Estimates of Wenatchee Steelhead Redds and Spawners
Spawn Year 2023

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Abstract

This report contains estimates of total steelhead redds in the Wenatchee, after accounting for observer error. It also includes estimates of spawners, as well as prespawn mortality.

Contents

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1 Introduction

Redd counts are an established method to provide an index of adult spawners (Gallagher et al. 2007). In the Wenatchee subbasin, index reaches are surveyed weekly during the steelhead spawning season (Mar 06, 2023 - May 30, 2023) and non-index reaches are surveyed once during the peak spawning period. The goal of this work is to:

1. Predict observer net error, using the model described in Murdoch et al. (2018).
2. Use estimates of observer net error rates and the mean survey interval to estimate the number of redds in each index reach, using a Gaussian area under the curve (GAUC) technique described in Millar et al. (2012) and Murdoch et al. (2018).
3. Estimate the total number of redds in the non-index reaches by adjusting the observed counts with the estimated net error where possible.
4. Sum the total number of estimated redds for the entire Wenatchee subbasin.
5. Translate the estimated number of redds into estimates of spawners, by origin.

2 Methods

2.1 Net Error Model

The net error (NE) for a reach i is defined as

$$NE_i = \frac{F_i - V_i}{V_i}$$

where F_i is the number of redds the surveyor reported and V_i is the true number of redds in the reach. Therefore, if we have an estimate of net error $(\hat{NE_i})$, we can calculate the true number of redds based on that estimate and the number of redds the surveyor reported, F_i:

$$V_i = \frac{F_i}{\hat{NE_i} + 1} \tag{1}$$

The model for observer net error is fully described in Murdoch et al. (2018). It uses covariates of the log of observer experience, mean discharge, the observed redd density and mean thalweg CV as a proxy for channel complexity. After normalizing these covariates, the model coefficients are shown in Table 1. Positive coefficients indicate that higher values of that covariate lead to higher predicted values of net error, while negative coefficients cause higher values of that covariate to lead to lower predicted net errors.

We have made one slight modification to the model since that publication. We have subtracted one from the net error, to center values of net error around zero instead of one, for ease of interpretability. The response, net error, is scaled such that estimates of net error less than zero suggest more errors of omission, while estimates greater than zero suggest more errors of commission. An estimate of net error equal to zero would indicate the observed count equals the true number of redds.

Table 1: Net error model covariates and coefficients.

Term	Estimate	Std Error
(Intercept)	-0.318	0.043
Obs. Redd Density	0.268	0.063
Log Surveyor Exp.	0.123	0.047
Mean Thalweg CV	-0.116	0.051
Mean Discharge	0.109	0.053

