09
09/10	11.13	8.55	0.16
10/11	10.70	22.67	0.02
11/12	10.52	43.37	0.04
12/13	11.14	41.49	0.14
13/14	11.26	21.70	0.06
14/15	12.06	19.42	0.00
15/16	12.35	14.26	0.04
16/17	11.42	35.89	0.01
17/18	11.62	35.61	0.01
18/19	11.57	14.60	0.06
19/20	11.59	13.27	0.08
20/21	11.49	19.19	0.08
21/22	11.52	15.57	0.04
22/23	11.21	30.36	0.07
23/24	12.23	10.31	0.09



Rock Island Dam

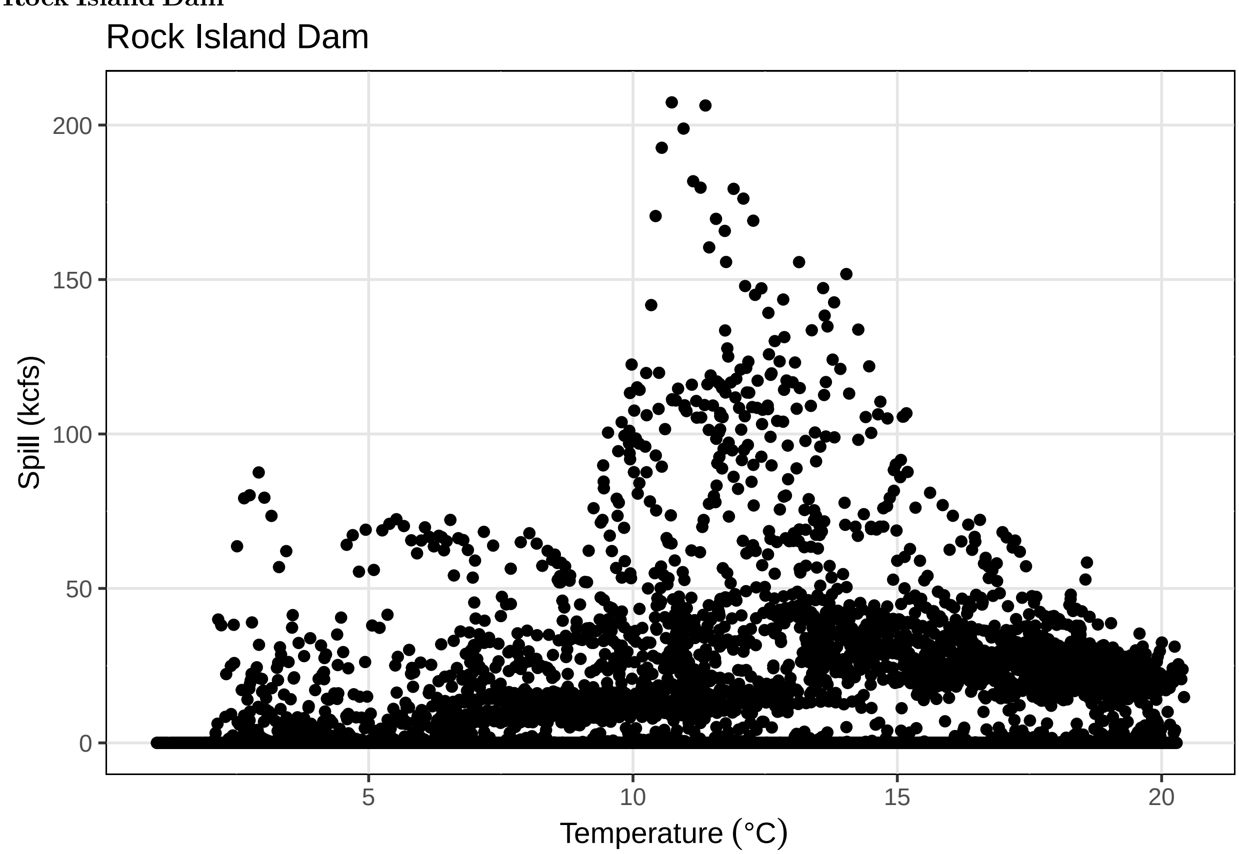
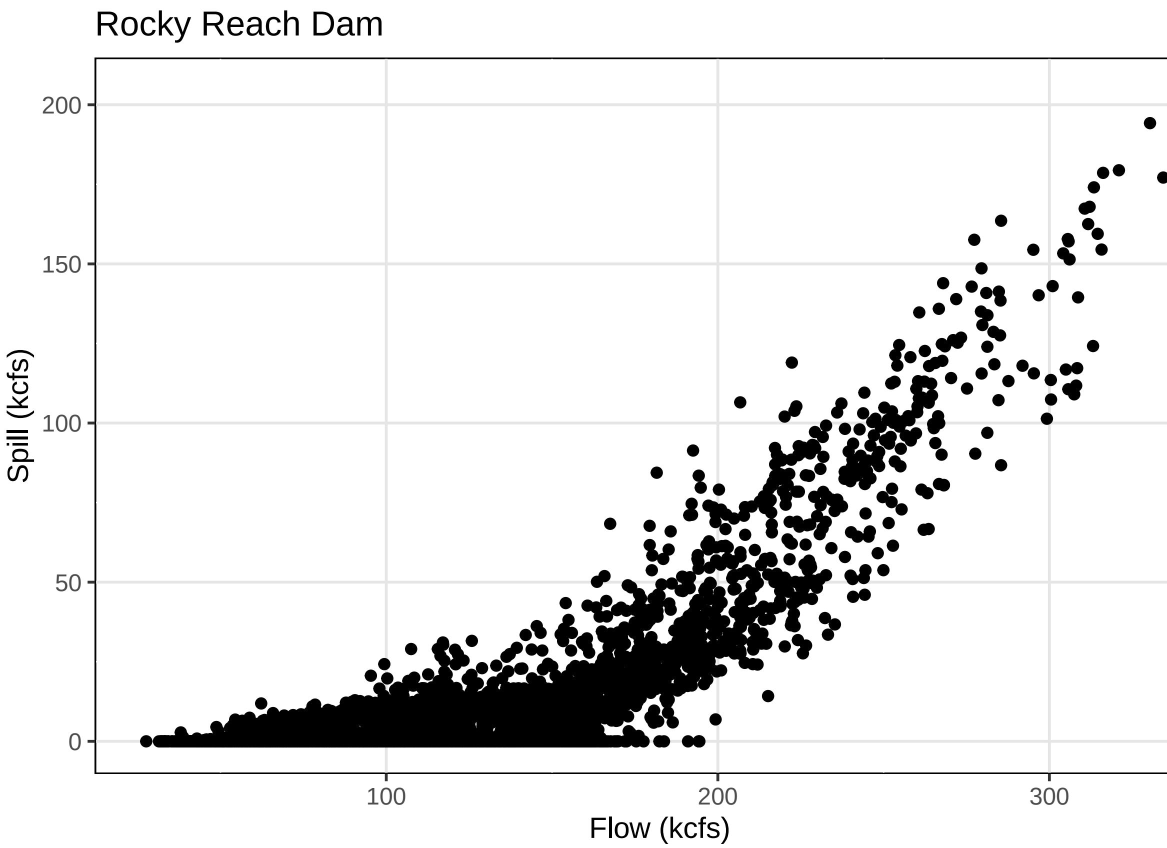


Table 11: Correlation between spill and flow for each year, for Rock Island Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	110.06	9.17	0.61
06/07	117.21	8.11	0.48
07/08	102.50	8.01	0.59
08/09	103.16	7.92	0.66
09/10	85.63	5.91	0.50
10/11	120.70	11.34	0.60
11/12	139.25	18.61	0.84
12/13	140.42	16.55	0.78
13/14	118.38	15.52	0.49
14/15	121.38	13.09	0.00
15/16	106.98	7.67	0.38
16/17	131.33	20.11	0.80
17/18	131.02	24.07	0.82
18/19	101.78	8.49	0.69
19/20	99.23	9.74	0.54
20/21	113.29	14.76	0.69
21/22	112.32	9.05	0.19
22/23	118.21	20.68	0.82
23/24	86.04	5.97	0.26

Table 12: Correlation between spill and temperature for each year, for Rock Island Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	10.55	9.17	0.10
06/07	10.66	8.11	0.16
07/08	10.29	8.01	0.26
08/09	10.10	7.92	0.13
09/10	10.75	5.91	0.20
10/11	10.32	11.34	0.03
11/12	10.14	18.61	0.08
12/13	10.77	16.55	0.12
13/14	10.88	15.52	0.00
14/15	11.68	13.09	0.50
15/16	11.98	7.67	0.08
16/17	11.04	20.11	0.00
17/18	11.25	24.07	0.00
18/19	11.19	8.49	0.11
19/20	11.21	9.74	0.05
20/21	11.11	14.76	0.09
21/22	11.14	9.05	0.16
22/23	10.83	20.68	0.05
23/24	11.86	5.97	0.12



Rocky Reach Dam

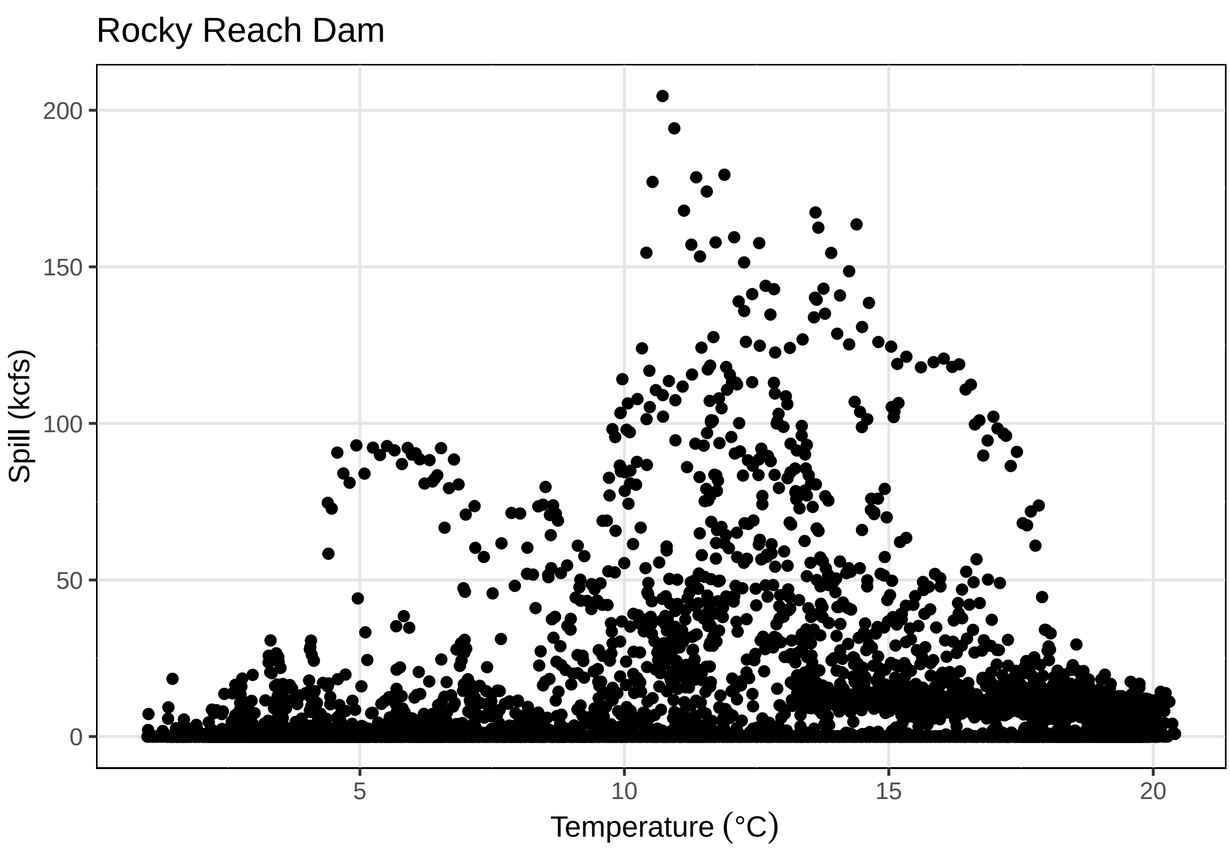
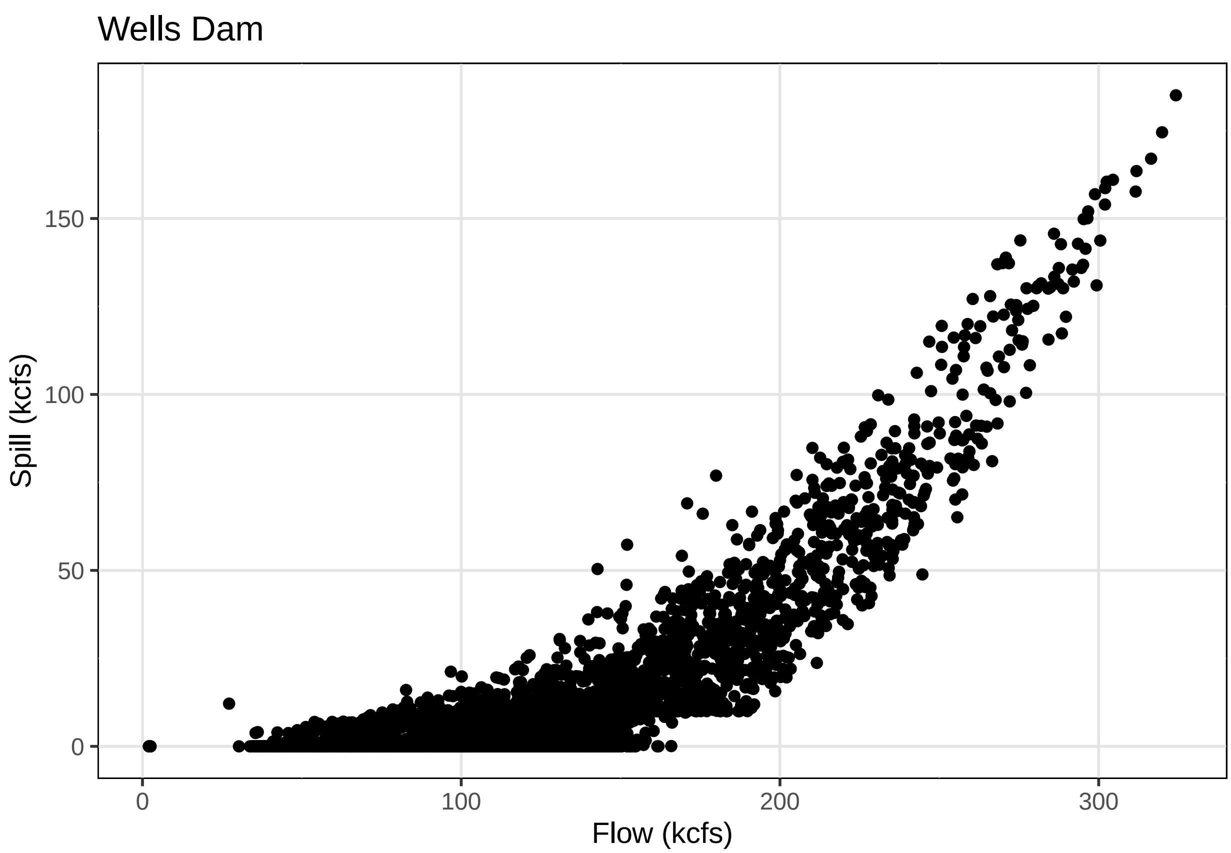


Table 13: Correlation between spill and flow for each year, for Rocky Reach Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	108.94	5.45	0.50
06/07	114.19	5.14	0.48
07/08	100.63	3.82	0.55
08/09	100.67	4.99	0.62
09/10	83.22	2.01	0.23
10/11	116.85	7.73	0.56
11/12	136.80	18.67	0.81
12/13	136.59	18.44	0.73
13/14	114.24	6.61	0.63
14/15	114.86	5.14	0.50
15/16	100.19	3.48	0.41
16/17	128.59	19.61	0.85
17/18	126.77	18.67	0.78
18/19	96.54	5.45	0.62
19/20	93.93	6.19	0.65
20/21	107.89	10.09	0.63
21/22	106.24	3.11	0.11
22/23	114.82	11.20	0.71
23/24	84.06	1.58	0.12

Table 14: Correlation between spill and temperature for each year, for Rocky Reach Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	10.54	5.45	0.04
06/07	10.64	5.14	0.04
07/08	10.28	3.82	0.12
08/09	10.09	4.99	0.10
09/10	10.74	2.01	0.24
10/11	10.31	7.73	0.02
11/12	10.13	18.67	0.03
12/13	10.75	18.44	0.09
13/14	10.87	6.61	0.10
14/15	11.67	5.14	0.04
15/16	11.96	3.48	0.03
16/17	11.03	19.61	0.03
17/18	11.23	18.67	0.00
18/19	11.18	5.45	0.04
19/20	11.20	6.19	0.00
20/21	11.10	10.09	0.08
21/22	11.13	3.11	0.22
22/23	10.82	11.20	0.03
23/24	11.85	1.58	0.15


Wells Dam
Spill (kcfs)
Flow (kcfs)
0
50
100
150
0
100
200
300

Wells Dam

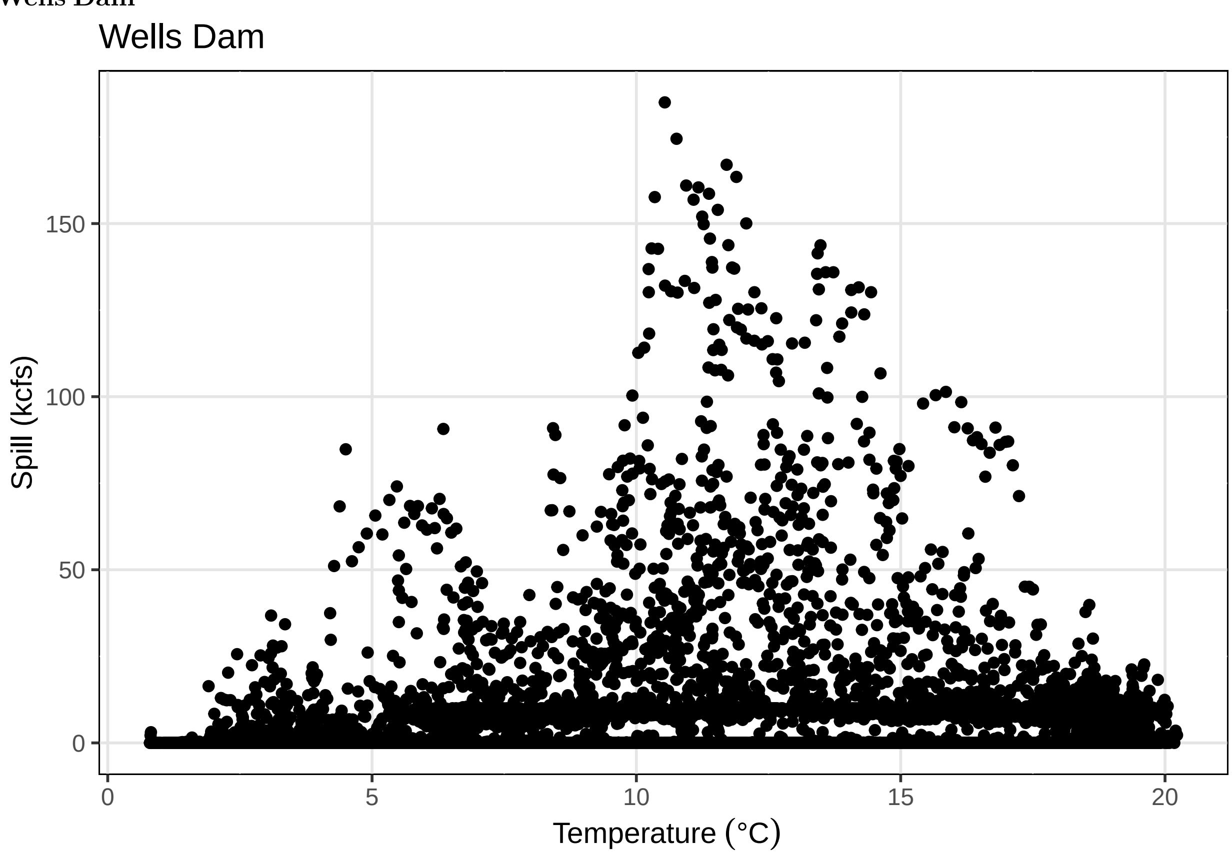
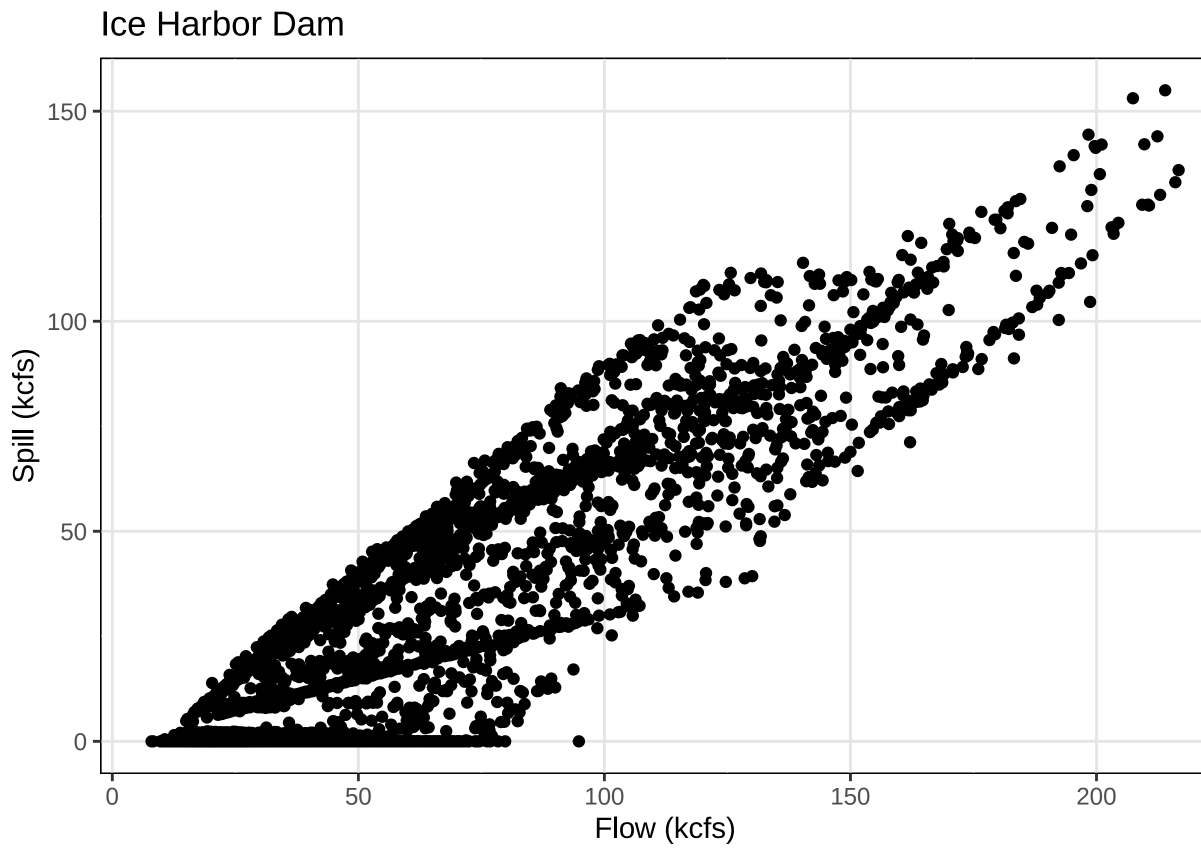

Wells Dam
Spill (kcfs)
Temperature (°C)
0
50
100
150
0
5
10
15
20

Table 15: Correlation between spill and flow for each year, for Wells Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	109.27	6.93	0.55
06/07	113.57	9.49	0.62
07/08	101.25	4.60	0.56
08/09	101.33	6.90	0.67
09/10	83.73	2.86	0.52
10/11	116.28	8.77	0.59
11/12	135.89	21.32	0.82
12/13	136.07	17.36	0.75
13/14	114.37	7.12	0.70
14/15	116.89	4.86	0.43
15/16	101.79	4.63	0.60
16/17	127.72	12.14	0.76
17/18	125.75	17.40	0.79
18/19	97.89	6.87	0.66
19/20	95.25	5.36	0.56
20/21	109.59	10.14	0.69
21/22	105.17	6.65	0.32
22/23	114.67	14.26	0.80
23/24	82.86	2.68	0.23

Table 16: Correlation between spill and temperature for each year, for Wells Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	10.36	6.93	0.01
06/07	10.46	9.49	0.02
07/08	10.10	4.60	0.05
08/09	9.90	6.90	0.06
09/10	10.56	2.86	0.18
10/11	10.13	8.77	0.00
11/12	9.94	21.32	0.03
12/13	10.57	17.36	0.09
13/14	10.68	7.12	0.02
14/15	11.49	4.86	0.04
15/16	11.78	4.63	0.02
16/17	10.85	12.14	0.01
17/18	11.05	17.40	0.00
18/19	11.00	6.87	0.07
19/20	11.01	5.36	0.02
20/21	10.91	10.14	0.07
21/22	10.94	6.65	0.02
22/23	10.64	14.26	0.03
23/24	11.66	2.68	0.04



Ice Harbor Dam

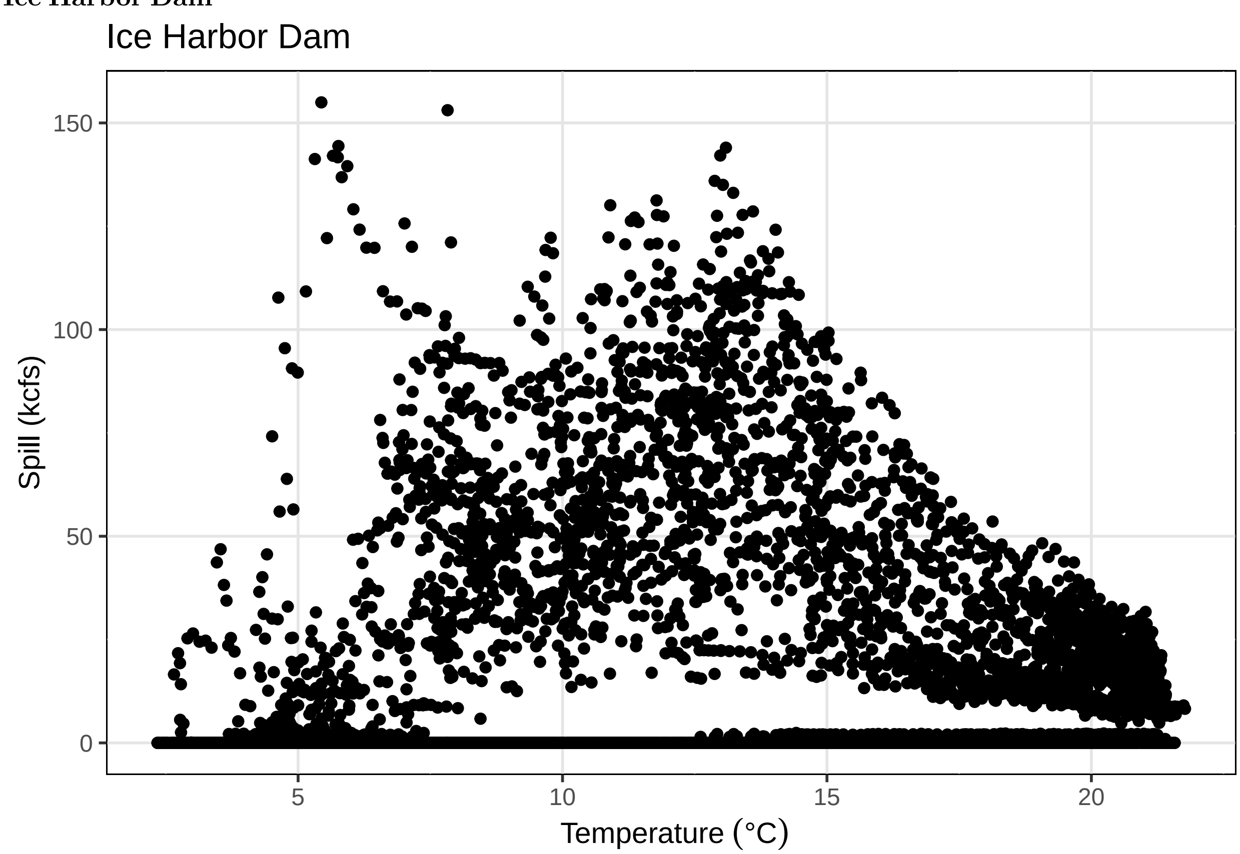
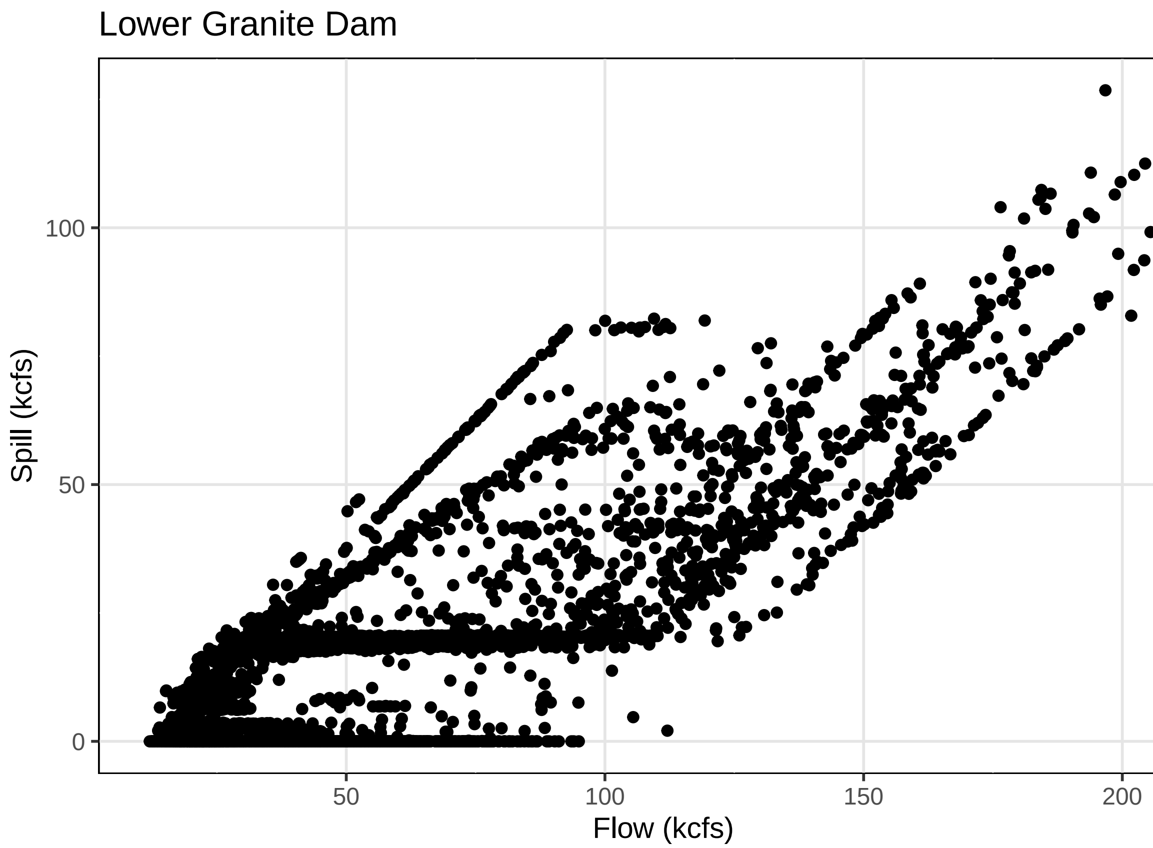


Table 17: Correlation between spill and flow for each year, for Ice Harbor Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	50.14	16.50	0.76
06/07	40.76	13.98	0.65
07/08	36.80	13.54	0.83
08/09	52.24	20.56	0.83
09/10	38.52	14.49	0.76
10/11	59.71	22.48	0.82
11/12	65.12	27.35	0.89
12/13	40.98	16.08	0.77
13/14	42.29	15.22	0.69
14/15	41.15	13.89	0.50
15/16	39.07	12.97	0.68
16/17	59.80	29.43	0.95
17/18	60.97	27.93	0.84
18/19	48.72	23.44	0.93
19/20	42.16	16.00	0.93
20/21	40.35	14.71	0.88
21/22	33.88	12.65	0.84
22/23	46.97	21.91	0.93
23/24	40.87	16.60	0.86

Table 18: Correlation between spill and temperature for each year, for Ice Harbor Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	11.90	16.50	0.01
06/07	12.00	13.98	0.06
07/08	11.64	13.54	0.01
08/09	11.44	20.56	0.04
09/10	12.10	14.49	0.12
10/11	11.67	22.48	0.00
11/12	11.49	27.35	0.03
12/13	12.11	16.08	0.04
13/14	12.23	15.22	0.00
14/15	13.03	13.89	0.06
15/16	13.32	12.97	0.01
16/17	12.39	29.43	0.06
17/18	12.59	27.93	0.00
18/19	12.54	23.44	0.00
19/20	12.56	16.00	0.00
20/21	12.46	14.71	0.01
21/22	12.49	12.65	0.00
22/23	12.18	21.91	0.00
23/24	13.20	16.60	0.00



