Workshop on Methods for Analysis of Fall Chinook Salmon Data

Application of the Classic CJS Mark-Recapture Model

Steven G. Smith
Northwest Fisheries Science Center
NOAA Fisheries

- Mark-Recapture Data and “Classic” CJS

- Mark-Recapture Data and “Classic” CJS

- Simple Examples
  - Downstream detections as sample to estimate upstream parameters

- Mark-Recapture Data and “Classic” CJS

- Simple Examples
  - Downstream detections as sample to estimate upstream parameters

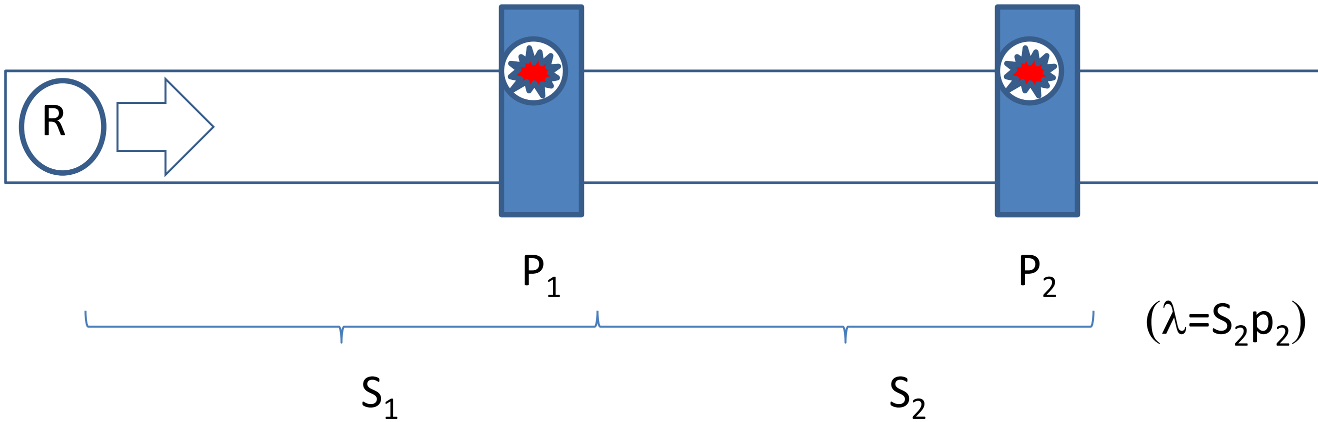
- CJS as Foundation of Estimation of LGR Equivalents

- Mark-Recapture Data and “Classic” CJS
- Simple Examples
  - Downstream detections as sample to estimate upstream parameters
- CJS as Foundation of Estimation of LGR Equivalents
- Model Assumptions
  - Consequences of violations

- Mark-Recapture Data and “Classic” CJS
- Simple Examples
  - Downstream detections as sample to estimate upstream parameters
- CJS as Foundation of Estimation of LGR Equivalents
- Model Assumptions
  - Consequences of violations
  - Relation to data from fall Chinook salmon
    - Protracted migration
    - Changing conditions (esp. spill, transport)
    - Overwintering in reservoirs
    - Undetected passage