2.2 Data

Redd counts were conducted on a nearly weekly basis for index reaches, and once during the peak spawning period for non-index reaches. The covariates in the observer error model of Murdoch et al. (2018) were collected during each survey. The covariate of mean thalweg CV was calculated based on all measurements taken within a reach across years (assuming this covariate does not vary through time within a reach). They were compared with the covariates contained in the model data set, as well as the estimates of net error (Figure 1).
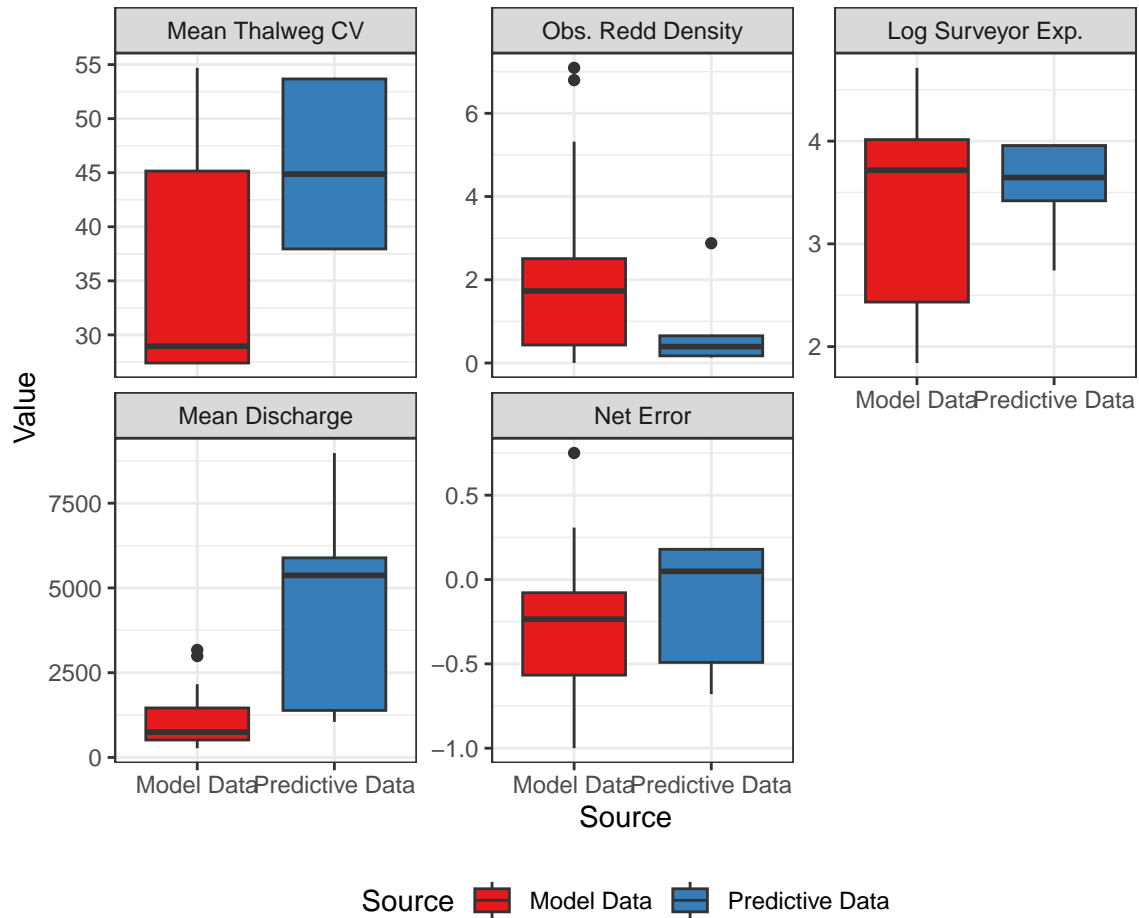

Figure 1: Net error covariate values. Colors correspond to either the original study (Model Data) or the surveys where the model was used in this report (Predictive Data).

Those covariates in the observer error model were collected during each survey in 2023, but we only used predictions of net error for surveys when visible redds were present. From these survey specific estimates of net error, a mean and standard error of net error was calculated for each reach. The standard deviation was calculated by taking the square root of the sum of the squared standard errors for all predictions within a reach.

2.3 Estimating Redds

Use of the GAUC methodology was limited to index reaches with a minimum of two redds and at least three weeks with at least one new redd found. For those reaches, we used the method described in Millar et al. (2012) and Murdoch et al. (2018). The GAUC model was developed with spawner counts in mind. As it is usually infeasible to mark every individual spawner, only total spawner counts can be used, and an estimate

of average stream life must be utilized to translate total spawner days to total unique spawners. However, in adapting this for redd surveys, we note that individual redds can be marked, and therefore the GAUC model can be fit to new redds only. The equivalent of stream life is thus the difference between survey numbers, which can be fixed at 1. We applied the average net error from all the surveys when redds were visible, so as to not bias the estimate from early weeks when no redds were found, and the observed redd density was zero.