Lower Granite Dam

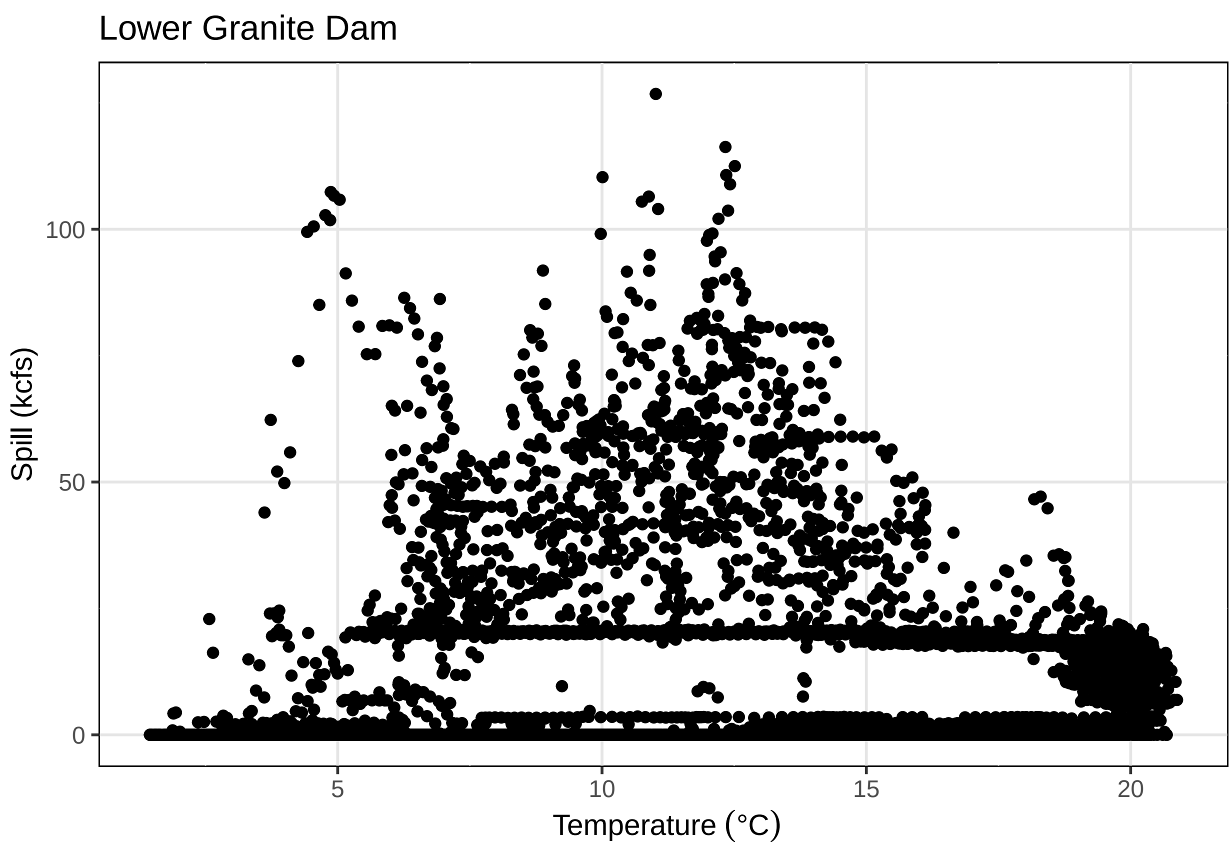


Table 19: Correlation between spill and flow for each year, for Lower Granite Dam

Run Year	Mean Flow	Mean Spill	R-squared
05/06	49.31	12.10	0.73
06/07	40.13	8.91	0.59
07/08	36.57	9.87	0.85
08/09	51.32	12.31	0.81
09/10	38.75	8.67	0.70
10/11	58.88	14.32	0.79
11/12	64.01	15.30	0.82
12/13	40.20	9.08	0.66
13/14	41.63	8.78	0.55
14/15	40.86	7.98	0.39
15/16	39.24	6.92	0.49
16/17	58.95	19.21	0.87
17/18	59.50	14.83	0.71
18/19	47.94	12.87	0.81
19/20	41.78	13.87	0.80
20/21	39.78	13.45	0.82
21/22	33.49	10.96	0.77
22/23	46.82	16.43	0.86
23/24	40.60	17.13	0.85

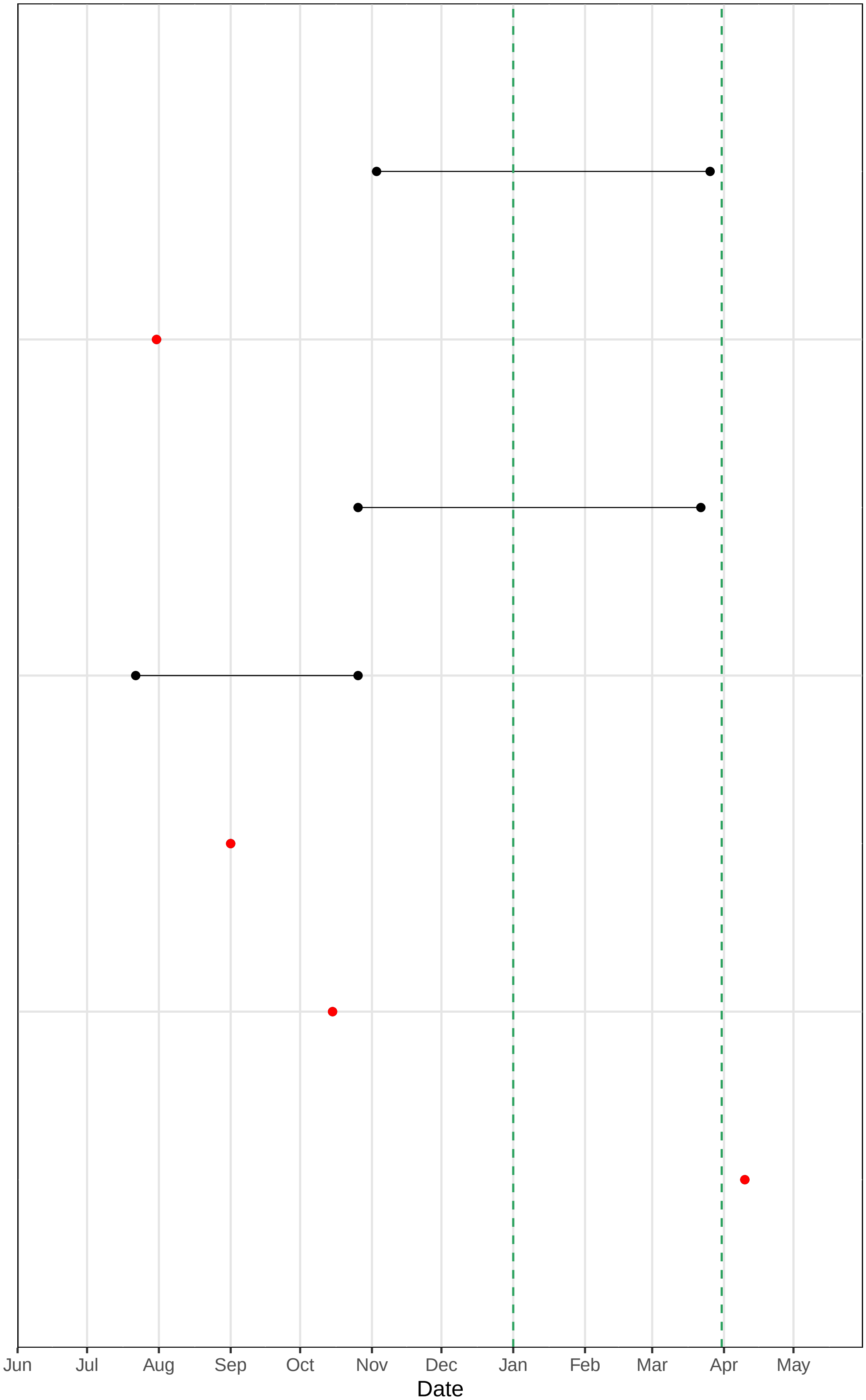
Table 20: Correlation between spill and temperature for each year, for Lower Granite Dam

Run Year	Mean Temperature	Mean Spill	R-squared
05/06	11.01	12.10	0.02
06/07	11.11	8.91	0.12
07/08	10.75	9.87	0.03
08/09	10.55	12.31	0.06
09/10	11.21	8.67	0.14
10/11	10.78	14.32	0.01
11/12	10.59	15.30	0.05
12/13	11.22	9.08	0.08
13/14	11.33	8.78	0.05
14/15	12.13	7.98	0.11
15/16	12.43	6.92	0.09
16/17	11.50	19.21	0.03
17/18	11.70	14.83	0.03
18/19	11.65	12.87	0.01
19/20	11.66	13.87	0.02
20/21	11.56	13.45	0.02
21/22	11.59	10.96	0.00
22/23	11.29	16.43	0.00
23/24	12.31	17.13	0.00

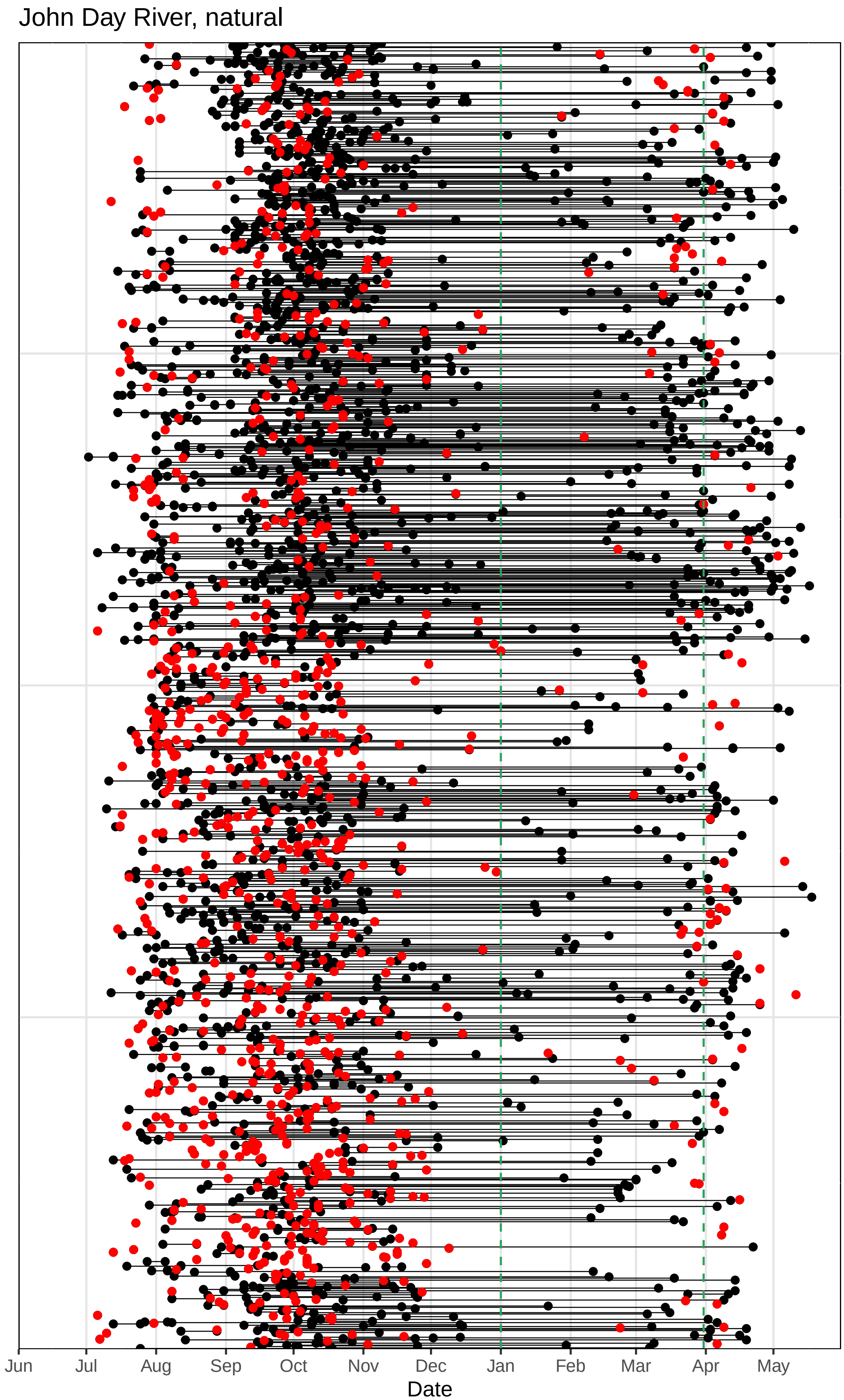
3 Post-overshoot fallback timing

These figures show the timing of observations of overshoot (first point) and first observation following post-overshoot fallback (second point) for each fish from a given population. Red points indicate terminal overshoot observations (where fish were not seen again below an overshoot dam following overshoot). Lines connecting overshoot observations with post-overshoot fallback observations indicate that time period in which a fallback event must have occurred. Dashed green lines indicate the winter months (January, February, and March) that were used to characterize the likely spill conditions encountered by fish in overshoot states. In our model, any fish that was last observed overshooting (red dots) or where based on their detection history, may have fallen back during January, February, or March (any black lines that are at least partially between the two dashed green lines) are affected by the winter spill days covariate.

Deschutes River, natural

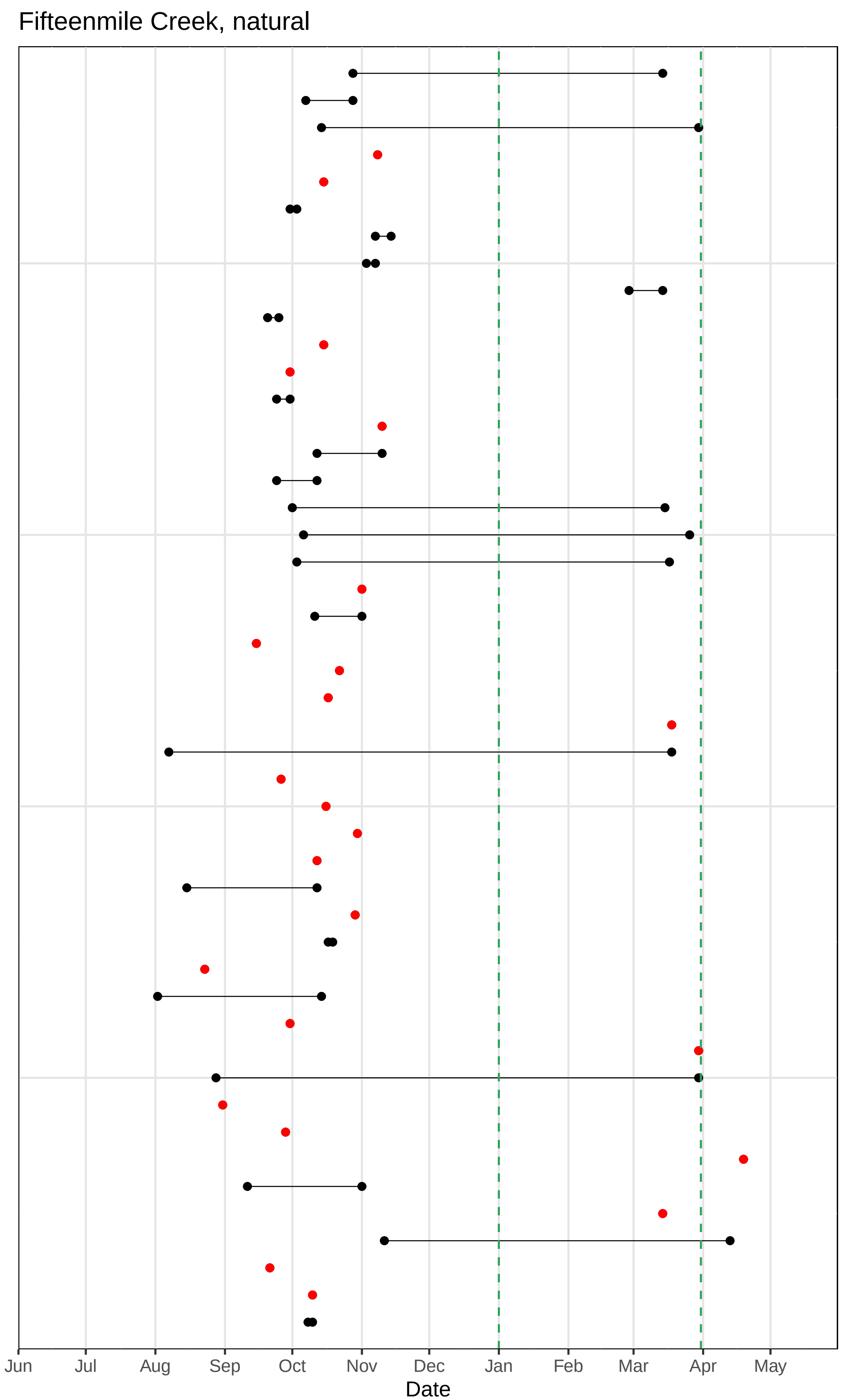


Deschutes (N)

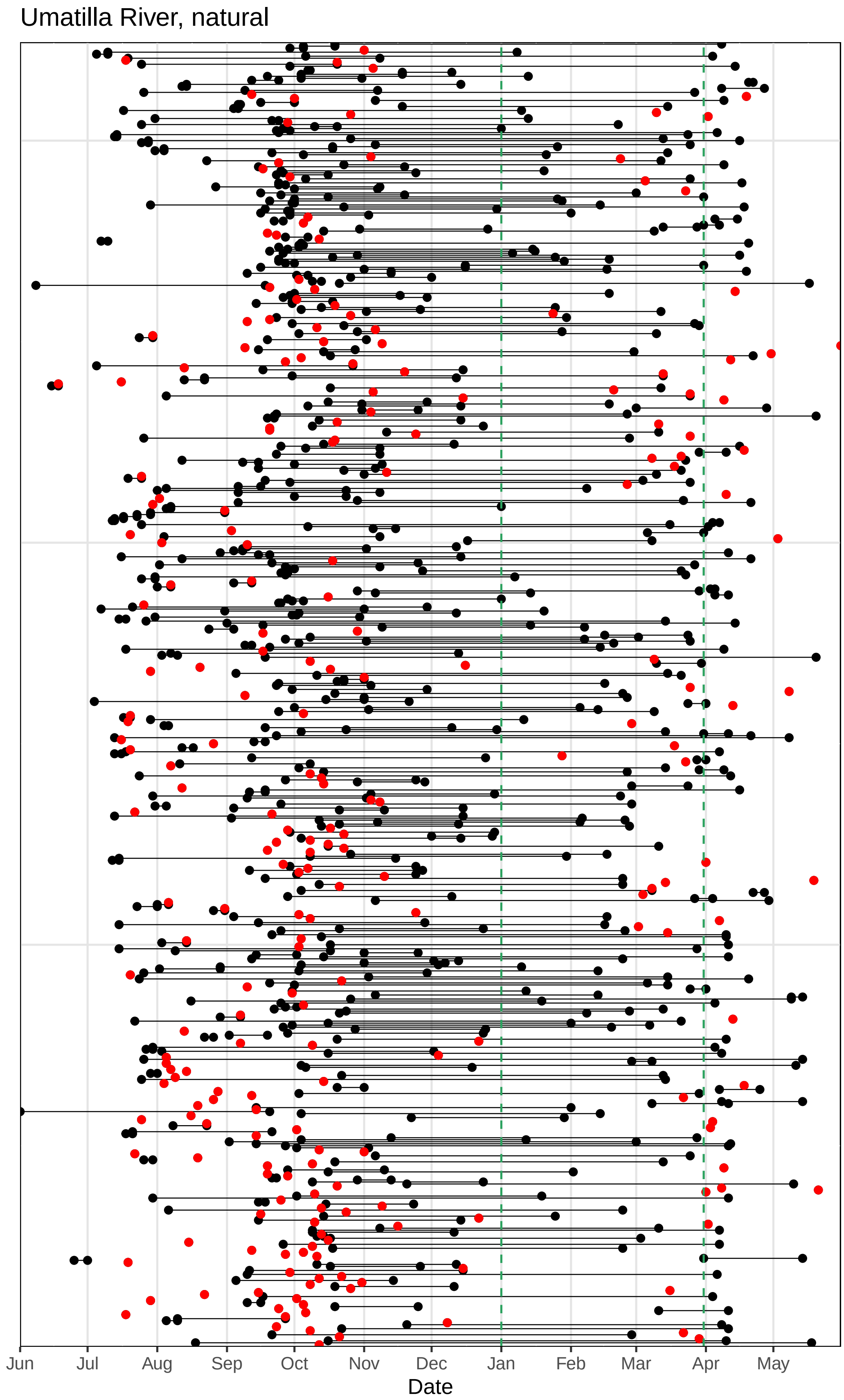


John Day River, natural
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Date

John Day (N)

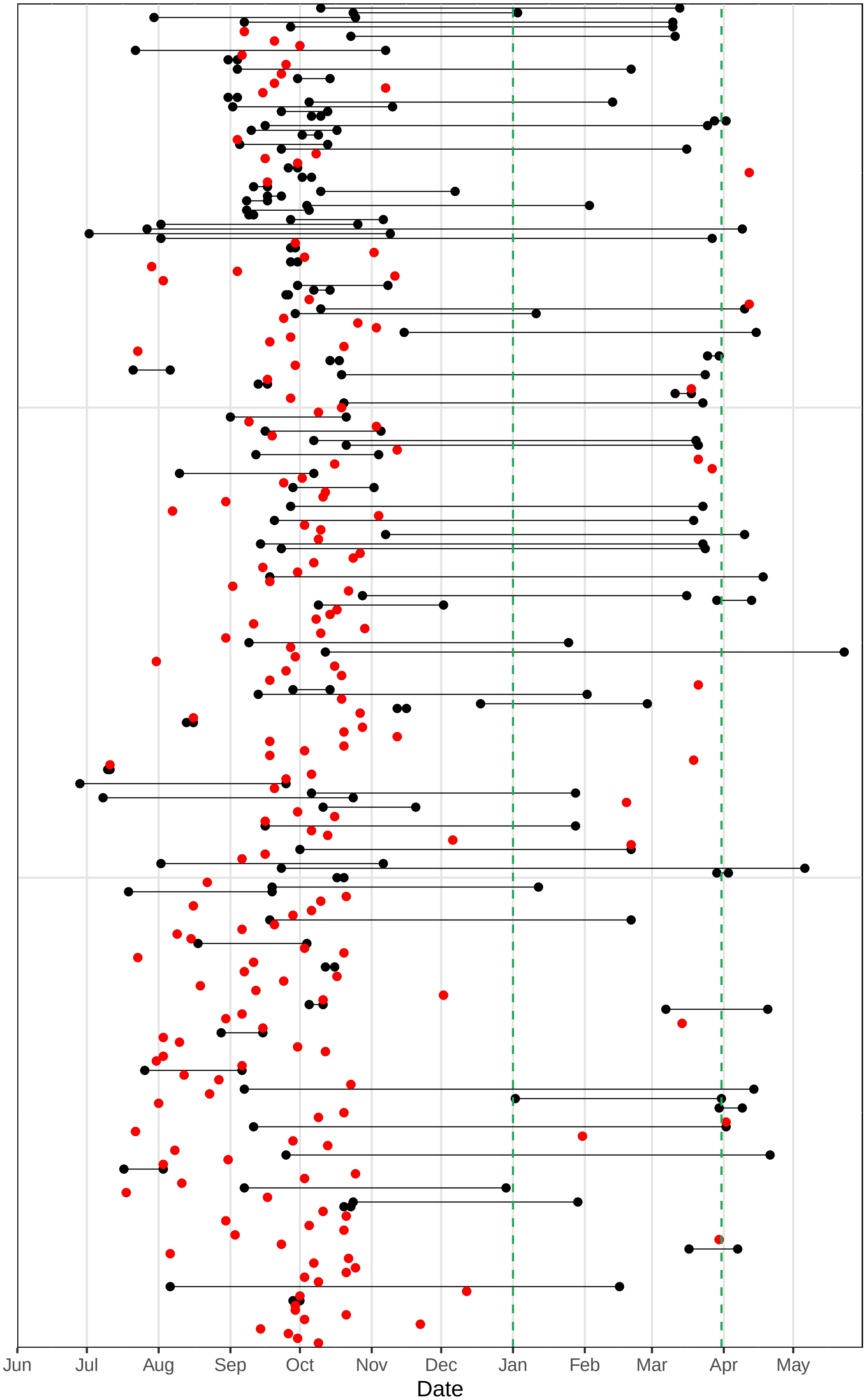


Fifteenmile (N)

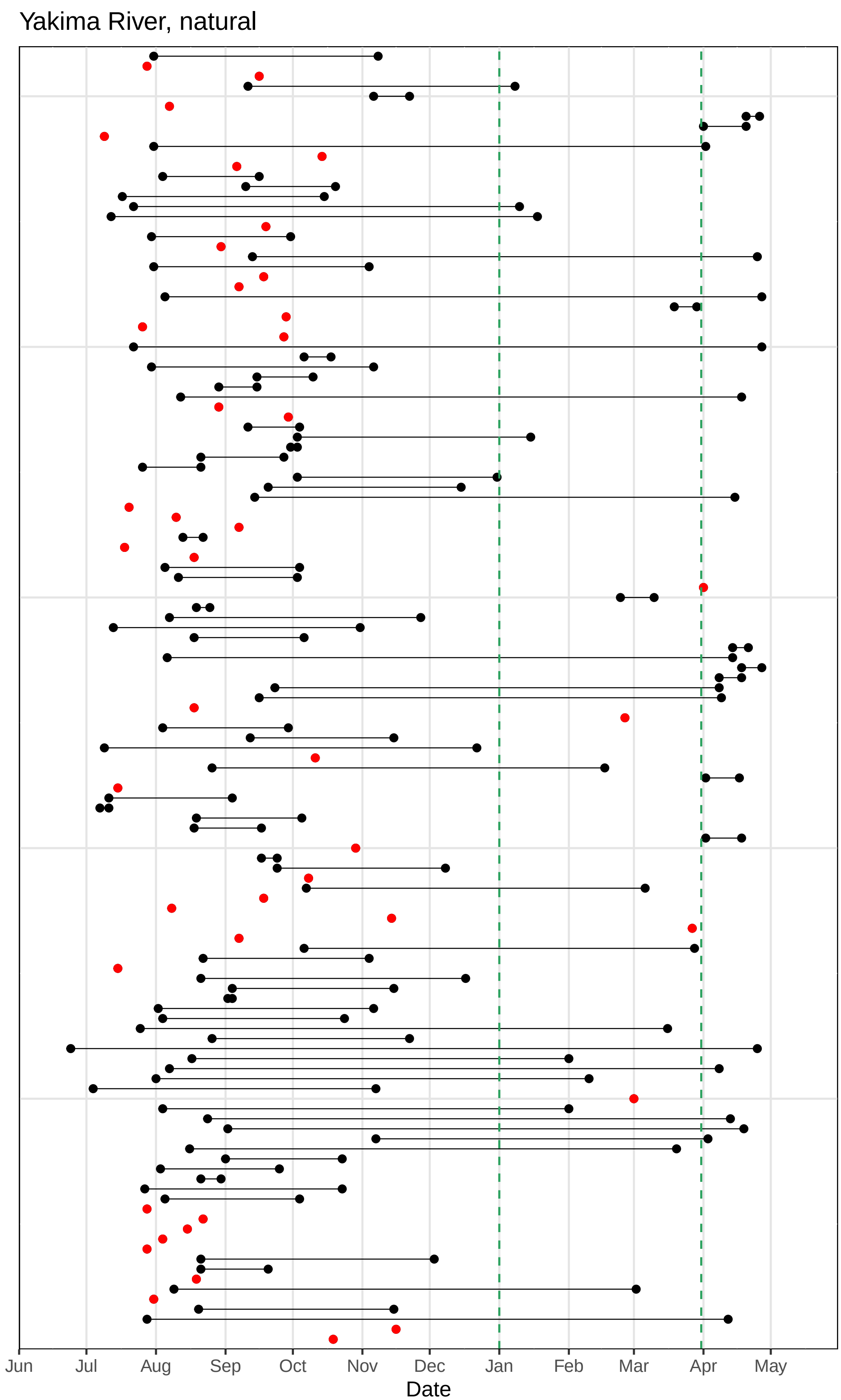

Umatilla River, natural
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Date

Umatilla (N)

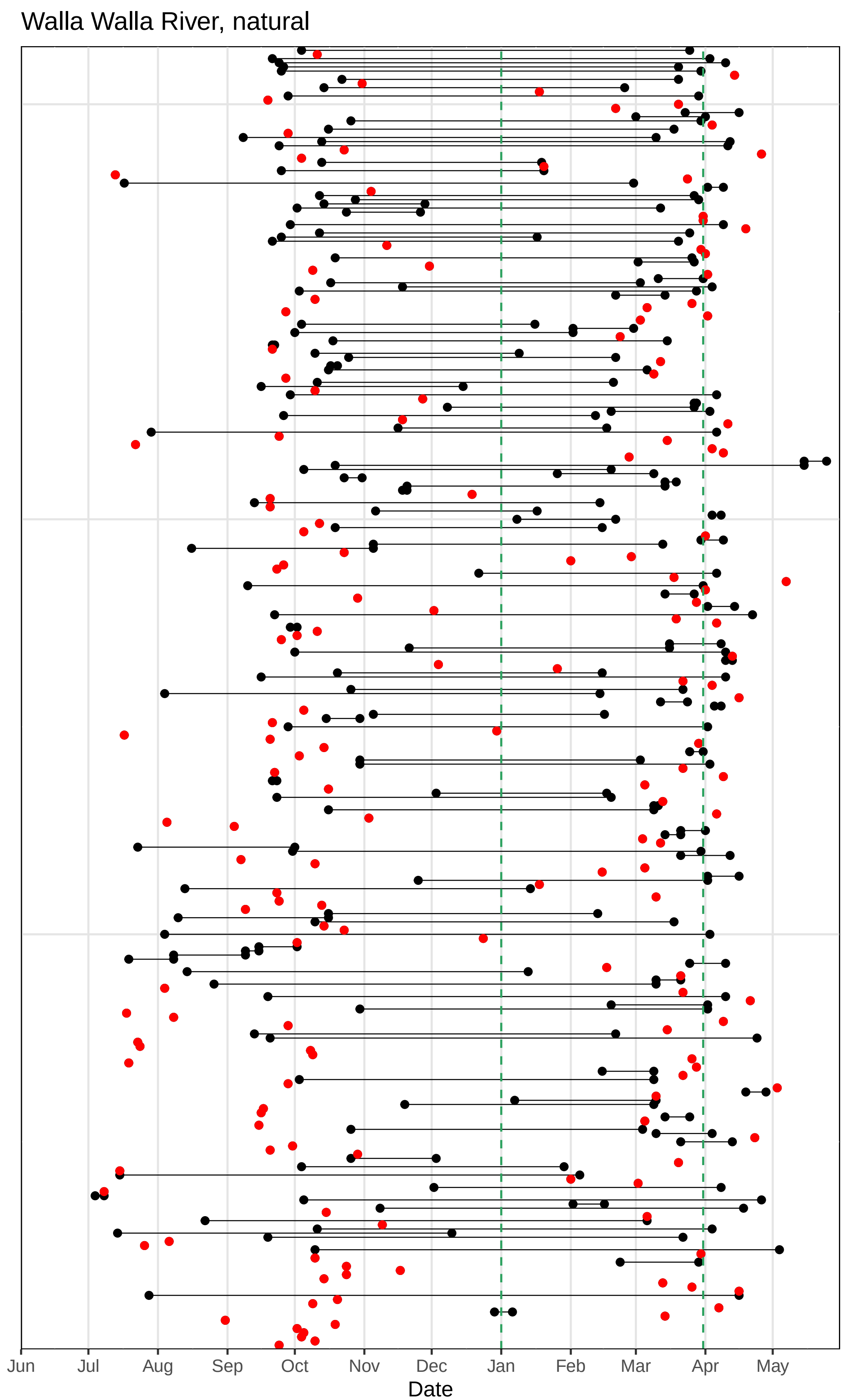
Umatilla River, hatchery



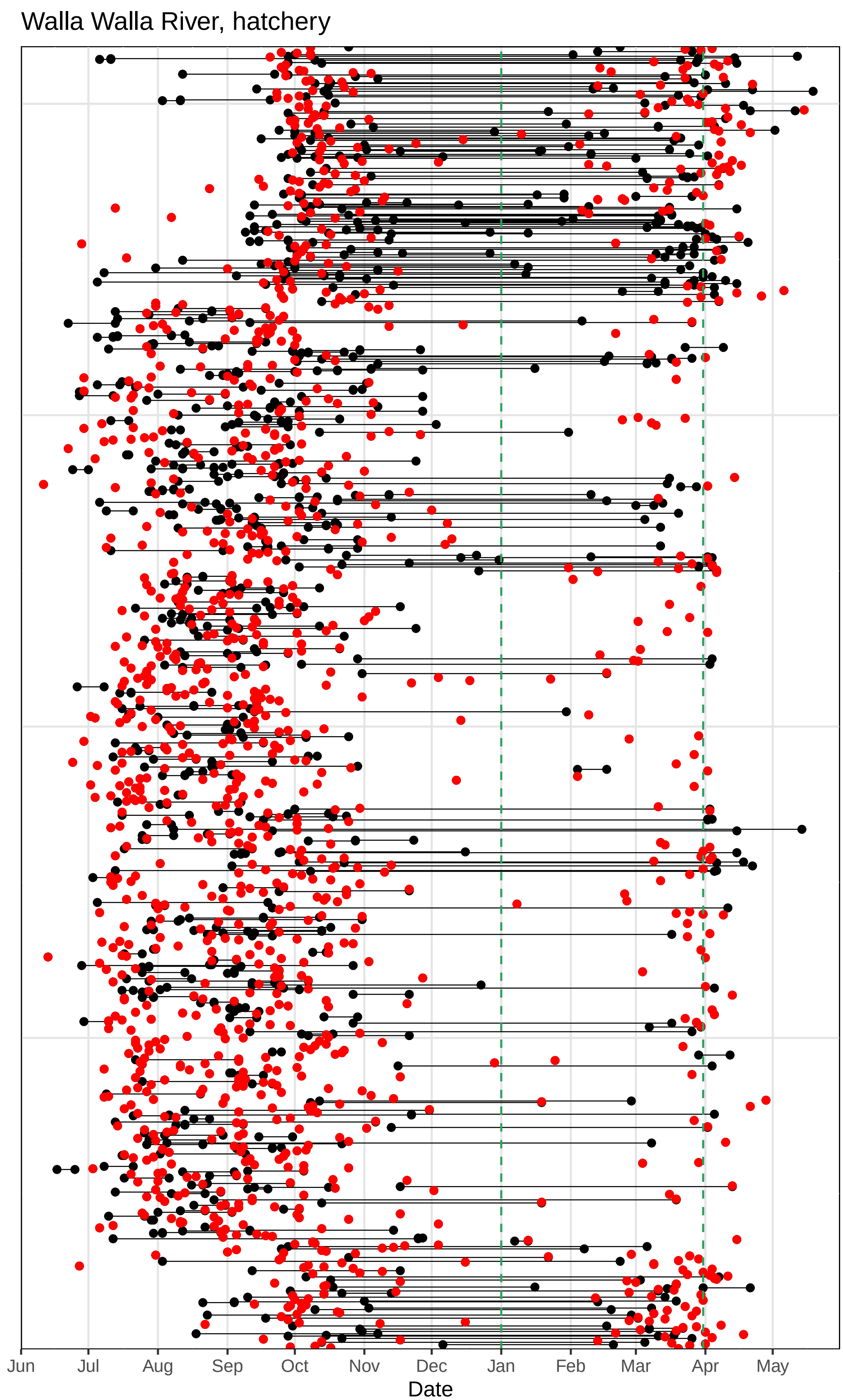
Umatilla (H)