Single-Release of Tagged Individuals

Two "recapture" occasions

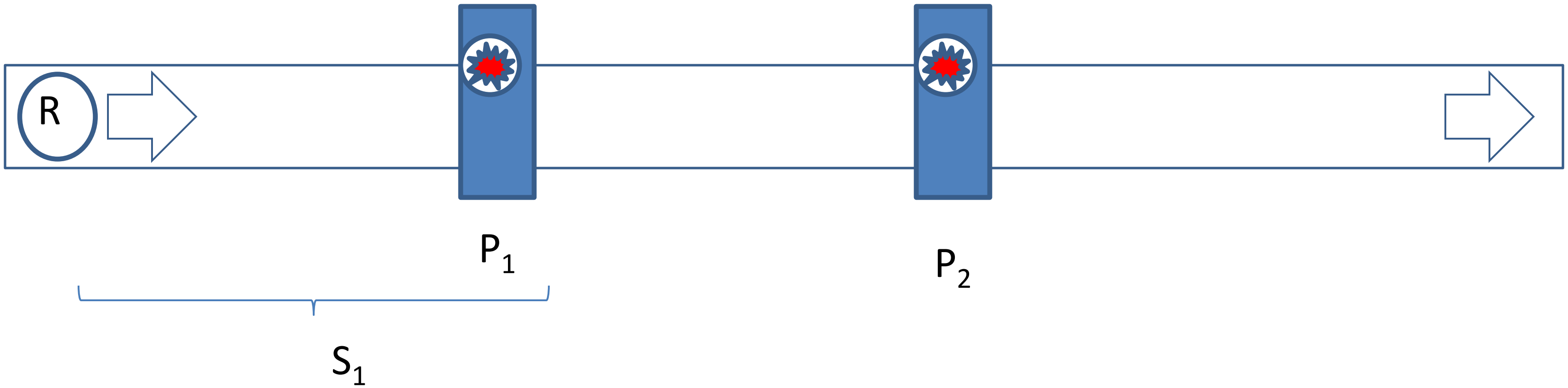


Mark-Recapture Data = Possible PIT-Tag Detection Histories

Detection histories record outcome of series of conditionally independent events.
Histories constitute multinomial sample.
Probability of each history depends on conditional survival and detection probabilities.

111 : $S_1P_1\lambda$ 110 : $S_1P_1\,(1-\lambda)$ 101 : $S_1(1\text{-}P_1)\,\lambda$ 100 : $(1-S_1)+S_1(1\text{-}P_1)\,(1-\lambda)$

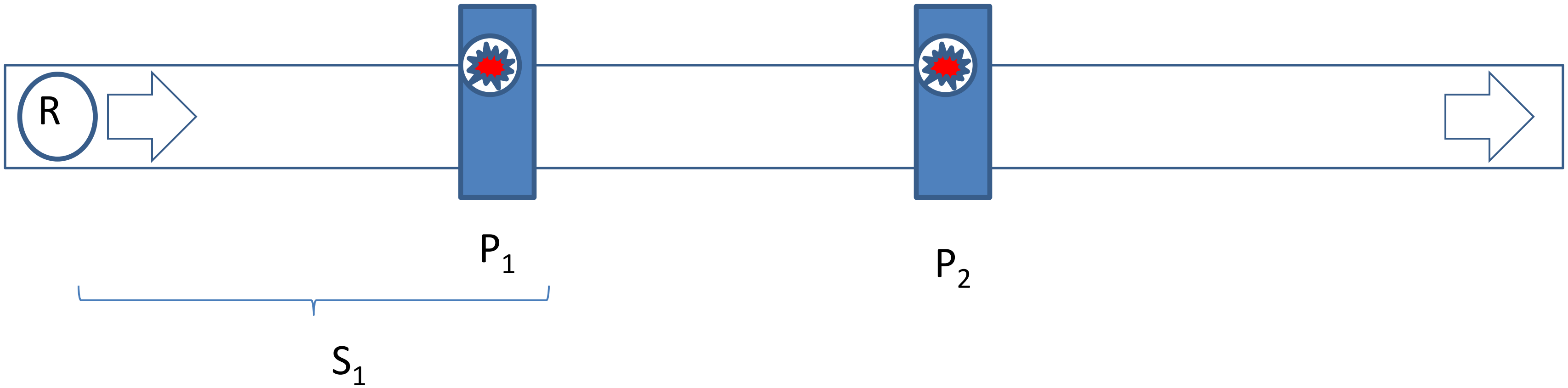
Two "recapture" occasions – estimation of S_1 and P_1