For non-index reaches, which were surveyed only once during peak spawning, the estimate of total redds was calculated by dividing the observed redds by the estimate of net error associated with that survey (Eq. (1)). This assumes that no redds were washed out before the non-index survey, and that no new redds appeared after that survey. As the number of redds observed in the non-index reaches ranged from 0 to 4, any violation of this assumption should not affect the overall estimates very much. Any index reaches that did not meet the thresholds described above were treated as non-index reaches, and the total observed redds in those reaches were divided by the mean estimate of net error for each reach.

When summing reach-scale estimates to obtain estimates at the stream scale, an attempt was made to incorporate the fact that the reaches within a stream are not independent. Estimates of correlation between the reaches within a stream were made based on weekly observed redds. This method may not be perfect, since spawners could use certain reaches preferentially at different times in the season, but it may be the best we can do. Because correlations are often quite high between reaches, this is a better alternative than to naively assume the standard errors between reaches are independent of one another. These correlation estimates were combined with estimates of standard error at the reach scale to calculate a covariance matrix for the reaches within each stream, which was used when summing estimates of total redds to estimate the standard error at the stream scale. Failure to incorporate the correlations between reaches would result in an underestimate of standard error at the stream scales. Different streams (and therefore reaches in different streams) were assumed to be independent.

2.4 Estimating Spawners

Estimates of escapement to various tributaries in the Wenatchee were made using a Dam Adult Branch Occupancy Model (DABOM) (Waterhouse et al. 2020) based on PIT tag detections of fish tagged at Priest Rapids dam. All fish that escaped to the various tributaries were assumed to be spawners (i.e. prespawn mortality only occurs in the mainstem). Reaches below the PIT tag arrays in some tributaries were surveyed for redds, but we assumed there was no observer error in those reaches.

To convert estimates of redds in mainstem areas into estimates of natural and hatchery spawners, the estimates of redds were multiplied by a fish per redd (FpR) estimate and then by the proportion of hatchery or wild fish. The fish per redd estimate was based on PIT tags from the branching patch-occupancy model observed to move into the lower or upper Wenatchee (below or above Tumwater dam), but not into tributaries upstream of Tumwater. FpR was calculated as the ratio of male to female fish, plus 1. Reaches W1 - W7 are below Tumwater, while reaches W8 - W10 are above Tumwater. For reaches in tributaries below the tributary PIT tag array, FpR was calculated based on observed PIT tags moving into the lower regions of each tributary.

In some years, we have noticed a discrepancy in the sex calls at Priest Rapids and the sex calls from broodstock collection at Wells Hatchery and in the Wenatchee. Therefore, we developed a correction factor that accounts for the error rate in female and male calls independently, and adjusts the fish / redd estimate accordingly. The error rate of sex calls at Priest are shown in Appendix A.1 in Table 10.

The proportion of hatchery and natural origin fish was calculated based on the ratio of hatchery to wild run escapement estimates to the lower and upper Wenatchee, as well as various tributaries. When PIT tags of both origins in the DABOM model are observed in a tributary, this ratio is equivalent to basing it on the ratio of hatchery to wild PIT tags detected in that tributary. However, if tags from only one origin are observed in a particular tributary, our DABOM framework still allows us to estimate escapement of both origins. Therefore the ratio of escapement estimates rather than detected tags is more consistent with the overall methodology, and so we applied that estimator to all relevant areas.

Table 2: Known number of fish removed at dams or due to harvest, by origin.

Spawn Year	Removal Location	Agency	Source	Natural	Hatchery
2023	Dryden	WDFW-Wenatchee Research Office	Adult Trapping Surplus	0	0
2023	Dryden	WDFW-Wenatchee Research Office	Brood Collections	2	32
2023	Dryden	WDFW-Wenatchee Research Office	Harvest	0	0
2023	Tumwater	WDFW-Wenatchee Research Office	Adult Trapping Surplus	0	0
2023	Tumwater	WDFW-Wenatchee Research Office	Brood Collections	60	20
2023	Tumwater	WDFW-Wenatchee Research Office	Harvest	0	0