Yakima River, natural
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Date

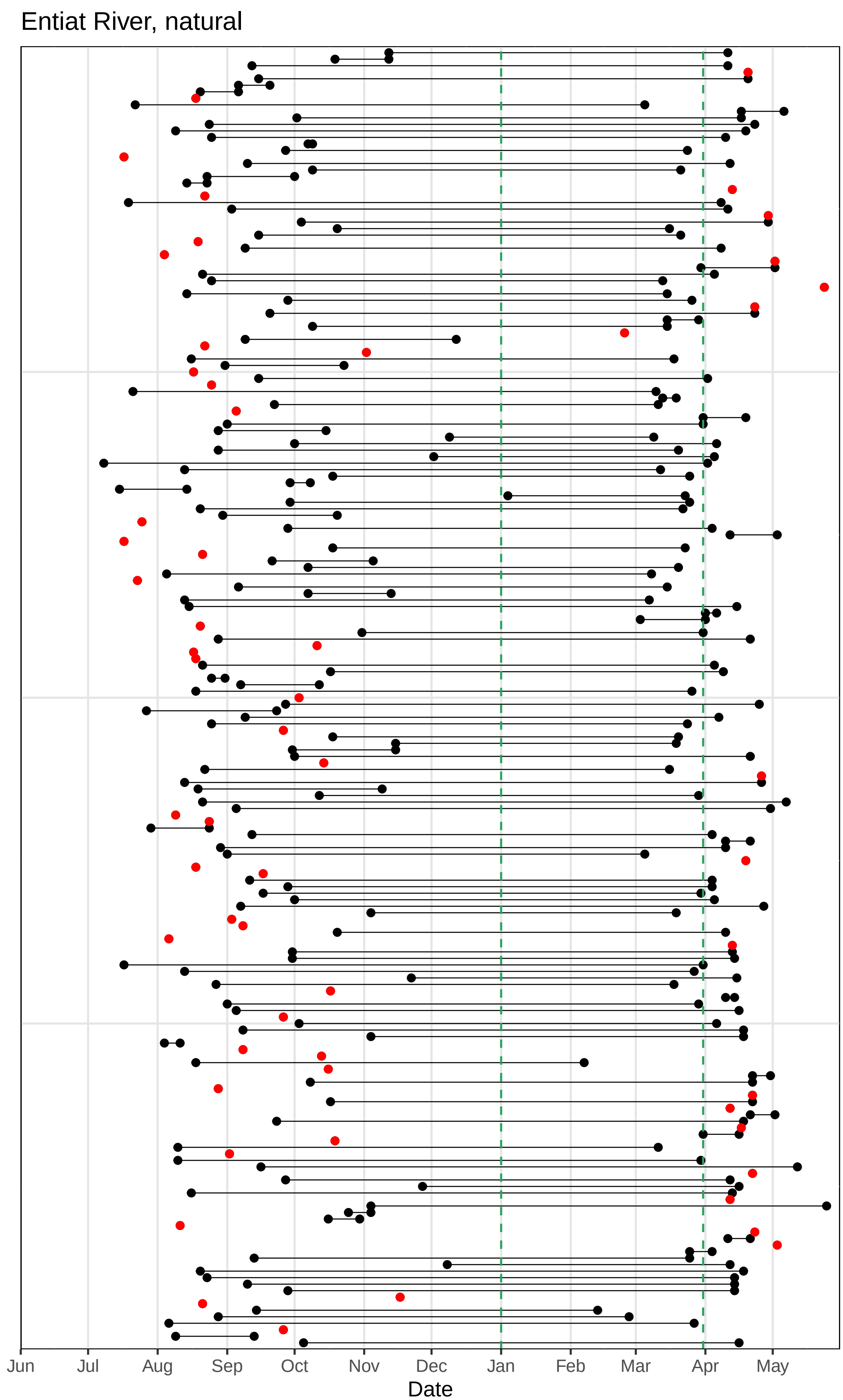
Yakima (N)



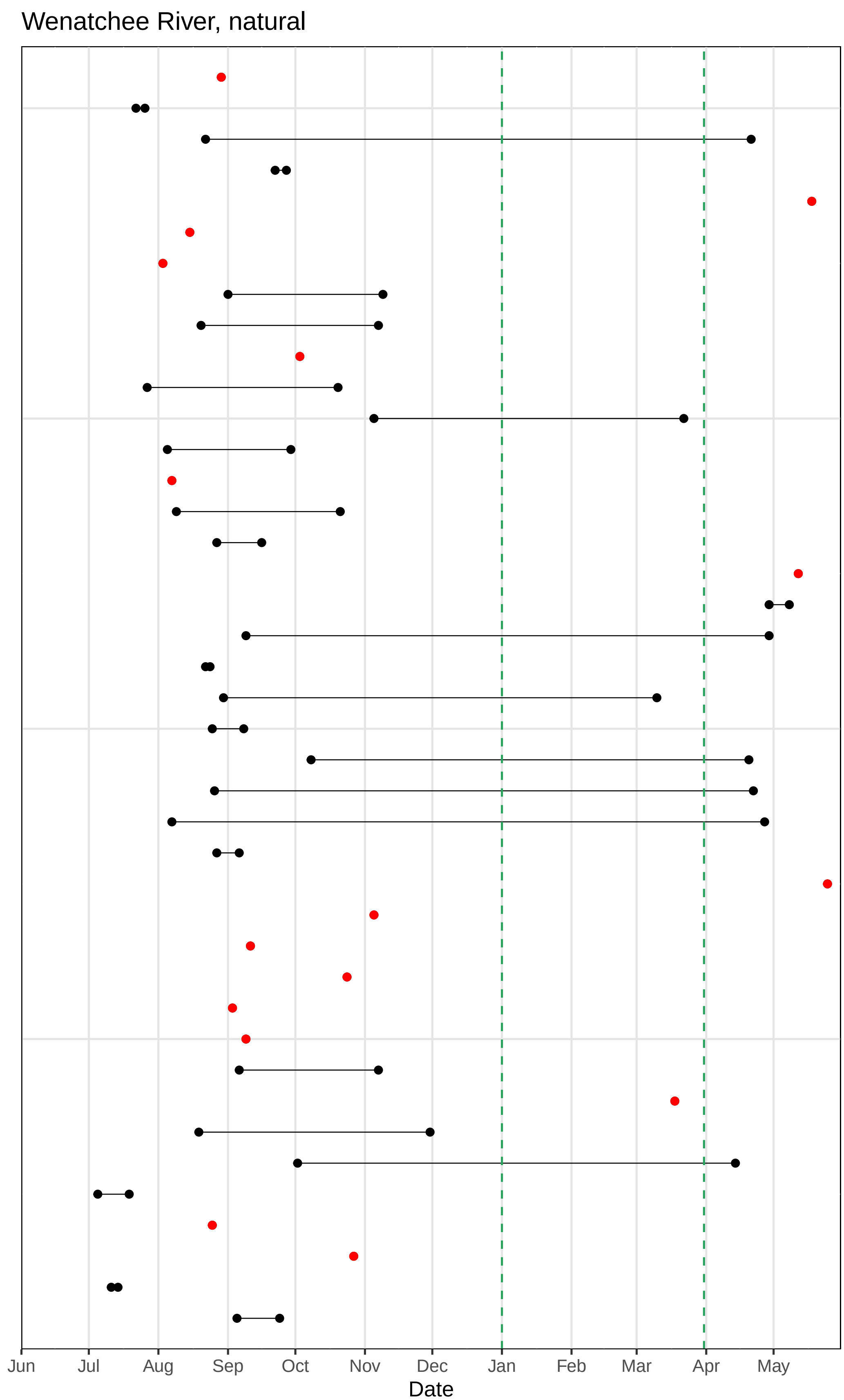
Walla Walla (N)



Walla Walla (H)


Entiat River, natural
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Date

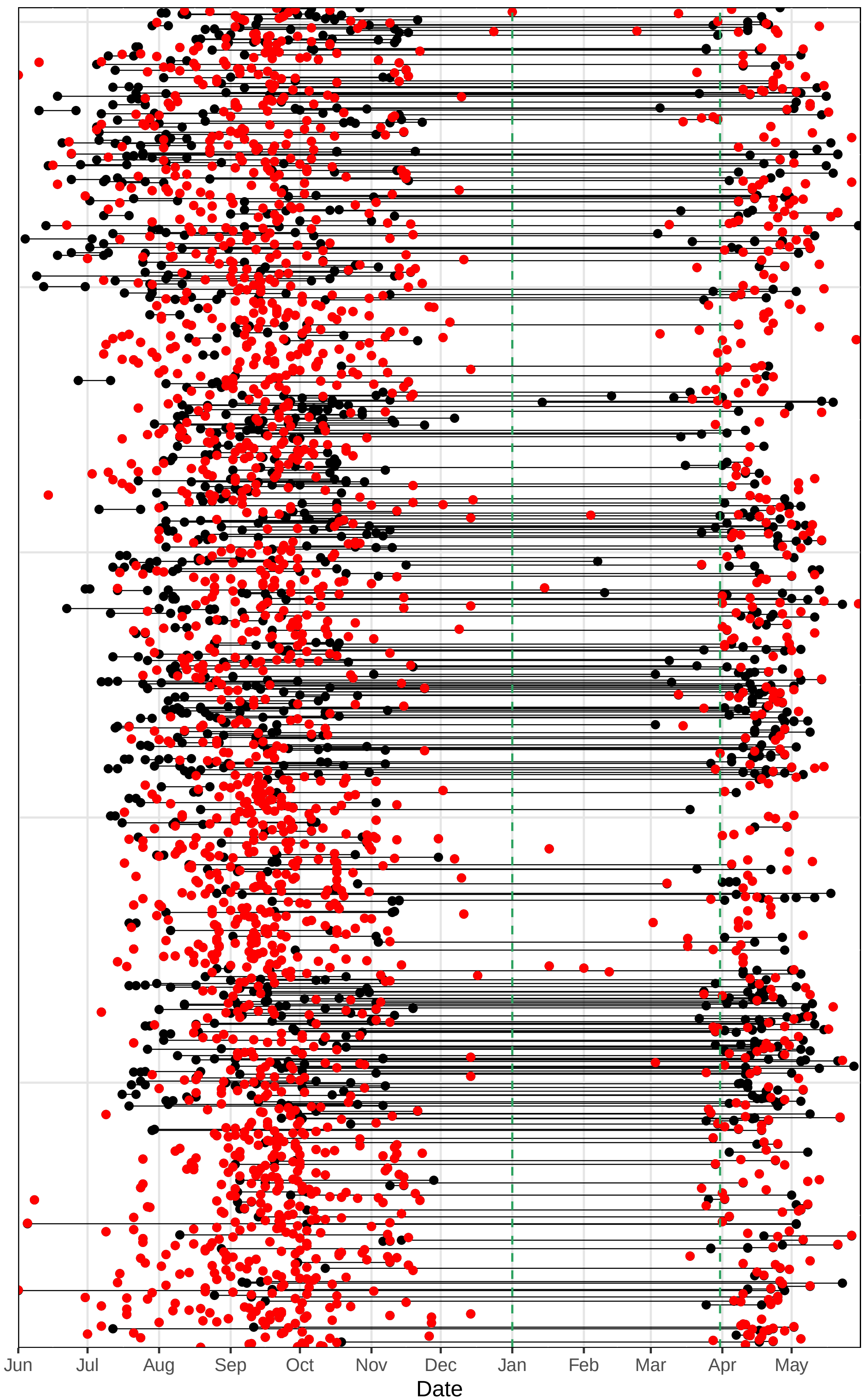
Entiat (N)



Wenatchee River, natural
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Date

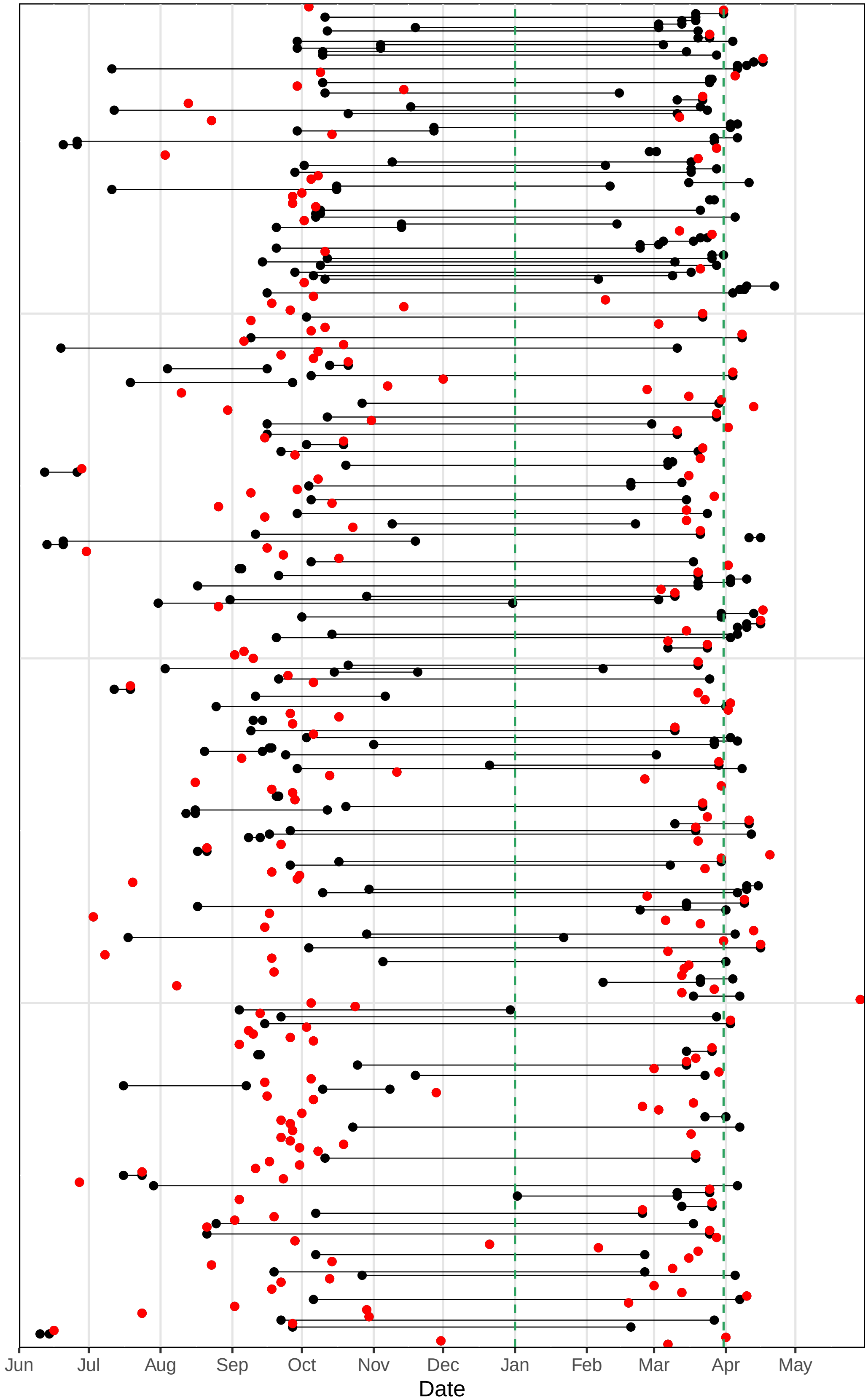
Wenatchee (N)

Wenatchee River, hatchery



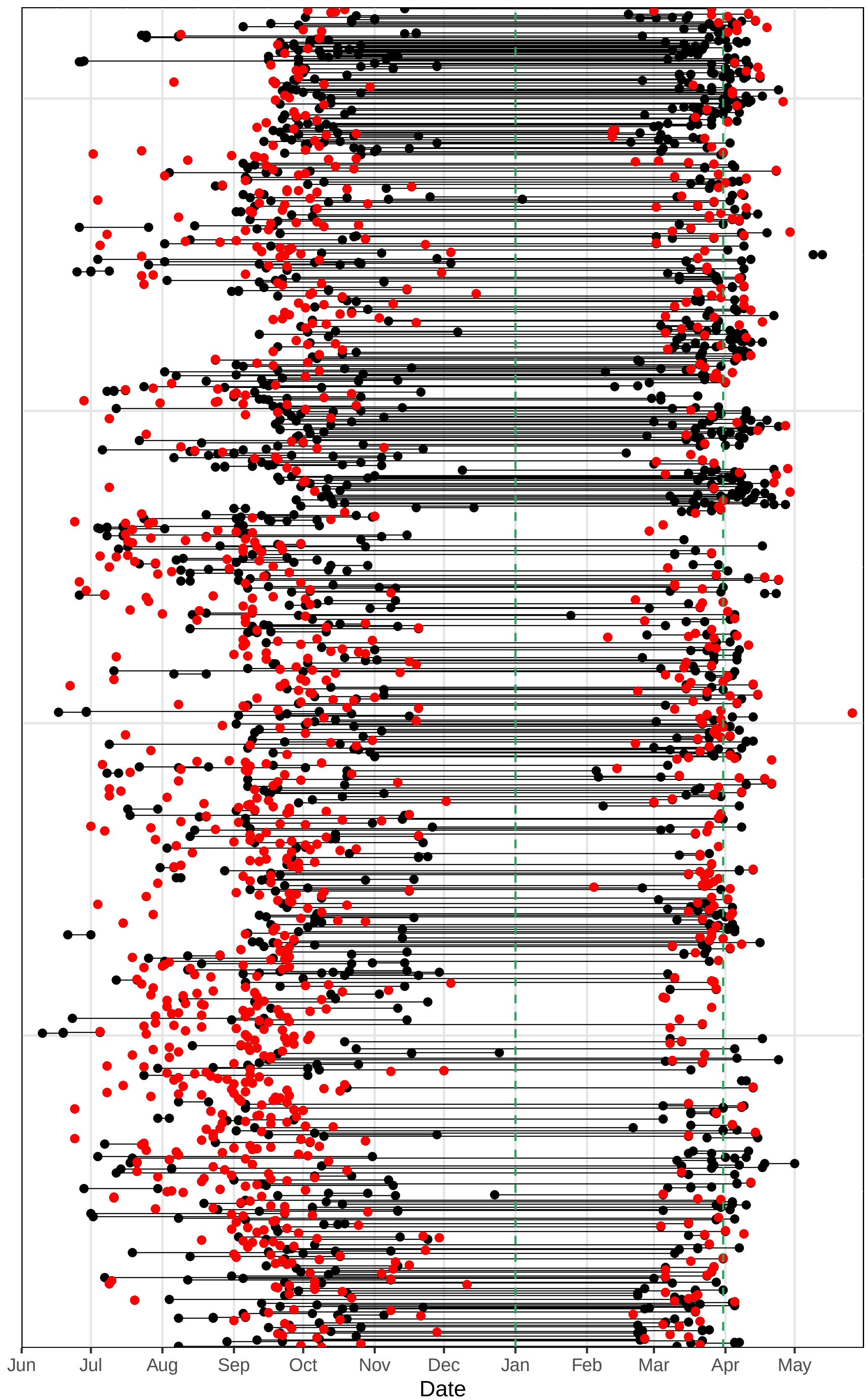
Wenatchee (H)

Tucannon River, natural



Tucannon (N)

Tucannon River, hatchery



Tucannon (H)

4 Detection efficiency estimation

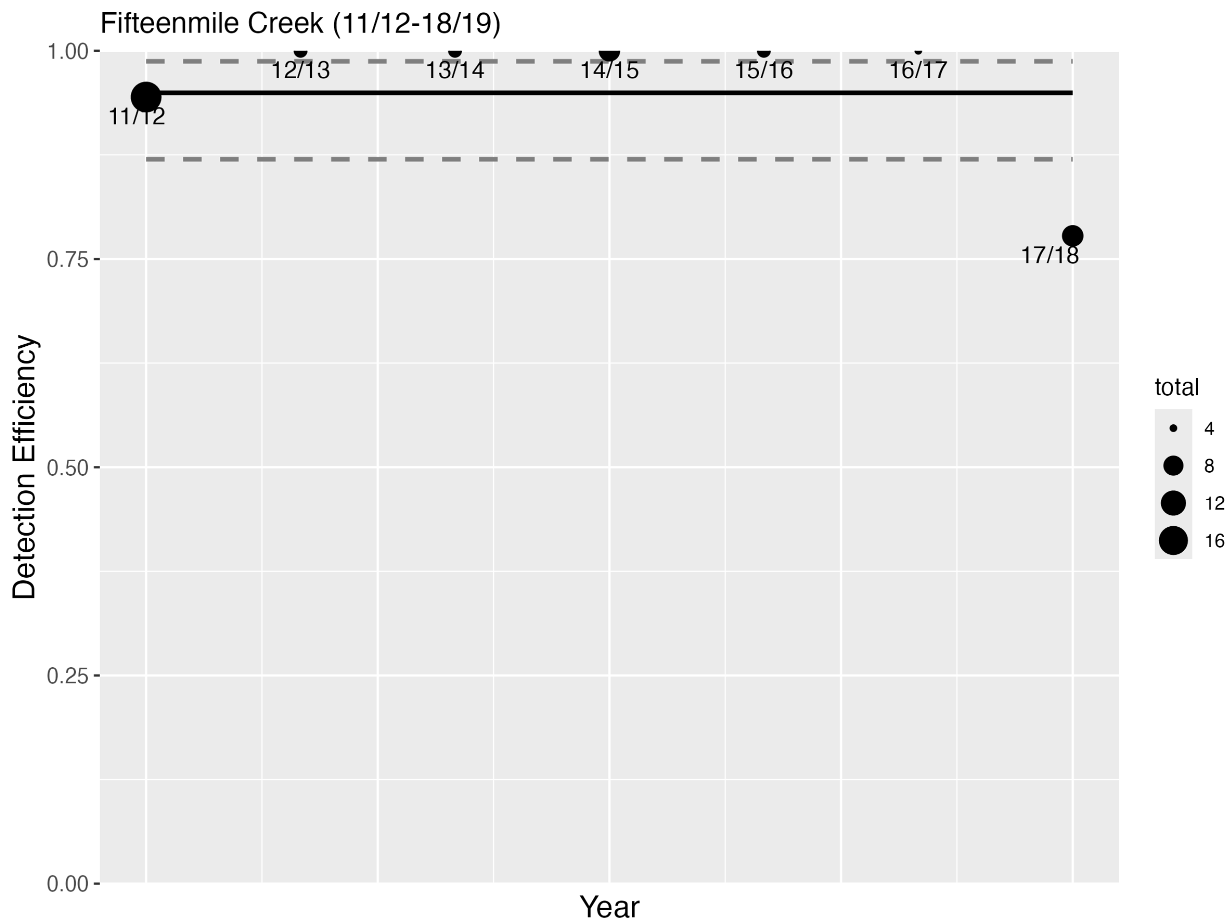


Figure 1: Fifteenmile Creek, estimated detection efficiency.

Fifteenmile Creek

Deschutes River

John Day River

Umatilla River

Walla Walla River

Yakima River

Wenatchee River

Entiat River

Methow River

Okanogan River

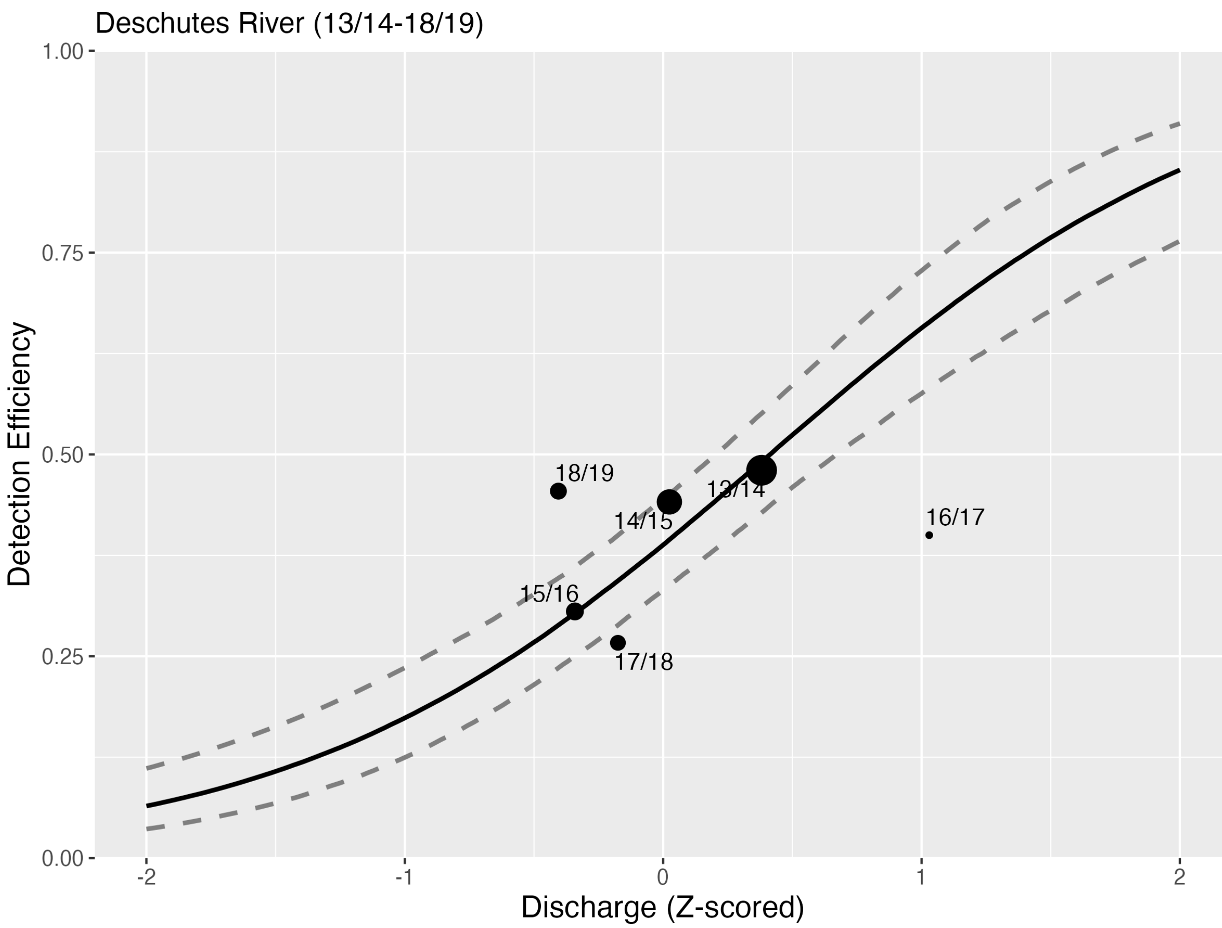


Figure 2: Deschutes River, estimated detection efficiency.

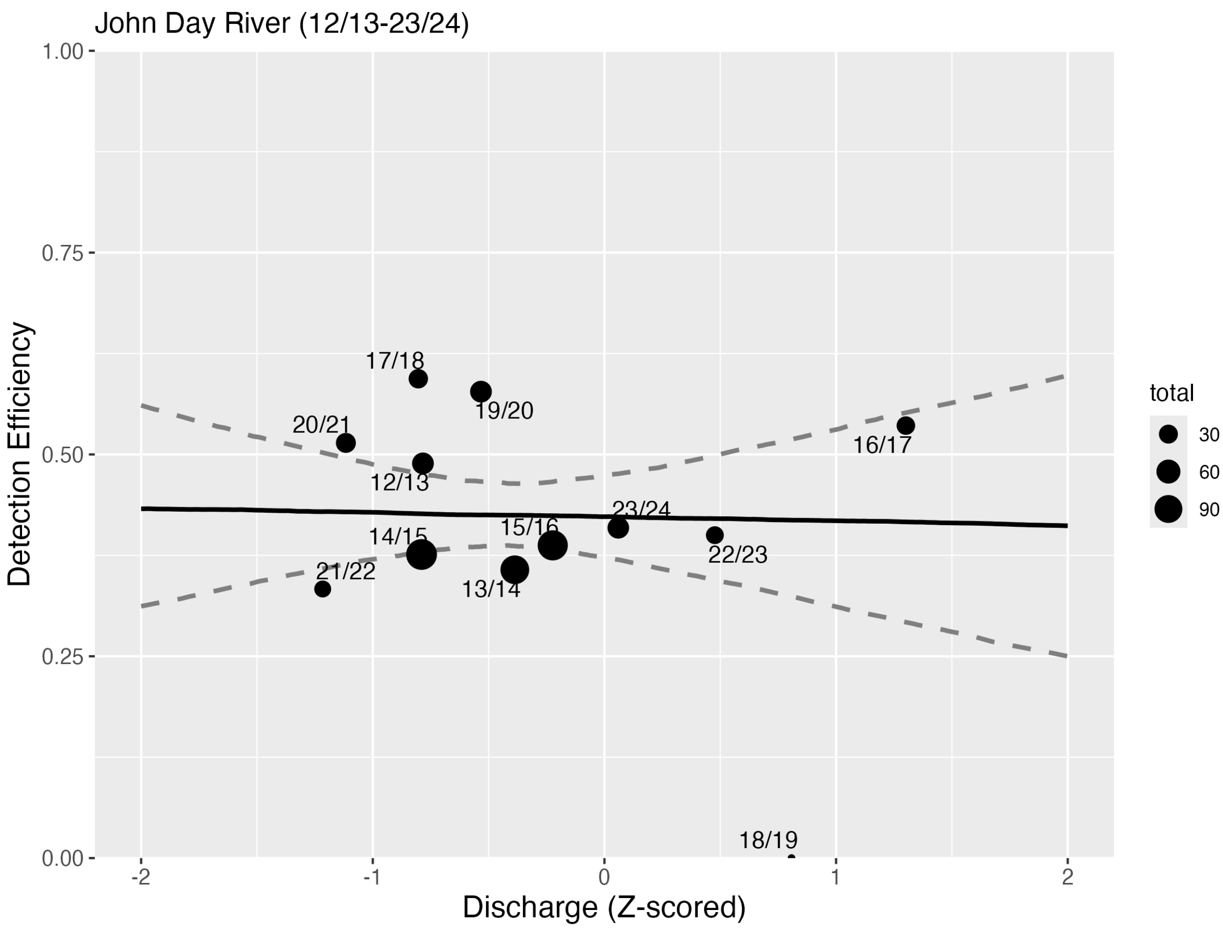


Figure 3: John Day River, estimated detection efficiency.