Probability of surviving to AND being detected at first dam = S_1P_1

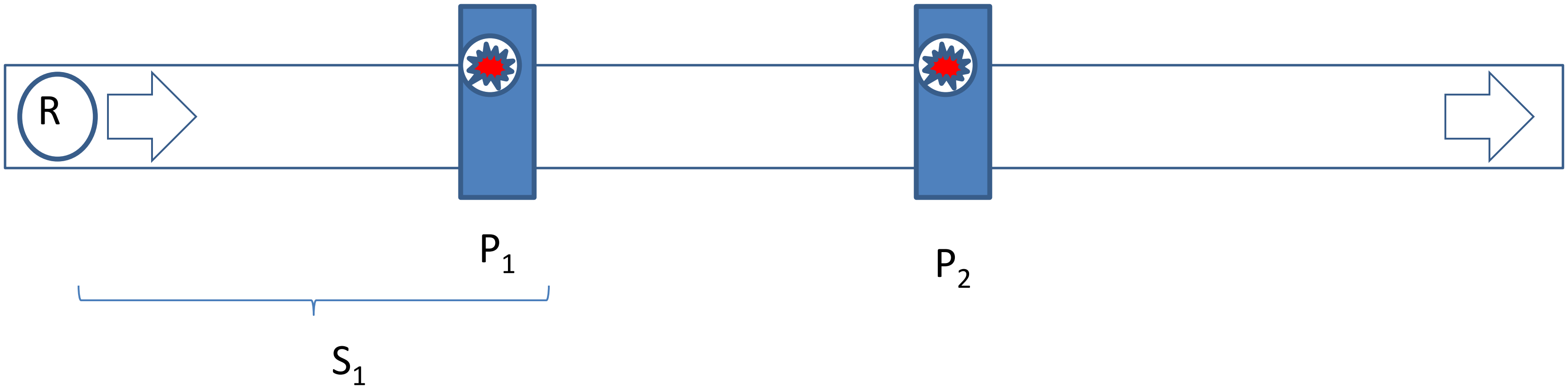
$$\frac{(n_{111} + n_{110})}{R} = \overline{S_1}\,\overline{P_1}$$

Two "recapture" occasions – estimation of S_1 and P_1



Given estimate of joint probability of survival and detection, need an estimate of one probability separately to separate.

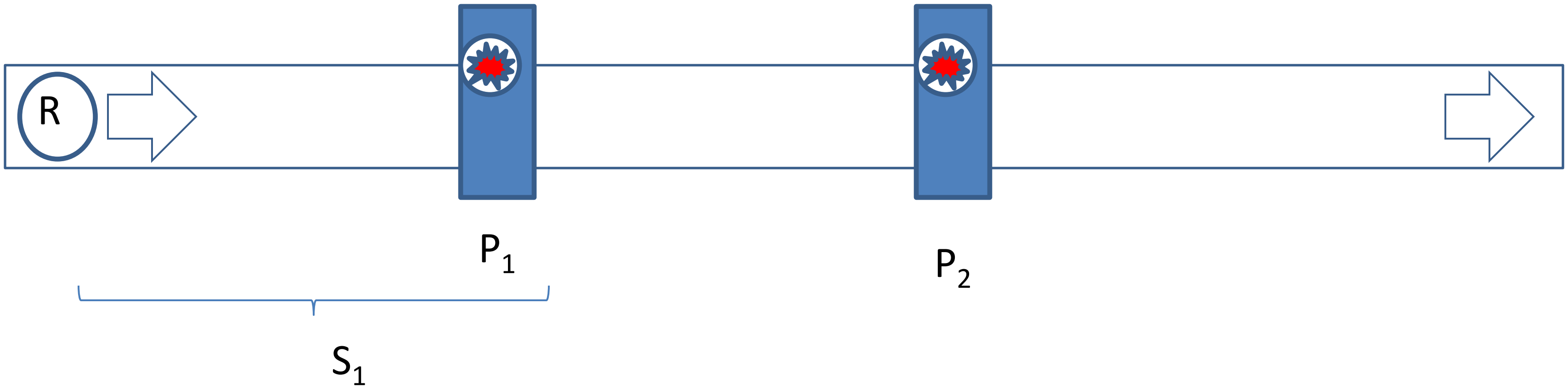
Two "recapture" occasions – estimation of S_1 and P_1



Given estimate of joint probability of survival and detection, need an estimate of one probability separately to separate.

$$\hat{P}_1 = \frac{n_{111} + n_{110}}{(n_{111} + n_{110} + n_{101} + n_{100})}$$ no good because some "100" fish were not alive at dam 1.

Two "recapture" occasions – estimation of S_1 and P_1



Given estimate of joint probability of survival and detection, need an estimate of one probability separately to separate.

$$\hat{P}_1 = \frac{n_{111} + n_{110}}{(n_{111} + n_{110} + n_{101} + n_{100})}$$ no good because some "100" fish were not alive at dam 1.

