Monitoring repopulation of anadromous fishes in the Upper Klamath River Basin Following Dam Removal

Klamath Basin PIT Tag Database
Collaborative Spring Meeting

February 25, 2022

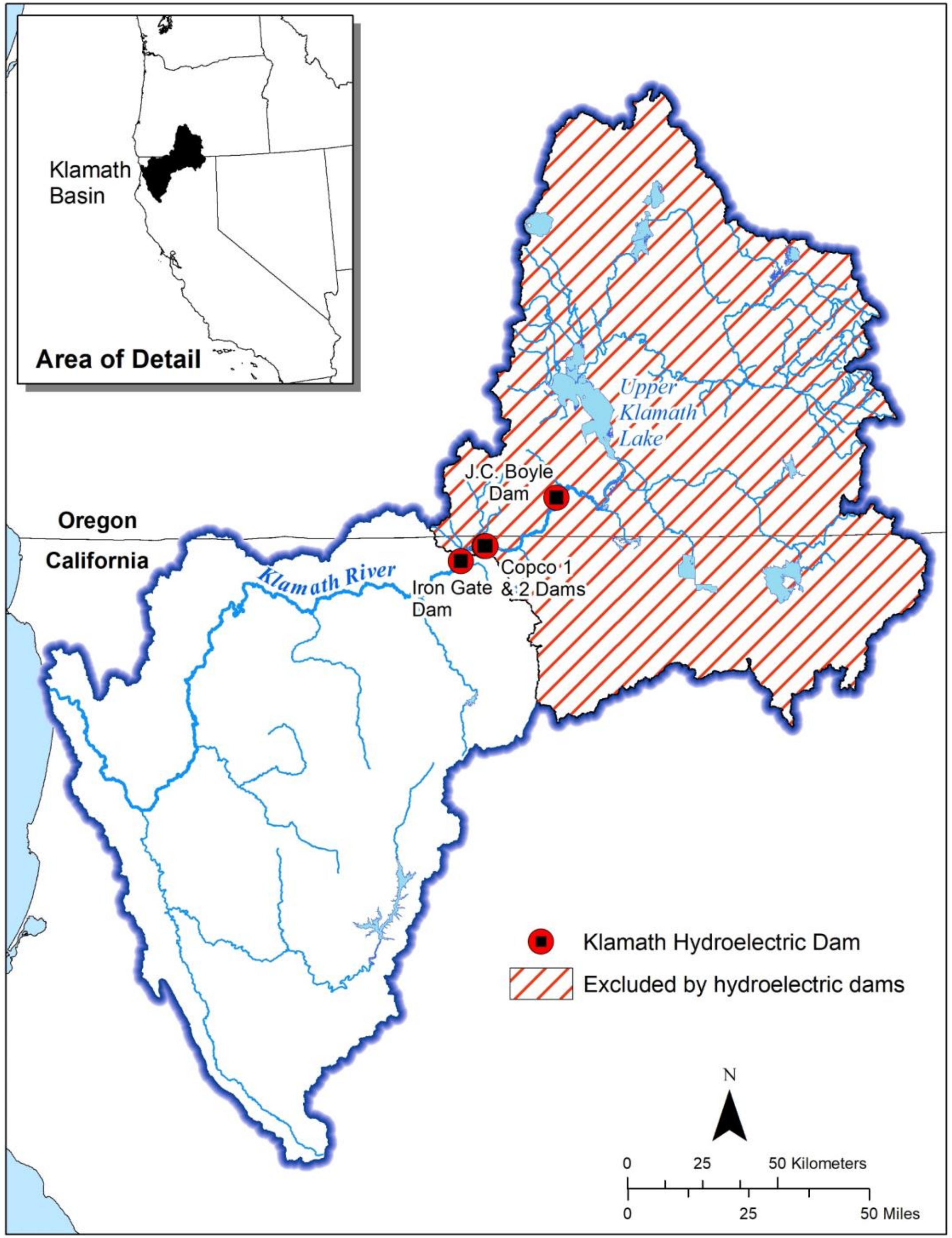
Mark Hereford
Oregon Department of Fish and Wildlife

- Construction of the first Klamath Hydroelectric Dam blocked anadromous fishes from Oregon in 1912
- Additional dams further blocked migration
- Anadromous fish have been extirpated from Oregon for over 100 years

Copco 1 Dam, CA

Iron Gate Dam, CA

J.C. Boyle Dam, OR



Dam removal

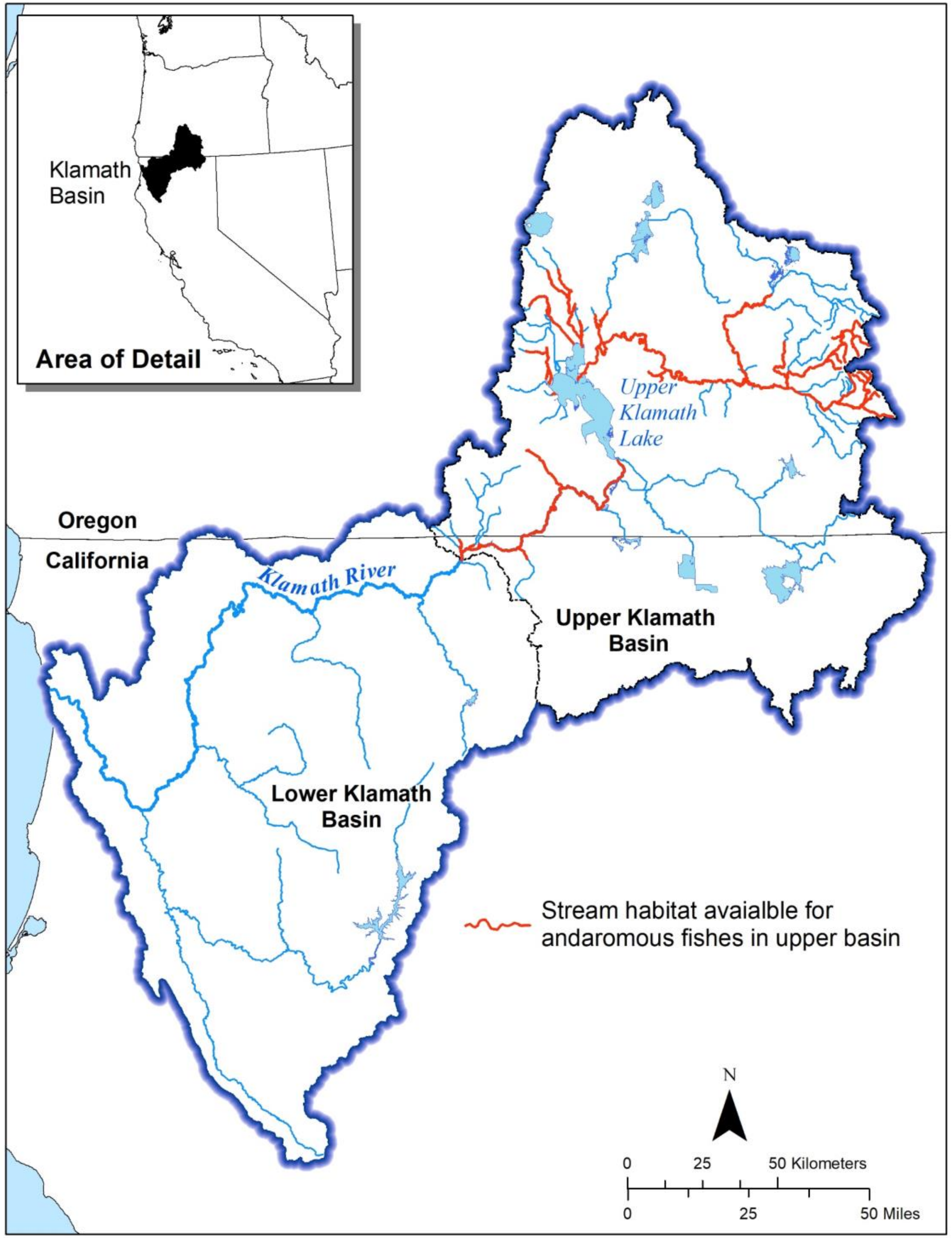
- Will open over 400 miles of stream habitat
- Access thermally diverse habitat that includes the largest groundwater inputs in the basin will improve conditions and allow fish a better chance to adapt and tolerate a changing climate

Chinook Salmon (spring and fall-run)

Coho Salmon

Pacific Lamprey

Steelhead Trout (anadromous *O.mykiss*)



Reintroduction Approaches

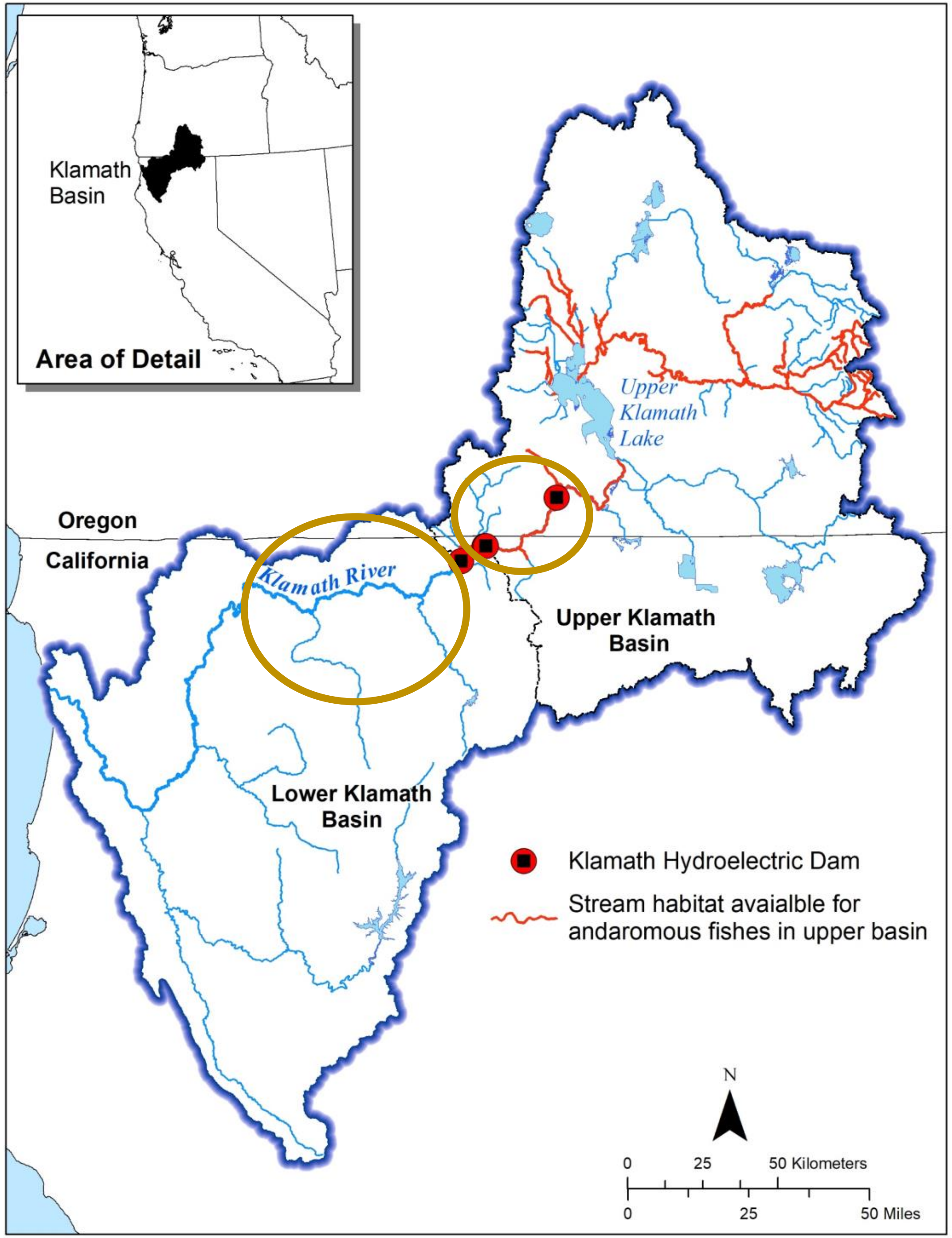
Natural Repopulation – Hands off approach

- Fall-run Chinook Salmon
- Coho Salmon
- Steelhead Trout
- Pacific Lamprey

- Currently exist immediately below Iron Gate Dam
- Habitat immediately above dams

Timeframe = 3 fish generations

- 9 years – Coho Salmon
- 12 years – fall-run Chinook Salmon
- 15 years – Steelhead and Pacific Lamprey



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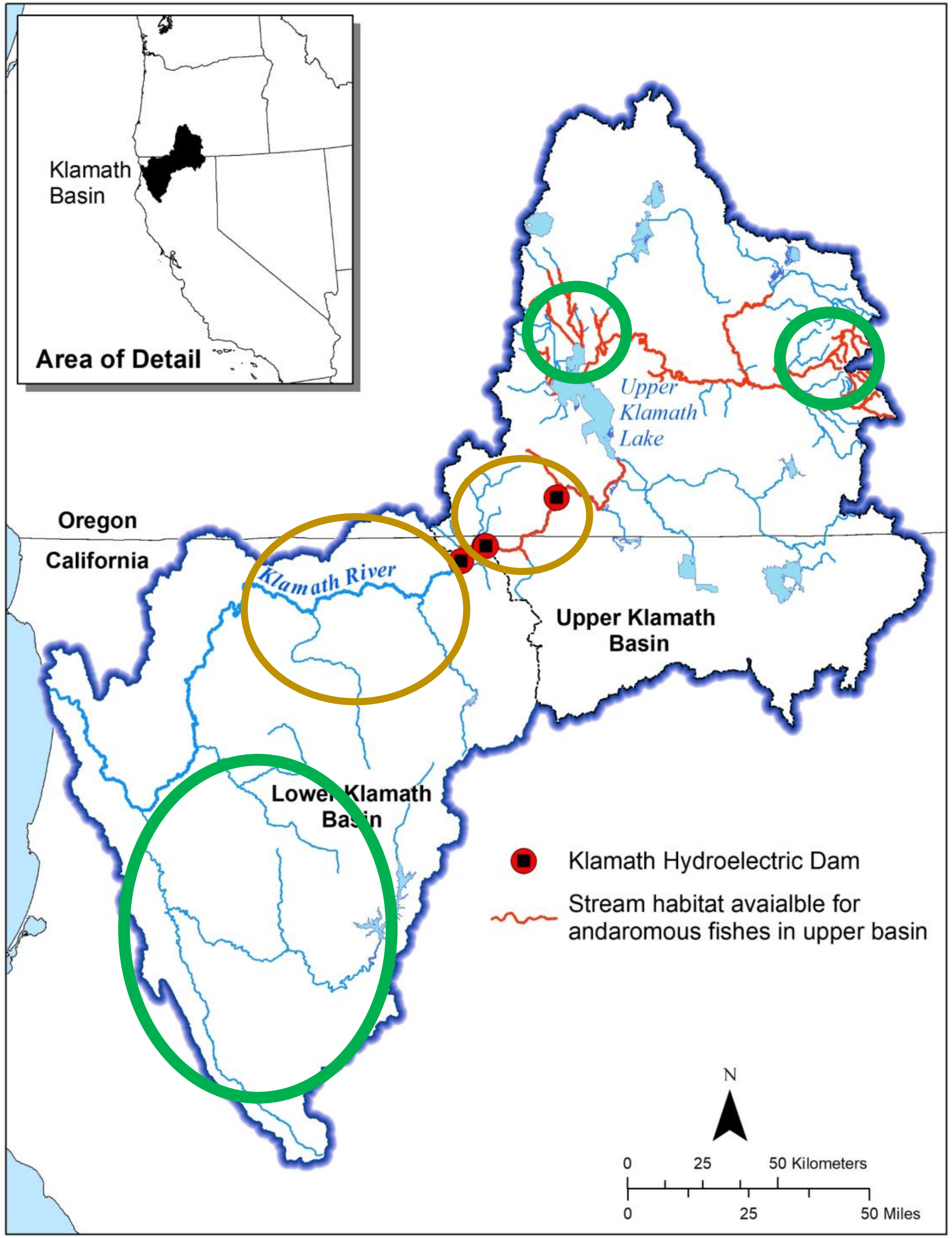
Active Repopulation – actively transporting fish