2.5 Prespawn Mortality

After translating estimates of redds to estimates of spawners by origin, we can then compare the spawner estimates to escapement estimates made using PIT tags, and estimate a prespawn mortality rate. Taking the total PIT-tag based escapement estimate, by origin, to the Wenatchee, we then subtract any fish removed at Tumwater or Dryden for broodstock or surplus, as well as any deaths due to harvest (Table 2), and then subtract the total estimate of spawners, including the tributaries, to provide an estimate of how many fish succumbed to prespawn mortality. Dividing that number by the total escapement estimate provides an estimate of the prespawn mortality rate, by origin, across the entire Wenatchee population.

If either origin had a higher estimates of spawners compared to escapement, we fixed our prespawn mortality estimate at 0, reflecting a very low level of prespawn mortality. There is uncertainty in both the escapement and spawner estimates, which could explain why these types of scenarios could arise.

3 Results

3.1 Redd estimates

The estimated net error, observed redds and estimates of redds at the reach scale are shown in Table 3. The results are summarized by major areas and population scale in Table 4.

Table 3: Estimates of mean net error and redds for each reach.

River	Reach	Type	Net Error	Net Error SE	Observed Redds	Estimated Redds	Std. Err. Redds	Redds CV
Chiwawa	C1	Tributary	0	0	0	0	0	-
Nason	N1	Tributary	0	0	0	0	0	-
Peshastin	P1	Tributary	0	0	0	0	0	-
Wenatchee	W1	Non-Index	0	0	0	0	0	-
Wenatchee	W2	Non-Index	0	0	0	0	0	-
Wenatchee	W2	Index	0	0	0	0	0	-
Wenatchee	W3	Non-Index	0	0	0	0	0	-
Wenatchee	W4	Non-Index	0	0	0	0	0	-
Wenatchee	W5	Non-Index	0	0	0	0	0	-
Wenatchee	W6	Index	0	0	0	0	0	-
Wenatchee	W7	Non-Index	0	0	0	0	0	-
Wenatchee	W8	Non-Index	0	0	0	0	0	-
Wenatchee	W8	Index	-0.273	0.222	2	3	0.8	0.281
Wenatchee	W9	Non-Index	0	0	0	0	0	-
Wenatchee	W9	Index	-0.147	0.298	3	4	1.2	0.307
Wenatchee	W10	Non-Index	-0.103	0.056	4	4	0.3	0.07
Wenatchee	W10	Index	0.016	0.319	4	4	1.2	0.309

Table 4: Estimate of redds in mainstem Wenatchee, above and below Tumwater Dam, and any tributaries surveyed.

River	Index	Location	# Reaches	Observed Redds	Estimated Redds	Std Err Redds	Redds CV
Chiwawa	Tributary	Tributaries	1	0	0	0	-
Nason	Tributary	Tributaries	1	0	0	0	-
Peshastin	Tributary	Tributaries	1	0	0	0	-
Wenatchee	N	Below Tumwater (mainstem)	6	0	0	0	-
Wenatchee	Y	Below Tumwater (mainstem)	2	0	0	0	-
Wenatchee	N	Above Tumwater (mainstem)	3	4	4	0.3	0.07
Wenatchee	Y	Above Tumwater (mainstem)	3	9	11	3.1	0.278
Total	**-**	**-**	**17**	**13**	**15**	**3.1**	**0.205**

3.2 Spawner Estimates

Demographic data about sex and origin were derived from the PIT tags detected within each area (Table 5).

Table 5: Number of PIT tags detected in each area by sex and origin.