Fish detected at second dam (111 and 101) constitute a **sample of all fish alive** at dam 1,

=> sample proportion detected is an estimate of overall probability of detection

=> detection probability at dam 2 (P_2) is a sampling rate

$$\hat{P}_1 = \frac{n_{111}}{(n_{111} + n_{101})}$$

$$\hat{S}_1 = \frac{\widehat{S_1 P_1}}{\hat{P}_1}$$

Assumptions:

* All individuals from a release group alive at head of reach have same probability of survival to end of reach.

* All individuals from a release group alive at a detection location have same probability of detection.

Assumptions:

* All individuals from a release group alive at head of reach have same probability of survival to end of reach.

* All individuals from a release group alive at a detection location have same probability of detection.

Fish are not balls in an urn – inherent variability among individuals violates these assumptions.

Assumptions:

* All individuals from a release group alive at head of reach
have same probability of survival to end of reach.

* All individuals from a release group alive at a detection location
have same probability of detection.

Fish are not balls in an urn – inherent variability among individuals
violates these assumptions.

- Parameter estimates are of *average* probabilities across individuals,

Assumptions:

* All individuals from a release group alive at head of reach
have same probability of survival to end of reach.

* All individuals from a release group alive at a detection location
have same probability of detection.

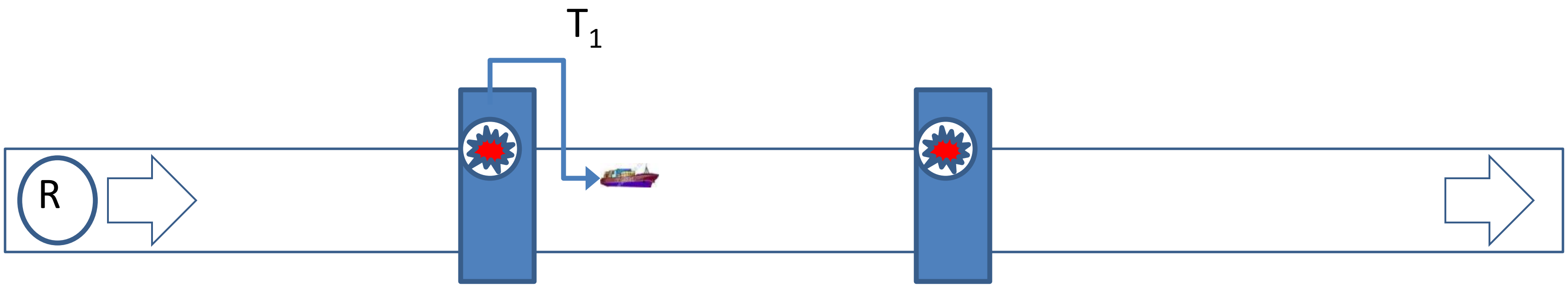
Fish are not balls in an urn – inherent variability among individuals
violates these assumptions.

- Parameter estimates are of *average* probabilities across individuals,

BUT, unbiased only if downstream sample is ***representative*** of all alive upstream.

Operations can affect representativeness of downstream sample.

Effect on sample of fish detected downstream: Transportation



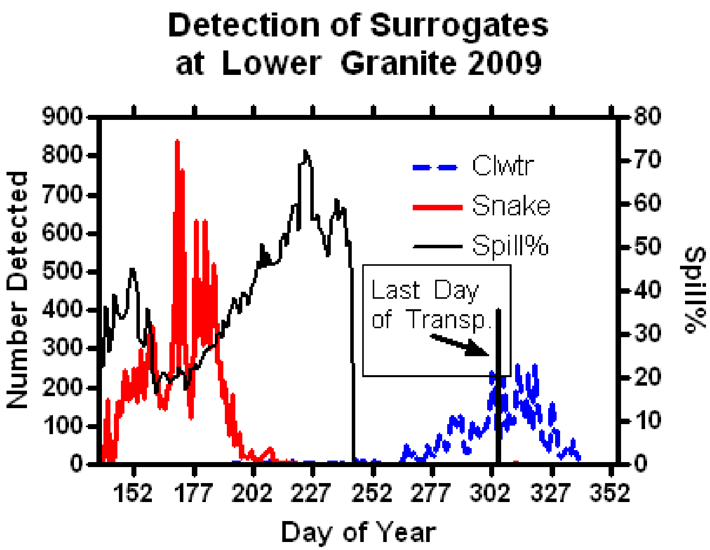
Detection history for fish transported from dam 1: 120