- Spring-run Chinook Salmon
- Juveniles from an in-basin source

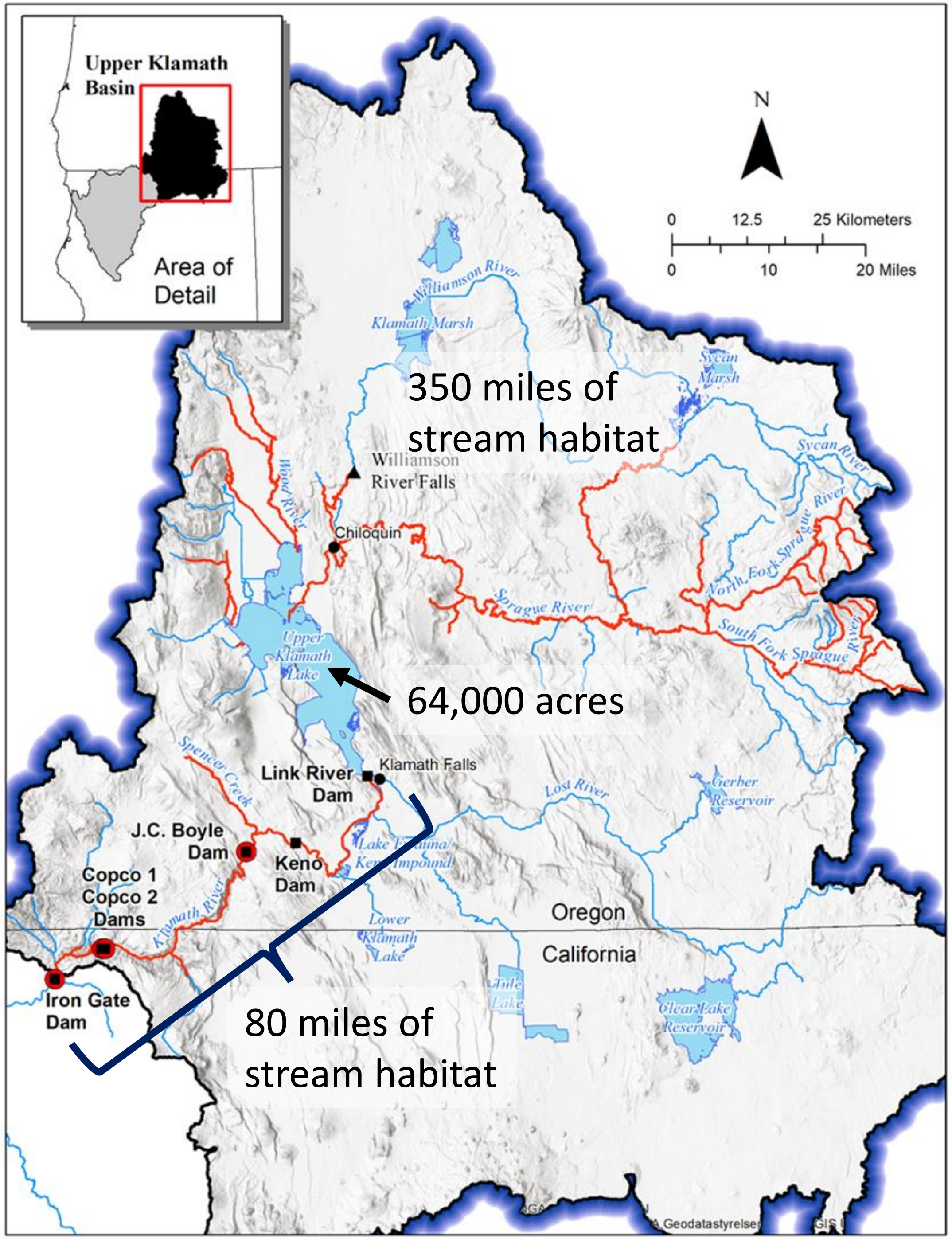


Monitoring Natural Repopulation

- **Determine if anadromous fishes are migrating upstream of the removed dams**
  - If so, what species and how many?
- Large amount of habitat to monitor
- Initially focus on habitat immediately above the dam sites
  - Mainstem and tributary spawning/carcass surveys
  - Tributary lifecycle monitoring stations
    - Video weir, PIT arrays, downstream juvenile trap
  - eDNA, SONAR

Adult salmon carcass surveys

Lifecycle monitoring station

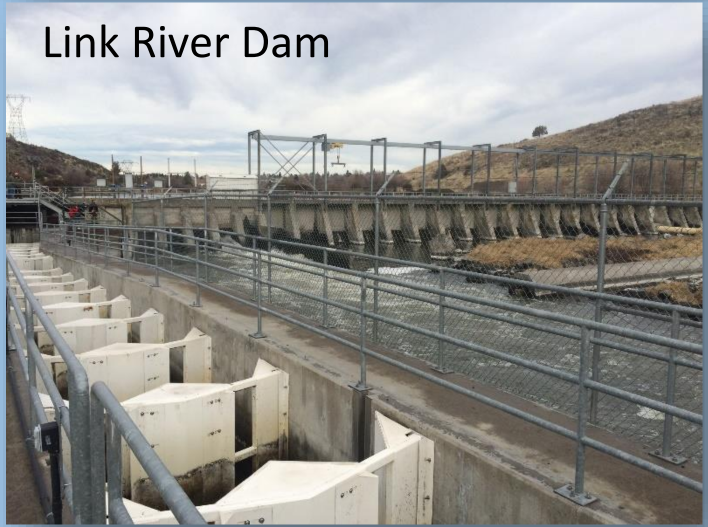


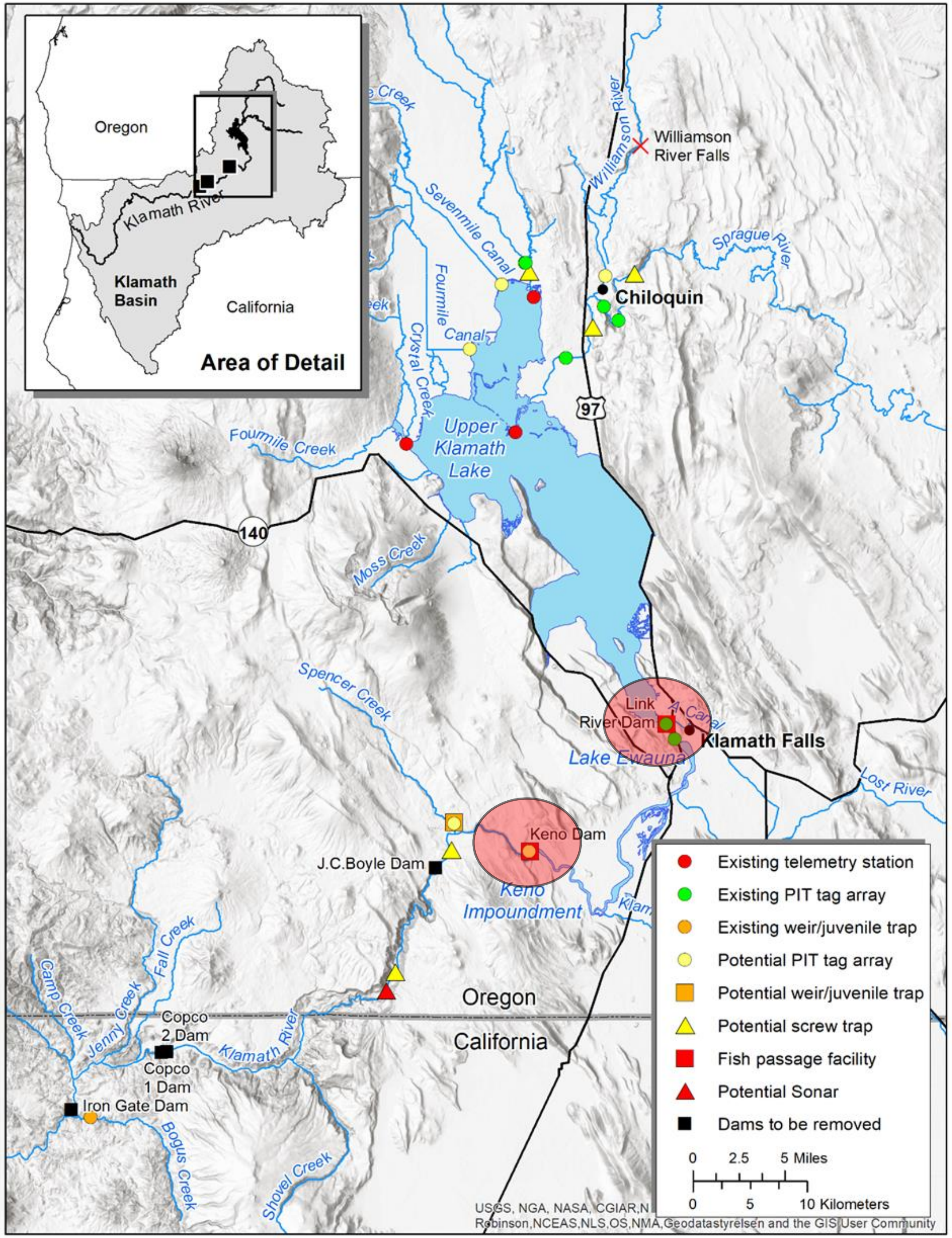
Monitoring Natural Repopulation

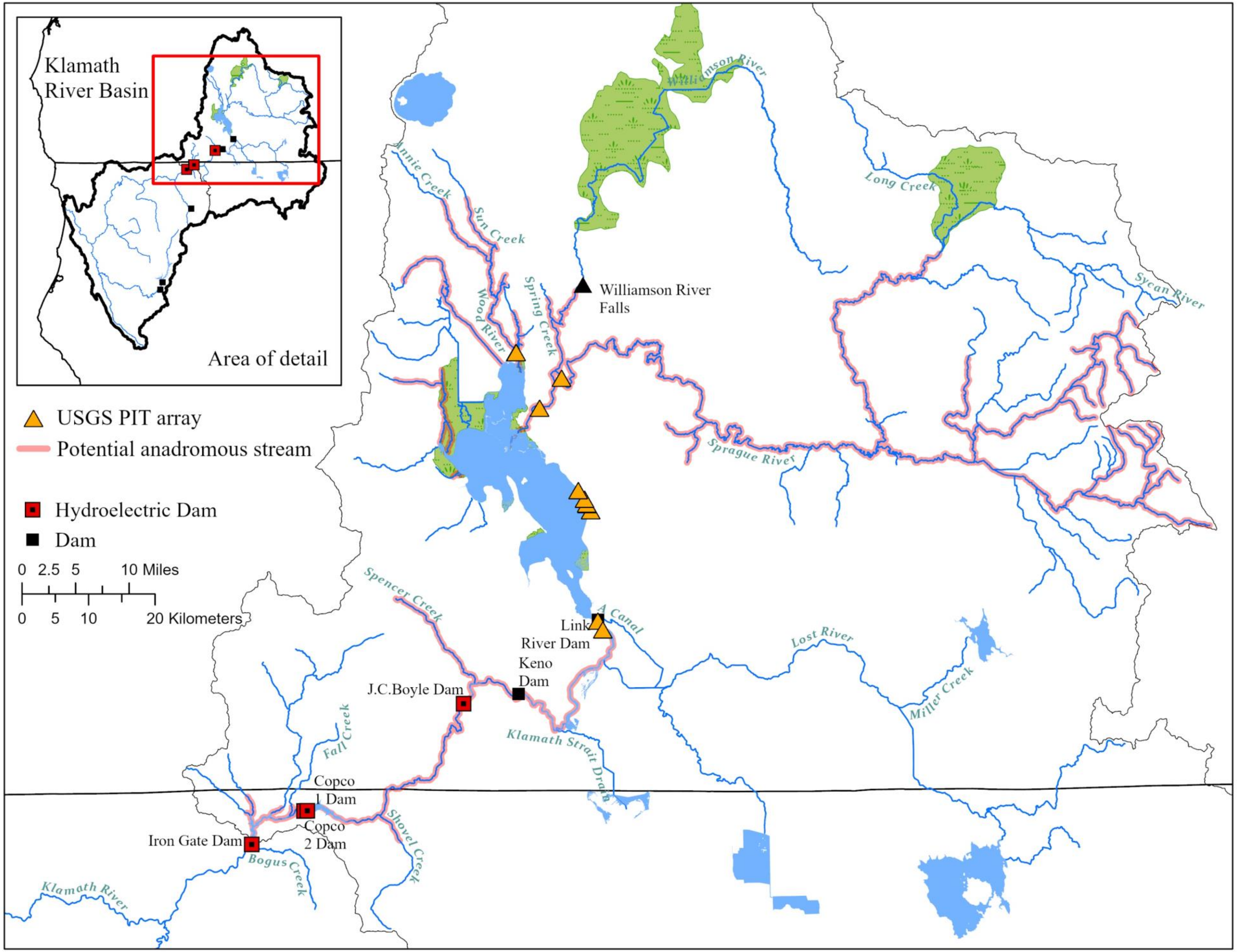
Upstream of Keno Dam and Link River Dam

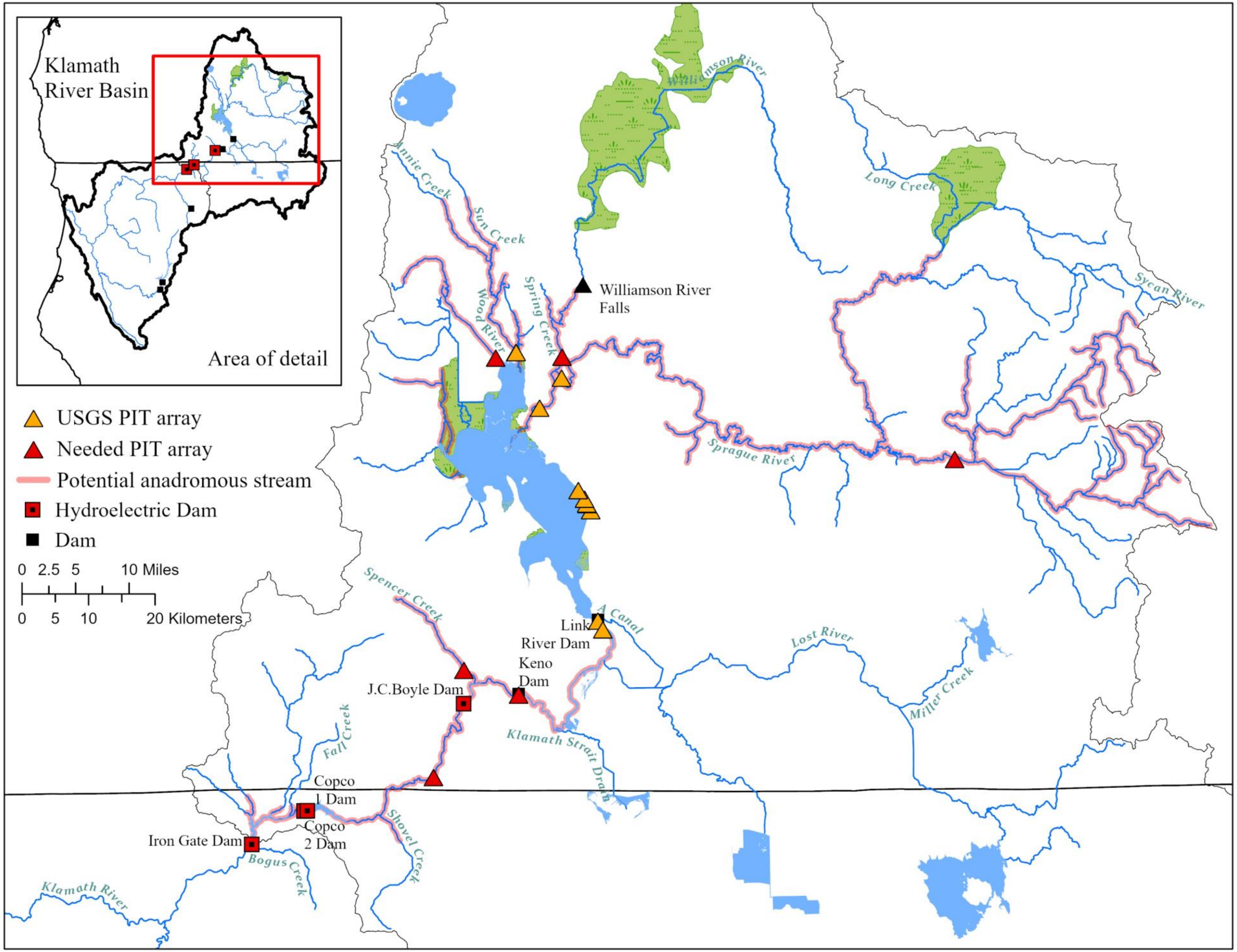
Fish Passage Facilities

- Sample adults migrating upstream through fish ladder
- Tag with telemetry tags
- Counting facility
- Assess movement through Upper Klamath Lake
- Identify location of tagged adults in tributaries of UKL
- Focus monitoring efforts in tributaries above UKL based on detections of tagged adults