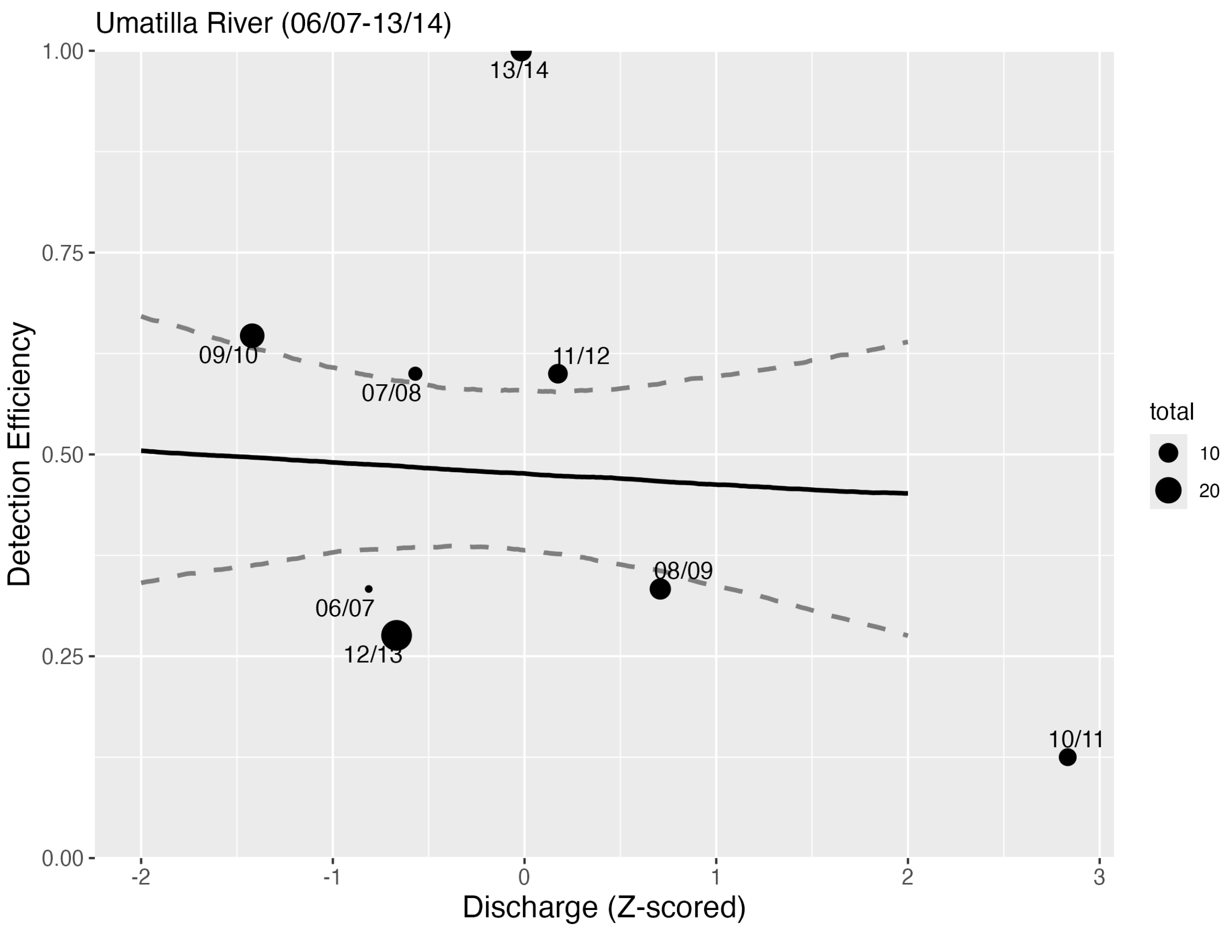


Figure 4: Umatilla River, estimated detection efficiency in time period 1.

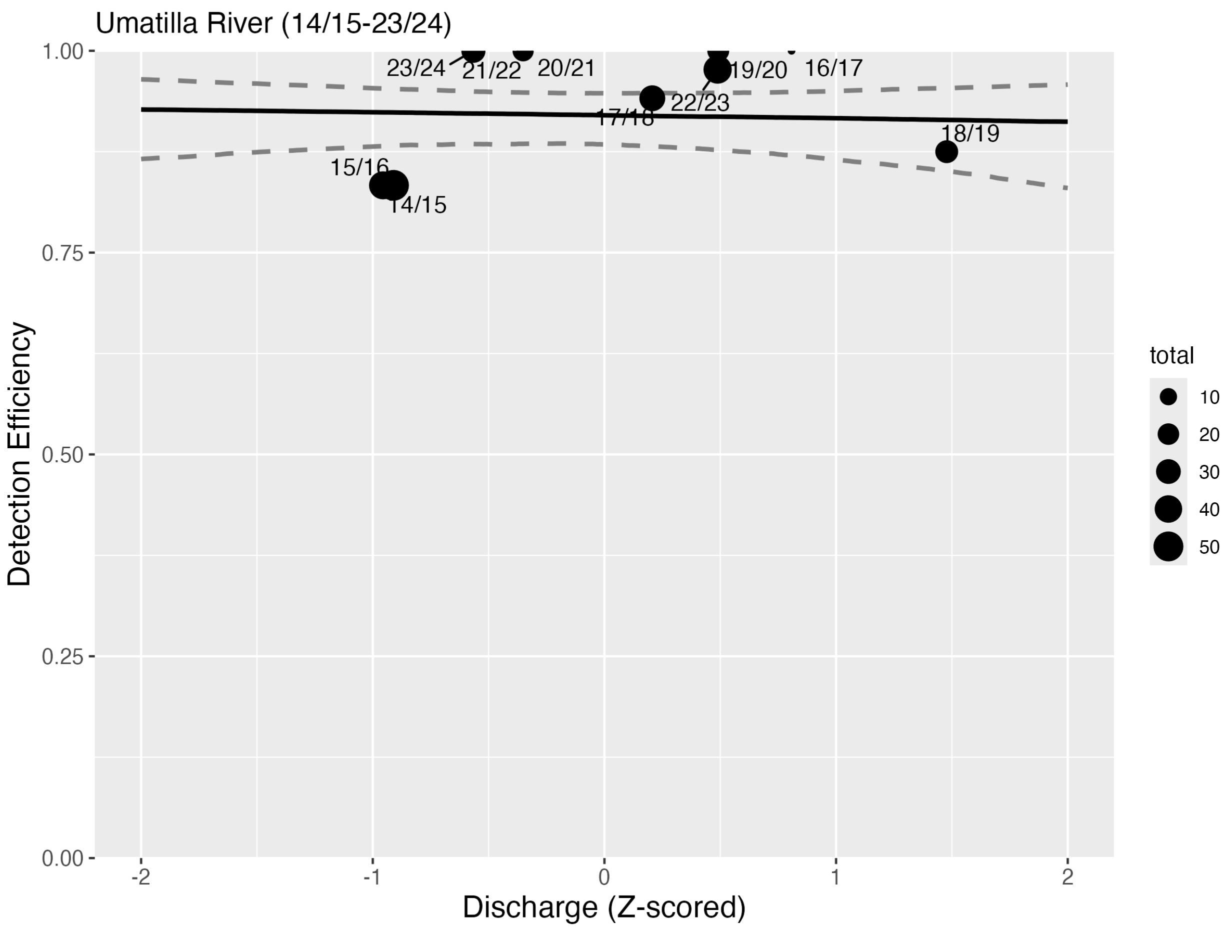


Figure 5: Umatilla River, estimated detection efficiency in time period 2.

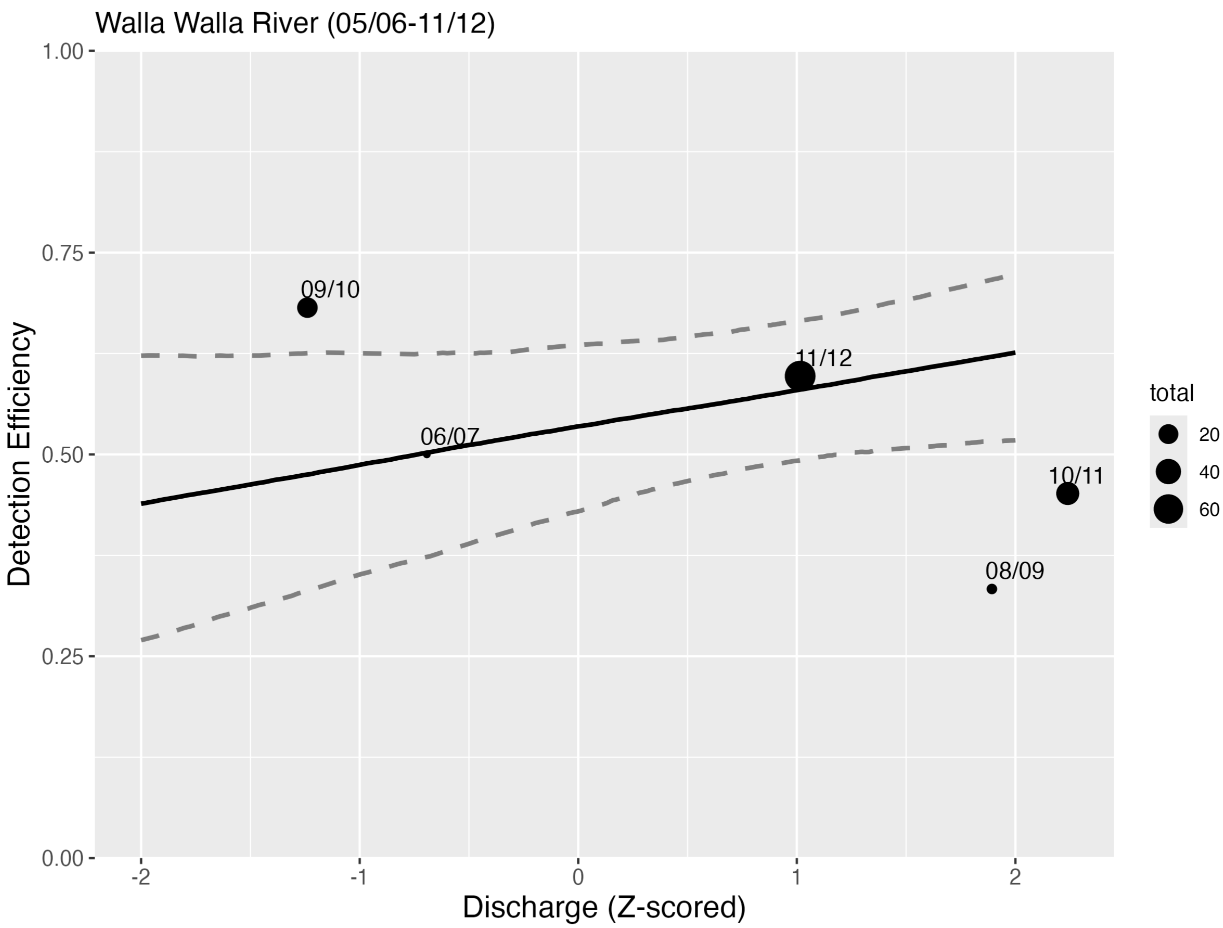


Figure 6: Walla Walla River, estimated detection efficiency in time period 1.

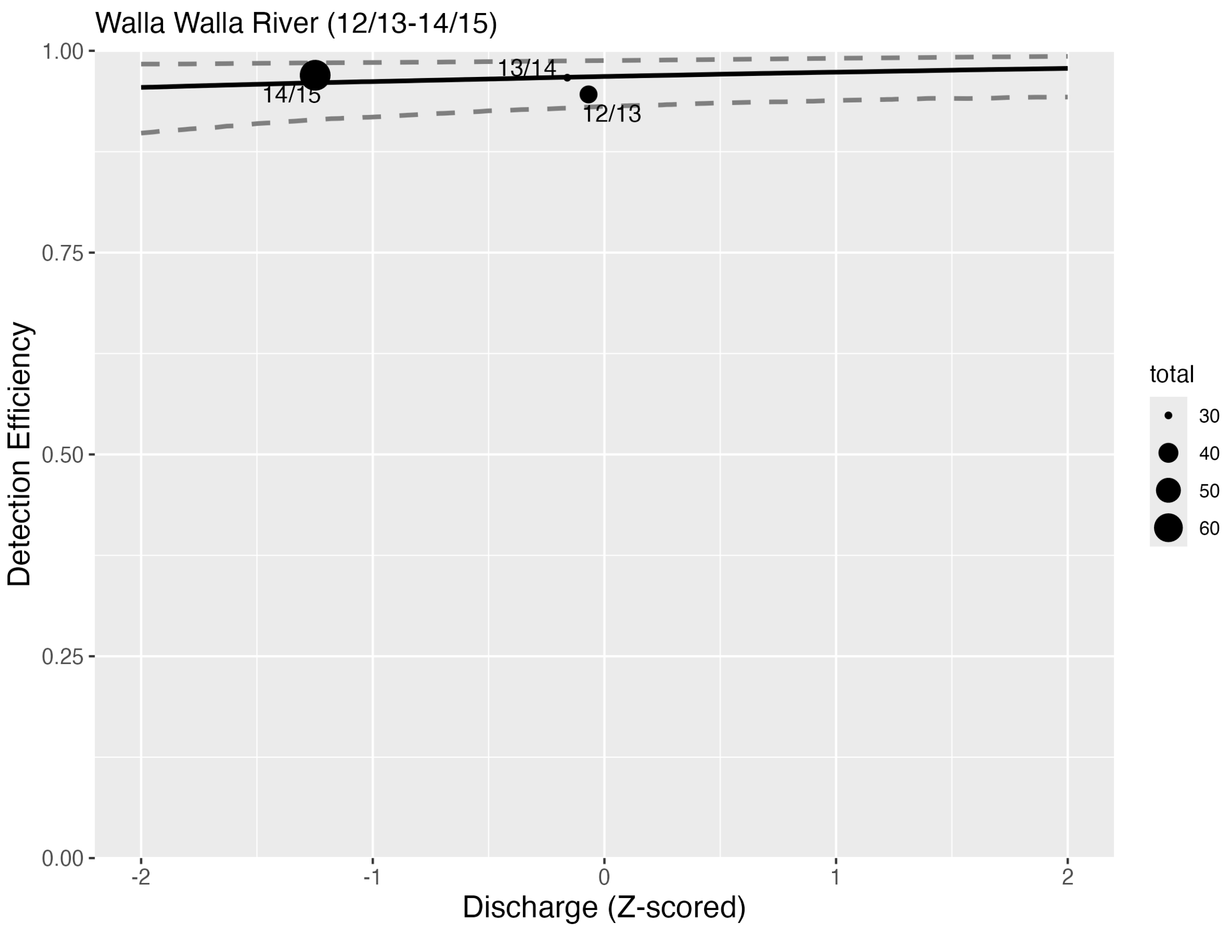


Figure 7: Walla Walla River, estimated detection efficiency in time period 2.

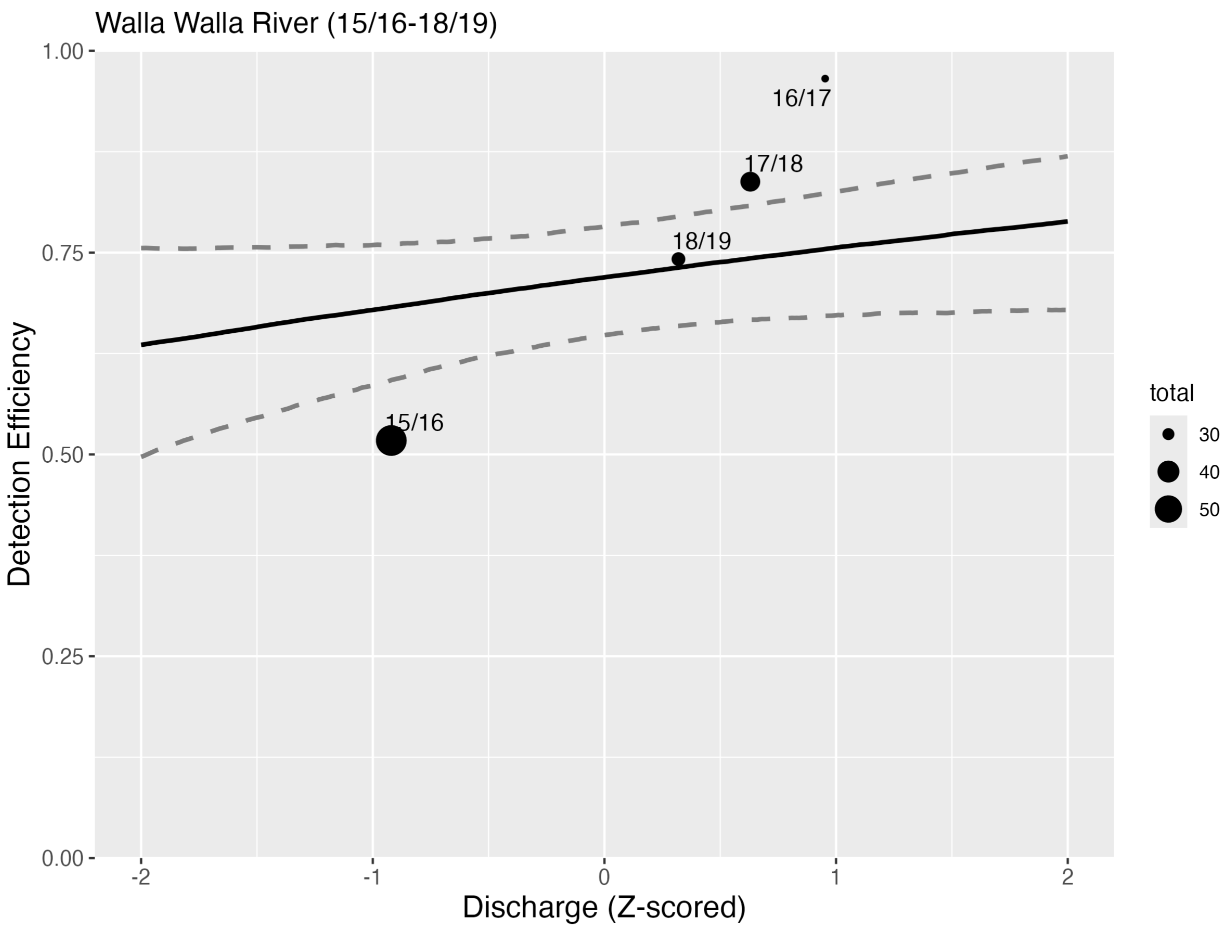


Figure 8: Walla Walla River, estimated detection efficiency in time period 3.

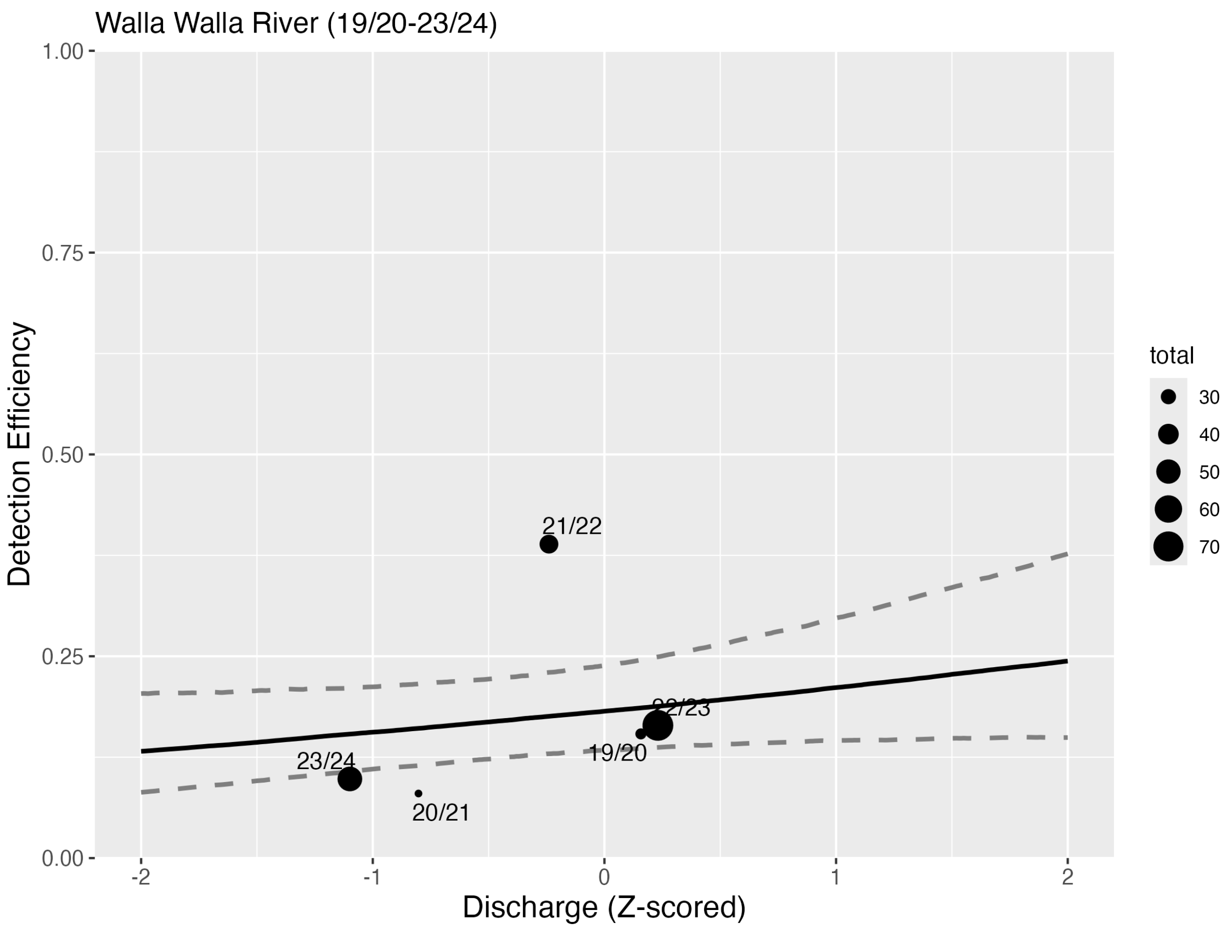


Figure 9: Walla Walla River, estimated detection efficiency in time period 4.

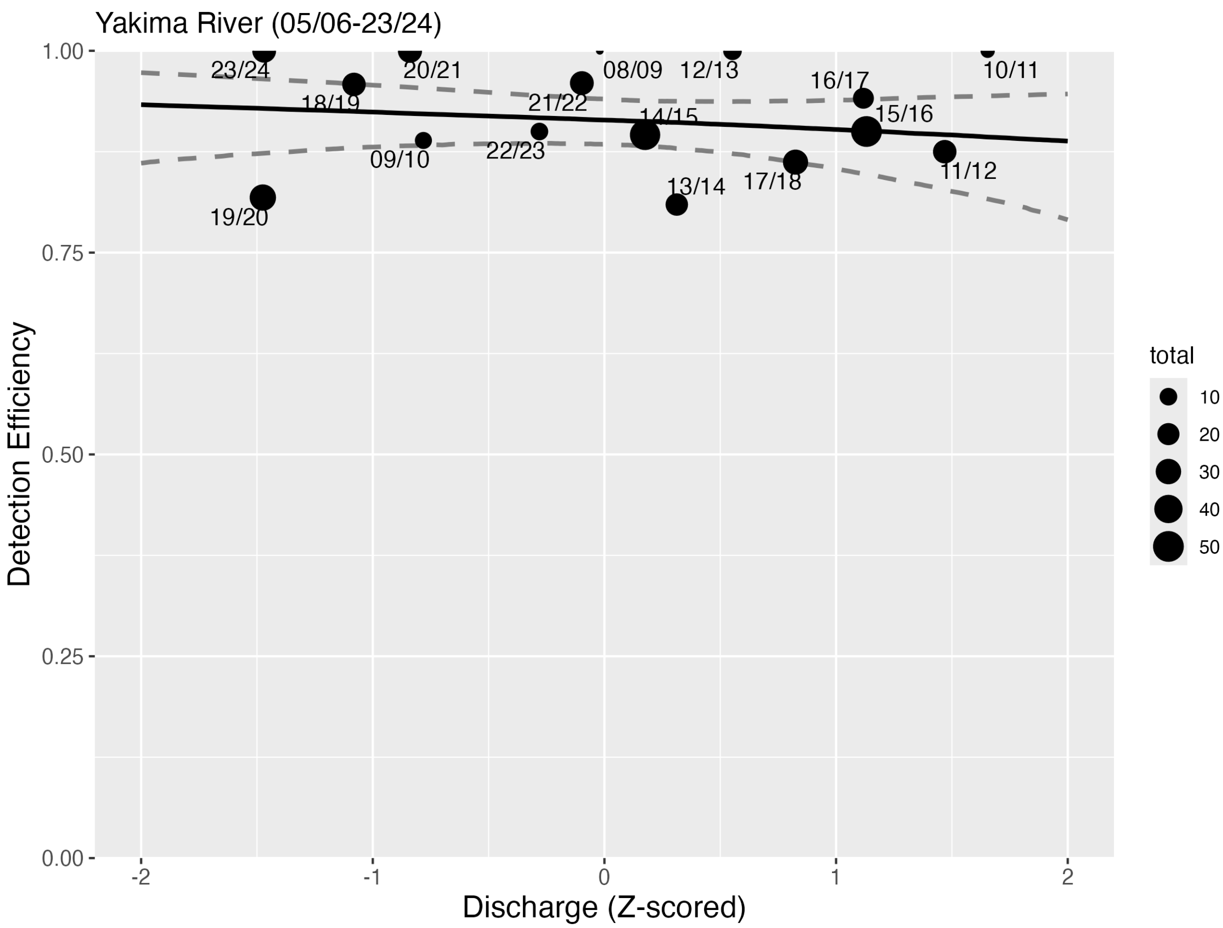


Figure 10: Yakima River, estimated detection efficiency.

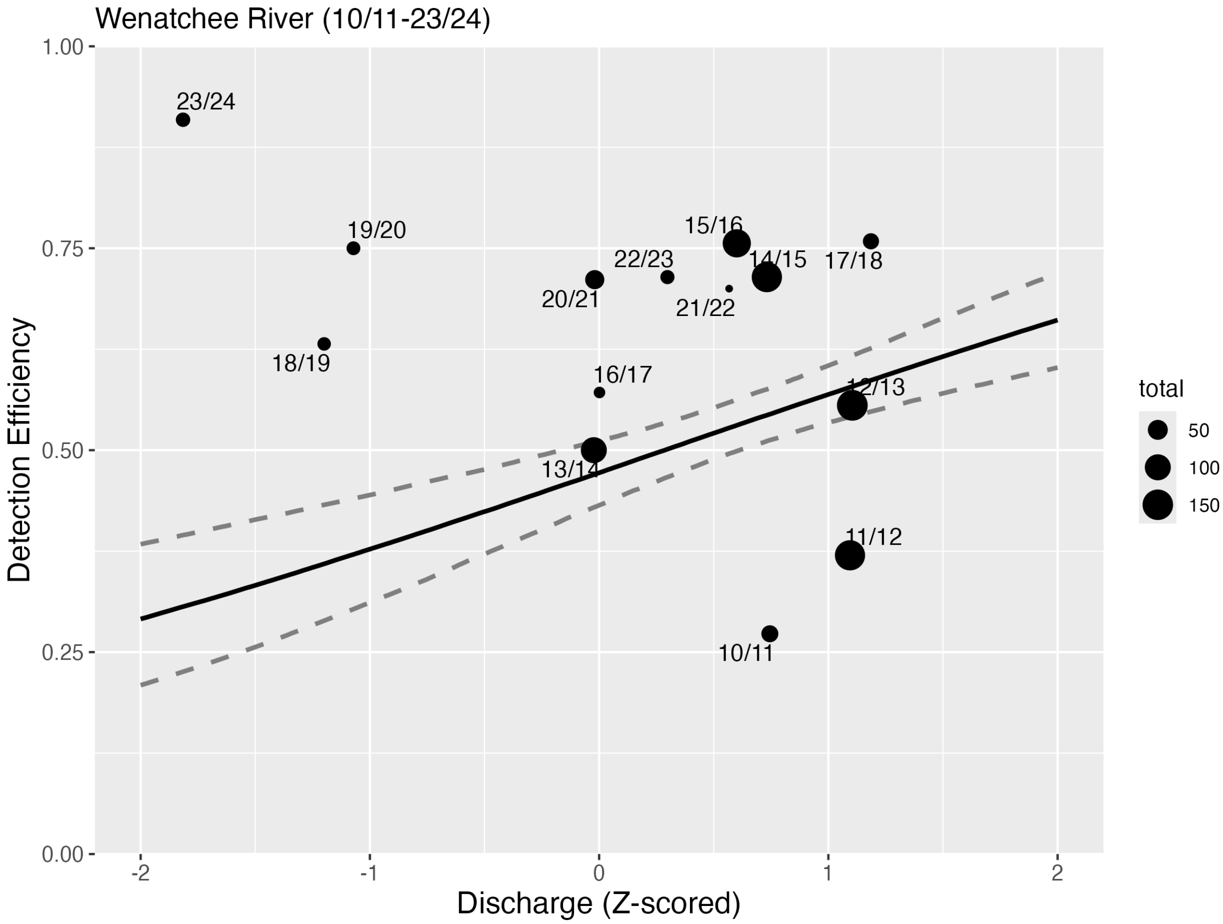


Figure 11: Wenatchee River, estimated detection efficiency.

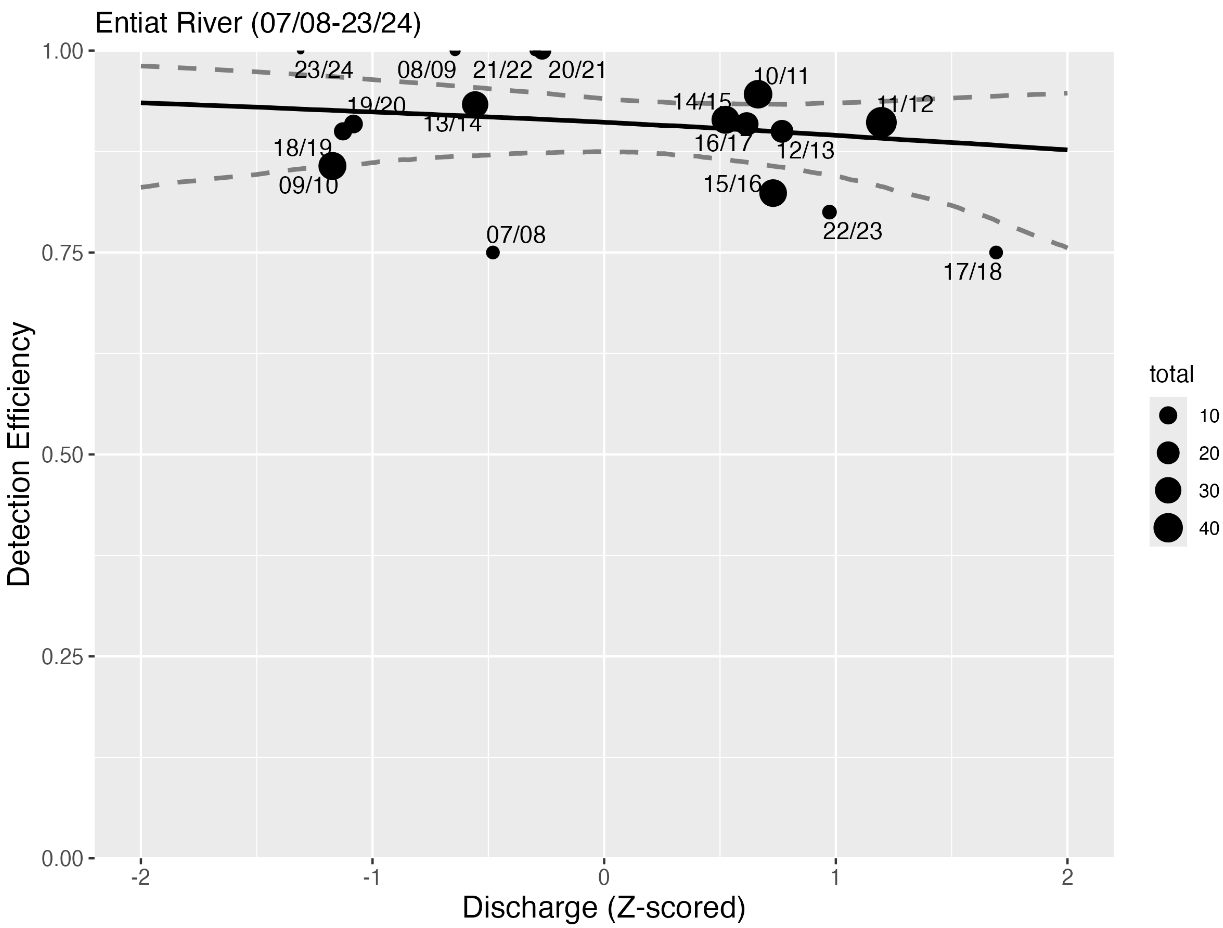


Figure 12: Entiat River, estimated detection efficiency.