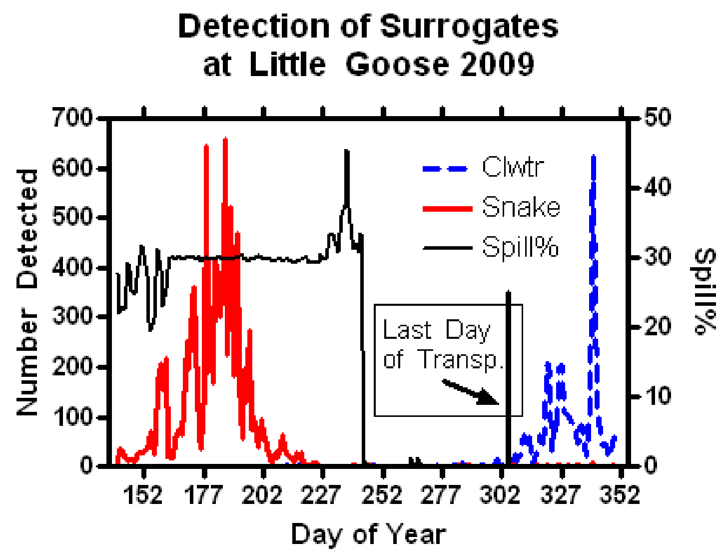
Proportion transported: $$T_1 = \frac{n_{120}}{(n_{111} + n_{110} + n_{120})}$$

$$\hat{P}_1 = \frac{n_{111}}{\left(n_{111} + n_{101}(1 - T_1)\right)}$$

$$\hat{S}_1 = \frac{\overline{S_1 P_1}}{\hat{P}_1}$$

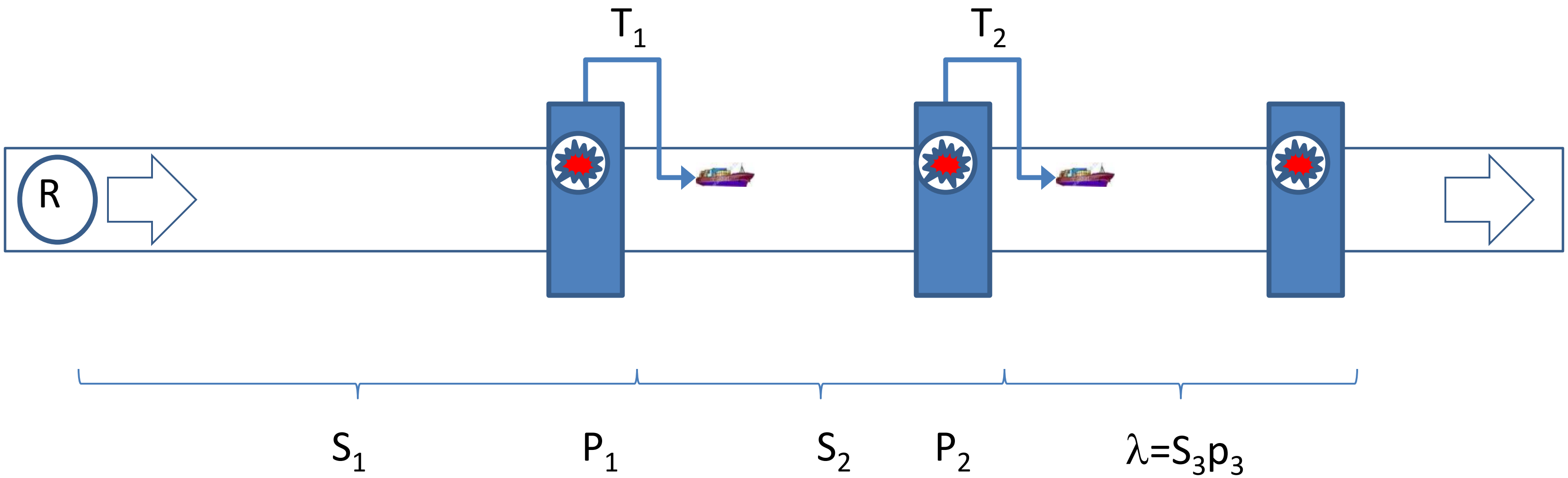
Potential Issues with Data From PIT-Tagged Fall Chinook Salmon