Klamath River Basin
Area of detail
USGS PIT array
Potential anadromous stream
Hydroelectric Dam
Dam
0 2.5 5 10 Miles
0 5 10 20 Kilometers
Williamson River
Long Creek
Annie Creek
Sun Creek
Spring Creek
Wood River
Williamson River Falls
Sycan River
Sprague River
Spencer Creek
A Canal
Link River Dam
Keno Dam
J.C.Boyle Dam
Lost River
Miller Creek
Fall Creek
Klamath Strait Drain
Copco 1 Dam
Copco 2 Dam
Iron Gate Dam
Shovel Creek
Bogus Creek
Klamath River



Klamath River Basin
Area of detail
USGS PIT array
Needed PIT array
Potential anadromous stream
Hydroelectric Dam
Dam
0 2.5 5 10 Miles
0 5 10 20 Kilometers
Williamson River
Annie Creek
Sun Creek
Wood River
Spring Creek
Williamson River Falls
Long Creek
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Lost River
Miller Creek
Fall Creek
Klamath Strait Drain
Copco 1 Dam
Copco 2 Dam
Iron Gate Dam
Shovel Creek
Bogus Creek
Klamath River

Spring-run Chinook Salmon Active Repopulation

Phased Approach

- **Phase 1** –investigations involving the release of a small number of tagged juveniles into suitable tributaries above Upper Klamath Lake
  - Track fish as they migrate through the upper basin
  - Identify any potential limiting factors
- **Phase 2** – Apply lessons learned from Phase 1, but with increased abundance in numbers released to achieve returning adults

- Active repopulation efforts will be focused on streams that have suitable habitat and are more buffered to the immediate impacts of climate change

Klamath River near Klamath Falls, below Upper Klamath Lake

Williamson River entering Upper Klamath Lake

Spring-run Chinook Salmon Release Study

- In the spring of 2022 ODFW and partners will be conducting a juvenile Chinook Salmon release study in the Upper Klamath Basin using multiple telemetry technologies to investigate how outmigrating Chinook Salmon may navigate the current landscape

NOAA FISHERIES
National Oceanic and Atmospheric Administration

OREGON Fish & Wildlife

Oregon Conservation Recreation

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

The Nature Conservancy

UC DAVIS CENTER FOR WATERSHED SCIENCES

HUMBOLDT STATE UNIVERSITY

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF LAND MANAGEMENT

THE KLAMATH TRIBES KLAMATH · MODOC · YAHOOSKIN

U.S. FISH & WILDLIFE SERVICE DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

TROUT UNLIMITED

USGS science for a changing world

Spring-run Chinook Salmon Release Study

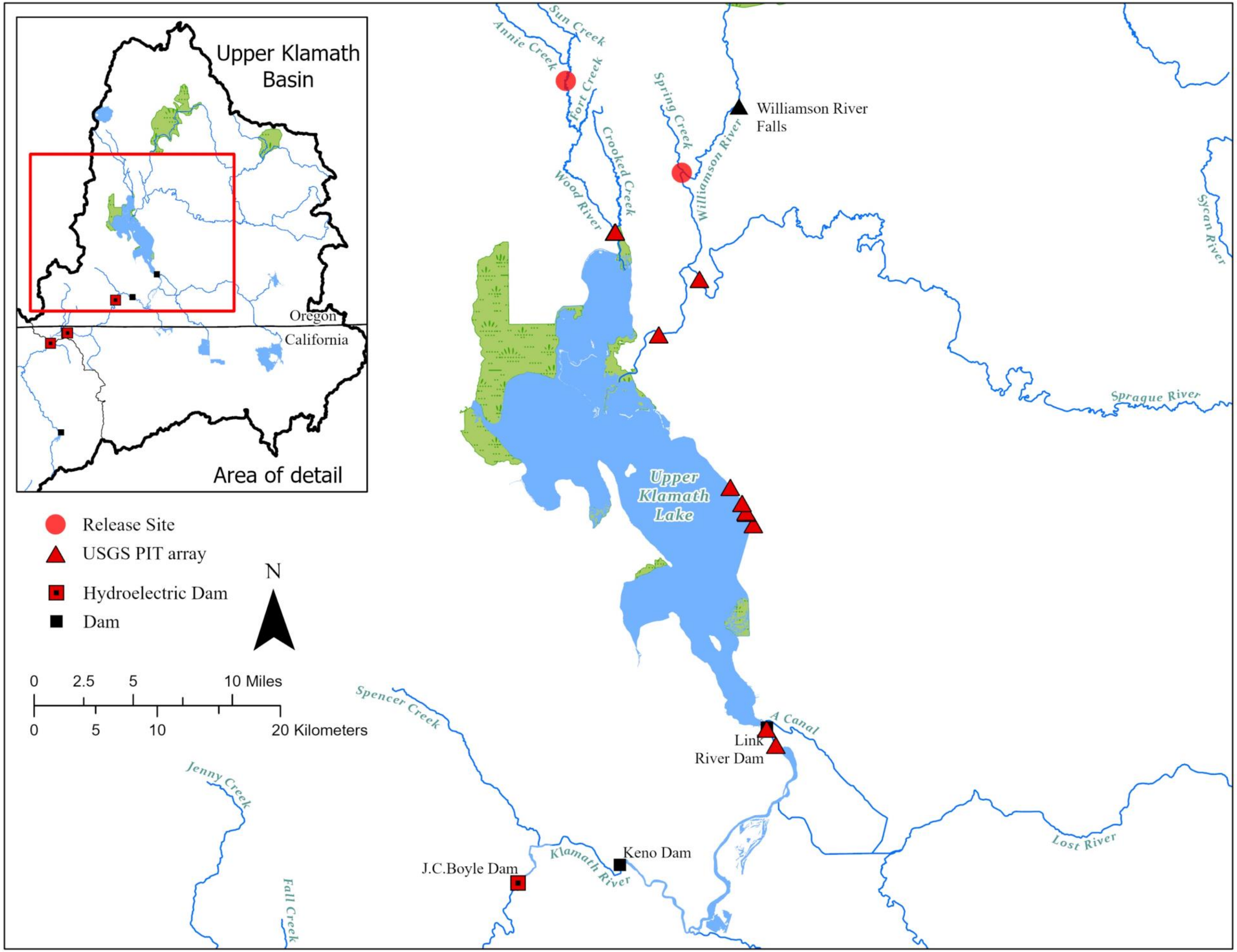
Objective 1 – assess outmigration from tributaries through UKL

- **UC Davis**
  - Mimic a hypothetical outmigration from the tributaries of Upper Klamath Lake, through the lake, and through the outlet
  - Release tagged hatchery reared juvenile Chinook Salmon – Spring of 2022
    - ~8,000 fish – 50% Wood River, 50% Williamson River
    - Acoustic, PIT tags
  - Track fish as they migrate through the upper basin
    - From tributaries to outlet of Upper Klamath Lake
    - Estimate reach-specific survival
  - Obtain a better understanding how juvenile Chinook might navigate and survive outmigration in the current landscape
    - Identify any limiting factors
    - Identify potential locations for restoration

Tagged juvenile Chinook Salmon

Upper Klamath Lake

Outlet of Upper Klamath Lake/Link River Dam



Upper Klamath Basin
Oregon
California
Area of detail
Release Site
USGS PIT array
Hydroelectric Dam
Dam
N
0 2.5 5 10 Miles
0 5 10 20 Kilometers
Sun Creek
Annie Creek
Fort Creek
Spring Creek
Williamson River Falls
Crooked Creek
Wood River
Williamson River
Sycan River
Sprague River
Upper Klamath Lake
A Canal
Link River Dam
Spencer Creek
Jenny Creek
Lost River
Keno Dam
J.C.Boyle Dam
Klamath River
Fall Creek

Spring-run Chinook Salmon Release Study

Objective 2 - assess migration from above Link River Dam through Keno Dam

- **Cal Poly Humboldt (Humboldt State)**

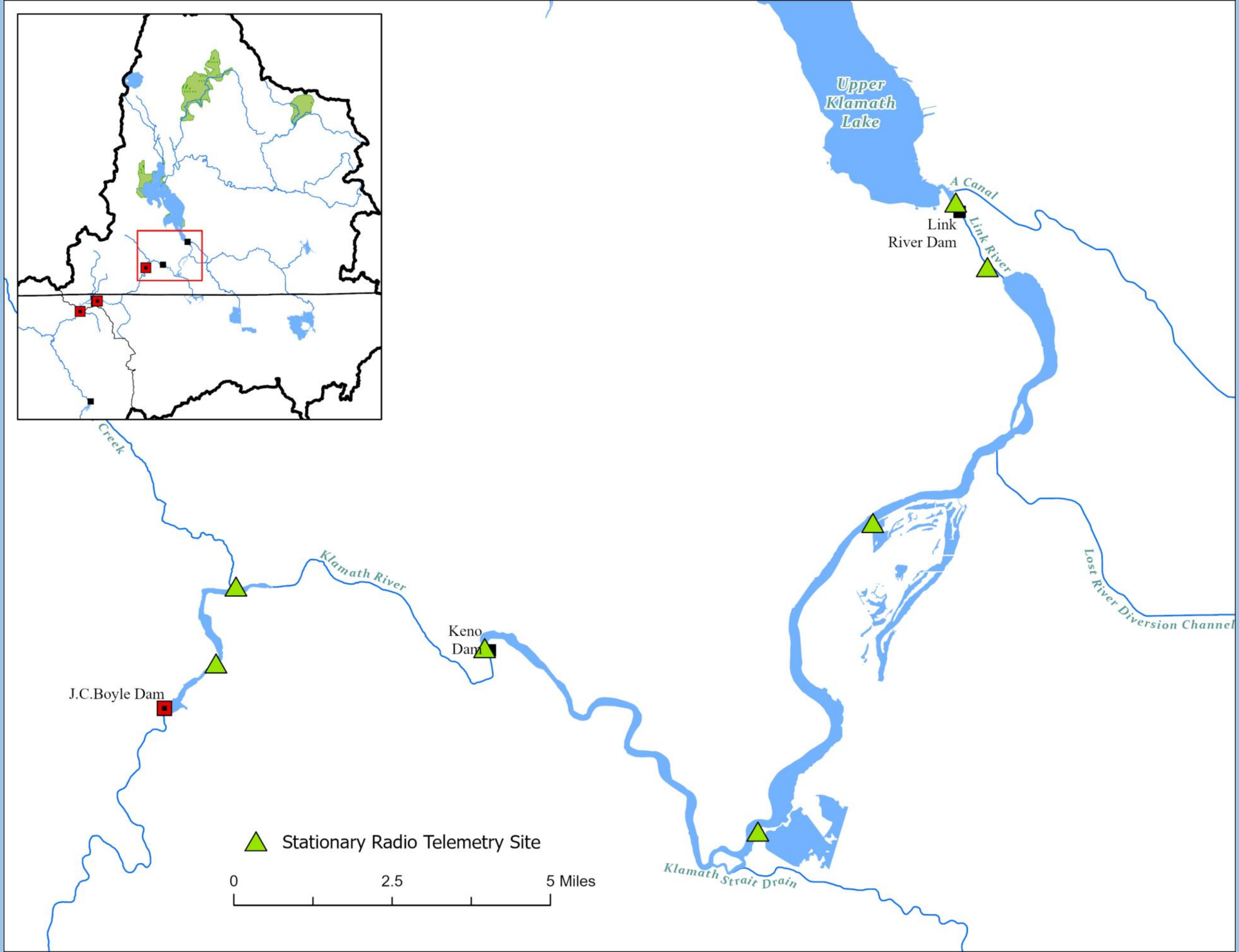
- Release juvenile Chinook Salmon above Link River Dam and Keno Dam and track their movements through the Link River, Lake Ewauna, Klamath River, and through Keno Dam
- Release ~200 VHF NanoTagged fish in spring of 2022
  - 30% above Link River Dam
  - 60% below Link River Dam (Lake Ewauna)
  - 10% above Keno Dam
- Detect tagged fish via 7 stationary receivers mobile tracking (motorboat and vehicle)
- Identify any impediments or delays to migration through this reach

Tagged juvenile Chinook Salmon

Link River Dam

Lake Ewauna /Klamath River

Keno Dam


Upper Klamath Lake
A Canal
Link River Dam
Link River
Creek
Klamath River
Keno Dam
J.C.Boyle Dam
Lost River Diversion Channel
Klamath Strait Drain
Stationary Radio Telemetry Site
0
2.5
5 Miles

Questions?

Klamath River downstream of J.C. Boyle Powerhouse, OR

Klamath River Juvenile Coho Salmon Life History Behavior

Jimmy Faukner
Yurok Tribe Fisheries Department
Lower Klamath Program
Klamath, CA

Klamath River Juvenile Coho Salmon Life History Behavior

1. **Stay in general area they are spawned through entire freshwater cycle.**

   — Frequent

2. **Move downstream in spring as fry/parr but do not leave the natal watershed.**

   — Frequent

3. **Move downstream as parr in the fall/winter but do not leave the natal watershed.**

   — Frequent

4. **Move downstream as spring fry/parr in the natal watershed and then move back upstream to overwinter in the natal watershed.**

   — Less Frequent

5. **Move downstream in late spring in their first year (age-0) as parr and rear in the mainstem Klamath. As water temperatures increase they move into areas adjacent to the mainstem Klamath in areas of thermal refugia. They remain in these habitats until they outmigrate as smolts.**

   — Varies among years – frequent to rare. More common in the Mid Klamath Region than the Lower Klamath Region

6. **Move downstream in late spring in their first year (age-0) as parr and rear in the mainstem Klamath. As water temperatures increase they move into areas adjacent to the mainstem Klamath in areas of thermal refugia. At the onset of higher flows in fall and winter they seek a different tributary for overwintering.**

   — Varies among years – frequent to rare

7. **Rear in natal watershed and then move downstream during higher flows in the fall and winter and overwinter in a different watershed that has natal production.**

   — Varies among years – frequent to rare

Klamath River Juvenile Coho Salmon Life History Behavior
(continued)

8. Rear in natal watershed and then move downstream during higher flows in the fall and winter and overwinter in a different watershed that does not have natal production.

— ***Varies among years – frequent to rare***

9. Rear in natal watershed and then move downstream during higher flows in the fall and winter and overwinter in more than one tributary.