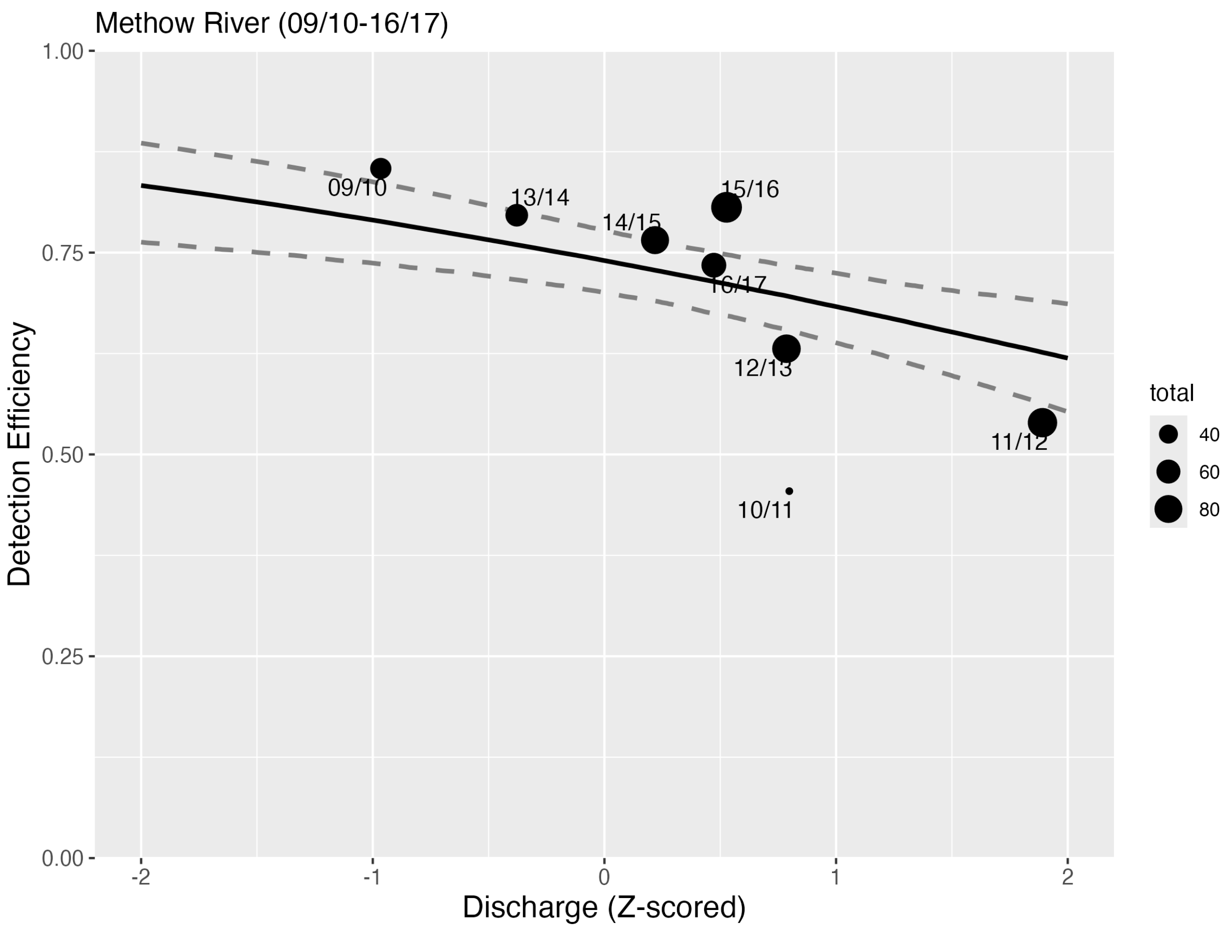


Figure 13: Methow River, estimated detection efficiency in time period 1.

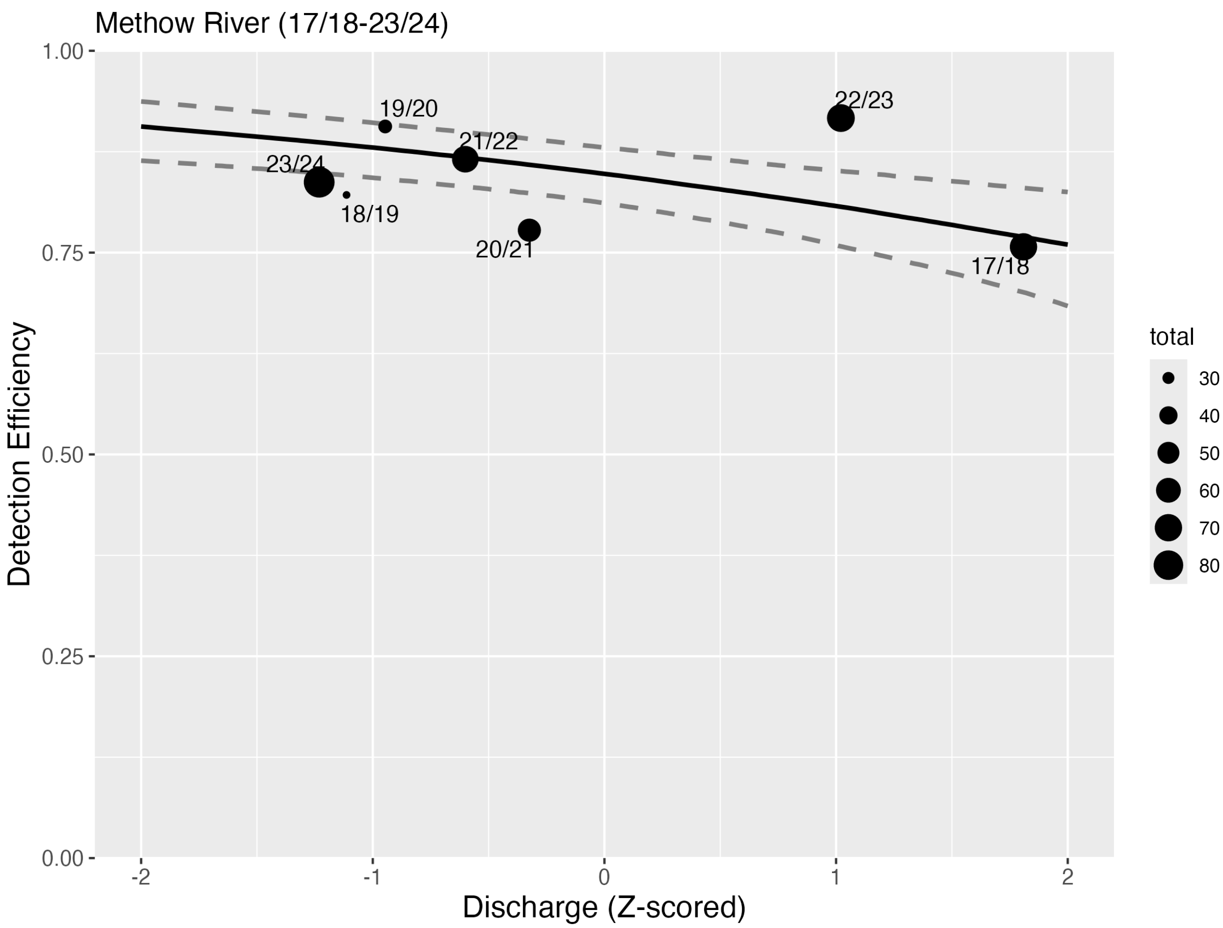


Figure 14: Methow River, estimated detection efficiency in time period 2.

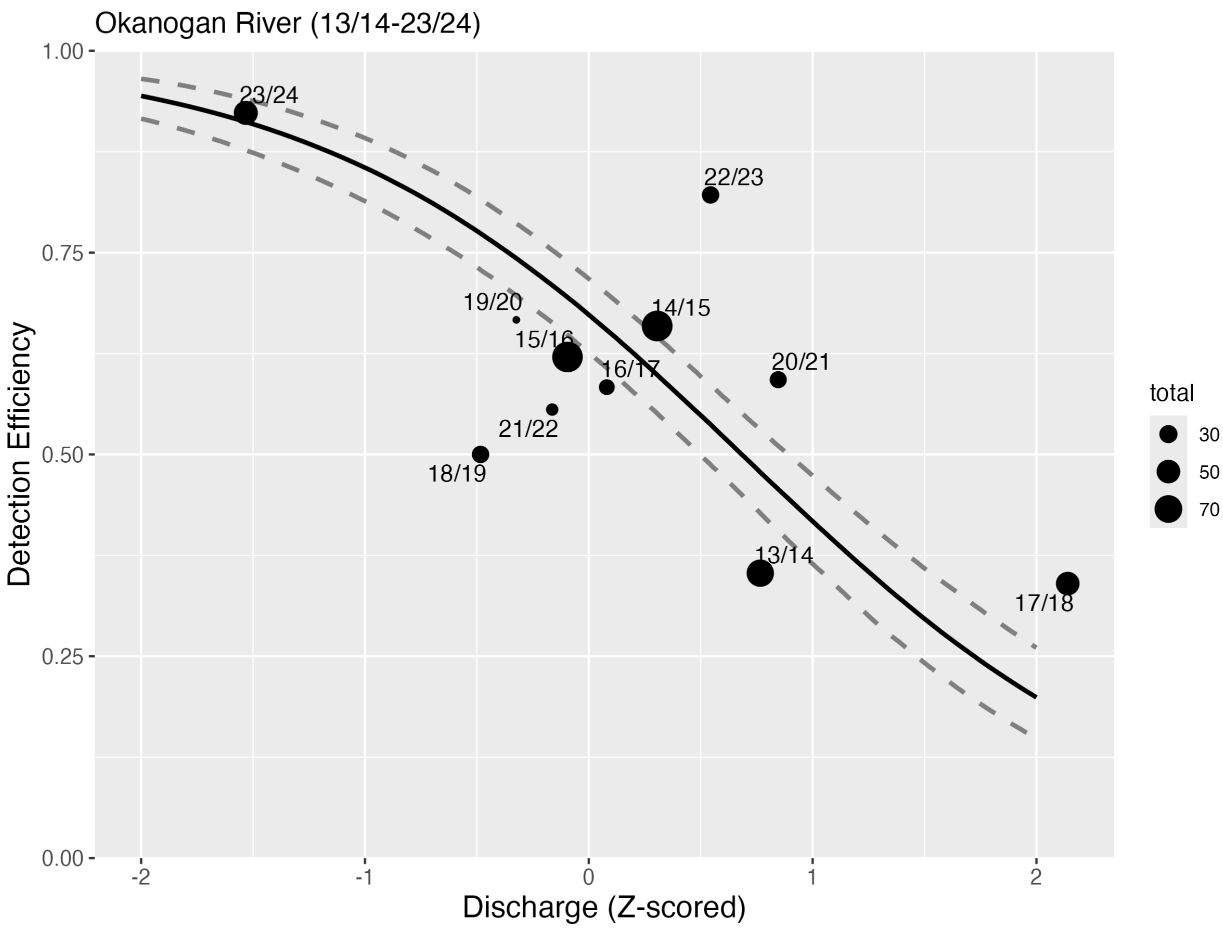


Figure 15: Okanogan River, estimated detection efficiency.

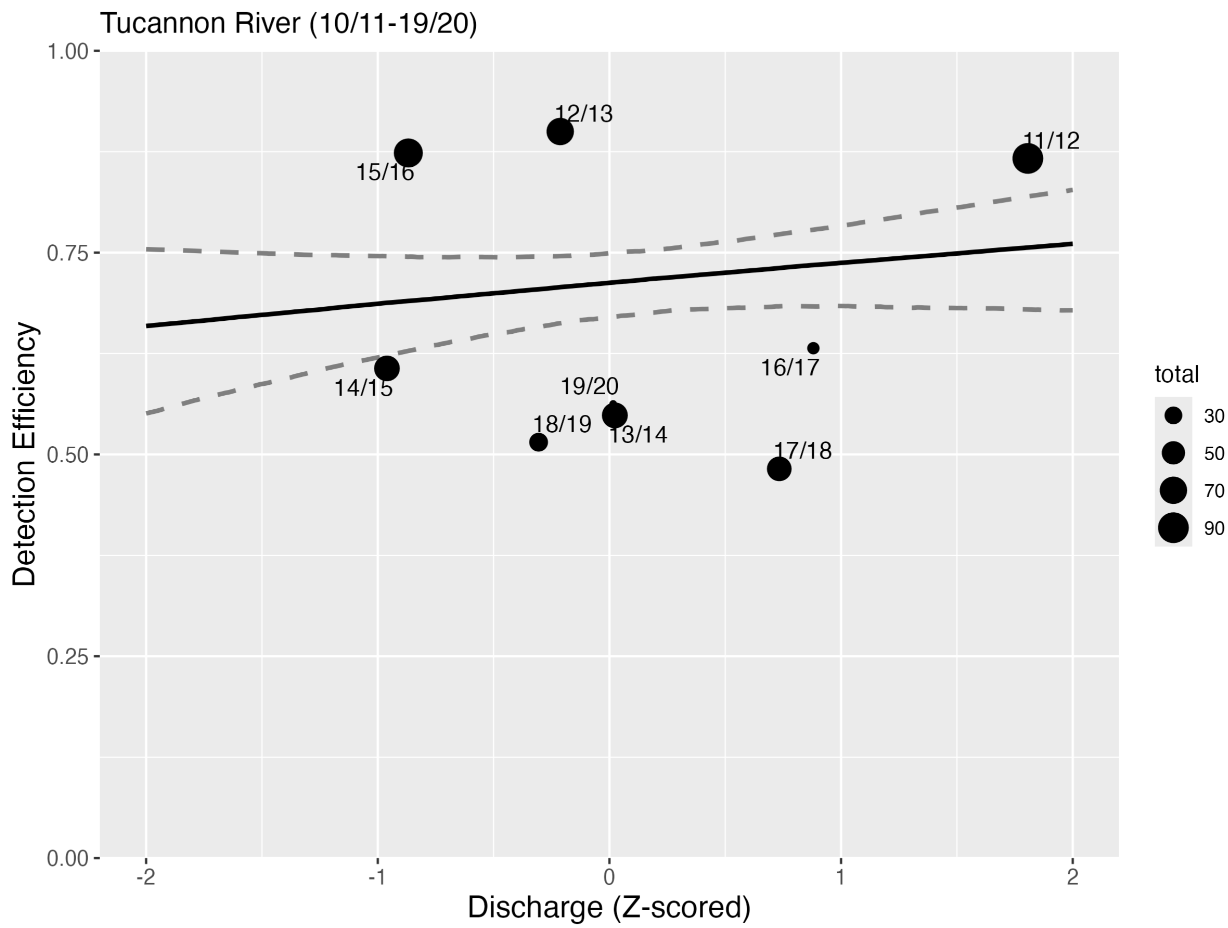


Figure 16: Tucannon River, estimated detection efficiency in time period 1.

Tucannon River

Asotin Creek

Imnaha River

5 Model diagnostic figures

6 Final fates, under median conditions

Fifteenmile Creek

Deschutes River

John Day River

Umatilla River

Walla Walla River

Yakima River

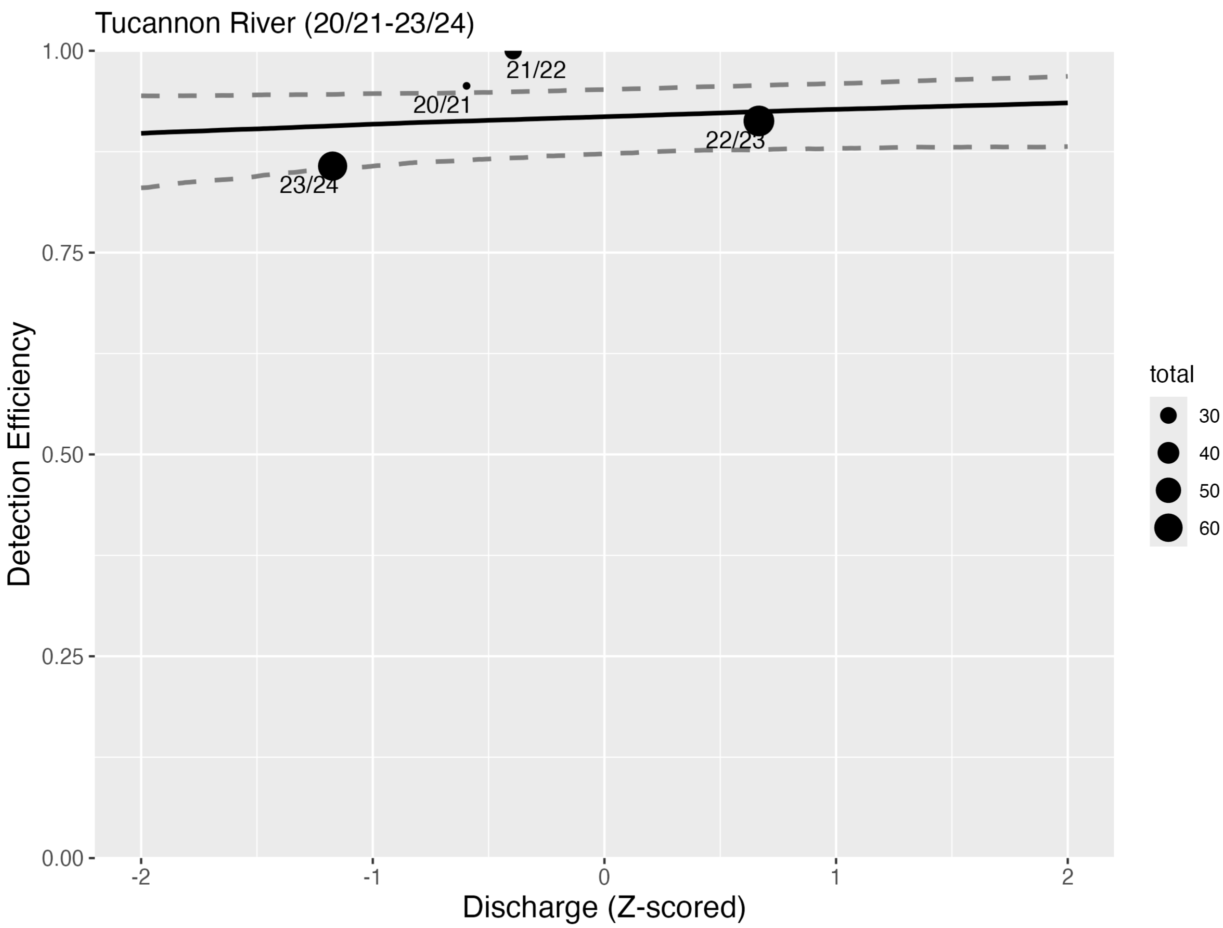


Figure 17: Tucannon River, estimated detection efficiency in time period 2.

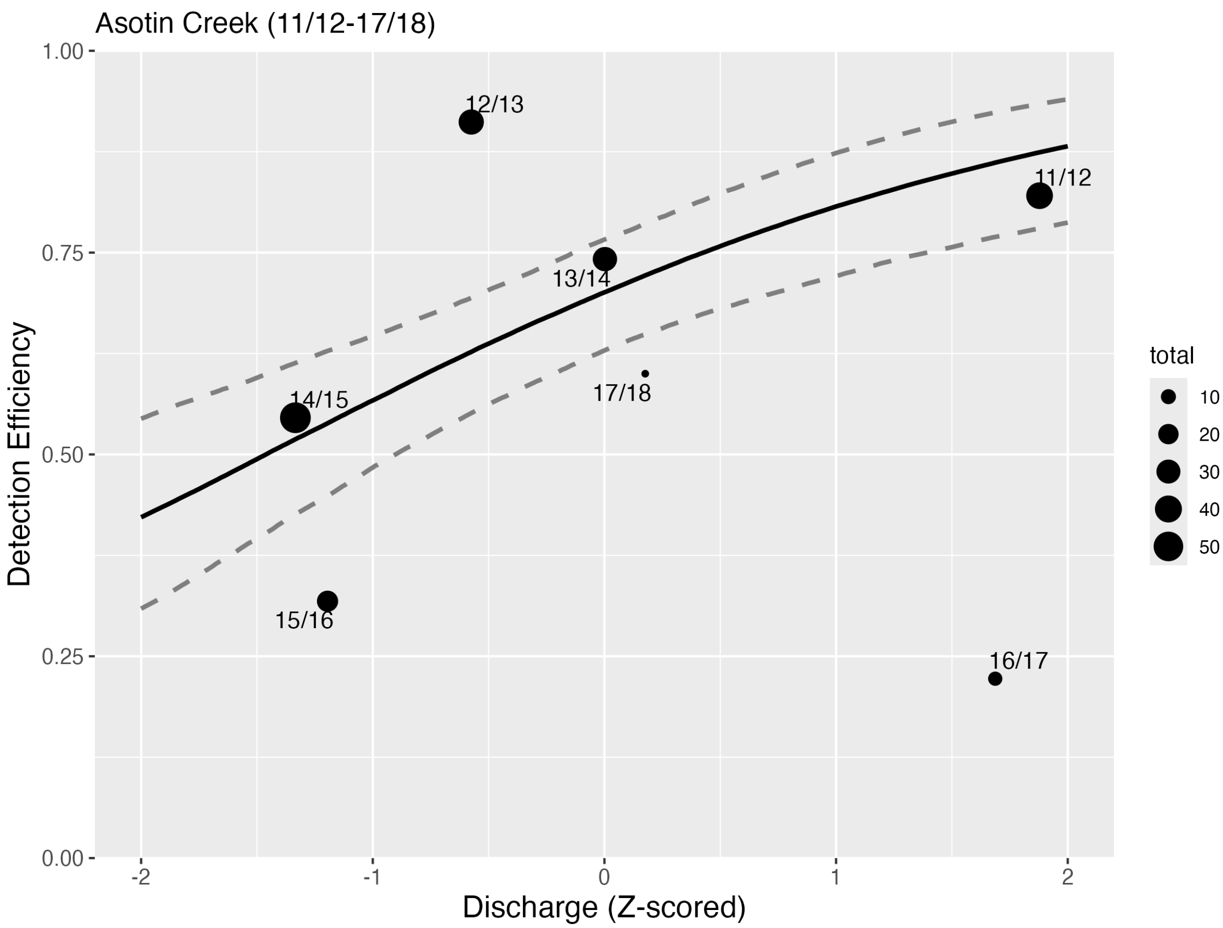


Figure 18: Asotin Creek, estimated detection efficiency in time period 1.

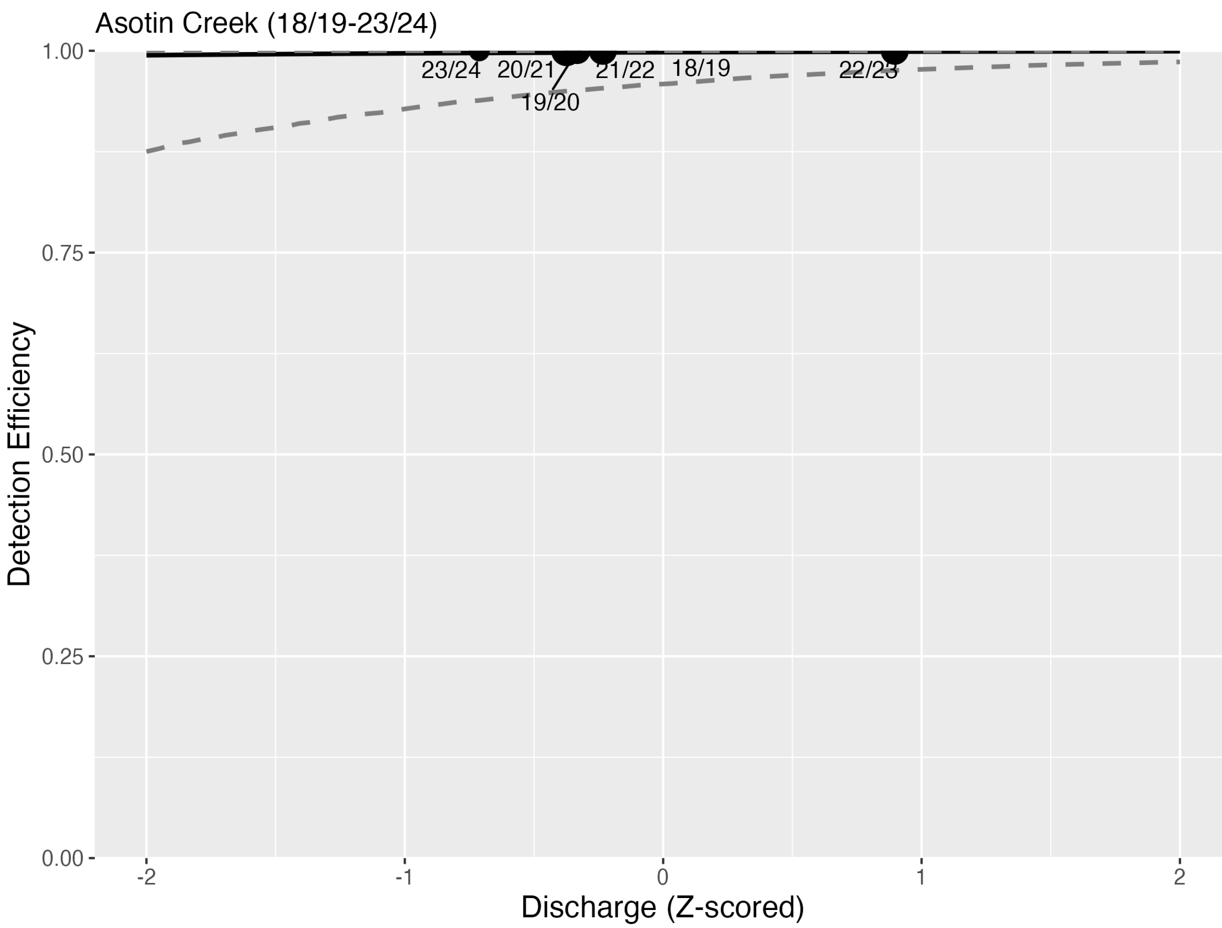


Figure 19: Asotin Creek, estimated detection efficiency in time period 2.

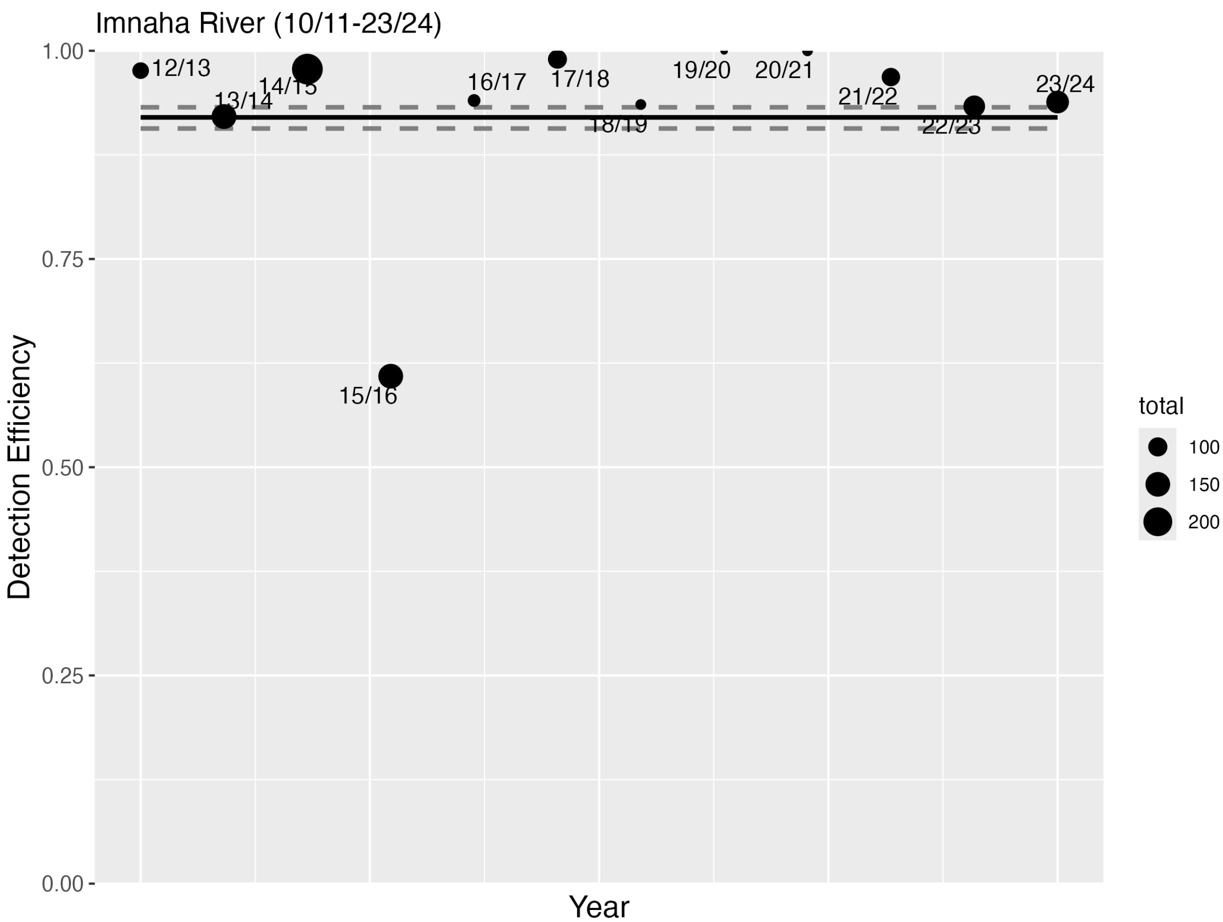


Figure 20: Imnaha River, estimated detection efficiency.

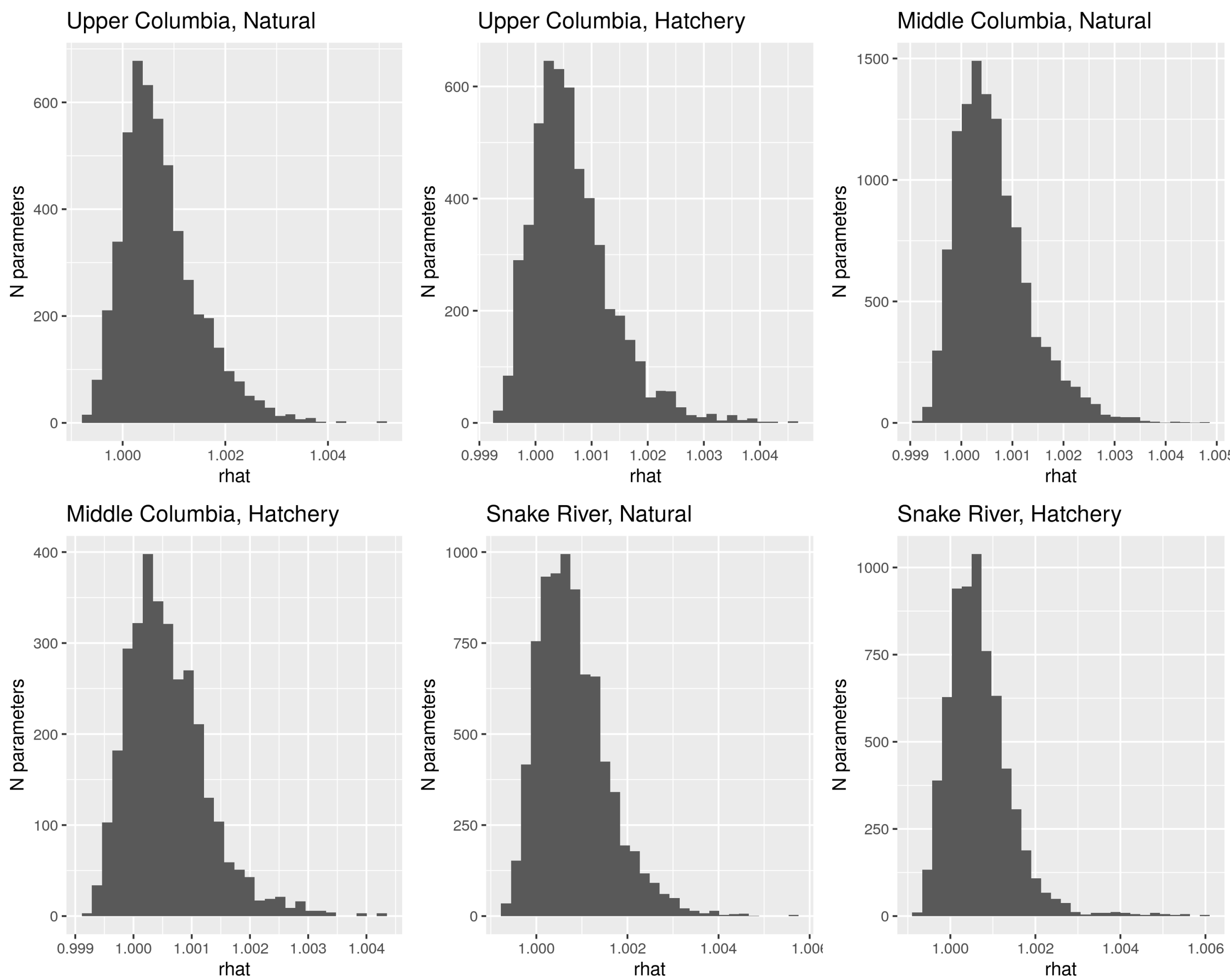


Figure 21: The R-hat convergence diagnostic for each of the six models run. The R-hat convergence diagnostic compares the between- and within-chain estimates for model parameters and other univariate quantities of interest. If chains have not mixed well (i.e., the between- and within-chain estimates don't agree), R-hat is larger than 1. We recommend running at least four chains by default and only using the sample if R-hat is less than 1.05. Stan reports R-hat which is the maximum of rank normalized split-R-hat and rank normalized folded-split-R-hat, which works for thick tailed distributions and is sensitive also to differences in scale.