Single-Release Experimental Design

Three "recapture" occasions



Possible PIT-Tag Detection Histories

1111	1011	1200
1110	1010	1120
1101	1001	1020
1100	1000	

PIT-Tagged Fall Chinook Salmon Surrogates 2009

	Snake		Clearwater	
	Bypass	Transport	Bypass	Transport
Released	118,870	118,871	45,010	45,006
Detection Histories Based on 2009 Detections				
1111	283	6	390	376
1110	617	23	1,020	917
1101	1,417	104	114	96
1100	4,591	787	1,511	1,253
1011	1,318	116	153	168
1010	3,012	265	527	471
1001	6,665	6,662	62	62
1000	100,242	100,071	40,898	40,925
1200	366	6,371	330	676
1120	56	113	4	7
1020	303	4,353	1	55
Adult Detectors In 2009				
GRA	1	2	5	2
MC1 or MC2	9	6	-	-
Fish Detected in 2010				
Total	47	44	1,205	1,097

PIT-Tagged Fall Chinook Salmon Surrogates 2009

	Snake	Clearwater
Survival Probability Estimates (Based on 2009 detections only)		
Rel-LGR	0.353 (0.005)	0.107 (0.001)
LGR-LGO	0.764 (0.018)	0.619 (0.010)
Detection Probability Estimates		
LGR	0.175 (0.003)	0.697 (0.007)
LGO	0.177 (0.004)	0.768 (0.011)
Proportion of Detected Transported		
LGR	0.457	0.150
LGO (all)	0.461	0.016
LGO (LGR = 0)	0.497	0.041
LGO (LGR = 1)	0.154	0.004

Lower Granite Equivalents

Three "recapture" occasions: LGR, LGO, "below" LGO

- Estimate CJS survival, detection, and transport probabilities.
- Estimate number arriving at LGR: $\hat{n}_{LGR} = R\hat{S}_1$
- Count "1"s and "2"s at LGR and estimate "0"s:

$$n_1 = n_{1111} + n_{1110} + n_{1101} + n_{1100} + n_{1120} \qquad n_2 = n_{1200}$$

$$\hat{n}_0 = \hat{n}_{LGR} - n_1 - n_2$$

- LGR-equivalents = number in each det.hist. category if there were no mortality downstream of LGR:

$$n^L_{20} = n_{1200} \qquad \hat{n}^L_{10} = n_1(1 - \hat{P}_2)$$

$$\hat{n}^L_{12} = n_1\hat{P}_2T_2 \qquad \hat{n}^L_{11} = n_1\hat{P}_2(1 - T_2) \qquad \hat{n}^L_{00} = \hat{n}_0(1 - \hat{P}_2) = C_0$$

$$\hat{n}^L_{02} = \hat{n}_0\hat{P}_2T_2 \qquad \hat{n}^L_{01} = \hat{n}_0\hat{P}_2(1 - T_2)$$

Illustrate Using Parameters of Snake River Surrogates:

Assumptions

Consequences of Violations

Remedies

Assn: P(Transport) does not depend on previous history

Scenario: LGO transport different for different LGR hist.

LGO (all)	0.461
LGO (LGR = 0)	0.497
LGO (LGR = 1)	0.154

Assn: P(Transport) does not depend on previous history

Scenario: LGO transport different for different LGR hist.

LGO (all)	0.461
LGO (LGR = 0)	0.497
LGO (LGR = 1)	0.154

	Actual	Estimated
Survival Probabilities		
Rel-LGR	0.353	0.353
LGR-LGO	0.764	0.764
Detection Probabilities		
LGR	0.175	0.175
LGO	0.177	0.177

	Actual	Estimated
LGR Equivalents		
20	6734	6734
12	218	654
02	6103	5667
11	1198	763
10	6577	6577
01	6175	6611
00	57011	57011

Assn: P(Transport) does not depend on previous history

Scenario: LGO transport different for different LGR hist.