— ***Rare***

10. Overwinter in the mainstem Klamath in slow water habitats.

— ***Varies among years, documented in Mid Klamath, unsure of frequency***

11. Overwinter in the estuary.

— ***Varies among years, lack of sampling effort, unsure of frequency***

12. Overwinter outside the Klamath Basin.

— ***Very rare? 2 juveniles PIT tagged in Lower Klamath Tributaries recaptured in Prairie Creek***

13. Outmigrate as age-0 smolts.

— ***Rare? Documented in the Shasta River.***

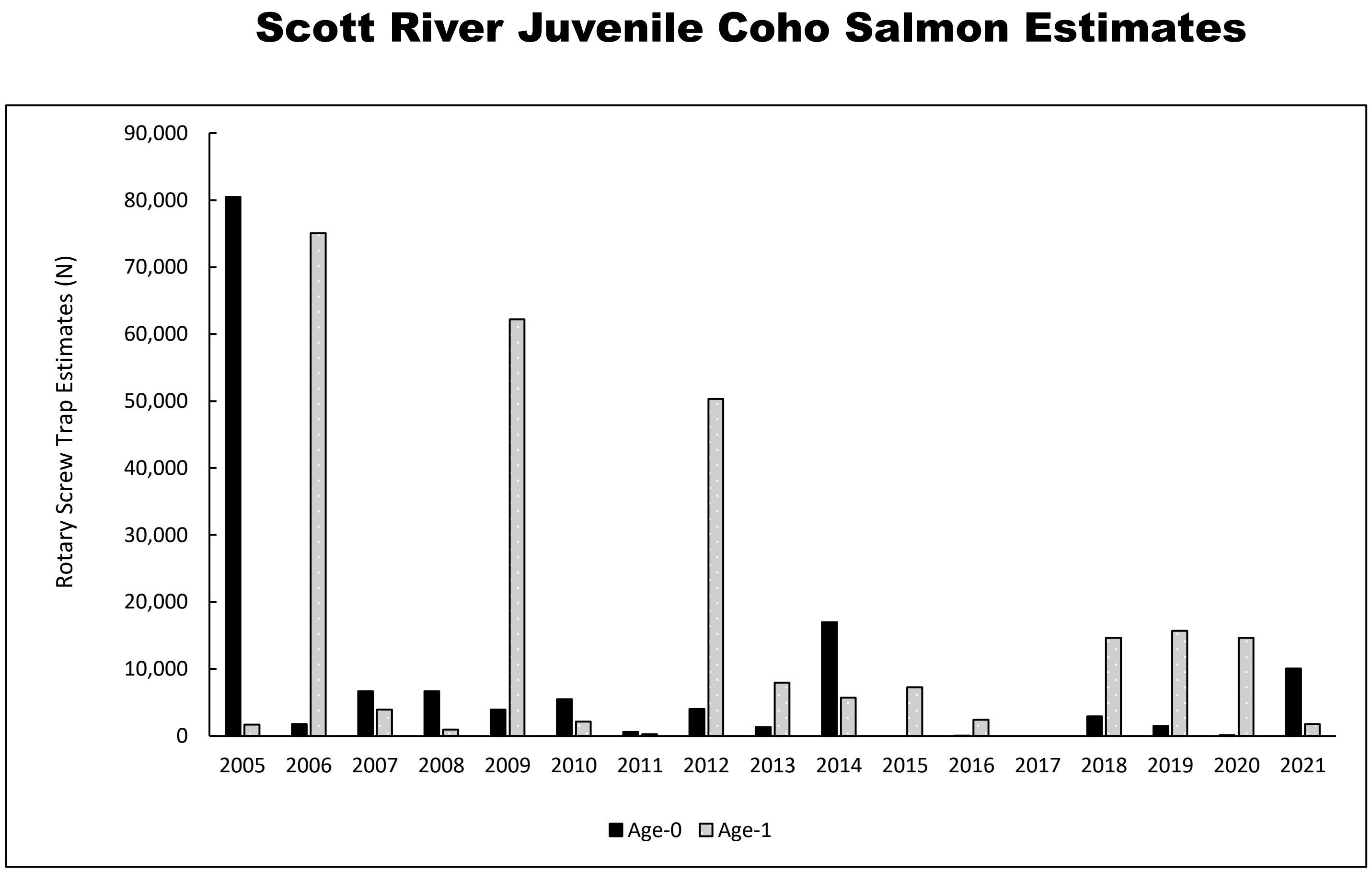
14. Outmigrate as age-1 smolts.

— ***Frequent***

15. Outmigrate as age-2 smolts.

— ***Rare? Appears to be geographically widespread (Shasta, Scott, Mid, Lower)***

Spring Fry/Parr That Leave Their Natal Stream



Spring Fry/Parr That Leave Their Natal Stream

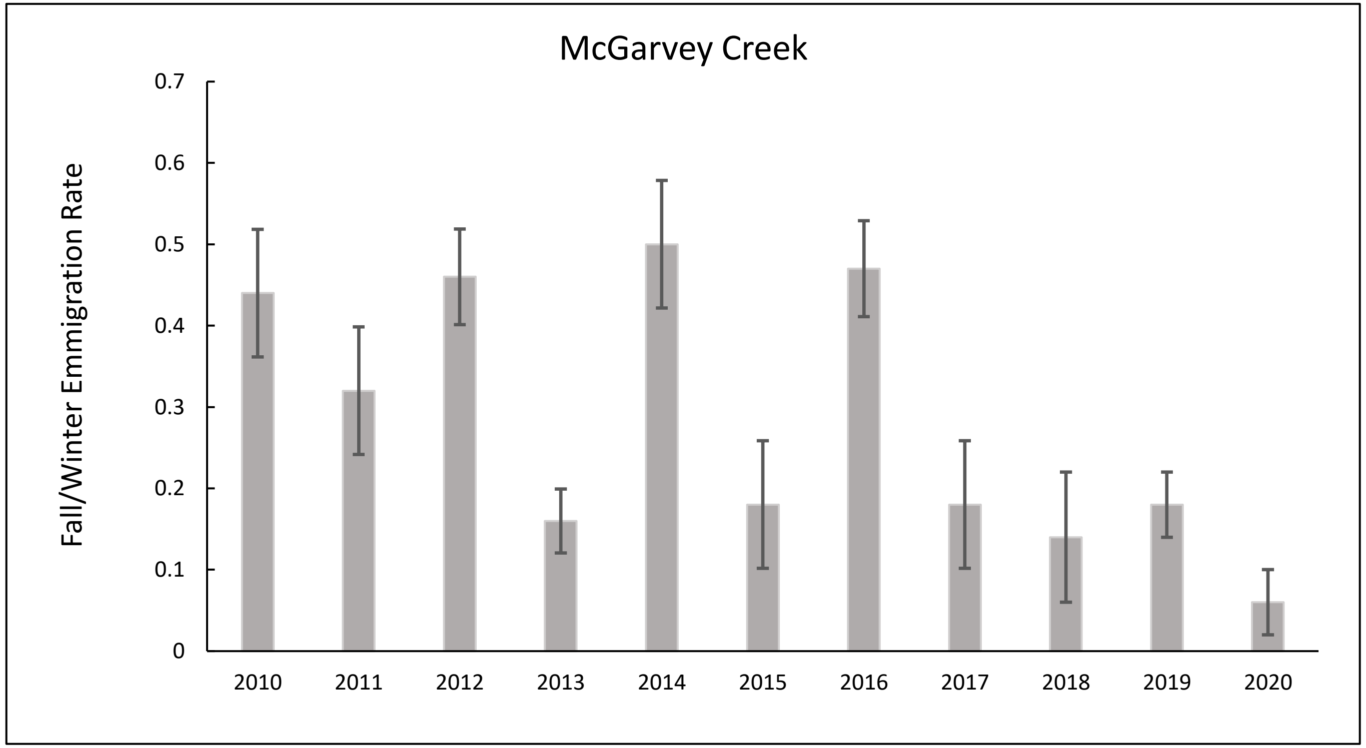
Move downstream in late spring in their first year (age-0) as parr and rear in the mainstem Klamath. As water temperatures increase they move into areas adjacent to the mainstem Klamath in areas of thermal refugia. At the onset of higher flows in fall and winter they seek a different tributary for overwintering.

PIT Tag #	Tagging Location	Tagging Date	FL at Tagging	Tributary	Winter Detection	Spring Detection
985121028464084	Tom Martin Creek	7/23/12	95	McGarvey	12/10/2012	
985121028853956	Tom Martin Creek	7/23/12	80	McGarvey	12/14/2012	5/3/2013
985121028844245	Tom Martin Creek	7/23/12	97	Panther	1/11/2013	
985121028845260	Tom Martin Creek	8/6/12	76	Panther	12/20/2012	
985121028481112	Tom Martin Creek	8/6/12	78	Salt Creek		5/2/2013
985121028851787	Tom Martin Creek	8/6/12	83	Salt Creek		5/7/2013
985121028872659	Tom Martin Creek	8/6/12	85	Salt Creek		5/8/2013
985121028848108	Tom Martin Creek	8/6/12	92	Waukell		5/8/2013
985121028860836	Tom Martin Creek	8/6/12	68	Waukell	12/25/2012	3/24/2013
985121028865774	Tom Martin Creek	7/23/12	81	Waukell	12/27/2012	5/7/2013
985121028897963	Tom Martin Creek	7/10/12	78	Waukell	12/9/2012	
985121028916697	Tom Martin Creek	7/10/12	76	Waukell	12/7/2012	

Parr That Leave Their Natal Stream In The Fall/Winter

Rear in natal watershed and then move downstream during higher flows in the fall and winter and overwinter in a different watershed that does not have natal production.

Fall/Winter Emigration Cutoff January 31st



Parr That Leave Their Natal Stream In The Fall/Winter
(continued)

Rear in natal watershed and then move downstream during higher flows in the fall and winter and overwinter in a different watershed that does not have natal production.

Numbers of PIT tagged juvenile Coho Salmon detected leaving McGarvey Creek from October 1st through January 31st and subsequently detected at PIT tag detection stations in Lower Klamath River tributaries.

	Exit	Enter				
Year	McGarvey	Waukell	Panther	Salt	Terwer	% Detected
2012−2013	166	48	12	8	0	41.0
2013−2014	47	7	2	2	1	27.7
2014−2015	93	29	7	2	3	44.1
2015−2016	23	5	2	3	0	43.5
2016−2017	76	21	6	2	6	46.0

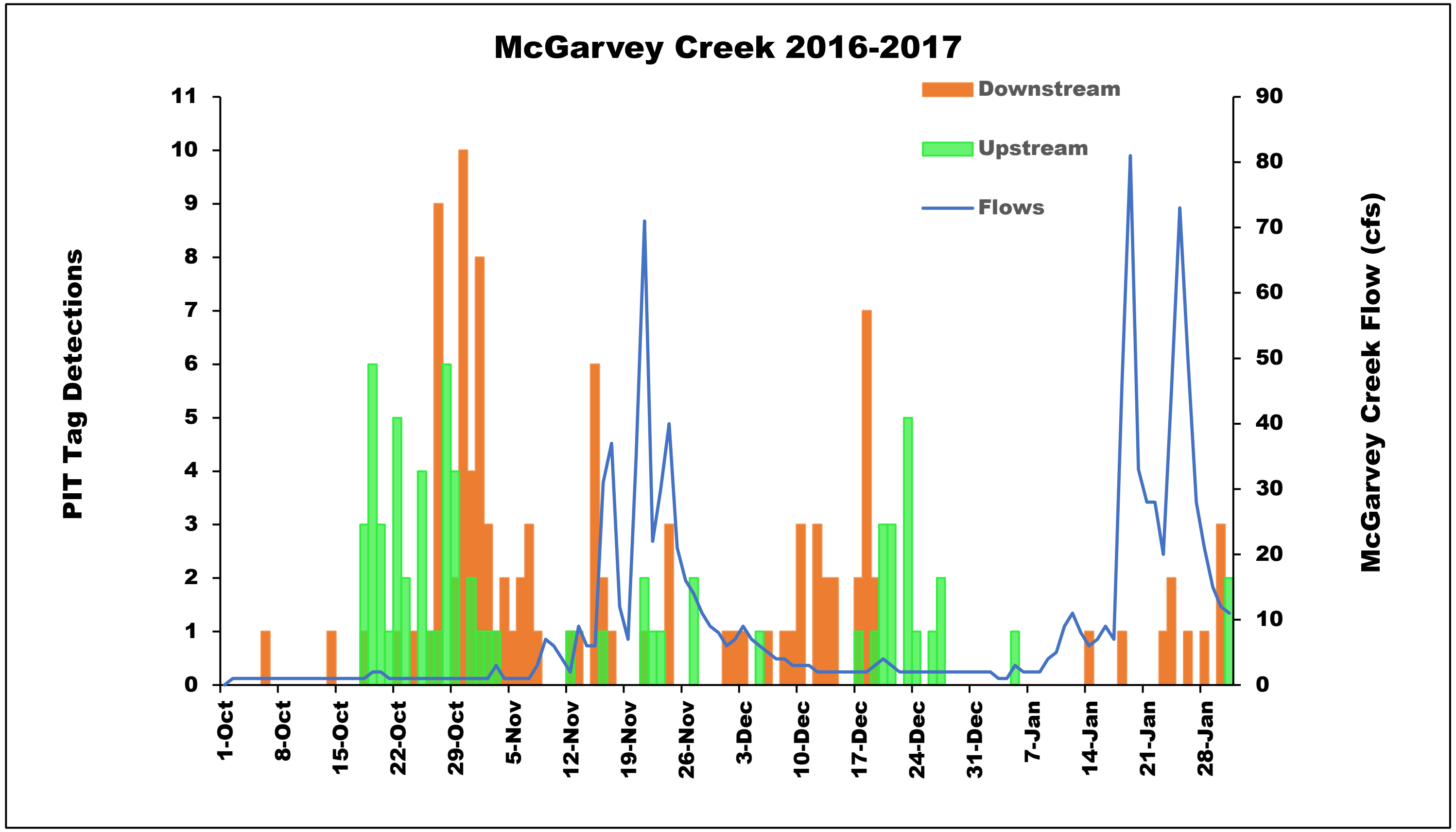
Parr That Leave Their Natal Stream In The Fall/Winter
(continued)

Rear in natal watershed and then move downstream during higher flows in the fall and winter and overwinter in a different watershed that has natal production.

PIT Tag	Tagging Location	Tagging Date	Enter McGarvey	Exit McGarvey
985121026870840	Ah Pah Creek	10/7/2014	11/16/2014	
985121026890612	Ah Pah Creek	10/7/2014	11/2/2014	5/11/2015
985121026905407	Ah Pah Creek	10/7/2014	10/24/2014	
985121030724611	Aikens Pool	10/30/2014	11/24/2014	
985121030813072	Aikens Pool	10/30/2014	11/29/2014	
985121030838510	Aikens Pool	10/14/2014	11/26/2014	
985121031224959	Aikens Pool	10/30/2014	12/11/2014	
985121031246077	Aikens Pool	10/14/2014	12/13/2014	
985121030755049	Big Bar RST	10/28/2014	12/11/2014	
985121030736495	Camp Creek	8/11/2014	12/3/2014	
985121030810514	Camp Creek	8/11/2014	11/28/2014	
985121030840690	Camp Creek	8/11/2014	12/7/2014	
985121030842923	Camp Creek	8/11/2014	12/4/2014	
985121030831347	China Creek	6/5/2014	12/24/2014	
985121031240917	Elk Creek East Fork	7/24/2014	2/8/2015	
985121030753224	Lewis Riffle K.R.	12/16/2014	2/9/2015	2/13/2015
985121030806184	Lewis Riffle K.R.	12/16/2014	12/28/2014	2/24/2014
985121031215774	Lewis Riffle K.R.	12/16/2014	12/24/2014	4/22/2015
985121031200293	Muddy Mile Eddy	11/21/2014	11/30/2014	
985121030832275	Red Cap Creek	11/13/2014	11/27/2014	
985121030841279	Red Cap Creek	11/13/2014	12/13/2014	
985121031186137	Red Cap Creek	11/13/2014	12/13/2014	
985121031200465	Red Cap Creek	11/13/2014	12/6/2014	
985121031228912	Red Cap Creek	11/13/2014	11/28/2014	
985121031186591	Sandy Bar	12/17/2014	2/27/2015	4/19/2015
985121031220284	Sandy Bar	12/17/2014	12/28/2014	
985121031197168	Seiad Creek	7/19/2014	12/15/2014	12/17/2014
985121031245526	Seiad Creek	8/27/2014	12/7/2014	5/19/2015
985121031248718	Seiad Creek	7/17/2014	12/25/2014	5/16/2015
985121030742899	Titus Creek	8/13/2014	12/27/2014	2/4/2015
985121031182465	Titus Creek	8/13/2014	12/13/2014	
985121031233831	Titus Creek	6/19/2014	12/14/2014	4/21/2015

Some Klamath River Tributaries That Support Natal Population Export and Import Juvenile Coho Salmon

Based on what is occurring in McGarvey Creek the same situation is likely occurring in many Klamath River Tributaries with natal production (e.g. Seiad and Horse Creeks).