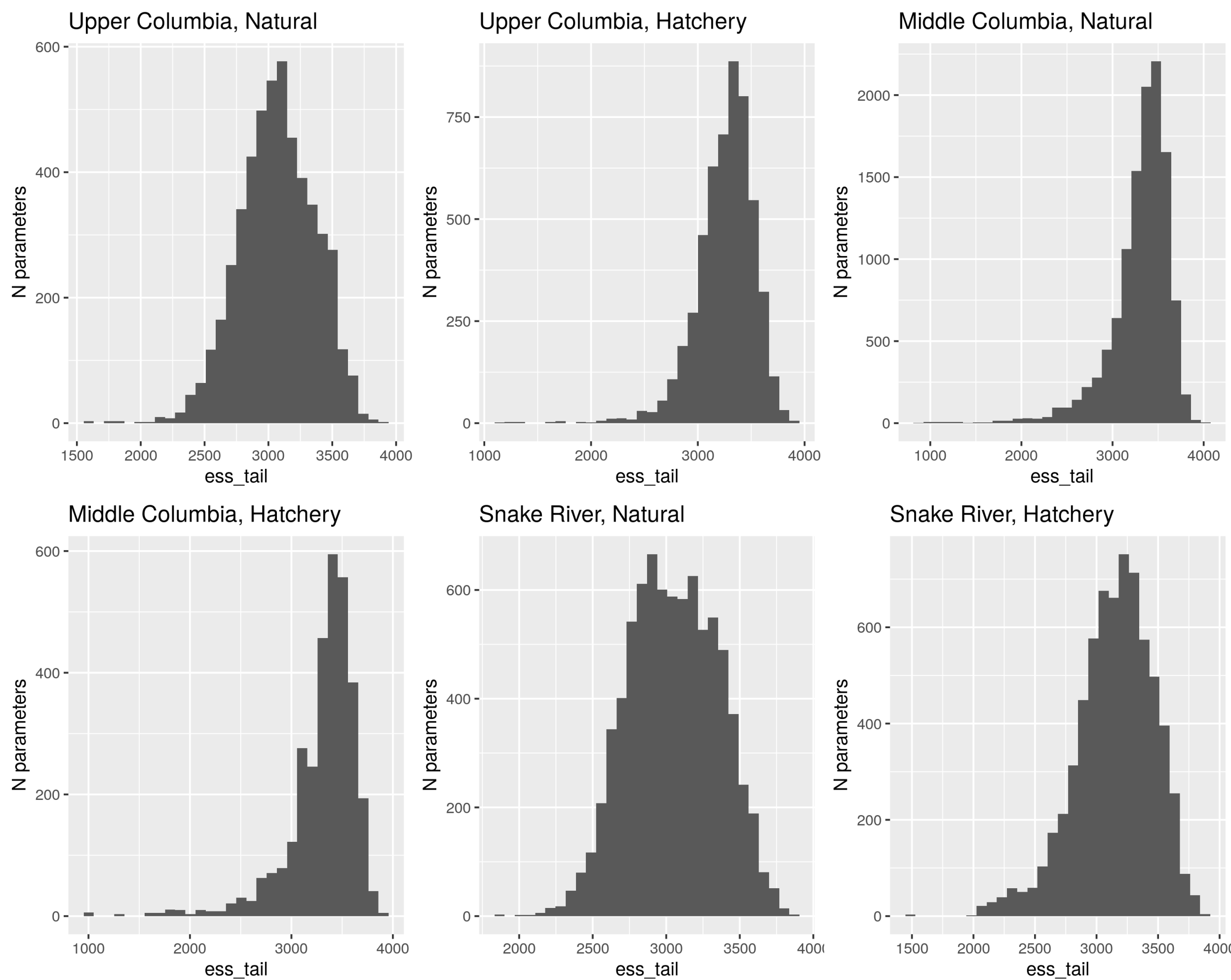


Figure 22: Bulk Effective Sample Size (bulk-ESS) using rank normalized draws, for each of the six models run. Bulk-ESS is useful measure for sampling efficiency in the bulk of the distribution (related to efficiency of mean and median estimates), and is well defined even if the chains do not have finite mean or variance. Both bulk-ESS and tail-ESS should be at least 100 (approximately) per Markov Chain in order to be reliable and indicate that estimates of respective posterior quantiles are reliable.

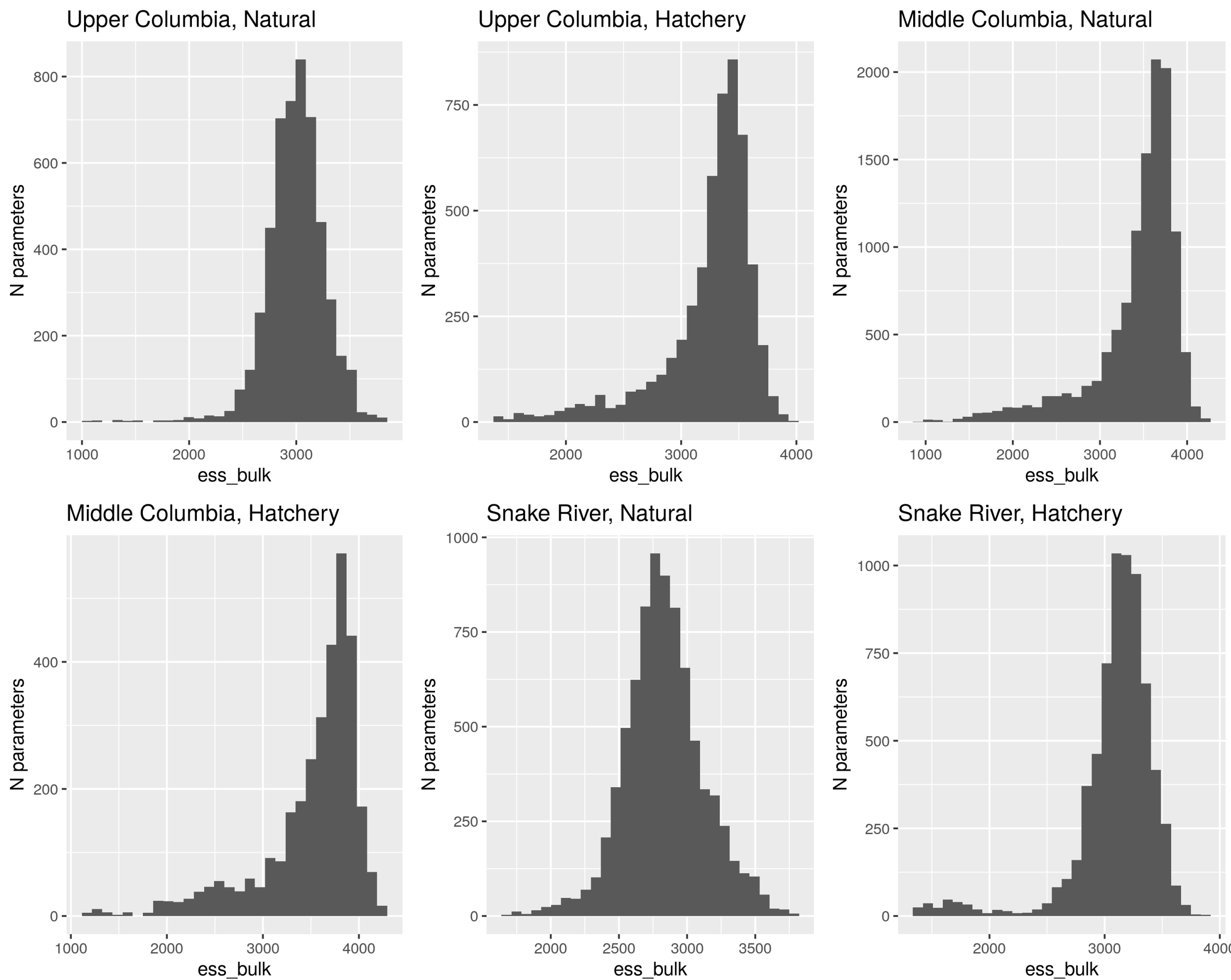


Figure 23: Tail Effective Sample Size (tail-ESS) using rank normalized draws, for each of the six models run. Tail-ESS is produces by computing the minimum of effective sample sizes for 5% and 95% quantiles. Tail-ESS is useful measure for sampling efficiency in the tails of the distribution (related to efficiency of variance and tail quantile estimates). Both bulk-ESS and tail-ESS should be at least 100 (approximately) per Markov Chain in order to be reliable and indicate that estimates of respective posterior quantiles are reliable.

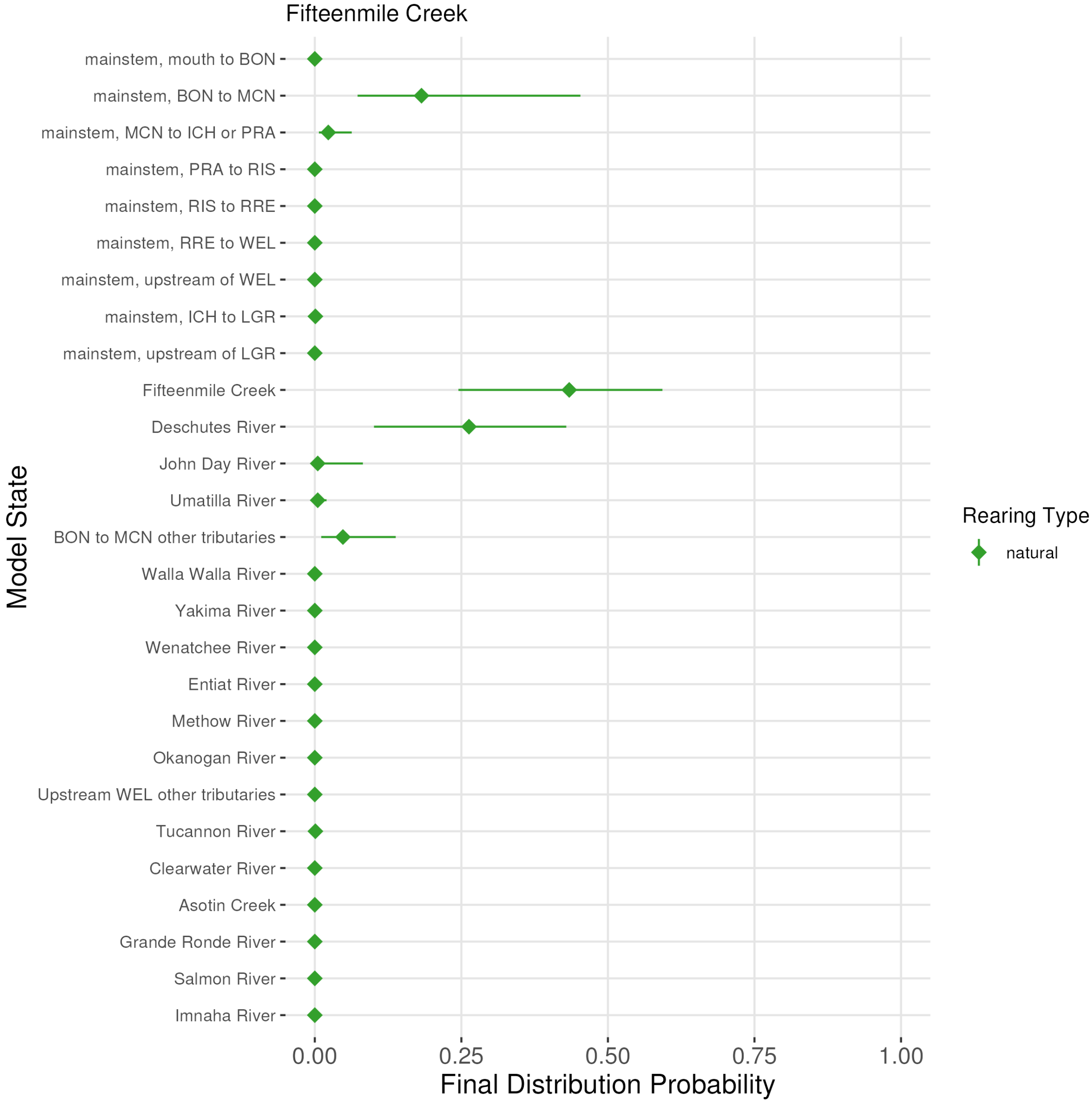


Figure 24: Fifteenmile Creek, estimated final fates under median conditions from 2005-2024.

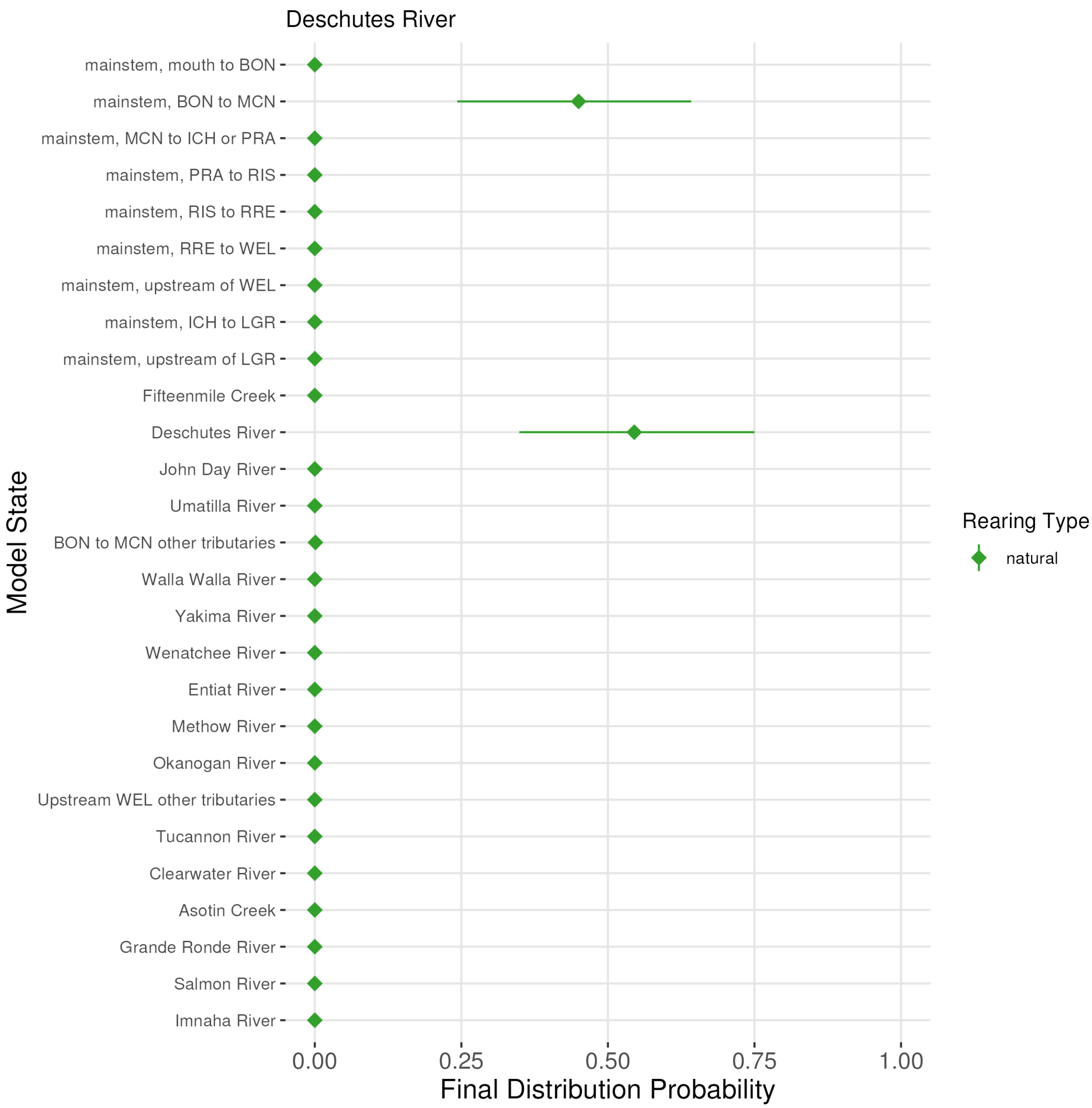


Figure 25: Deschutes River, estimated final fates under median conditions from 2005-2024.

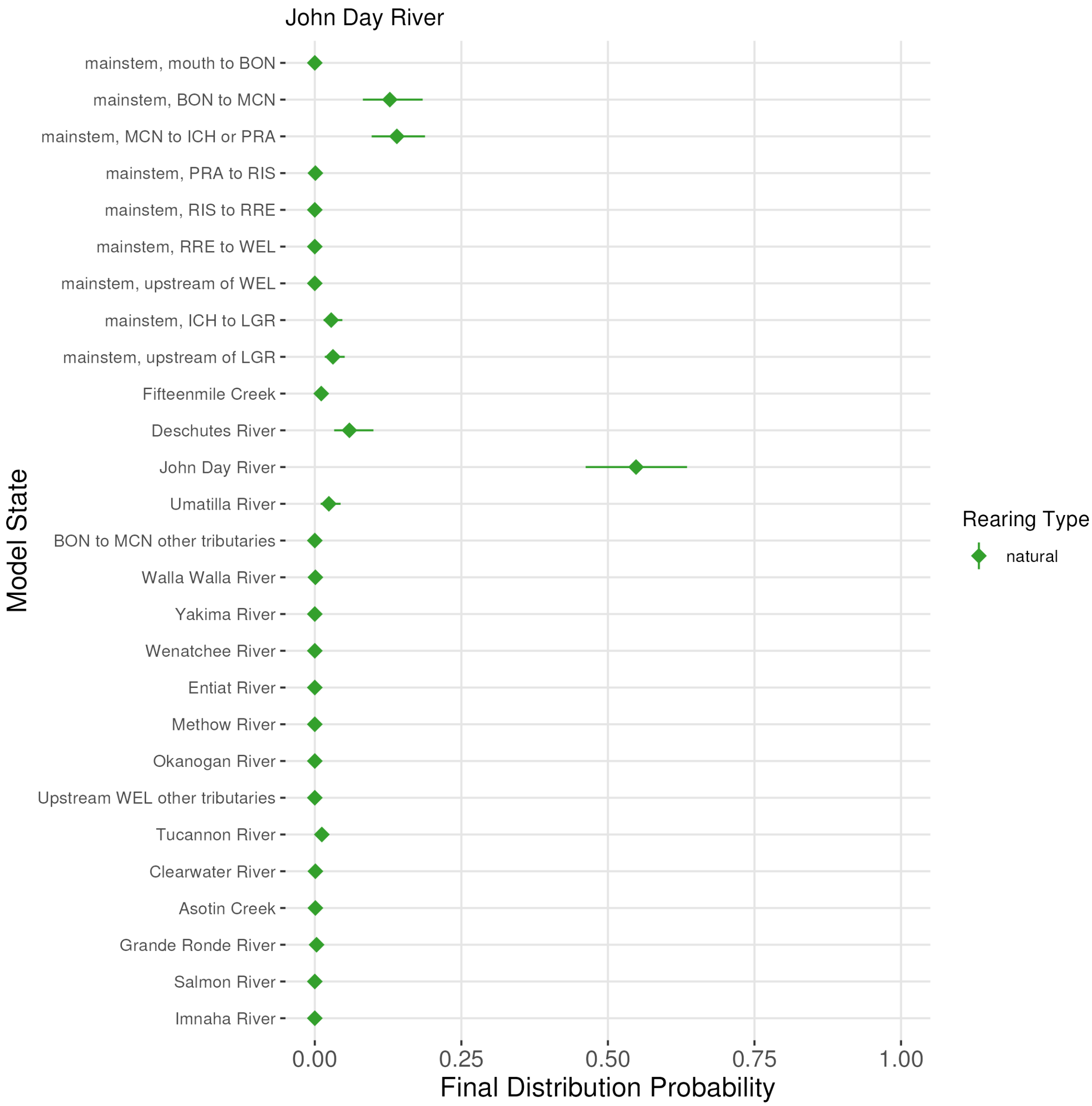


Figure 26: John Day River, estimated final fates under median conditions from 2005-2024.

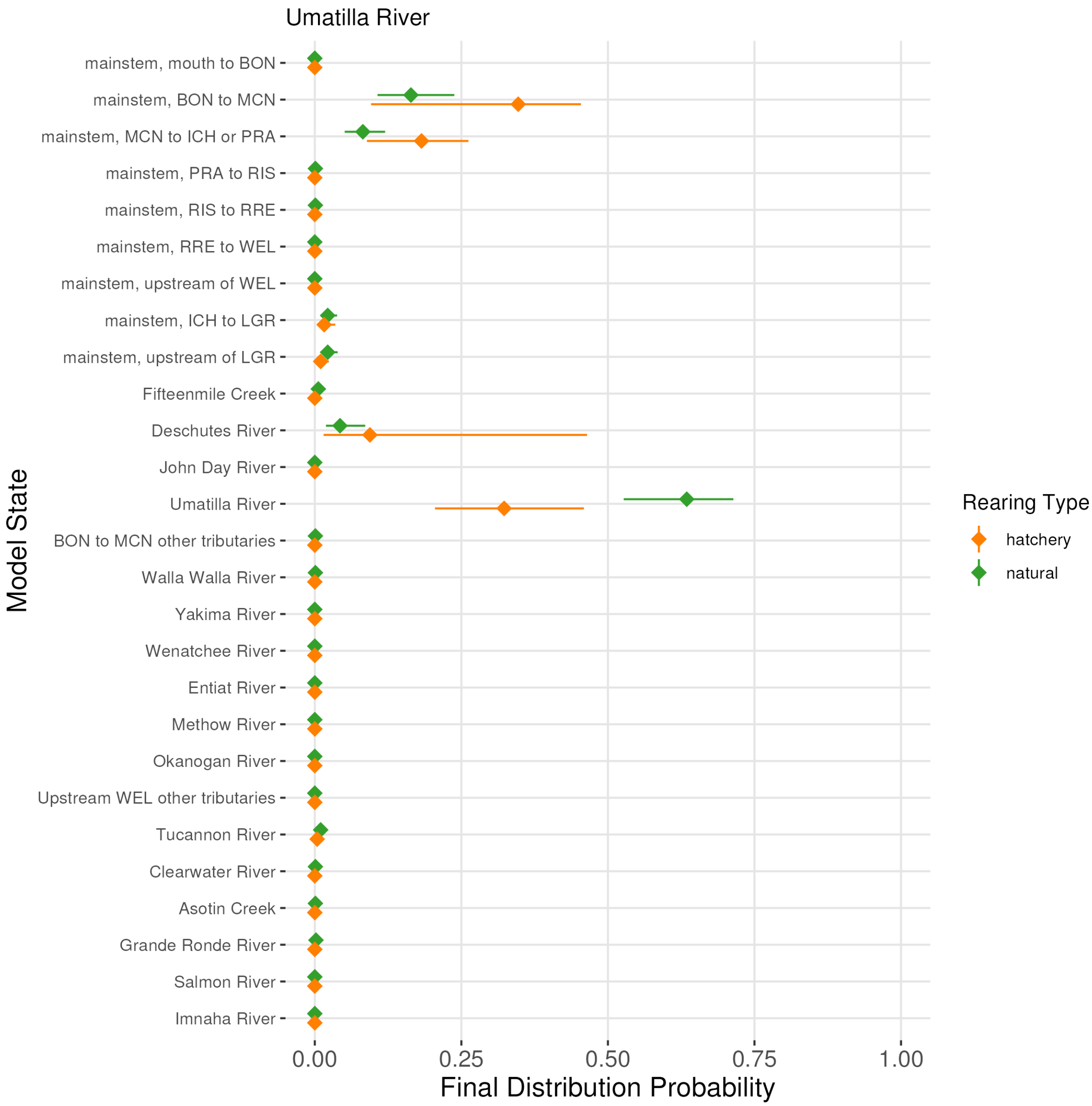


Figure 27: Umatilla River, estimated final fates under median conditions from 2005-2024.

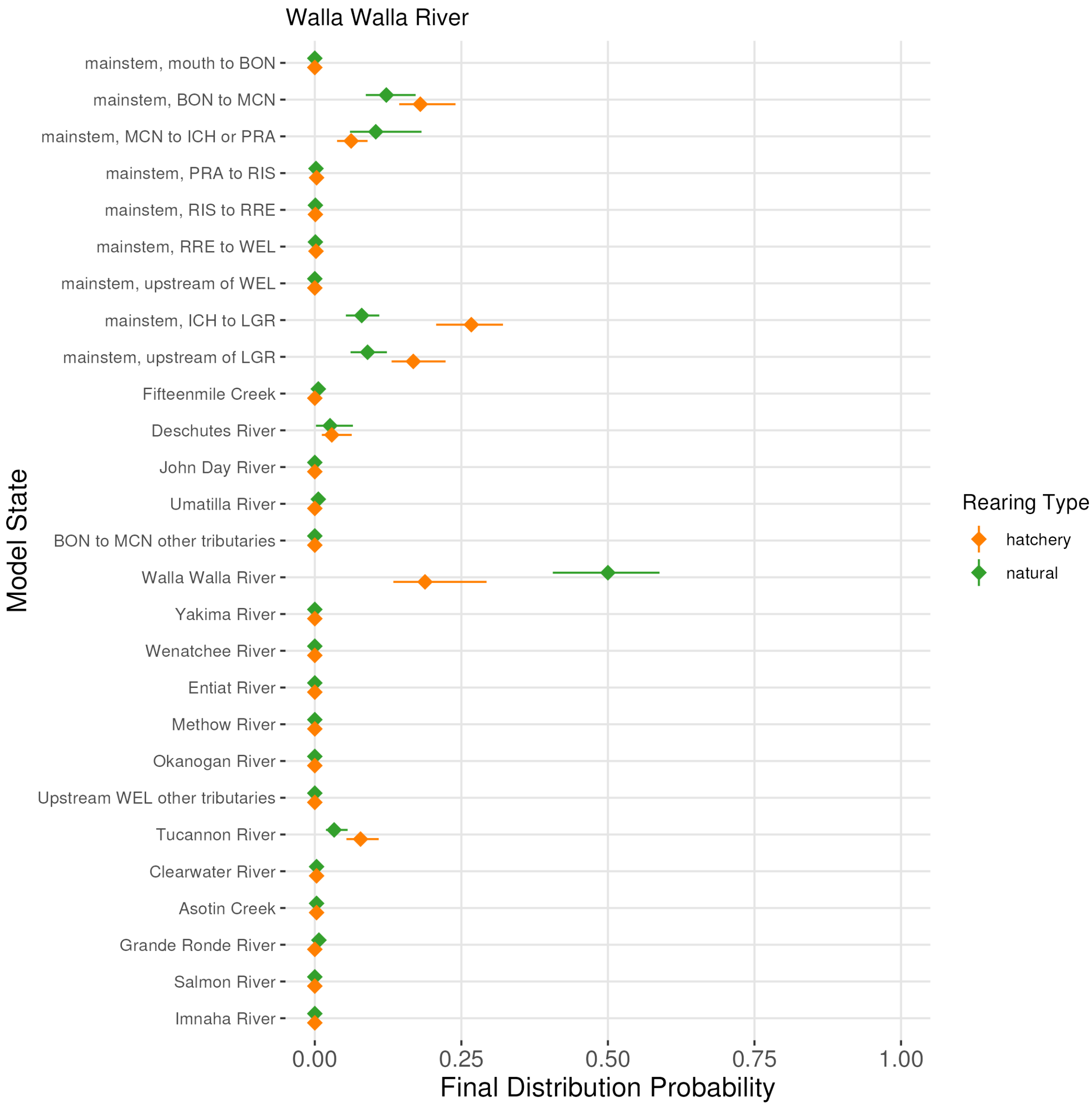


Figure 28: Walla Walla River, estimated final fates under median conditions from 2005-2024.

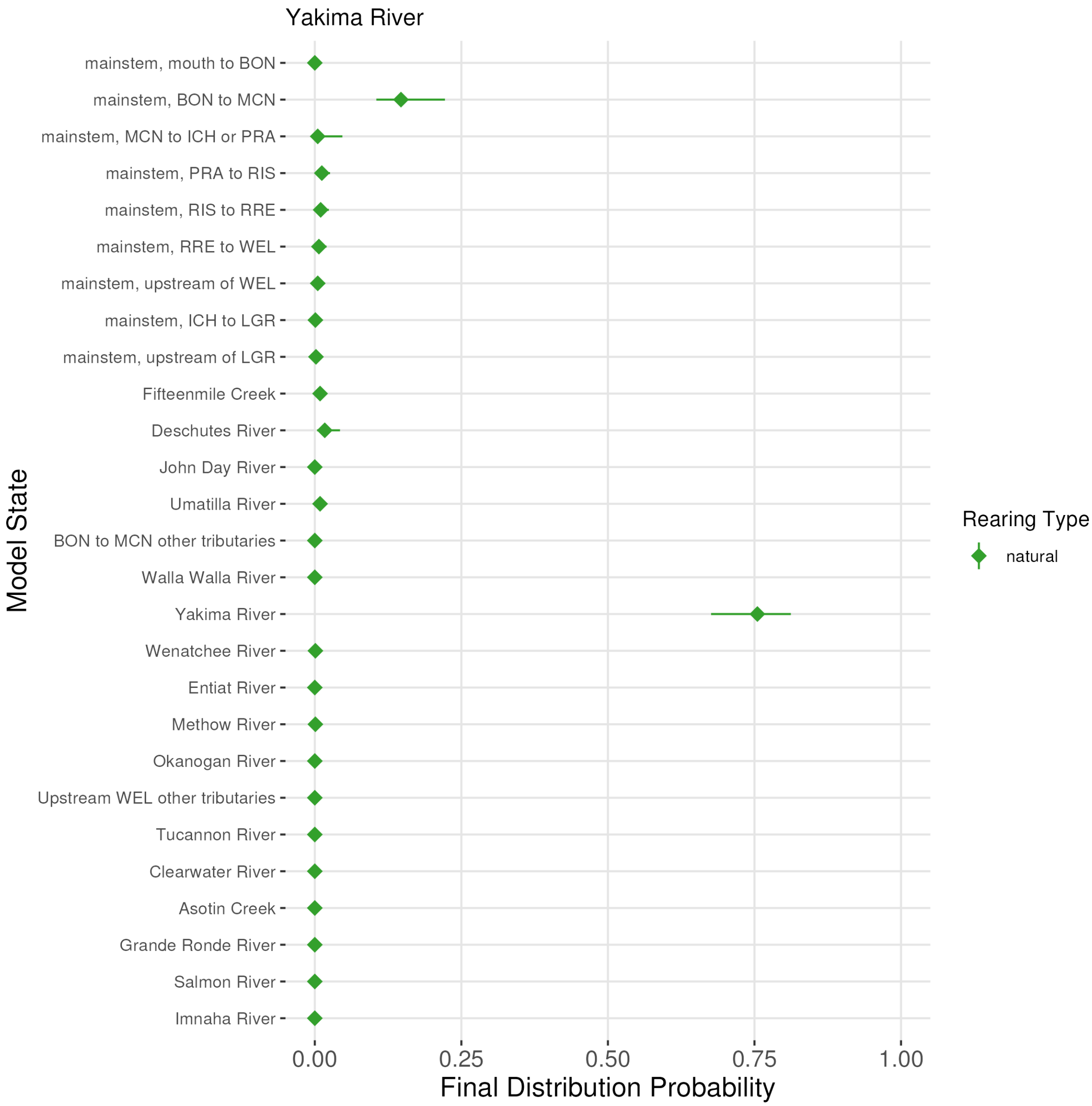


Figure 29: Yakima River, estimated final fates under median conditions from 2005-2024.

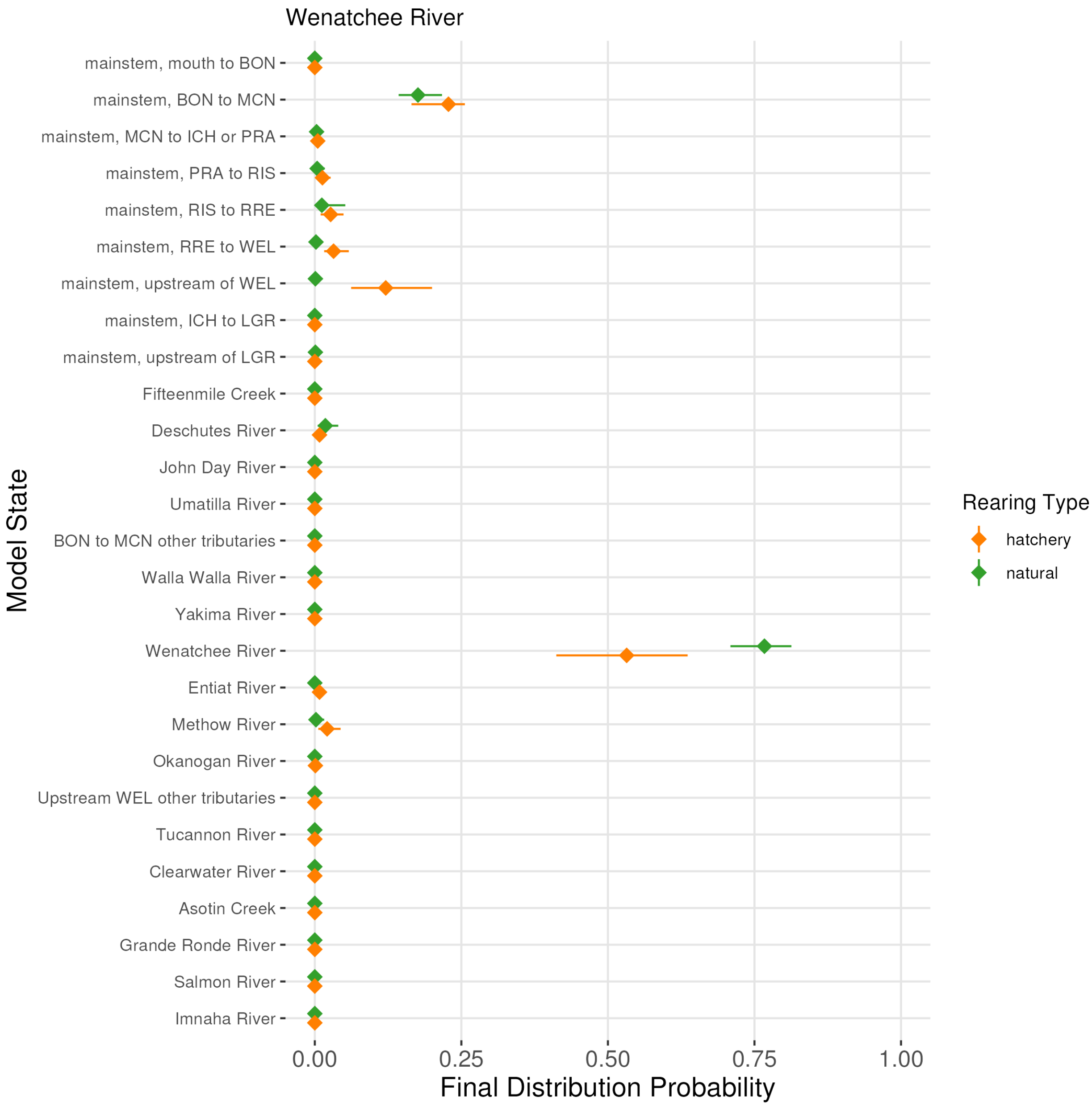


Figure 30: Wenatchee River, estimated final fates under median conditions from 2005-2024.