LGO (all)	0.461
LGO (LGR = 0)	0.497
LGO (LGR = 1)	0.154

	Actual	Estimated
Survival Probabilities		
Rel-LGR	0.353	0.353
LGR-LGO	0.764	0.764
Detection Probabilities		
LGR	0.175	0.175
LGO	0.177	0.177

	Actual	Estimated
LGR Equivalents		
20	6734	6734
12	218	218
02	6103	6103
11	1198	1198
10	6577	6577
01	6175	6175
00	57011	57011

Remedy:

$$\hat{n}_{12}^{L} = n_1 \hat{P}_2 T_{2.1} \qquad \hat{n}_{11}^{L} = n_1 \hat{P}_2 (1 - T_{2.1})$$

$$\hat{n}_{02}^{L} = \hat{n}_0 \hat{P}_2 T_{2.0} \qquad \hat{n}_{01}^{L} = \hat{n}_0 \hat{P}_2 (1 - T_{2.0})$$

Assn: P_2 independent of P_1 (and S_2, etc.)

Violated if Downstream sample not representative

1. Size-related detection and/or survival probabilities

Assn: P_2 independent of P_1 (and S_2, etc.)

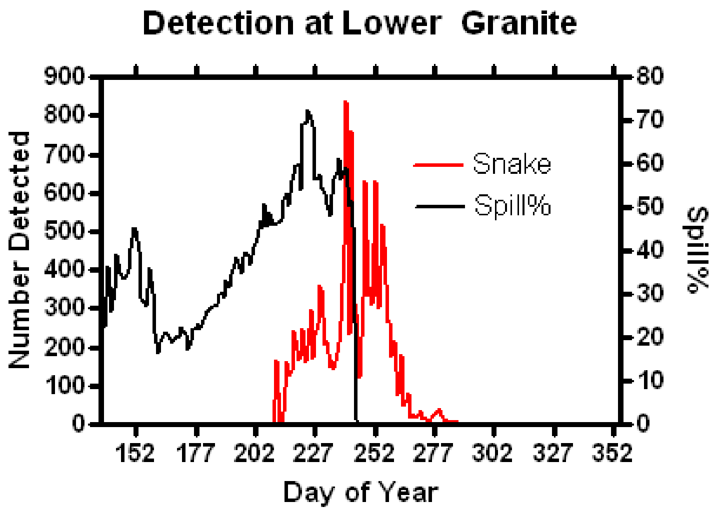
Violated if Downstream sample not representative

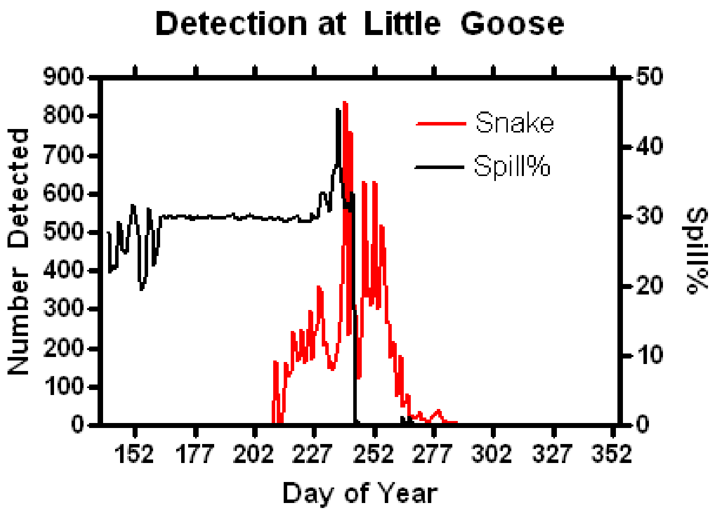
1. Size-related detection and/or survival probabilities
2. Behavioral responses to bypass/detection

Assn: P_2 independent of P_1 (and S_2, etc.)

Violated if Downstream sample not representative

1. Size-related detection and/or survival probabilities
2. Behavioral responses to bypass/detection
3. Detection probabilities changing at consecutive dams (illustrated below):





Assn: P_2 independent of P_1 (and S_2, etc.)

Scenario: Downstream probability (sampling rate) related to upstream probability/history

*** Instead of 0.177 detection at LGO for all,**
0.25 for fish detected at LGR
0.15 for fish not detected at LGR

	Actual	Estimated
Survival Probabilities		
Rel-LGR	0.353	0.311
LGR-LGO	0.764	0.878
Detection Probabilities		
LGR	0.175	0.199
LGO	0.168	0.160

	Actual	Estimated
LGR Equivalents		
20	6,734	6,734
12	308	197
02	5,166	4,722
11	1,691	1,084
10	5,995	6,712
01	5,227	4,778
00	58,896	49,746

Assn: P_2 independent of P_1 (and S_2, etc.)