Return Year	PIT Tag #	Tagging Location	Tagging Date	McGarvey Exit	McGarvey Enter	Age at Return	Non-natal Rearing	Tributary
2020/2011	**985120024719944**	Salt Creek	7/31/2009	?	11/10/2010	2	Yes	Salt
	985121013383993	Pipe Trap	11/8/2008	?	12/1/2010	3	Yes	Waukell
	985121015307021	Pipe Trap	11/17/2008	?	12/10/2010	3	Yes	Salt
2011/2012	**985121016221728**	Salt US	7/21/2010	?	12/29/2011	2	Yes	Salt
	985121016150652	Panther US	1/8/2010	?	1/2/2012	3	Yes	Panther
	985121025508998	McGarvey	5/5/2011	?	1/7/2012	2	No	
2012/2013								
2013/2014								
2014/2015	985121030726701	Pipe Trap	4/14/2014	4/18/2014	10/15/2014	2	No	
	985121028905234	Lower McGarvey	11/19/2013	**2/22/2014**	10/27/2014	2	No	
	985121025924698	WF McGarvey	11/13/2013	4/16/2014	10/28/2014	2	No	
	985121030736504	Pipe Trap	5/19/2014	5/22/2014	11/21/2014	2	No	
	985121028872639	Upstream Trap	11/11/2012	5/1/2013	11/22/2014	3	No	
	985121028872812	Pipe Trap	2/7/2013	4/26/2013	11/23/2014	3	No	
	985121028248905	Pipe Trap	3/8/2013	3/18/2013	11/23/2014	3	No	
	985121028924673	WF McGarvey	11/13/2013	3/3/2014	11/29/2014	2	No	
	985121030736460	Pipe Trap	3/28/2014	5/31/2014	12/20/2014	2	No	
	985121030804886	Pipe Trap	5/2/2014	5/7/2014	1/3/2015	2	No	
2015/2016	989001000496740	Pipe Trap	4/8/2016	4/13/2016	10/25/2016	2	No	
2016/2017	989001000495662	Upper McGarvey	9/4/2015	4/11/2016	11/24/2016	2	No	
	985121030821074	Alcove III	8/26/2014	**2/17/2015**	12/13/2016	3	No	
2017/2018	**989001000497976**	Upper McGarvey	9/28/2016	10/26/2016	1/20/2018	2	Yes	Waukell
2018/2019	**989001000497559**	WF McGarvey	9/29/2016	1/30/2017	11/23/2018	2	Yes	Unknown
	989001000497502	WF McGarvey	9/29/2016	5/11/2017	11/29/2018	2	No	
	989001000498508	Lower McGarvey	9/7/2017	4/24/2018	11/29/2018	2	No	
	989001000498561	Lower McGarvey	8/24/2017	11/24/2017	12/17/2018	2	Yes	Waukell
2019/2020								
2020/2021	989001006144735	Upstream Trap	2/4/2020	4/7/2020	11/15/2020	2	No	
	989001006263568	Fish Rescue	8/28/2019	1/31/2020	11/19/2020	2	Yes	Unknown
	989001006145099	Upstream Trap	2/4/2020	5/8/2020	12/15/2020	2	No	
2021/2022	989001006266441	Fish Rescue	8/19/2020	4/26/2021	10/22/2021	2	No	

PIT Tag #	Tagging Date	Tagging FL	Tagging Location	Enter McGarvey	Exit McGarvey	Enter Waukell
989001004681769	6/17/2016	87	Terwer Rescue	6/22/2016	11/1/2016	11/2/2016

Why Do I Think Documenting Juvenile Life History Behavior Is Important?

Do these behaviors persist over time?

How do these behaviors influence the juveniles out/adults in Life Cycle Monitoring strategy based on smolt estimates?

Where should stream restoration take place?

Do the non-natal rearing life history strategies contribute to adult returns?

How easy is it to do any of this without a functioning database?

Using the Klamath Basin PIT tag database to inform the Stream Salmonid Simulator (S3) for Juvenile Coho Salmon in the Klamath River

Russell W. Perry and Michael J. Dodrill

USGS, Western Fisheries Research Center

Nicholas A. Som and Christopher V. Manhard

USFWS, Arcata Fish and Wildlife Office

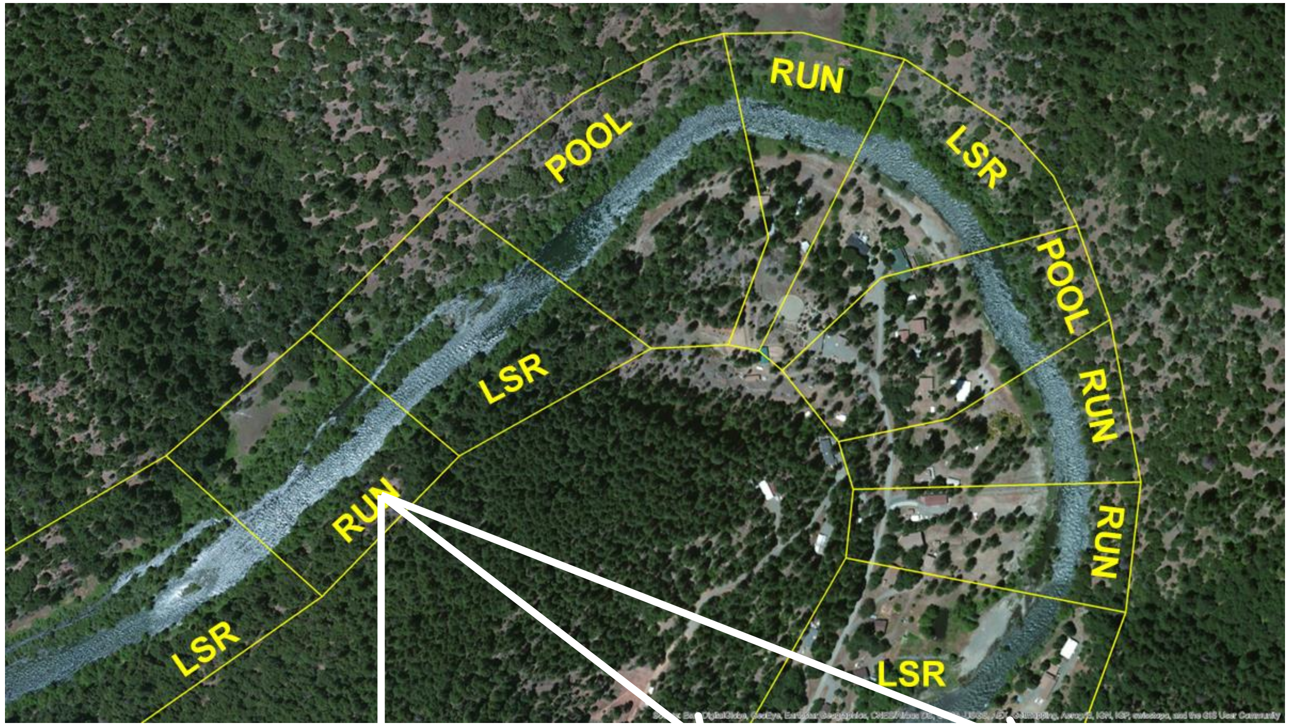
Overview

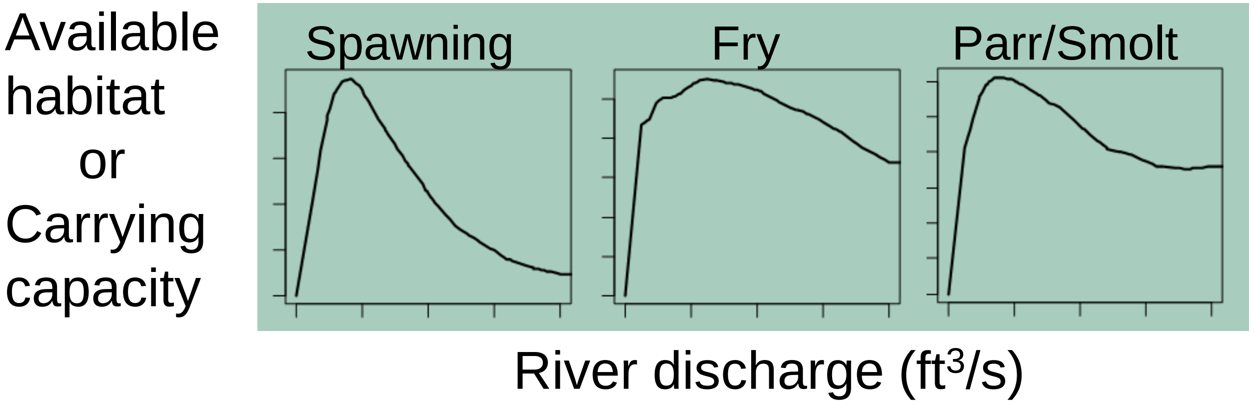
- Goal
  - How PIT tag database was used to inform S3 for Coho
- Brief intro to the Stream Salmon Simulator (S3)
- Analyses of PIT-tag data to support S3
- Examples of S3 model output for Coho

S3 is a Decision Support Model

- Quantify response of fish populations to
  - Factors affecting habitat (e.g., restoration)
  - Flow and temperature management
  - Disease from *C. shasta*
- Understand possible mechanisms of response
  - Comparing alternative hypotheses
- Identify data gaps for monitoring
  - Example: Fall Coho emigrants
- Aid in decision making

Underlying Basis of S3: Flow Affects Habitat





Underlying Basis of S3:
Habitat Affects Population Dynamics

Habitat Quantity and Quality

↓

Carrying Capacity

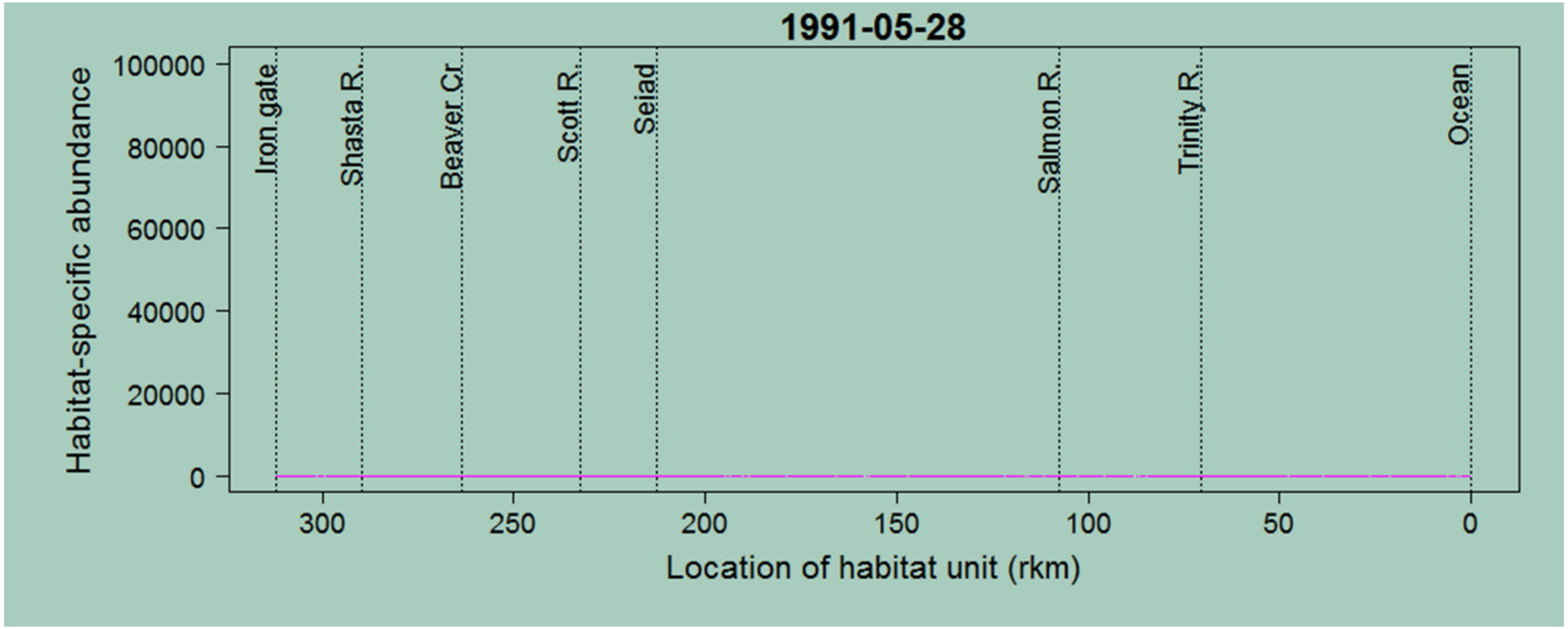
↓

Density Dependent
Population Dynamics

Growth | Movement | Survival

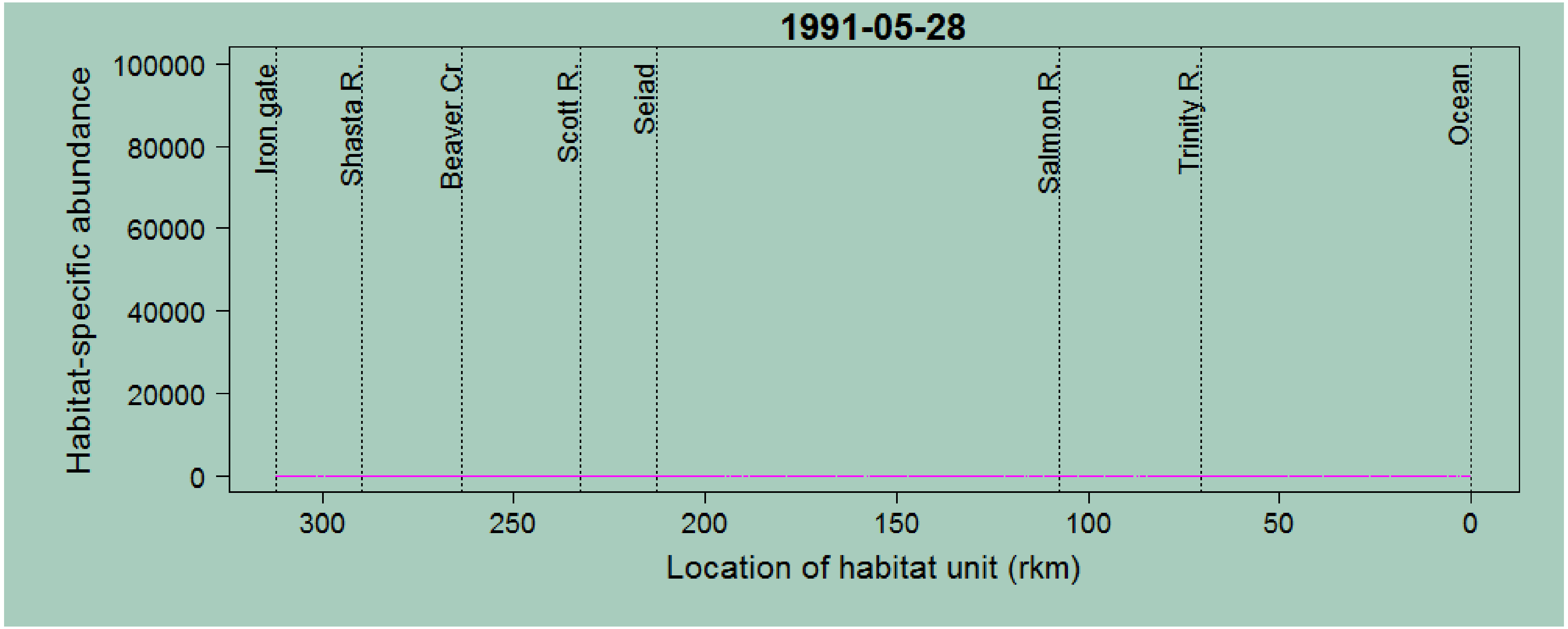
Visualizing Dynamics in S3

- Example from Iron Gate Hatchery
- 5 million juvenile Chinook salmon released on 5/29/1991



Visualizing Dynamics in S3

- Example from Iron Gate Hatchery
- 5 million juvenile Chinook salmon released on 5/29/1991



Key Elements of Coho Life History in S3

- Use of non-natal tributaries
  - Fundamental to life cycle

- Emigration timing from natal tributaries
  - Age 1 smolts in spring
  - Age 0 fry in spring
  - Age 0 juveniles in fall (no data)

- Mainstem movement and tributary colonization
  - Age 1 smolts migrate to ocean
  - Age 0 juveniles may colonize non-natal tribs

- Non-natal tributary residence
  - Overwinter survival
  - Mainstem re-entry timing
    - Fall/Winter
    - Spring as age-1 smolts

Important Uses of PIT Tag Data

U.S. Fish & Wildlife Service

Arcata Fisheries Technical Report TR 2018-33

Estimating Freshwater Productivity, Overwinter Survival, and Migration Patterns of Klamath River Coho Salmon

Christopher V. Manhard, Nicholas A. Som, Russell W. Perry, Jimmy R. Faukner and Toz Soto

https://www.fws.gov/arcata/fisheries/reports/technical/2018/EstimatingFreshwaterProductivityOverwinterSurvivalandMigrationPatternsofKlamathRiverCohoSalmon.pdf

Arrays used for these analyses

- Waukell Creek
- McGarvey Creek
- Seiad Creek
- Panther Creek
- Sandybar Floodplain Channel

- Except for mainstem migration rates, these analysis reference tribs other than Bogus, Shasta, Scott.