Wenatchee River

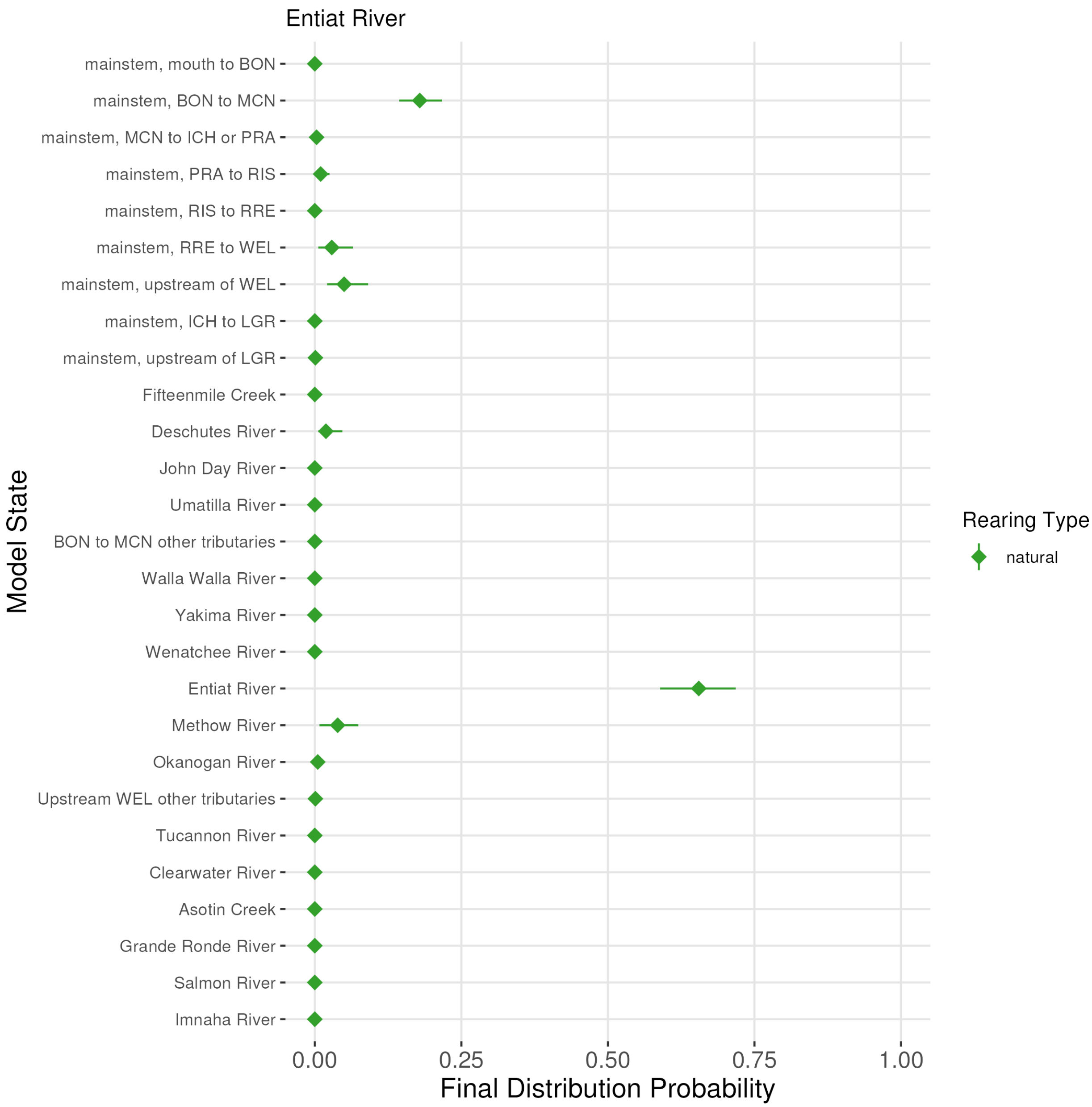


Figure 31: Entiat River, estimated final fates under median conditions from 2005-2024.

Entiat River

Methow River

Okanogan River

Tucannon River

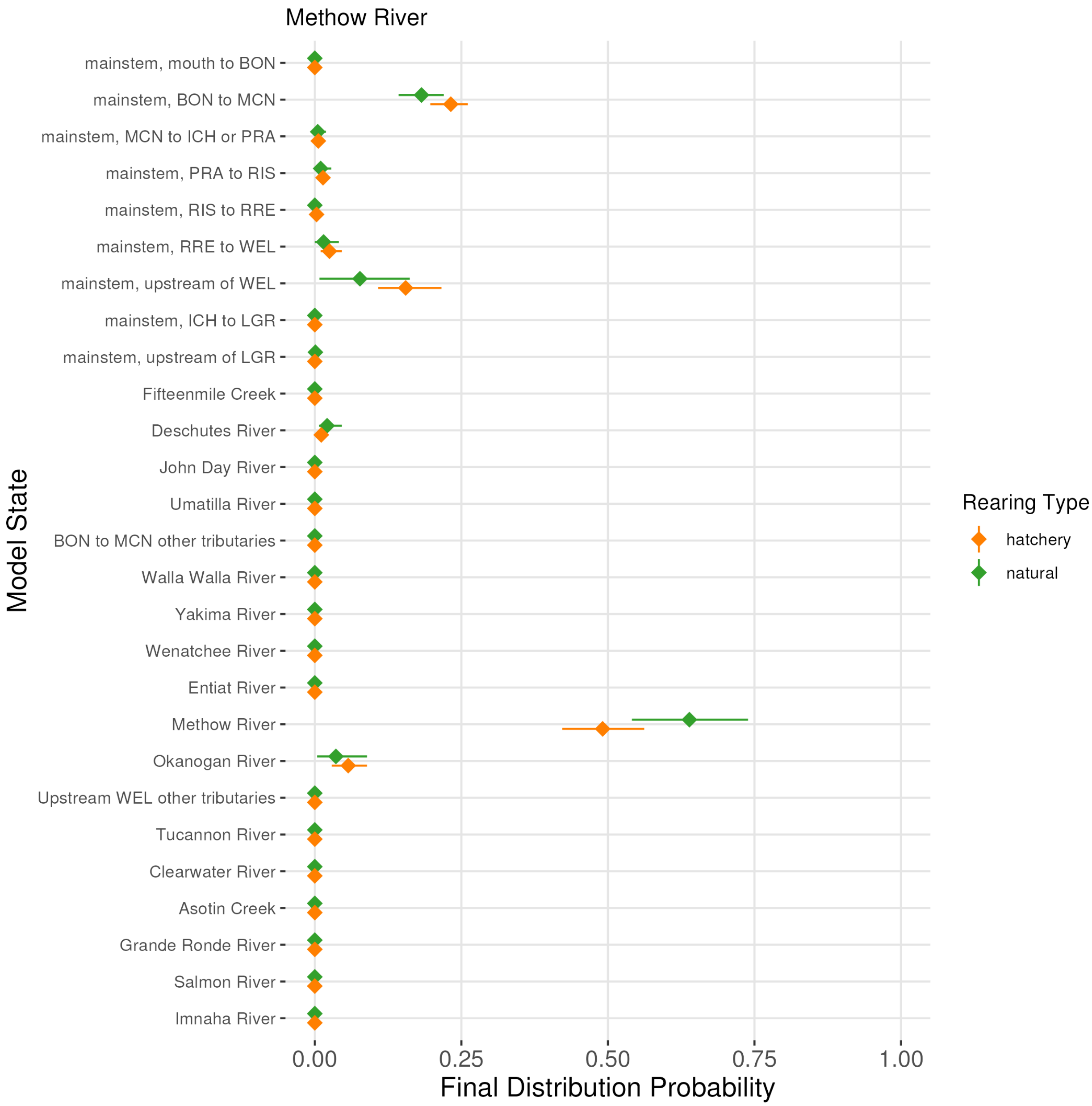


Figure 32: Methow River, estimated final fates under median conditions from 2005-2024.

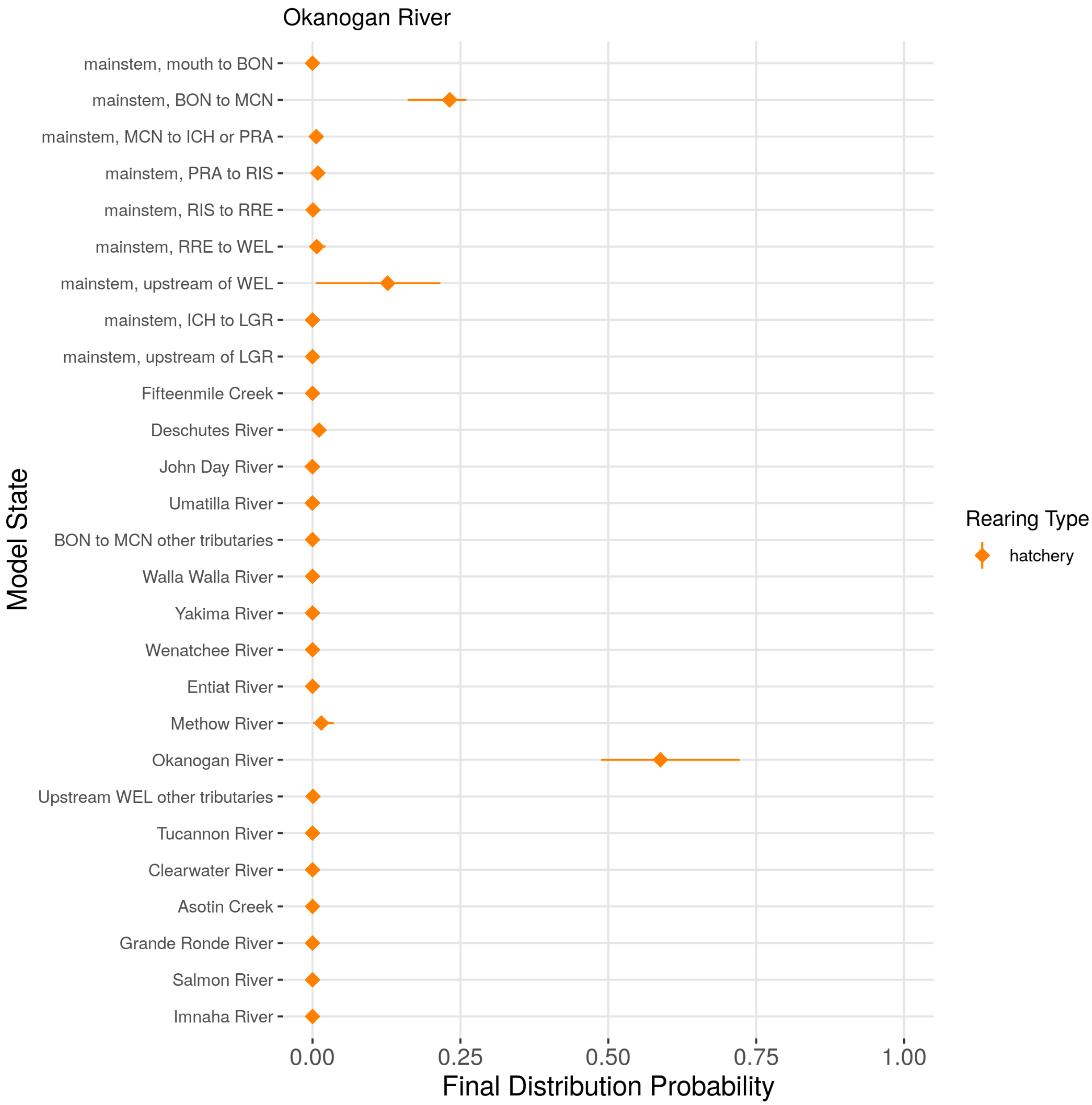


Figure 33: Okanogan River, estimated final fates under median conditions from 2005-2024.

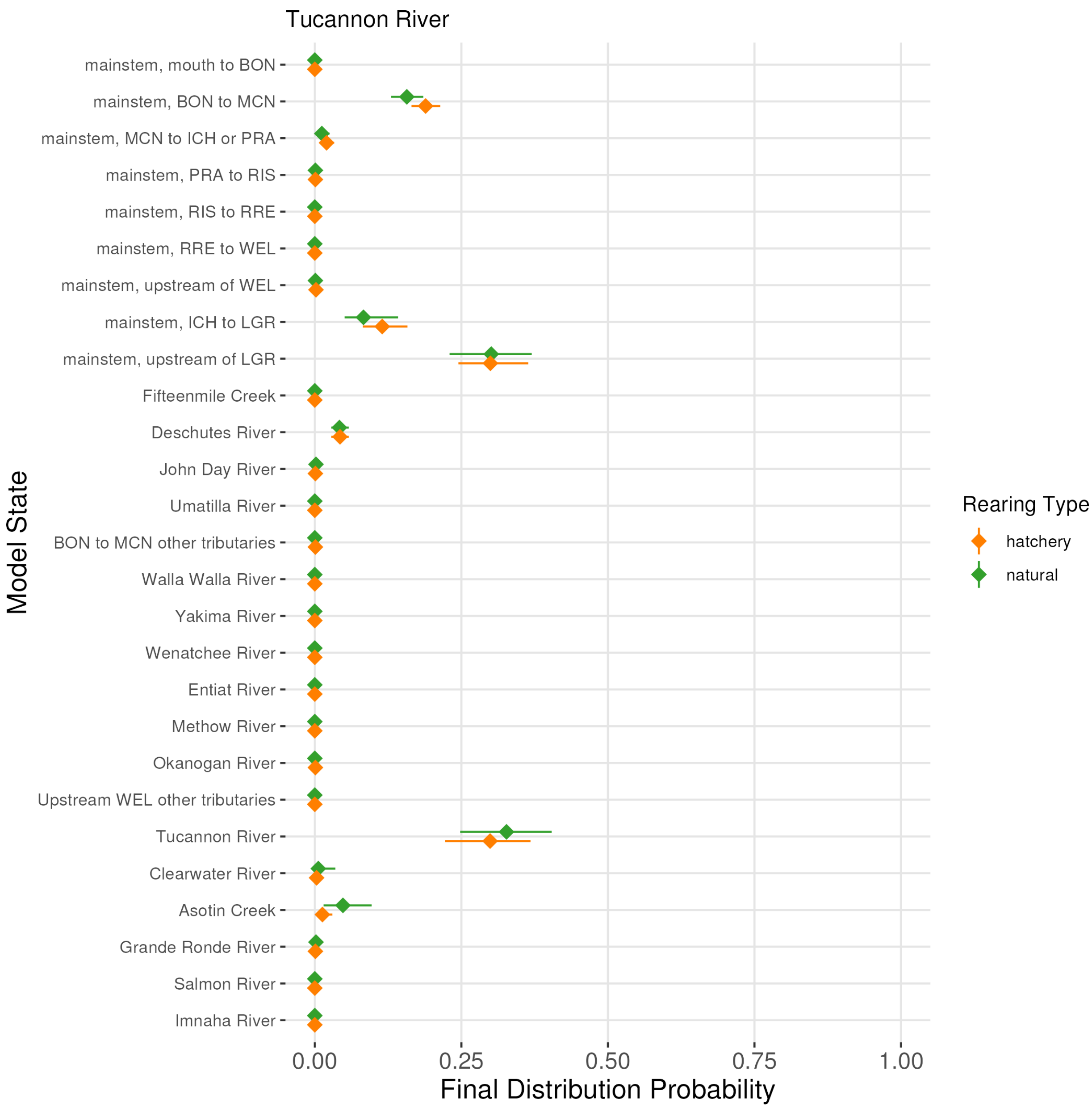


Figure 34: Tucannon River, estimated final fates under median conditions from 2005-2024.

Clearwater River NOTE: Detection efficiency could not be estimated for the Clearwater River, because of the lack of a site close to the confluence with the Snake River. Therefore, the estimate of final fate in the Clearwater River is biased low, while the estimate of final fate in the mainstem state that connects to the Clearwater river (mainstem, upstream of LGR) is biased high.

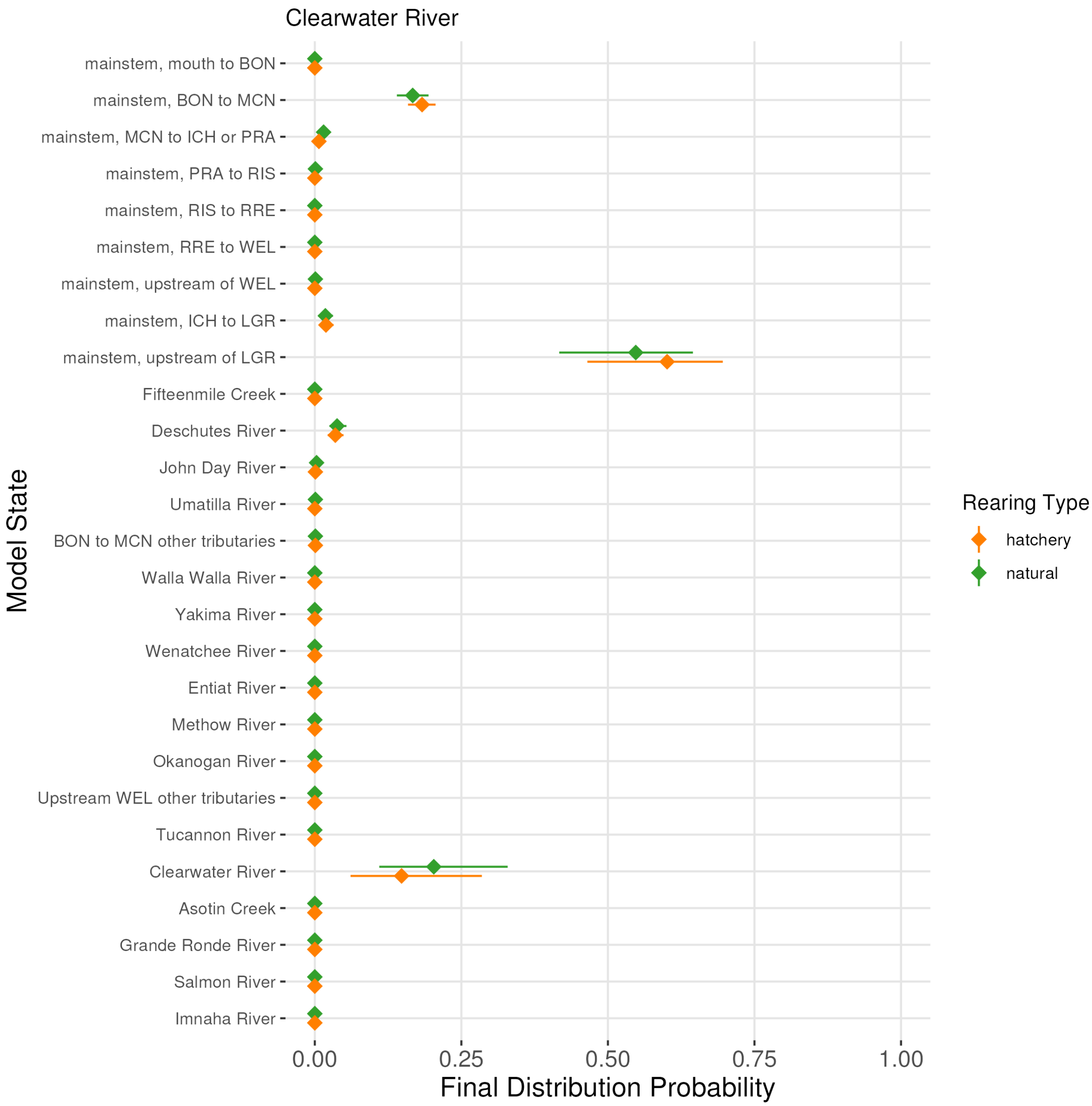


Figure 35: Clearwater River, estimated final fates under median conditions from 2005-2024.

Asotin Creek

Grande Ronde River NOTE: Detection efficiency could not be estimated for the Clearwater River, because of the lack of a site close to the confluence with the Snake River. Therefore, the estimate of final fate in the Clearwater River is biased low, while the estimate of final fate in the mainstem state that connects to the Clearwater river (mainstem, upstream of LGR) is biased high.

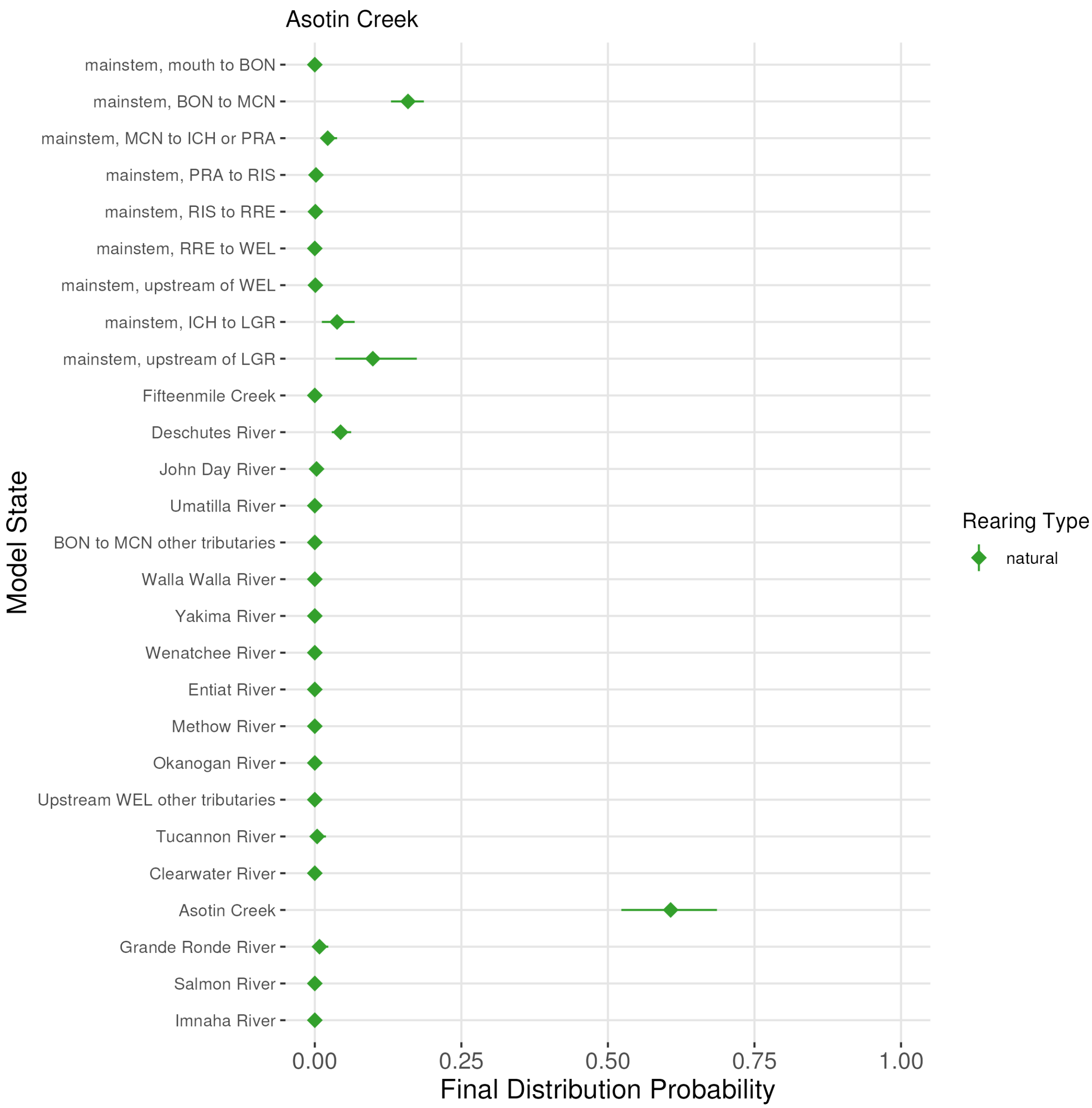


Figure 36: Asotin Creek, estimated final fates under median conditions from 2005-2024.

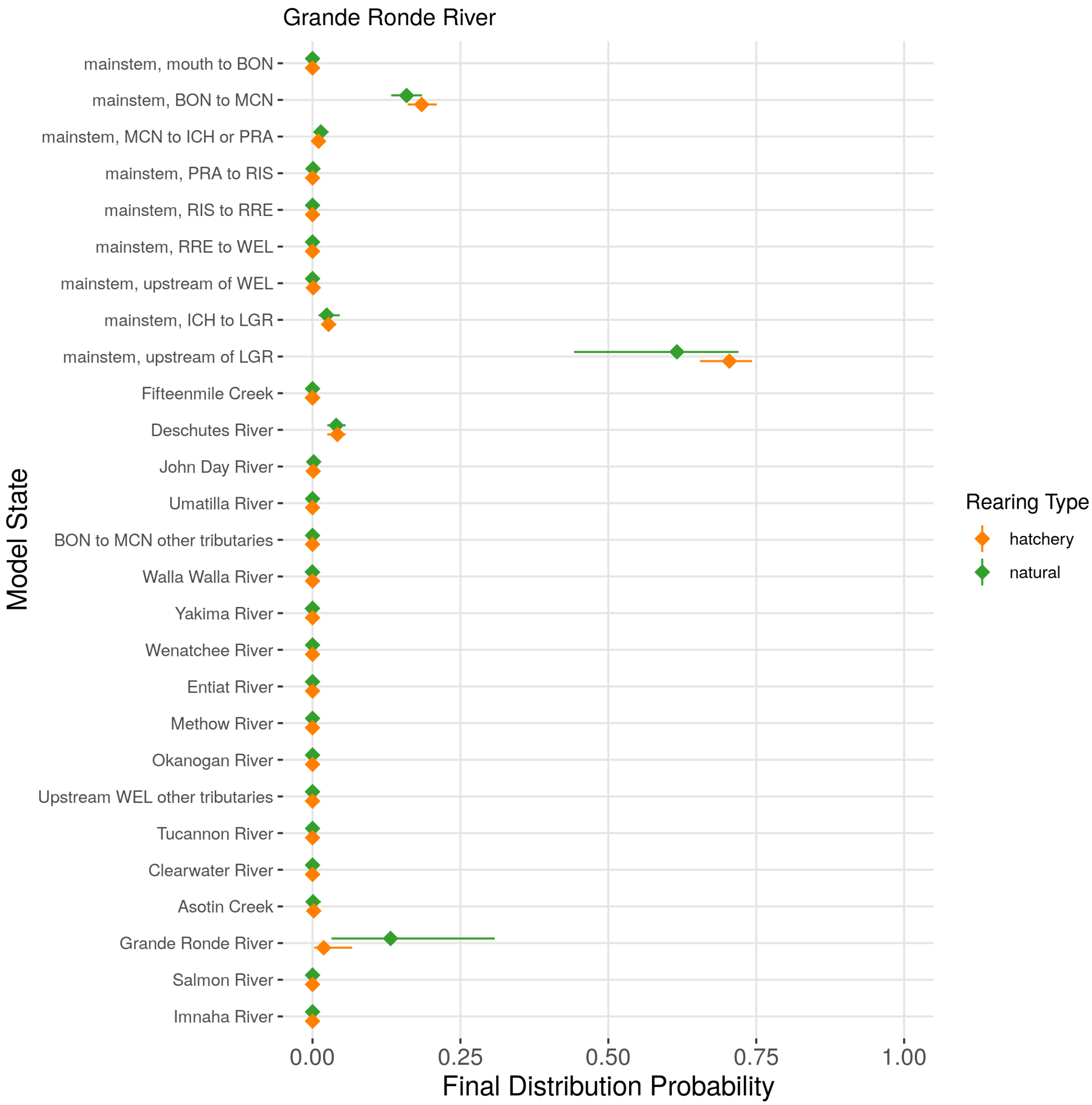


Figure 37: Grande Ronde River, estimated final fates under median conditions from 2005-2024.

Salmon River NOTE: Detection efficiency could not be estimated for the Clearwater River, because of the lack of a site close to the confluence with the Snake River. Therefore, the estimate of final fate in the Clearwater River is biased low, while the estimate of final fate in the mainstem state that connects to the Clearwater river (mainstem, upstream of LGR) is biased high.

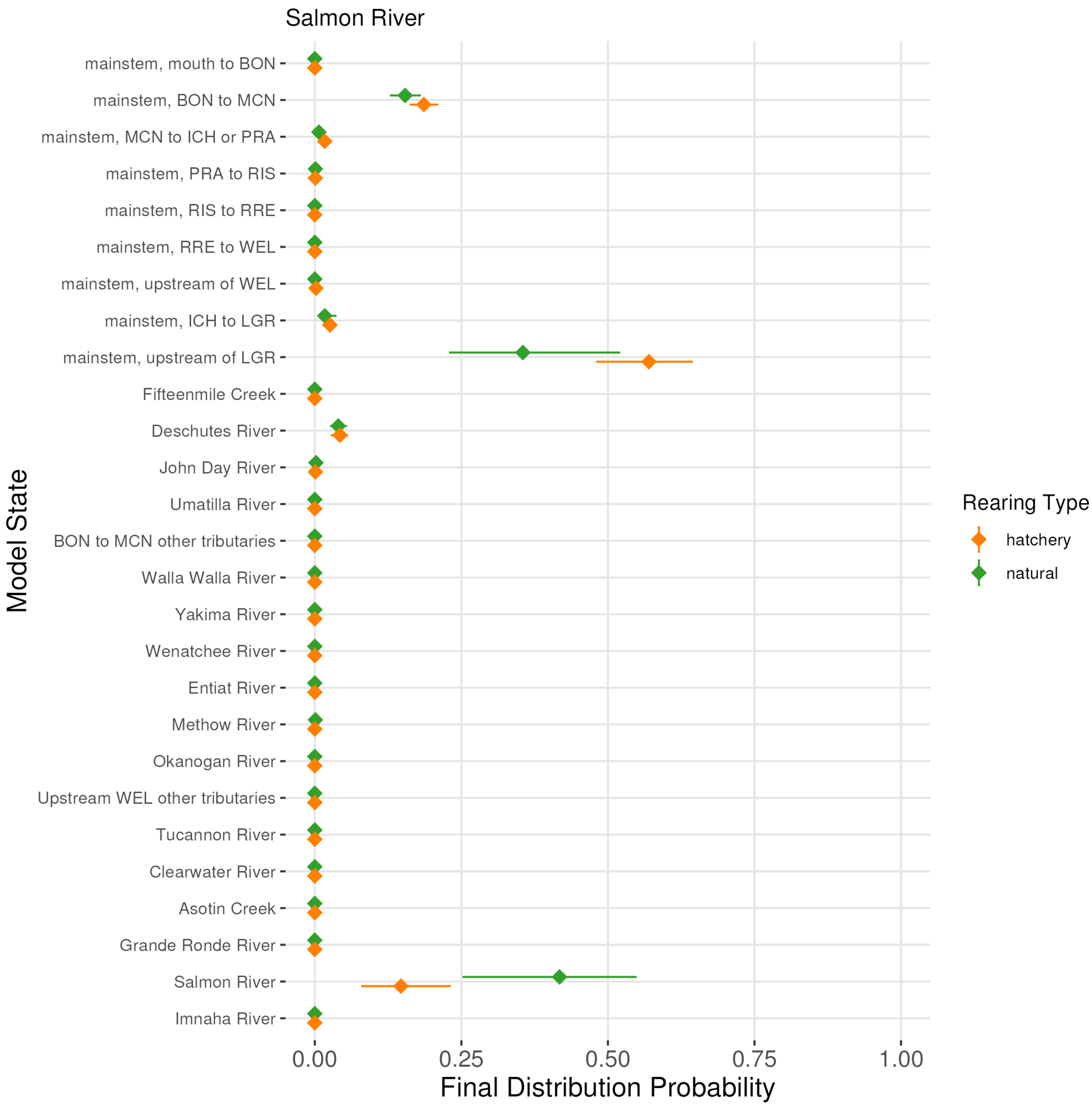


Figure 38: Salmon River, estimated final fates under median conditions from 2005-2024.