Location	Sex	Origin	N Tags
Below Tumwater (mainstem)	Female	H	20
Below Tumwater (mainstem)	Female	W	4
Below Tumwater (mainstem)	Male	H	4
Above Tumwater (mainstem)	Female	H	14
Above Tumwater (mainstem)	Female	W	7
Above Tumwater (mainstem)	Male	H	4
Above Tumwater (mainstem)	Male	W	6
Peshastin	Female	W	9
Peshastin	Male	W	2
Nason	Female	H	4
Nason	Female	W	4
Nason	Male	W	3
Chiwawa	Female	H	5
Chiwawa	Female	W	9
Chiwawa	Male	H	4
Chiwawa	Male	W	1

Parameter estimates for fish / redd and proportion hatchery based on this PIT tag data after adjusting for the sex call error rate (Appendix A.1) are shown in Table 6.

Table 6: Fish per redd and hatchery origin proportion estimates.

Area	Fish / redd	FpR Std. Error	Prop. Hatchery	Prop Std. Error
Below Tumwater (mainstem)	1.400	0.063	0.887	0.078
Above Tumwater (mainstem)	1.722	0.077	0.580	0.094
Peshastin	1.571	0.073	0.055	0.077
Nason	1.571	0.068	0.386	0.148
Chiwawa	1.583	0.069	0.473	0.116

Combining PIT tag-based estimates of spawners in the tributaries with adjusted redd-based estimates of spawners in the mainstem areas, Table 7 shows all of them, broken down by reach or tributary and origin. Table 8 shows a summary of spawners by origin across various areas including the Wenatchee mainstem and each tributary.

Table 7: Estimates (95% CI) of spawners by reach or tributary and origin.

River	Area	Reach	Type	Natural	Hatchery
Wenatchee	Below Tumwater (mainstem)	W1	Non-Index	0 (-)	0 (-)
Wenatchee	Below Tumwater (mainstem)	W2	Index	0 (-)	0 (-)
Wenatchee	Below Tumwater (mainstem)	W2	Non-Index	0 (-)	0 (-)

Table 7: Estimates (95% CI) of spawners by reach or tributary and origin. *(continued)*

River	Area	Reach	Type	Natural	Hatchery
Wenatchee	Below Tumwater (mainstem)	W3	Non-Index	0 (-)	0 (-)
Wenatchee	Below Tumwater (mainstem)	W4	Non-Index	0 (-)	0 (-)
Wenatchee	Below Tumwater (mainstem)	W5	Non-Index	0 (-)	0 (-)
Wenatchee	Below Tumwater (mainstem)	W6	Index	0 (-)	0 (-)
Wenatchee	Below Tumwater (mainstem)	W7	Non-Index	0 (-)	0 (-)
Wenatchee	Above Tumwater (mainstem)	W8	Index	2 (1 - 4)	3 (1 - 5)
Wenatchee	Above Tumwater (mainstem)	W8	Non-Index	0 (-)	0 (-)
Wenatchee	Above Tumwater (mainstem)	W9	Index	3 (1 - 5)	4 (1 - 7)
Wenatchee	Above Tumwater (mainstem)	W9	Non-Index	0 (-)	0 (-)
Wenatchee	Above Tumwater (mainstem)	W10	Index	3 (1 - 5)	4 (1 - 7)
Wenatchee	Above Tumwater (mainstem)	W10	Non-Index	3 (2 - 4)	4 (3 - 5)
Icicle	Icicle	-	DABOM	11 (0 - 31)	10 (0 - 29)
Peshastin	Peshastin	P1	Tributary	0 (-)	0 (-)
Peshastin	Peshastin	-	DABOM	81 (38 - 129)	5 (0 - 21)
Mission	Mission	-	DABOM	38 (11 - 74)	11 (0 - 33)
Chumstick	Chumstick	-	DABOM	50 (20 - 92)	5 (0 - 20)
Chiwaukum	Chiwaukum	-	DABOM	31 (7 - 67)	4 (0 - 20)
Chiwawa	Chiwawa	C1	Tributary	0 (-)	0 (-)
Chiwawa	Chiwawa	-	DABOM	64 (31 - 107)	57 (26 - 98)
Nason	Nason	N1	Tributary	0 (-)	0 (-)
Nason	Nason	-	DABOM	42 (15 - 77)	26 (7 - 54)
Little Wenatchee	Little Wenatchee	-	DABOM	-	-
White River	White River	-	DABOM	-	-
Total	**-**	**-**	**-**	**328 (235 - 421)**	**133 (76 - 190)**

Table 8: Estimates (95% CI) of spawners by area and origin.