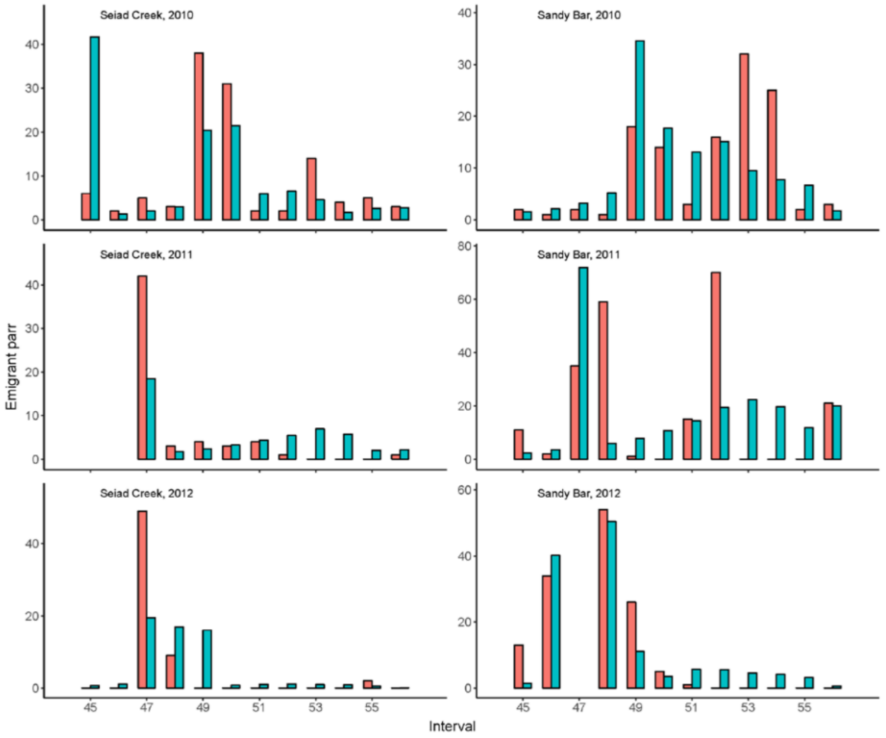
Winter Emigration Rates and Timing

- Tributary → Mainstem
- Fish tagged prior fall at age-0
- Winter Emigrant: last detected leaving before Jan 31
- Bayesian multistate mark-recapture model
  - States: not detected, winter emigrant, spring emigrant
  - Likelihood includes Emigration rates and Detection Efficiencies

- Detection efficiencies high (> 0.88)
- Overwinter survival generally ranged ~ 0.3 – 0.5
- Winter emigration rates ranges ~ 0.2 – 0.45

Winter Emigration Timing

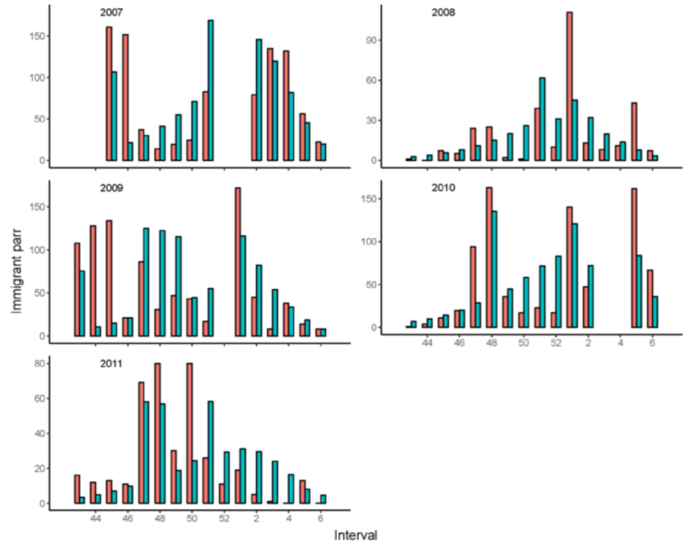
- Tributary →Mainstem
- Fish tagged prior fall at age-0.
- Winter Emigrant: last detected leaving before Jan 31
- Explored effects of several discharge variables, including freshets, floods, etc.



- Selected model indicated parr more likely to emigrate when discharge increases quickly, and this effect was magnified earlier in the winter.

Winter Refuge Entry Timing

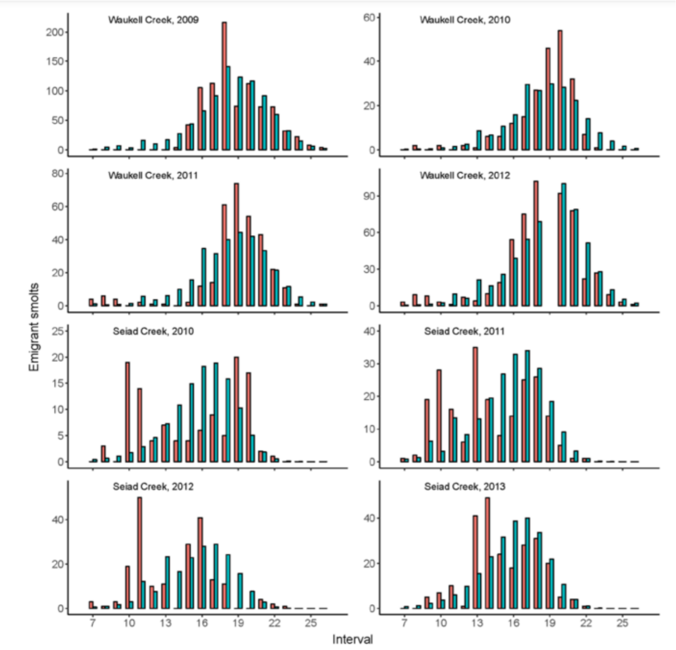
- Mainstem → Tributary
- Form of logistic mixed effects model (binomial)
- AIC model selection
- Explored effects of magnitude and variation of discharge
- I think this is Waukell only, double check

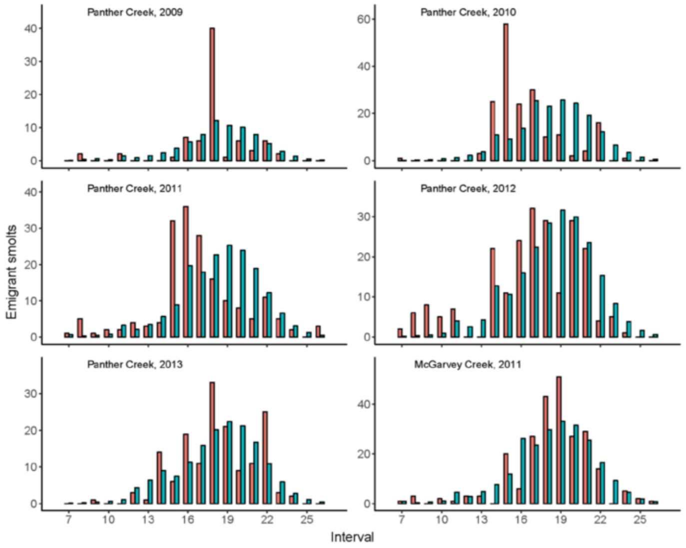


- Selected model similar to winter emigration model, suggesting that they quickly seek other tributary refugia exiting other tribs, and/or seek discharge refuge in tribs when mainstem discharge quickly increases.

Spring Smolt Emigration Timing

- Tributary → Mainstem
- Age-1+
- Form of logistic mixed effects model (binomial)
- Explored effects of basin location (mid or lower Klamath, photoperiod, water temperature, freshets, floods, etc.

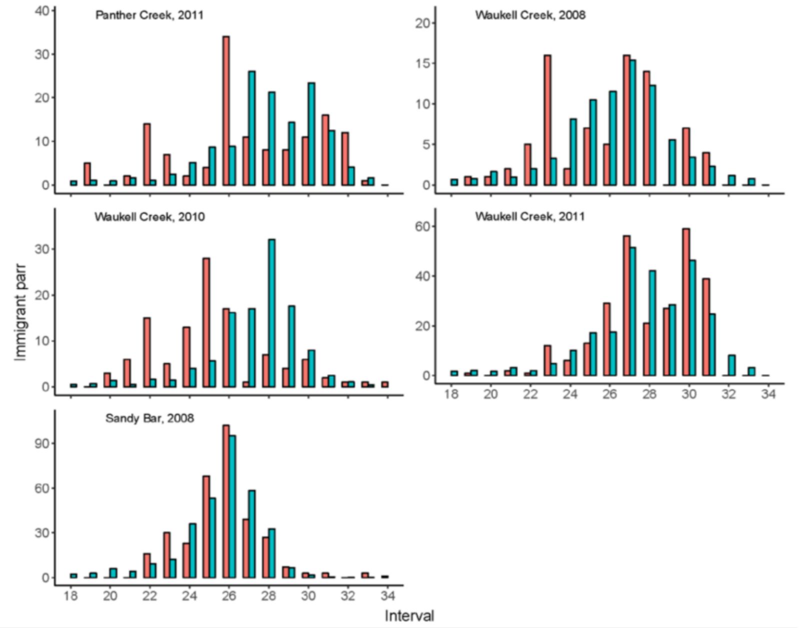




- Selected model indicated that smolts from tributaries higher up the mainstem initated mainstem migrations earlier, smolts were more likely to begin mainstem migrations after large increases in discharge

Summer Refuge Entry Timing

- Mainstem → Tributary
- Non-natal habitat use (duh)
- Summer refuge entry: May – August
- Form of logistic mixed effects model (binomial)
- Considered effects of temperature and discharge, including magnitude and variation.



- Selected model: probability of tributary entry increases with seasonally warming temperatures.

Mainstem Migration Rates

- Age-0 fish
- Summer and Winter, estimated separately
- Advection-diffusion model – accounts for speed movement and spread of a moving population in a downstream direction.
- Way more creeks than I listed for the other analyses.

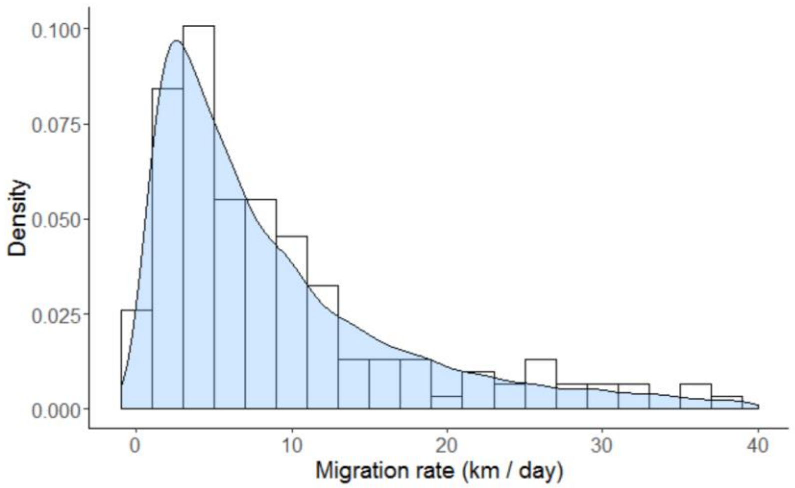


Figure 21. Histogram of migration rates in the mainstem Klamath River during winter redistributions. Migration rates were computed from 161 paired observations of juvenile Coho Salmon. A log-normal distribution with parameters estimated from the dataset is depicted by a density curve.

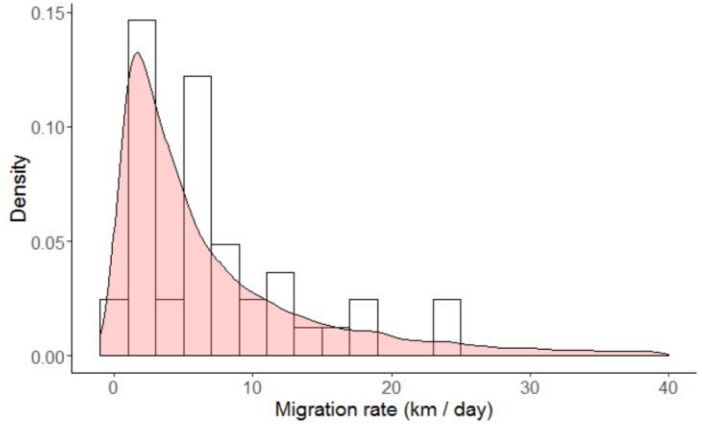
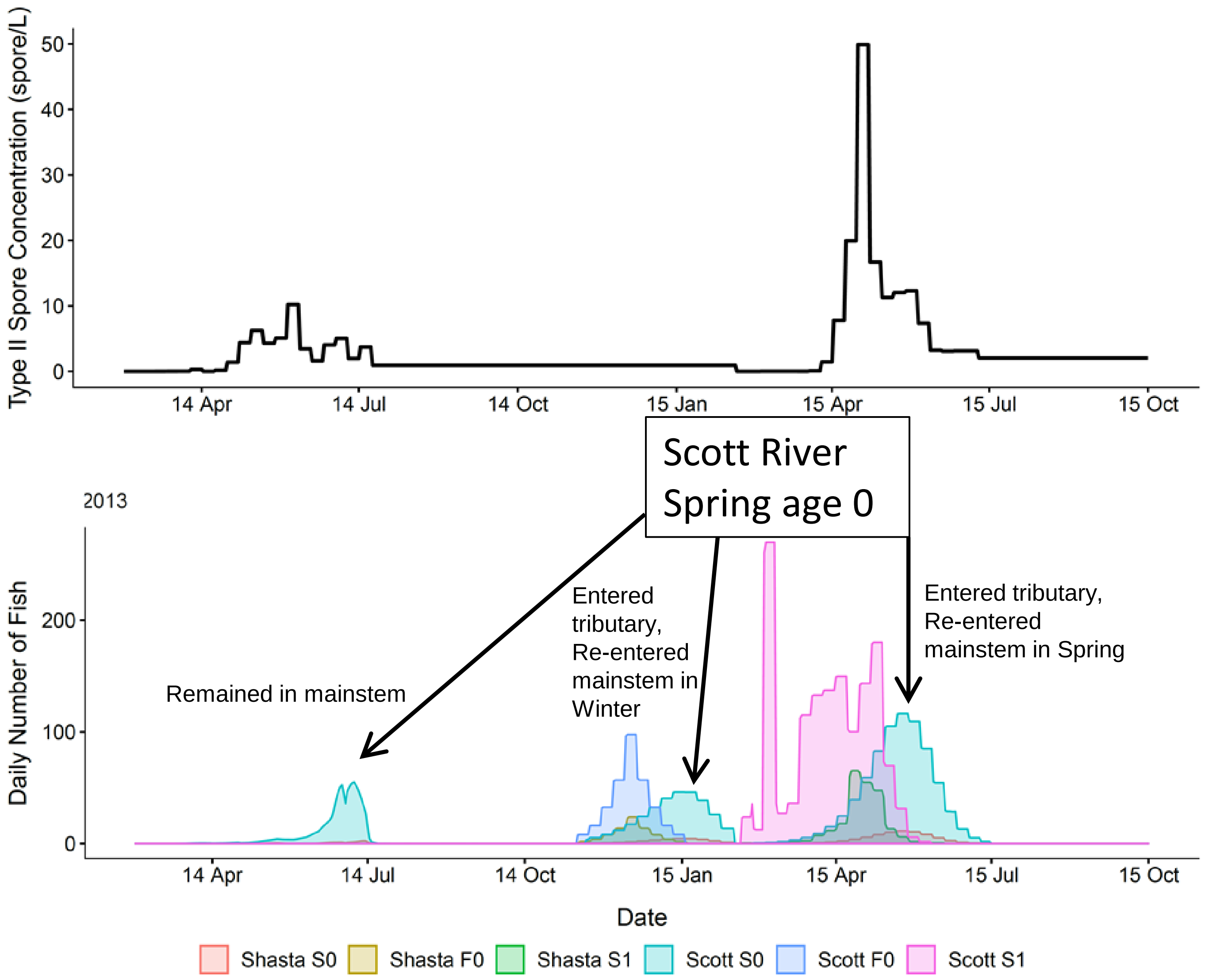


Figure 20. Histogram of migration rates in the mainstem Klamath River during summer redistributions. Migration rates were computed from 41 paired observations of age-0+ Coho Salmon. A log-normal distribution with parameters estimated from the dataset is depicted by a density curve.