Scenario: Size effect on detection at consecutive dams

- **Group 1 ("small"): Detection probabilities: 0.200, 0.202**
- **Group 2 ("large"): Detection probabilities: 0.150, 0.152**

	Actual	Estimated
Survival Probabilities		
Rel-LGR	0.353	0.350
LGR-LGO	0.764	0.767
Detection Probabilities		
LGR	0.175	0.177
LGO	0.177	0.178

	Actual	Estimated
LGR Equivalents		
20	6,734	6,734
12	218	219
02	6,103	6,063
11	1,198	1,204
10	6,577	6,570
01	6,175	6,135
00	57,011	56,295

Assn: P_2 independent of P_1 (and S_2, etc.)

Scenario: Size effect on detection at consecutive dams and survival in consecutive reaches

* Group 1 (“small”): Detection probabilities: 0.200, 0.206
  Survival probabilities: 0.328, 0.739
* Group 2 (“large”): Detection probabilities: 0.150, 0.152
  Survival probabilities: 0.378, 0.786

	Actual	Estimated
Survival Probabilities		
Rel-LGR	0.353	0.353
LGR-LGO	0.764	0.766
Detection Probabilities		
LGR	0.175	0.174
LGO	0.177	0.176

	Actual	Estimated
LGR Equivalents		
20	6,666	6,666
12	218	215
02	6,103	6,064
11	1,198	1,179
10	6,577	6,519
01	6,175	6,136
00	57,012	57,052

Assn: P_2 independent of P_1 (and S_2, etc.)

Violated if Downstream sample not representative

1. Size-related detection probabilities
2. Behavioral responses to bypass/detection
3. Detection probabilities changing at consecutive dams

Remedies

1. Model detection probability as function of size (not solved for LGR equivalents)

2, 3(?). Estimate different detection probability at dam 2 for detected and not detected at dam 1

Fish overwinter in reservoirs.

Scenario: 10% of fish spend winter in LGR reservoir, then migrate downstream monitored the following spring

Fish overwinter in reservoirs.

Scenario: 10% of fish spend winter in LGR reservoir, then migrate downstream monitored the following spring

Pooling Subyearling and Yearling Data		
	Actual	Estimated
LGR Equivalents		
20	6,495	6,495
12	220	213
02	5,559	5,659
11	1,210	1,170
10	6,281	6,328
01	5,919	5,726
00	52,308	52,106

Using Subyearling Data Only		
	Actual	Estimated
LGR Equivalents		
20	6,060	6,060
12	196	196
02	5,493	5,493
11	1,079	1,079
10	5,920	5,920
01	5,557	5,557
00	51,310	51,310

Fish overwinter in reservoirs.

Scenario: 5% of fish that enter any reservoir as a subyearling remain there until following spring, then migrate monitored the following spring

Pooling Subyearling and Yearling Data		
	Actual	Estimated
LGR Equivalents		
20	6,614	6,614
12	226	217
02	5,693	5,912
11	1,244	1,192
10	6,383	6,444
01	6,589	5,981
00	54,256	54,389

Using Subyearling Data Only		
	Actual	Estimated
LGR Equivalents		
20	6,397	6,397
12	197	207
02	5,508	5,798
11	1,028	1,139
10	5,640	6,249
01	5,294	5,866
00	48,880	54,161

Fish overwinter in reservoirs; some migrate unmonitored.

Scenario: 5% of fish that enter any reservoir as a subyearling remain there until bypass systems are dewatered.
50% of these migrate while detection is not possible.

Pooling Subyearling and Yearling Data		
	Actual	Estimated
LGR Equivalents		
20	6,506	6,506
12	211	212
02	5,601	5,855
11	1,136	1,155
10	6,011	6,346
01	5,942	5,923
00	51,568	54,265

Using Subyearling Data Only		
	Actual	Estimated
LGR Equivalents		
20	6,397	6,397
12	197	207
02	5,508	5,798
11	1,028	1,139
10	5,640	6,249
01	5,294	5,866
00	48,880	54,161