River	Location	Natural	Hatchery
Chiwaukum	Chiwaukum	31 (0 - 64)	4 (0 - 18)
Chiwawa	Chiwawa	64 (24 - 104)	57 (20 - 94)
Chumstick	Chumstick	50 (12 - 88)	5 (0 - 18)
Icicle	Icicle	11 (0 - 28)	10 (0 - 28)
Little Wenatchee	Little Wenatchee	-	-
Mission	Mission	38 (5 - 71)	11 (0 - 31)
Nason	Nason	42 (10 - 74)	26 (1 - 51)
Peshastin	Peshastin	81 (35 - 127)	5 (0 - 18)
Wenatchee	Below Tumwater (mainstem)	-	-
Wenatchee	Above Tumwater (mainstem)	11 (7 - 15)	15 (10 - 20)
White River	White River	-	-
Total	**-**	**328 (235 - 421)**	**133 (76 - 190)**

3.3 Prespawn Mortality

The estimates of overall prespawn mortality within the Wenatchee population, by origin, are shown in Table 9.

Table 9: Wenatchee prespawn mortality estimates. Includes estimates (standard error) of escapement, spawners, rate of prespawn mortality, and standard error and coefficient of variation of this rate, separated by origin.

Origin	Escapement	Spawners	Prespawn Mortality	SE	CV
Natural	372 (55)	328 (48)	0.119	0.183	1.531
Hatchery	348 (53)	133 (29)	0.618	0.102	0.165

4 Discussion

Most of the covariates collected in 2023 were within the range of those in the model data set from Murdoch et al. (2018), leading to estimates of net error in a very similar range to the model dataset (Figure 1). However, none of the reaches met the minimum thresholds of number of observed redds or number of weeks with at least one new redd observed, so we did not use the GAUC method for any reaches this year.

Neither hatchery nor natural origin steelhead PIT-tagged at Priest Rapids dam were detected in a few tributaries this year, so we did not produce estimates of spawners in those tributaries (Table 8). Because these estimates are based on a sample of the entire Upper Columbia steelhead run, it's possible a handful of steelhead may have spawned in those tributaries, but it's potentially more likely that there were zero steelhead spawners in those areas.

The estimate of pre-spawn mortality is particularly high for hatchery-origin steelhead this year (Table 9). While it is unclear exactly what led to this result this year, there are a few possibilities. Of the fish detected moving into the lower Wenatchee basin but not detected anywhere else, the proportion of hatchery-origin fish was quite high (Table 6), much higher than the proportion of hatchery-origin fish in the upper Wenatchee mainstem, above Tumwater. Potentially this could reflect that hatchery-origin fish were more likely to move into the lower Wenatchee but then leave (and remain undetected on another site) compared to natural-origin fish. Another explanation is that hatchery-origin fish were more susceptible to pre-spawn mortality this year, either because of something related to their origin, or because they were more likely to overwinter in

the lower Wenatchee and the conditions there (compared to the upper Wenatchee) led to higher overwinter mortality. Finally, it should be noted that no redds were found in reaches W1 - W7 in the lower Wenatchee. Regardless of the estimates of observer error, we currently do not adjust zero counts for entire reaches. If redds had been found in any of those reaches, because of the high pHOS in that area, most of those redds would have been assigned to hatchery spawners, lowering the hatchery prespawn mortality rates. However, we have no evidence that redd surveys were substantially different in the lower Wenatchee compared to the upper Wenatchee reaches, and it would require an estimate of a total of 139 redds in the lower Wenatchee reaches to lead to a pre-spawn mortality rate of 40% for hatchery-origin steelhead (and would result in a revised PSM rate of 7% for natural-origin steelhead). We find it unlikely that so many redds were missed completely, suggesting the high PSM rate for hatchery-origin steelhead had another explanation.