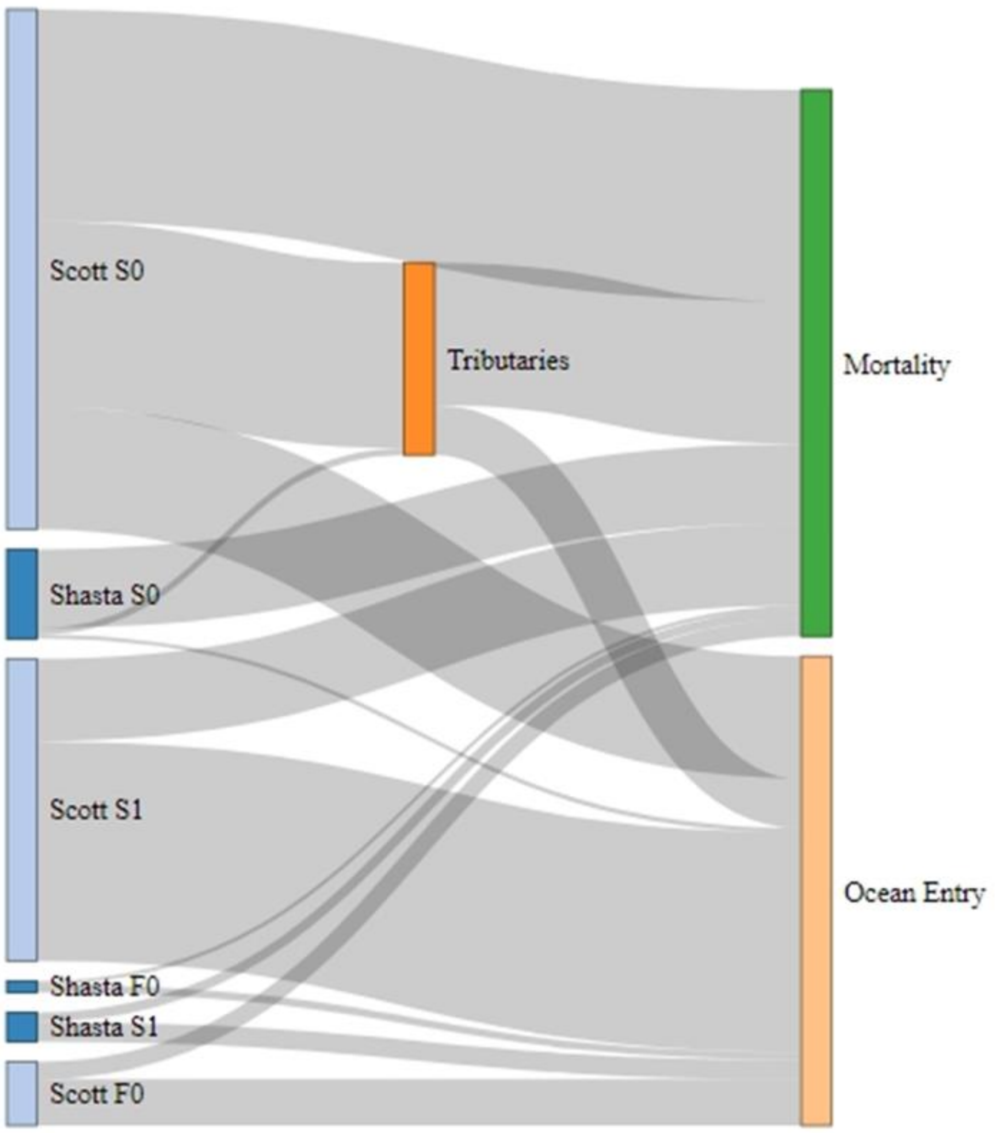
Examples of S3 Model Output for Coho

Simulated Migration past Seiad
Brood Year 2013

S0 = Spring age 0
F0 = Fall age 0
S1 = Spring age 1



Eventual Fates for Brood Year 2011



Publications

Prepared in cooperation with U.S. Fish and Wildlife Service

Extending the Stream Salmonid Simulator to Accommodate the Life History of Coho Salmon in the Klamath River Basin

By Michael J. Dodrill,[1] Russell W. Perry,[1] Nicholas A. Som,[2] Christopher V. Manhard,[3] and Julie D. Alexander[4]

[1]U.S. Geological Survey
[2]U.S. Fish and Wildlife Service
[3]AKRF, Inc.
[4]Oregon State University

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U.S. Fish & Wildlife Service

Arcata Fisheries Technical Report TR 2018-33

Estimating Freshwater Productivity, Overwinter Survival, and Migration Patterns of Klamath River Coho Salmon

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U.S. Fish and Wildlife Service
Arcata Fish and Wildlife Office
1655 Heindon Road
Arcata, CA 95521
(707) 822-7201

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February 2018

Acknowledgements

Not possible without collaborative data sharing of PIT tag data at a basin-wide scale from multiple groups

Estimating Survival of Migrating Fish with PIT Tags and Stationary Monitoring Stations

Dalton J. Hance

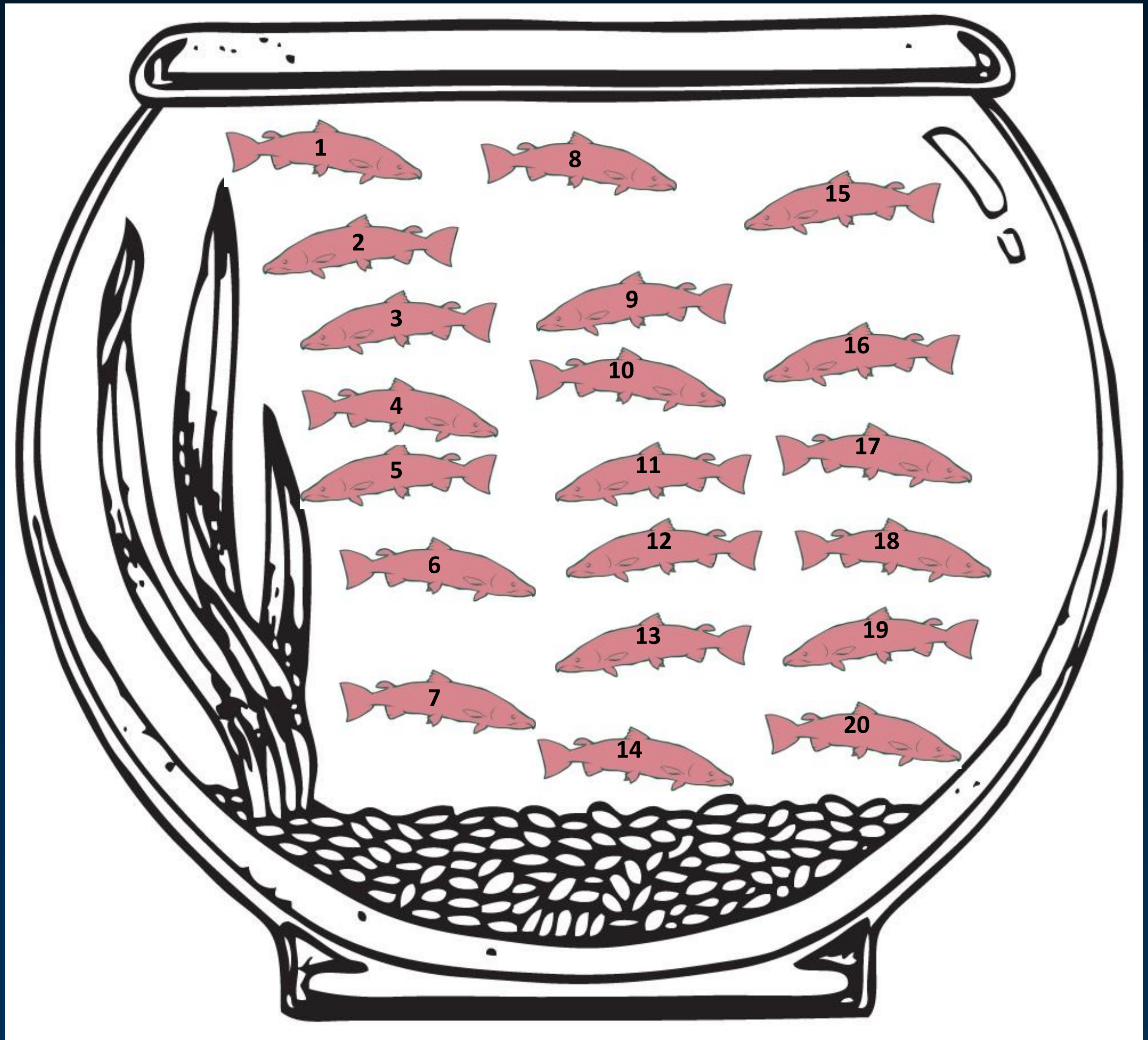
Adam C. Pope

Russell W. Perry

Western Fisheries Research Center

25 February 2022

Perfect Detection: Life and Death in a Fish Bowl



Goal: understand the <u>*probability*</u> of survival

Take a *representative sample* of 20 fish (R).

Assume fish are *individually identifiable.* (Important for what follows)

Now we wait.

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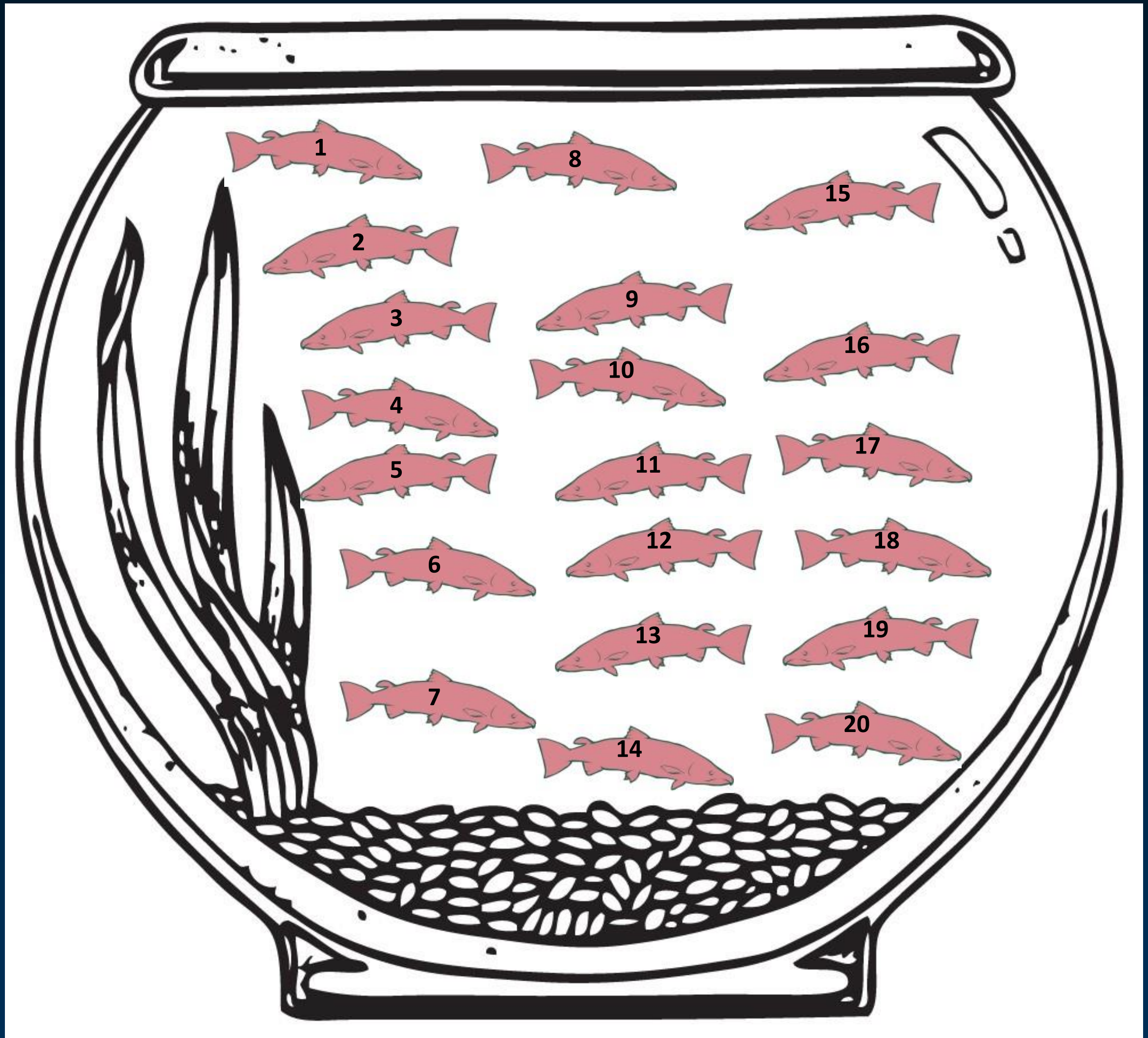
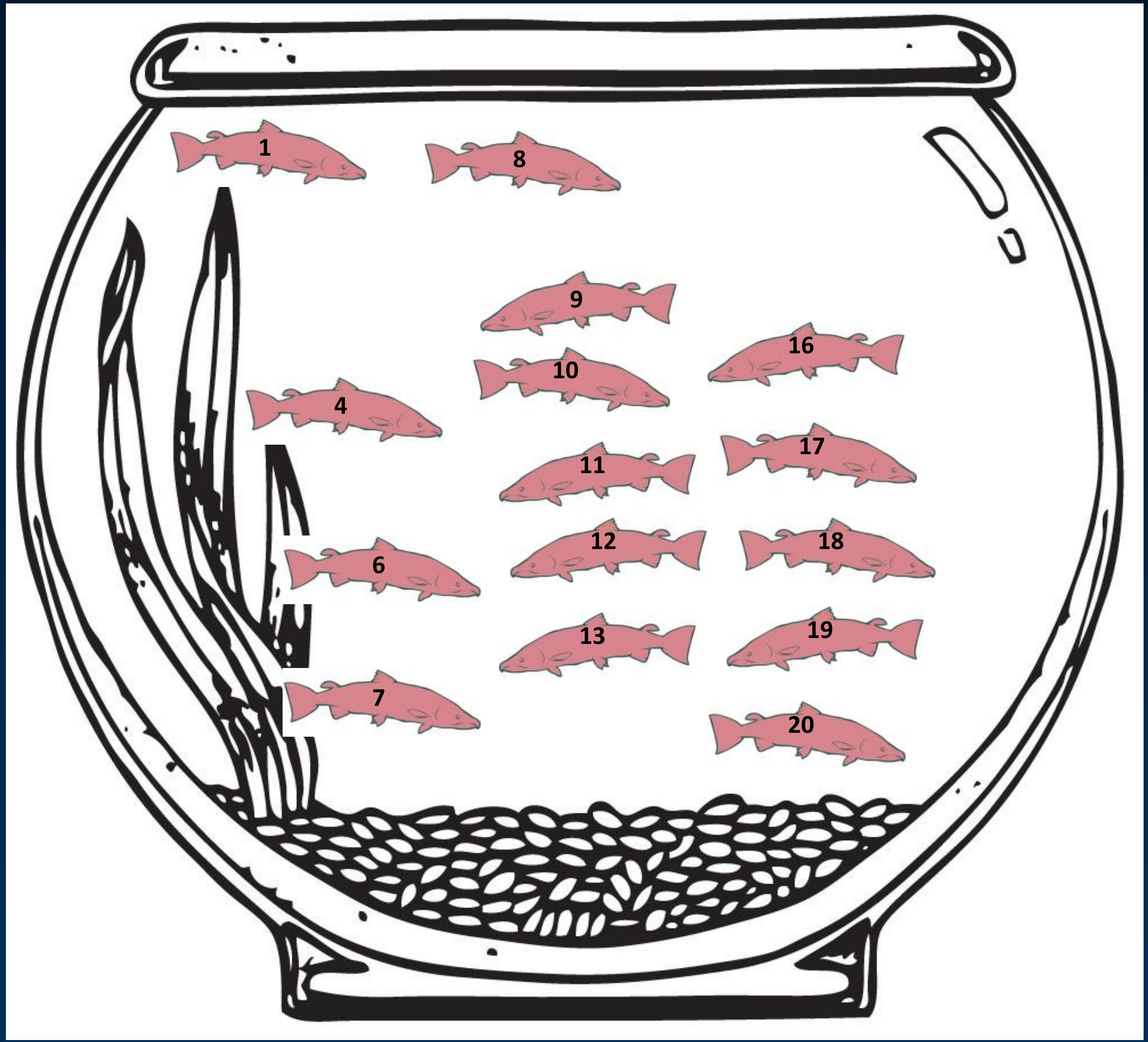
Goal: Estimate Probability of Survival Over Time