Imnaha River

7 Deschutes River movement

8 En-route fallback as a function of spill volume

Bonneville Dam

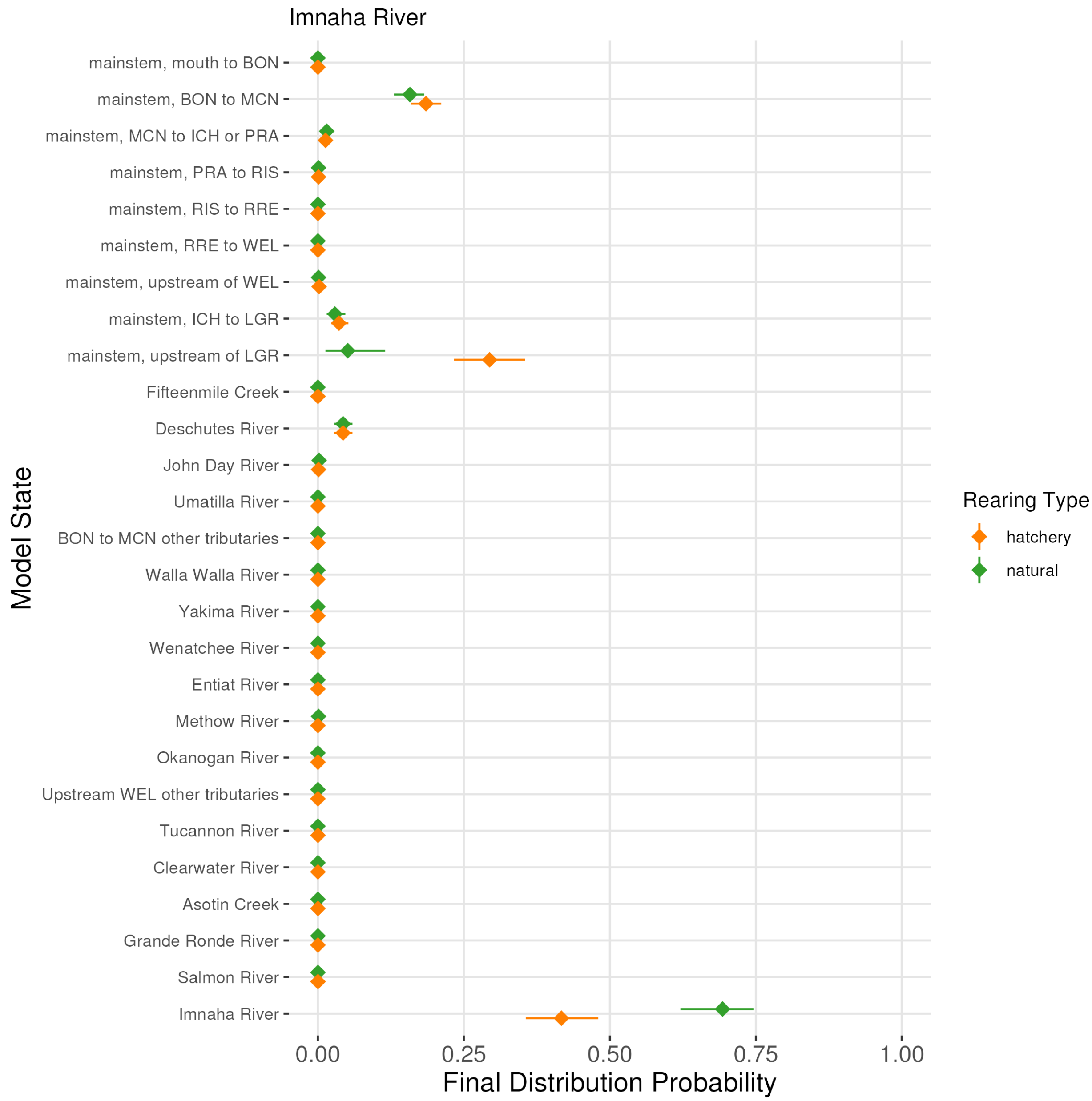


Figure 39: Imnaha River, estimated final fates under median conditions from 2005-2024.

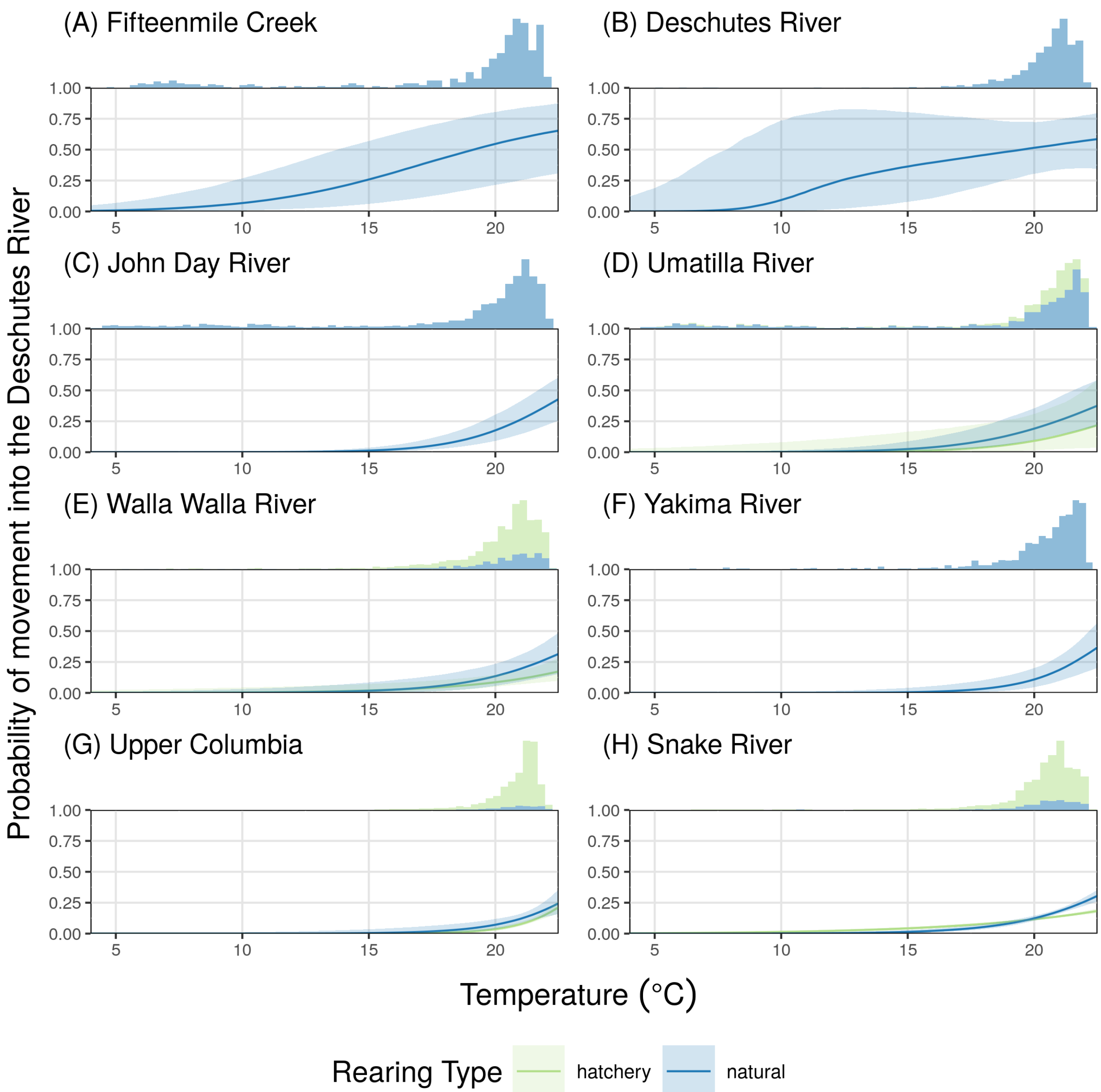


Figure 40: Probability of movement into the Deschutes River by temperature, conditional on being in the reach of the mainstem Columbia between Bonneville and McNary Dam. Histograms on the plot margins indicate the temperature experiences of individual fish. Because this movement occurs within the Middle Columbia DPS, those populations have separate probabilities of movement, and are shown in panels A-F, while fish from the Upper Columbia DPS and the Snake River DPS have shared movement probabilities for this movement and are shown in panels G and H.

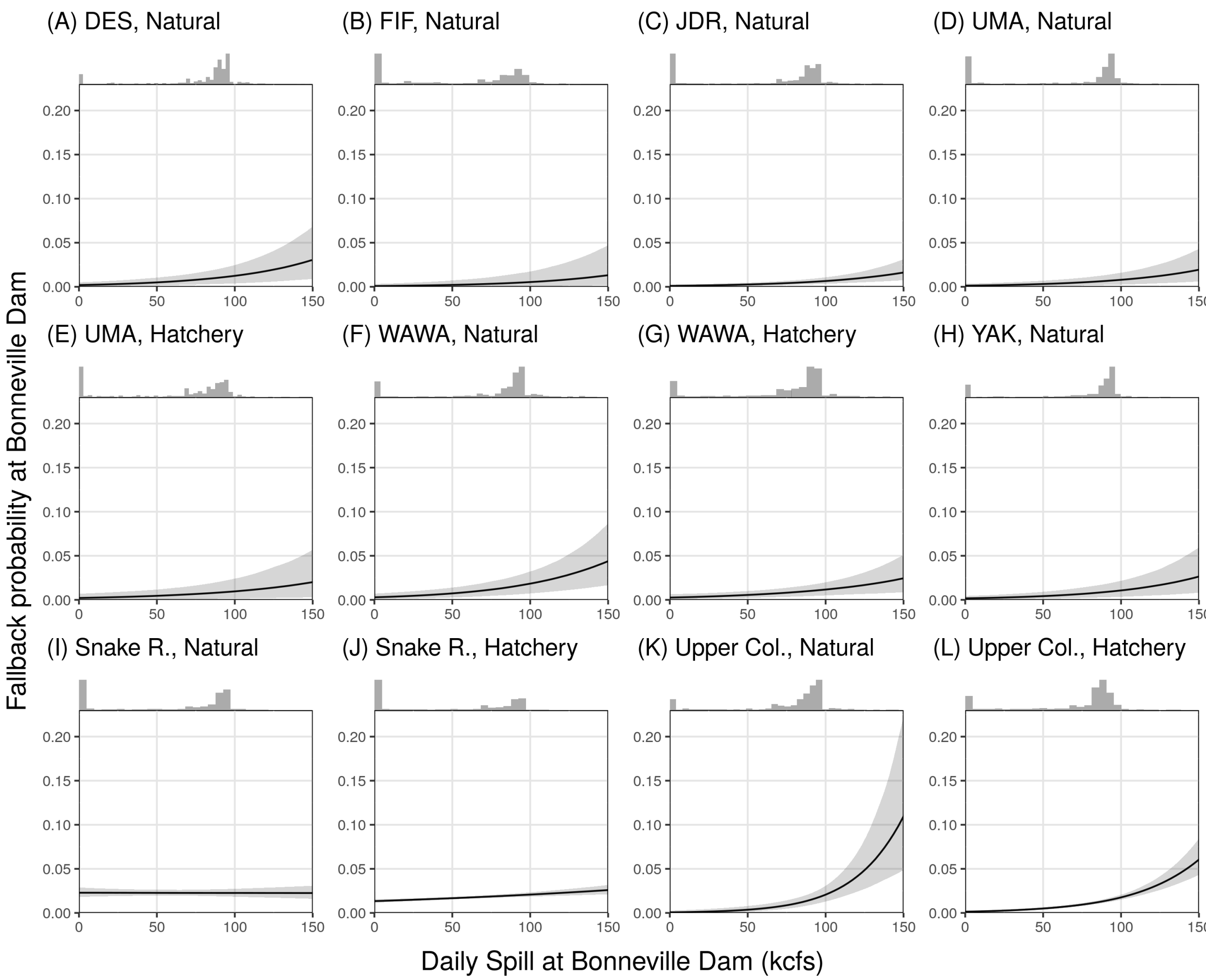


Figure 41: Probability of fallback at Bonneville Dam, by volume of spill. Because this movement occurs within the Middle Columbia DPS, those populations have separate probabilities of movement, and are shown in panels A-H, while fish from the Upper Columbia DPS and the Snake River DPS have shared movement probabilities for this movement and are shown in panels I-L. Histograms on the plot margins indicate the spill experiences of individual fish.

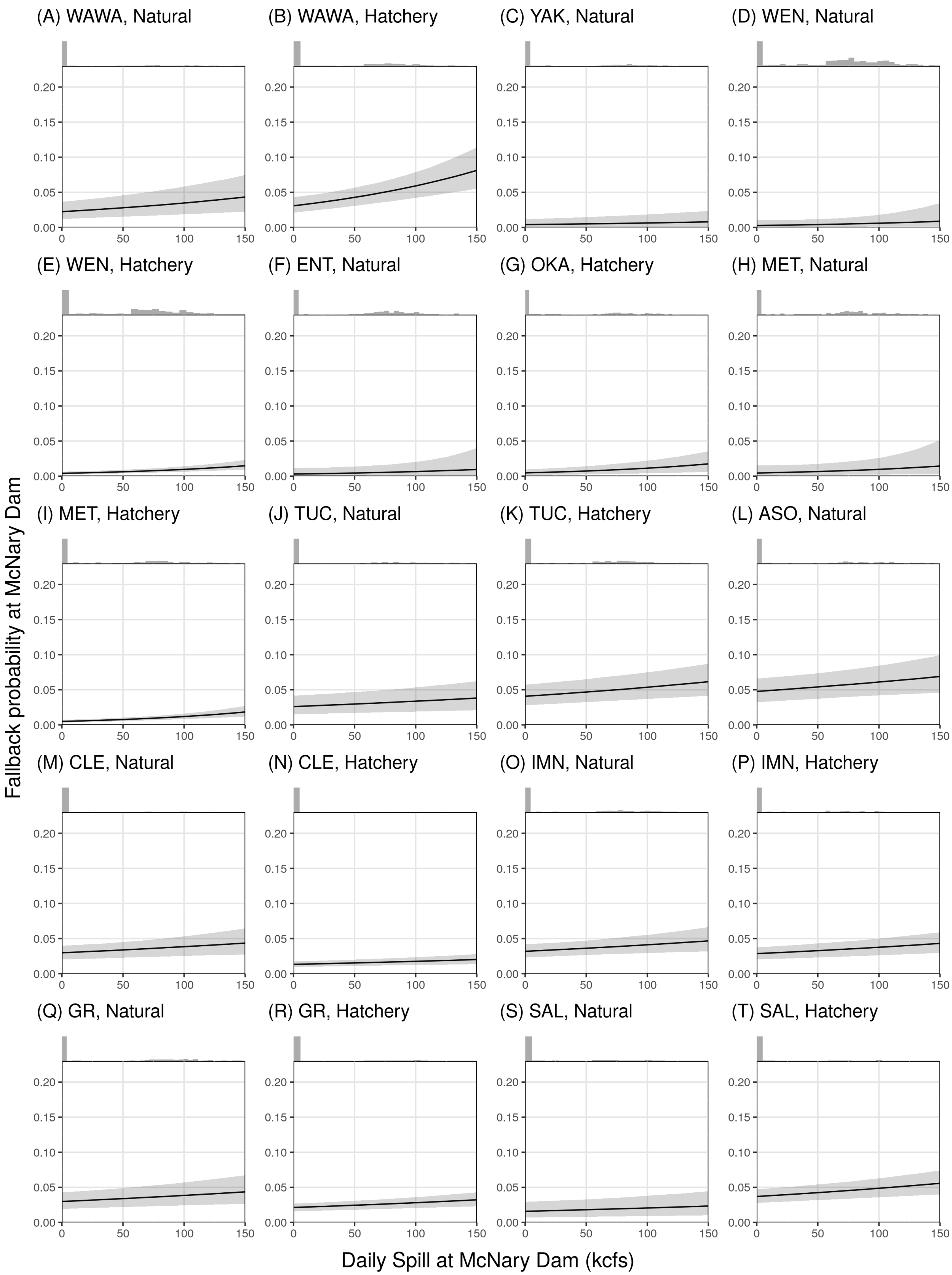


Figure 42: Probability of fallback at McNary Dam, by volume of spill. Because this movement at the juncture between the Middle Columbia, Upper Columbia, and Snake River DPS boundaries, every population has a unique probability of movement. All populations that are downstream of McNary Dam (the Fifteenmile Creek, Deschutes River, John Day River, and Umatilla River) are affected by winter spill days rather than spill volume for this movement, as it is a post-overshoot fallback movement. Histograms on the plot margins indicate the spill experiences of individual fish.

McNary Dam

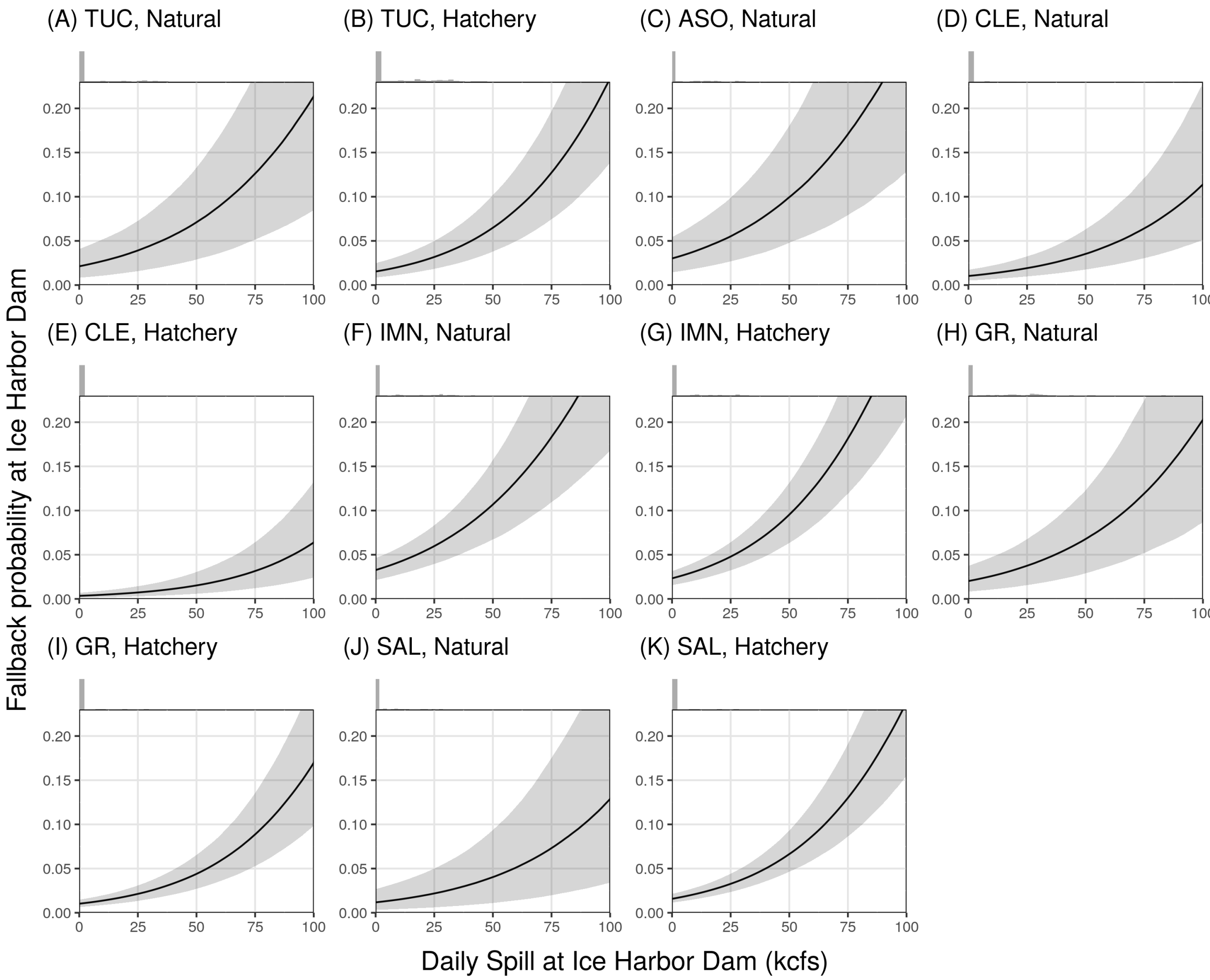


Figure 43: Probability of fallback at Ice Harbor Dam, by volume of spill. Only Snake River populations are shown because an ascent of Ice Harbor Dam by any populations from the Middle or Upper Columbia would be overshoot and therefore the probability of fallback is affected by winter spill days rather than spill volume. Histograms on the plot margins indicate the spill experiences of individual fish.

Ice Harbor Dam

Lower Granite Dam

9 Post-overshoot fallback as a function of March spill

This section presents the results of the same model, but run where only days of spill in March are used as a covariate instead of days of spill in January, February, and March (as is used in the base model).

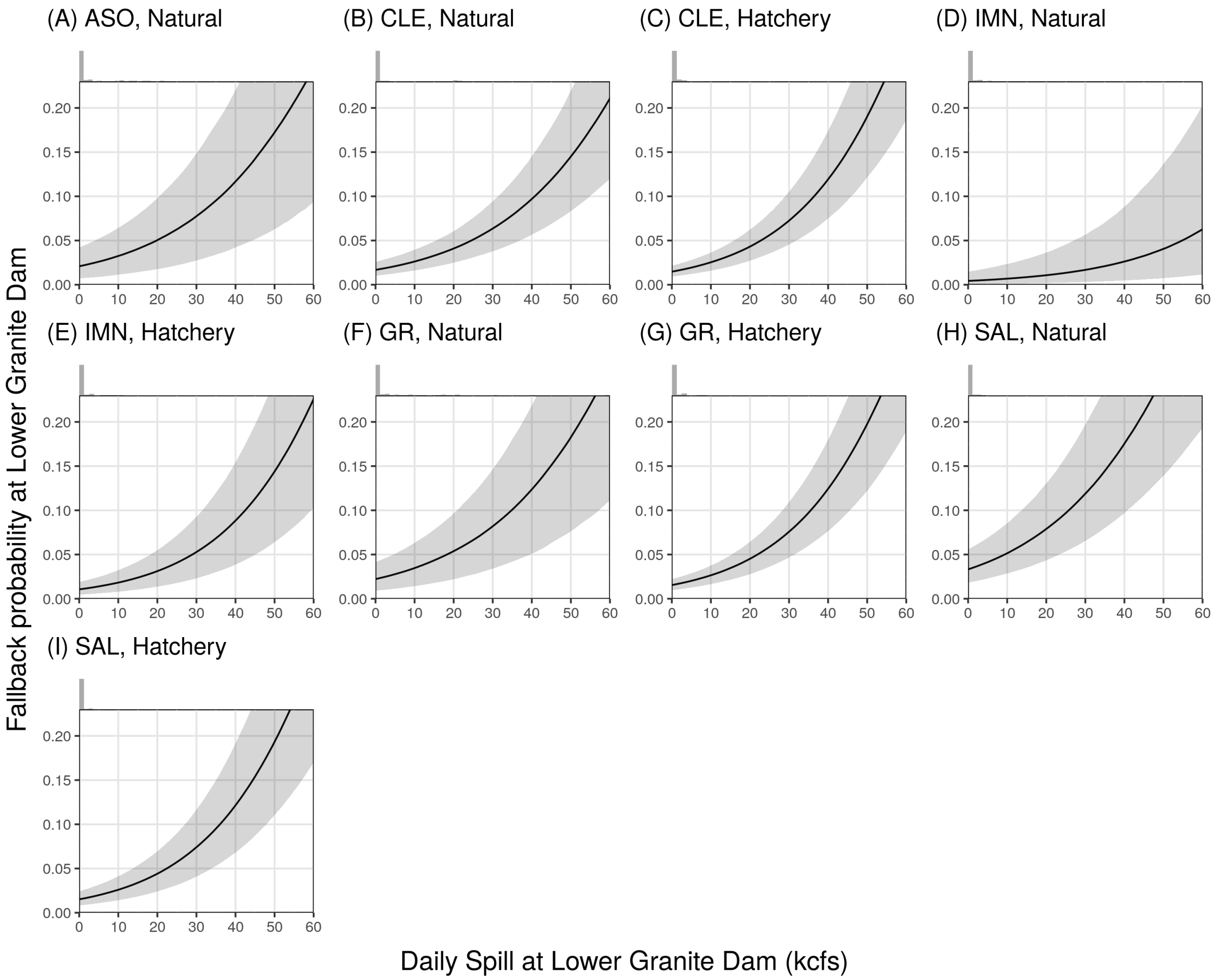


Figure 44: Probability of fallback at Lower Granite Dam, by volume of spill. Only Snake River populations are shown because an ascent of Lower Granite Dam by any populations from the Middle or Upper Columbia would be overshoot and therefore the probability of fallback is affected by winter spill days rather than spill volume. The Tucannon River is also not shown because Lower Granite Dam is an overshoot for that population. Histograms on the plot margins indicate the spill experiences of individual fish.

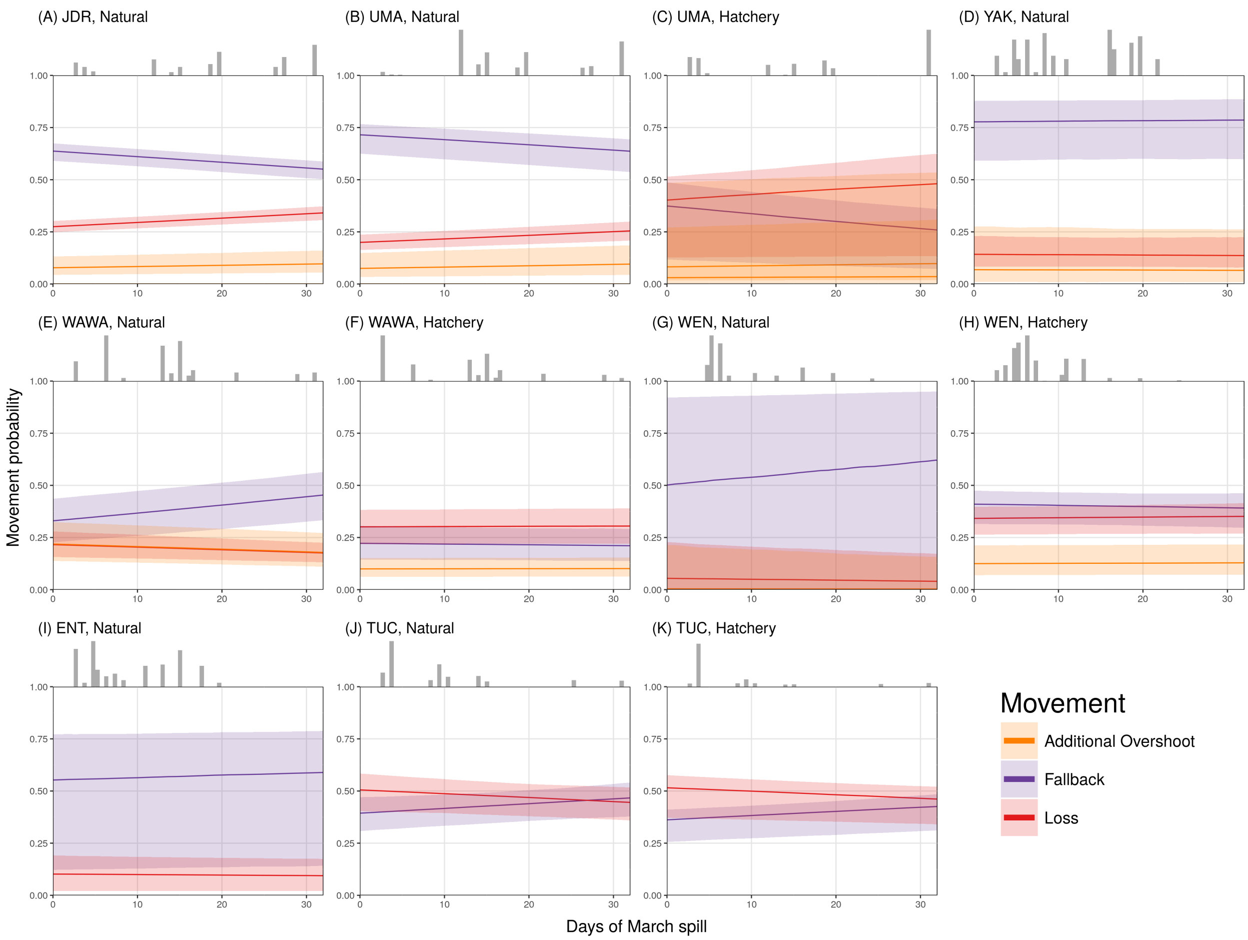


Figure 45: The effect of March spill days on movement probabilities out of the mainstem state directly upstream of the mainstem state that connects to the natal tributary for (A) John Day River natural origin Steelhead, (B) Umatilla River natural origin Steelhead, (C) Umatilla River hatchery origin Steelhead, (D) Yakima River natural origin Steelhead, (E) Walla Walla River natural origin Steelhead, (F) Walla Walla River hatchery origin Steelhead, (G) Wenatchee River natural origin Steelhead, (H) Wenatchee River hatchery origin Steelhead, (I) Entiat River natural origin Steelhead, (J) Tucannon River natural origin Steelhead, and (K) Tucannon River hatchery origin Steelhead. Histograms on the plot margins indicate the temperature experiences of individual fish.

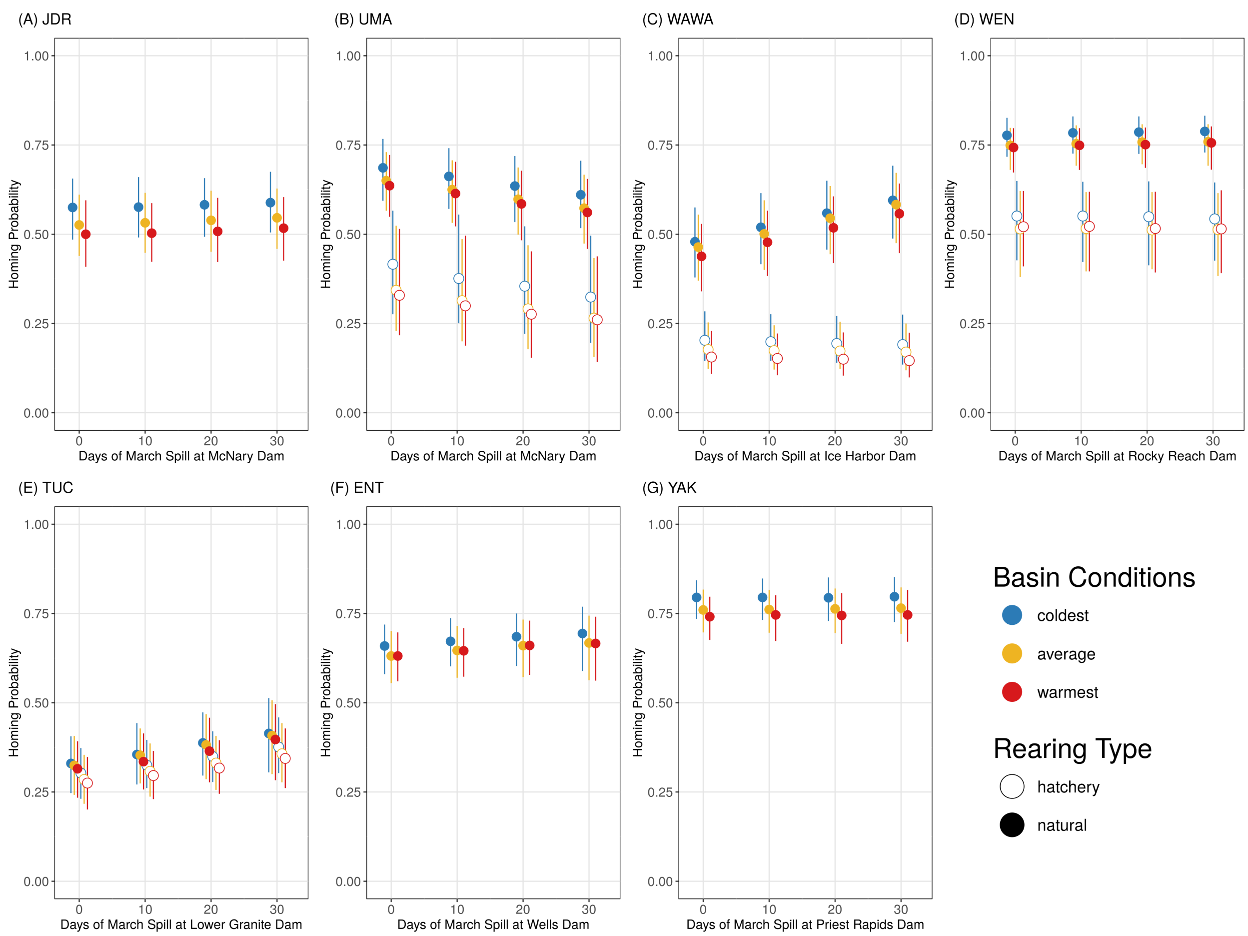


Figure 46: The homing probability for (A) John Day River, (B) Umatilla River, (C) Walla Walla River, (D) Wenatchee River, (E) Tucannon River, (F) Entiat River, and (G) Yakima River Steelhead under different scenarios for basin-wide temperature and March spill days (0, 10, 20, or 30 days) at the overshoot dam. The temperature scenarios are specific run years from the dataset, with the coldest year being the 2011/2012 run year, the average year being the 2005/2006 run year, and the warmest year being the 2015/2016 run year.