5   Acknowledgements

6 Literature cited

Gallagher, S. P., P. K. J. Hahn, and D. H. Johnson. 2007. Salmonid field protocols handbook: Techniques for assessing status and trends in salmon and trout populations. Pages 197–234 *in* D. H. Johnson, editor. American Fisheries Society, Bethesda, Maryland.

Millar, R. B., S. McKechnie, and C. E. Jordan. 2012. Simple estimators of salmonid escapement and its variance using a new area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences 69(6):1002–1015. NRC Research Press.

Murdoch, A. R., C. J. Herring, C. H. Frady, K. See, and C. E. Jordan. 2018. Estimating observer error and steelhead redd abundance using a modified Gaussian area-under-the-curve framework. Canadian Journal of Fisheries and Aquatic Sciences (999):1–10. NRC Research Press.

Waterhouse, L., J. White, K. See, A. Murdoch, and B. X. Semmens. 2020. A Bayesian nested patch occupancy model to estimate steelhead movement and abundance. Ecological Applications. Wiley Online Library.

A Appendix A

A.1 Sex Errors at Priest Rapids

Fish collected for broodstock at various locations throughout the Upper Columbia (e.g. Wells Hatchery and within the Wenatchee) had a known sex. Based on PIT tag detections of this broodstock collection, those sexes could be compared with the sex call at Priest when the fish was initially tagged. Assuming that this error rate is systematic across the entire run within a brood year, we combined all tags with this kind of comparison. Table 10 shows the sample sizes and results.

These error rates were used to adjust the counts of male and female tags within particular spawning areas before re-calculating the fish/redd estimate. For example, the adjusted number of males would be the initial number of males, minus the number of initial males times the error rate for male identification, plus the number of initial females times the error rate for female identification.

Table 10: Error rate in sex calls at Priest Rapids.

Spawn Year	Sex	N Tags	N True	N False	Perc False	Perc SE	Lower CI	Upper CI
2011	F	22	18	4	0.182	0.082	0.073	0.385
2011	M	16	14	2	0.125	0.083	0.035	0.360
2012	F	40	33	7	0.175	0.060	0.087	0.319
2012	M	20	19	1	0.050	0.049	0.009	0.236
2013	F	28	26	2	0.071	0.049	0.020	0.226
2013	M	23	23	0	0.000	0.000	0.000	0.143
2014	F	52	47	5	0.096	0.041	0.042	0.206
2014	M	55	53	2	0.036	0.025	0.010	0.123
2015	F	73	69	4	0.055	0.027	0.022	0.133
2015	M	62	59	3	0.048	0.027	0.017	0.133
2016	F	69	63	6	0.087	0.034	0.040	0.177
2016	M	66	65	1	0.015	0.015	0.003	0.081
2017	F	77	76	1	0.013	0.013	0.002	0.070
2017	M	47	46	1	0.021	0.021	0.004	0.111
2018	F	85	79	6	0.071	0.028	0.033	0.146
2018	M	79	77	2	0.025	0.018	0.007	0.088
2019	F	61	55	6	0.098	0.038	0.046	0.198
2019	M	34	33	1	0.029	0.029	0.005	0.149
2020	F	38	31	7	0.184	0.063	0.092	0.334
2020	M	33	31	2	0.061	0.042	0.017	0.196
2021	F	36	32	4	0.111	0.052	0.044	0.253
2021	M	11	8	3	0.273	0.134	0.097	0.566
2022	F	58	31	27	0.466	0.065	0.343	0.592
2022	M	21	21	0	0.000	0.000	0.000	0.155
2023	F	68	55	13	0.191	0.048	0.115	0.300
2023	M	32	29	3	0.094	0.052	0.032	0.242