Time 0 (t = 0), $R = 20$ Time 1 (t = 1), $m_1 = 15$

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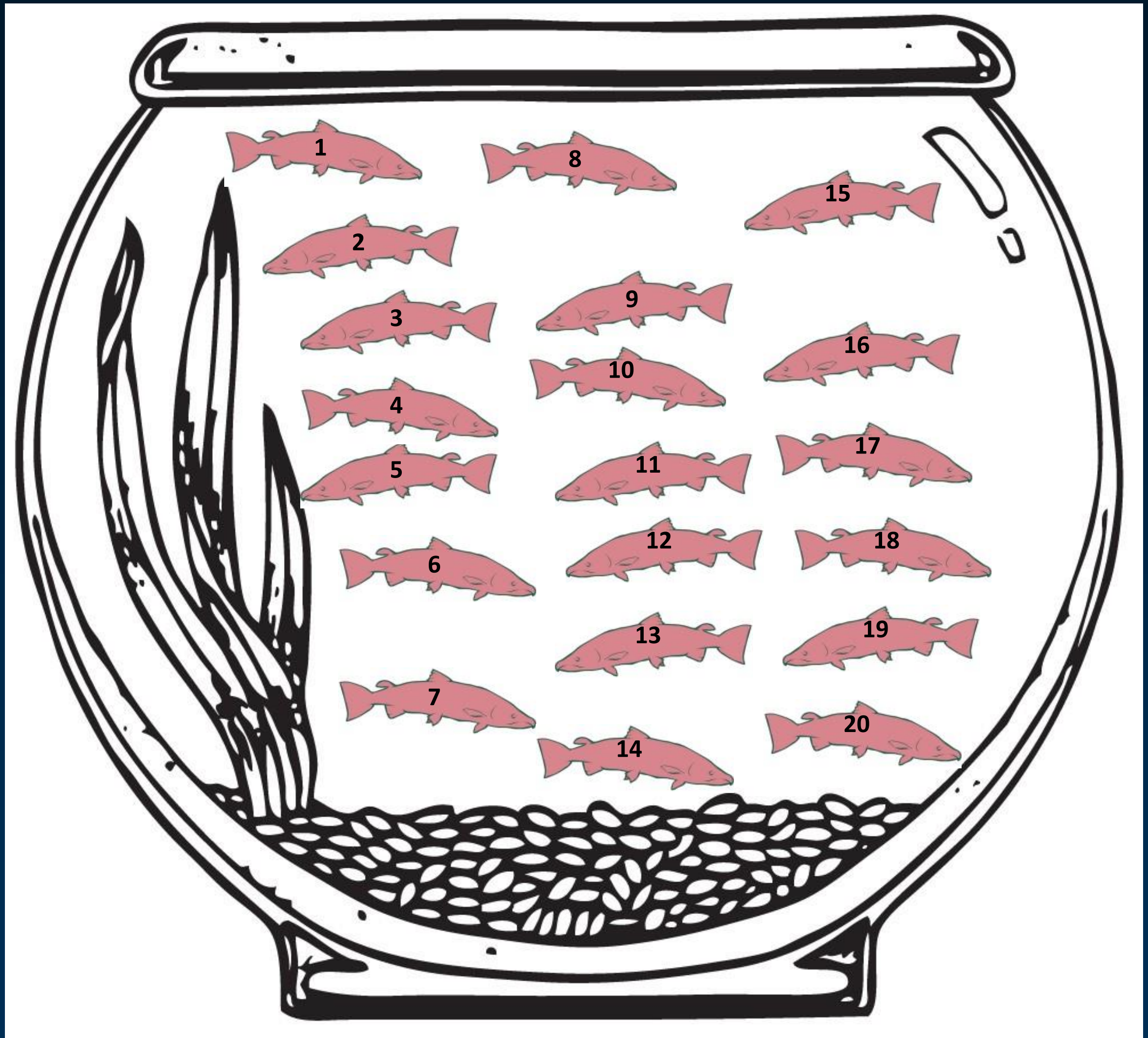
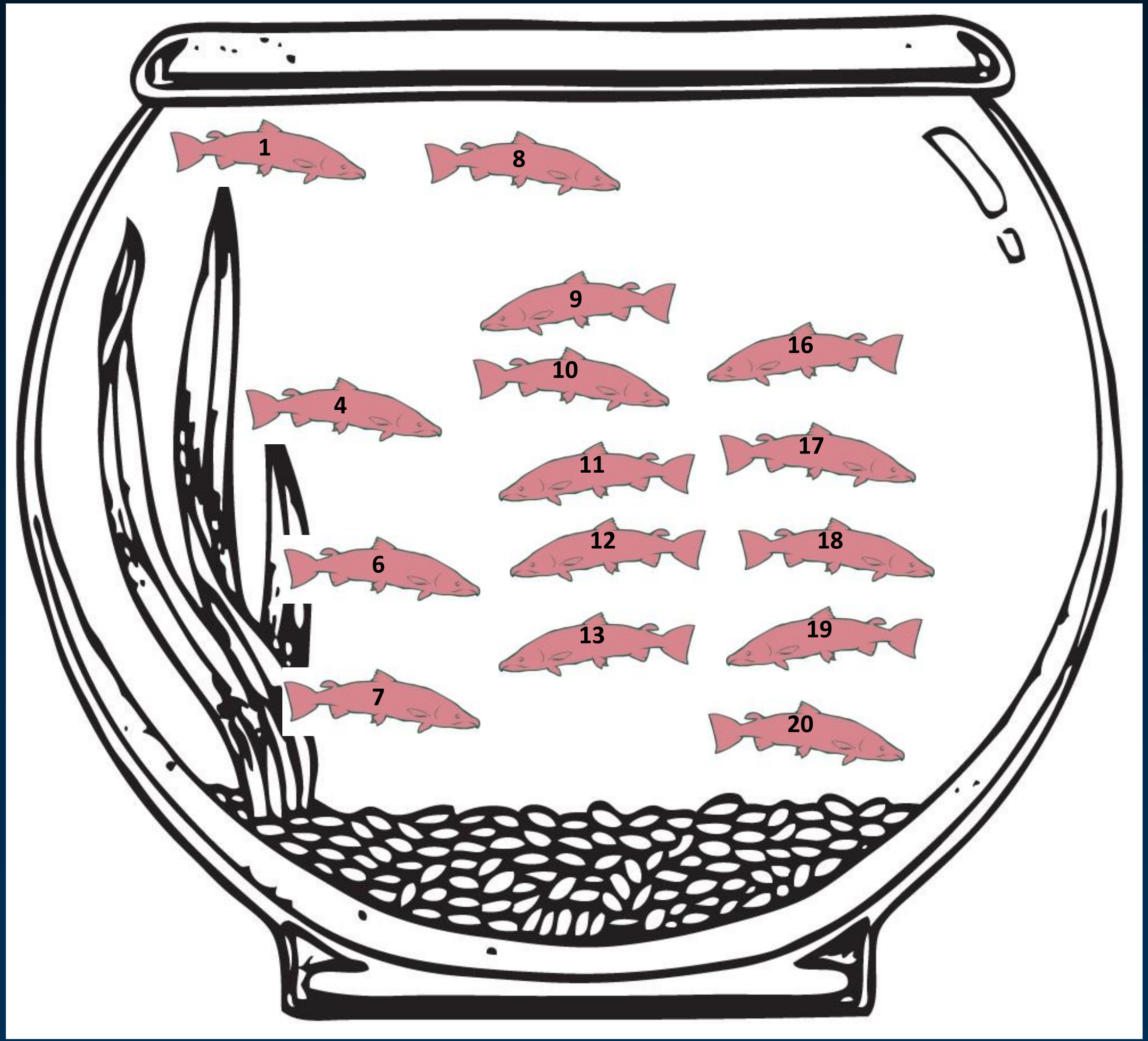
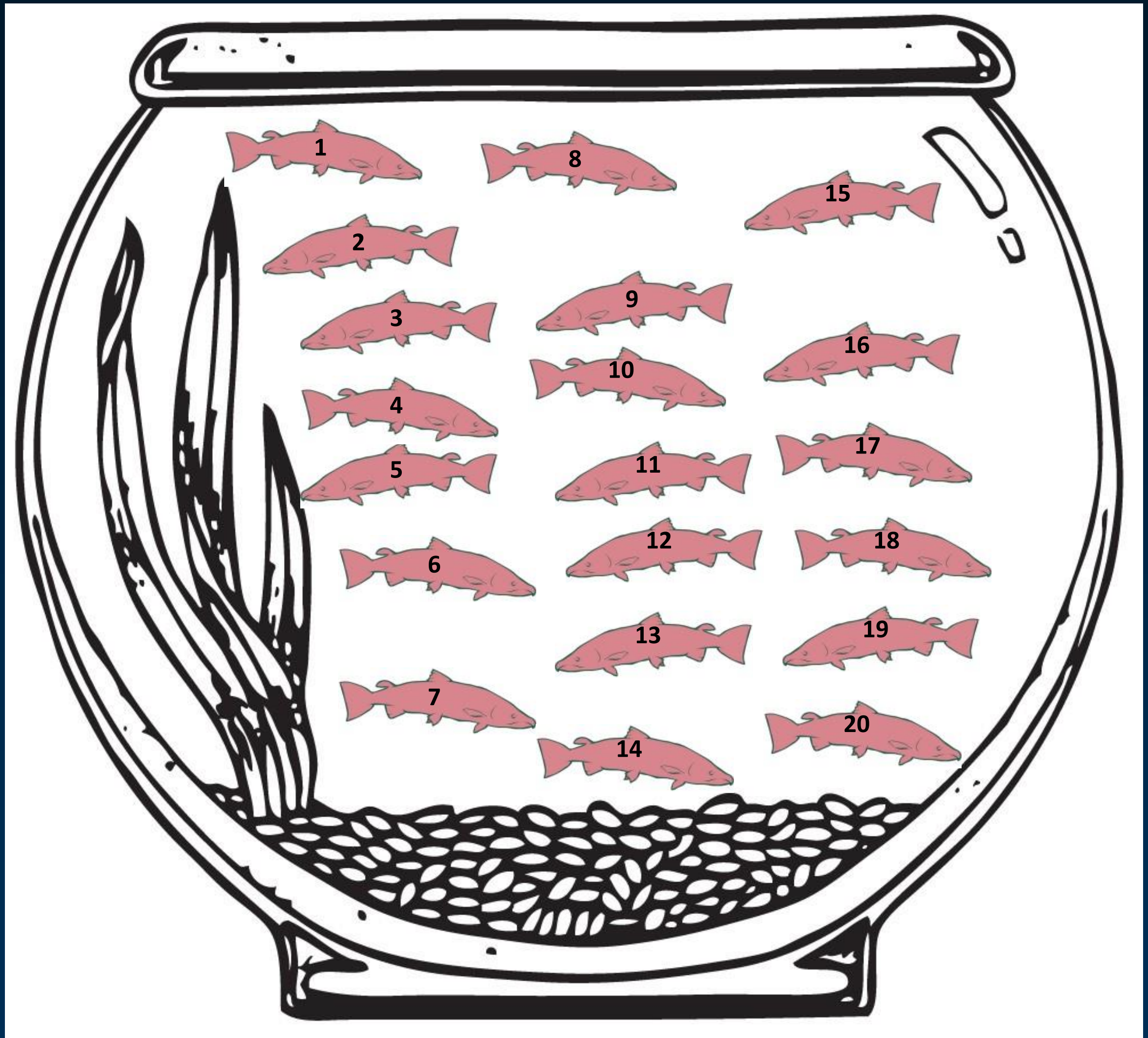
Goal: Estimate Probability of Survival Over Time

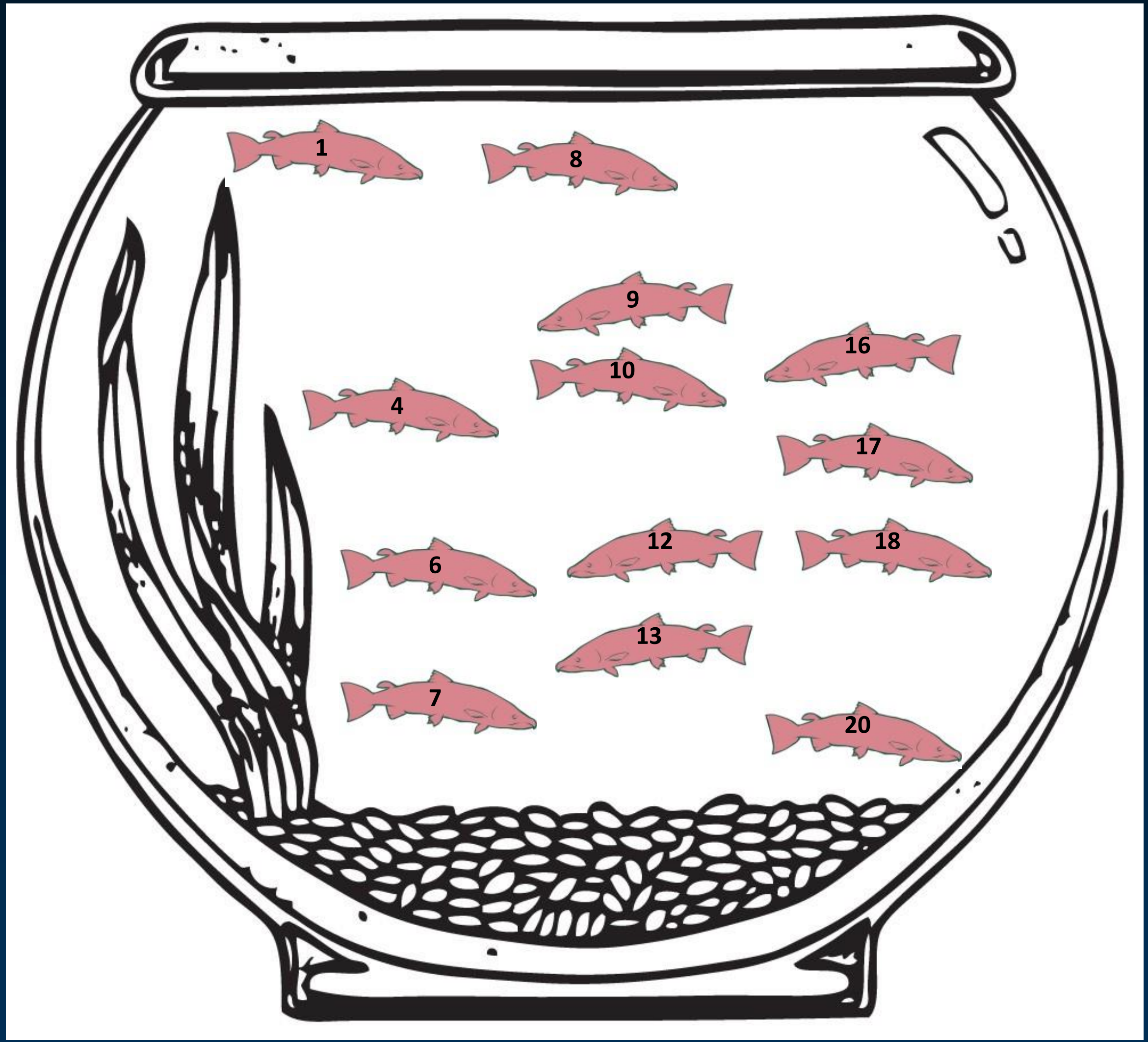




$$\hat{\phi} = {}^{15}/_{20} = 0.75$$

What if we try that again?



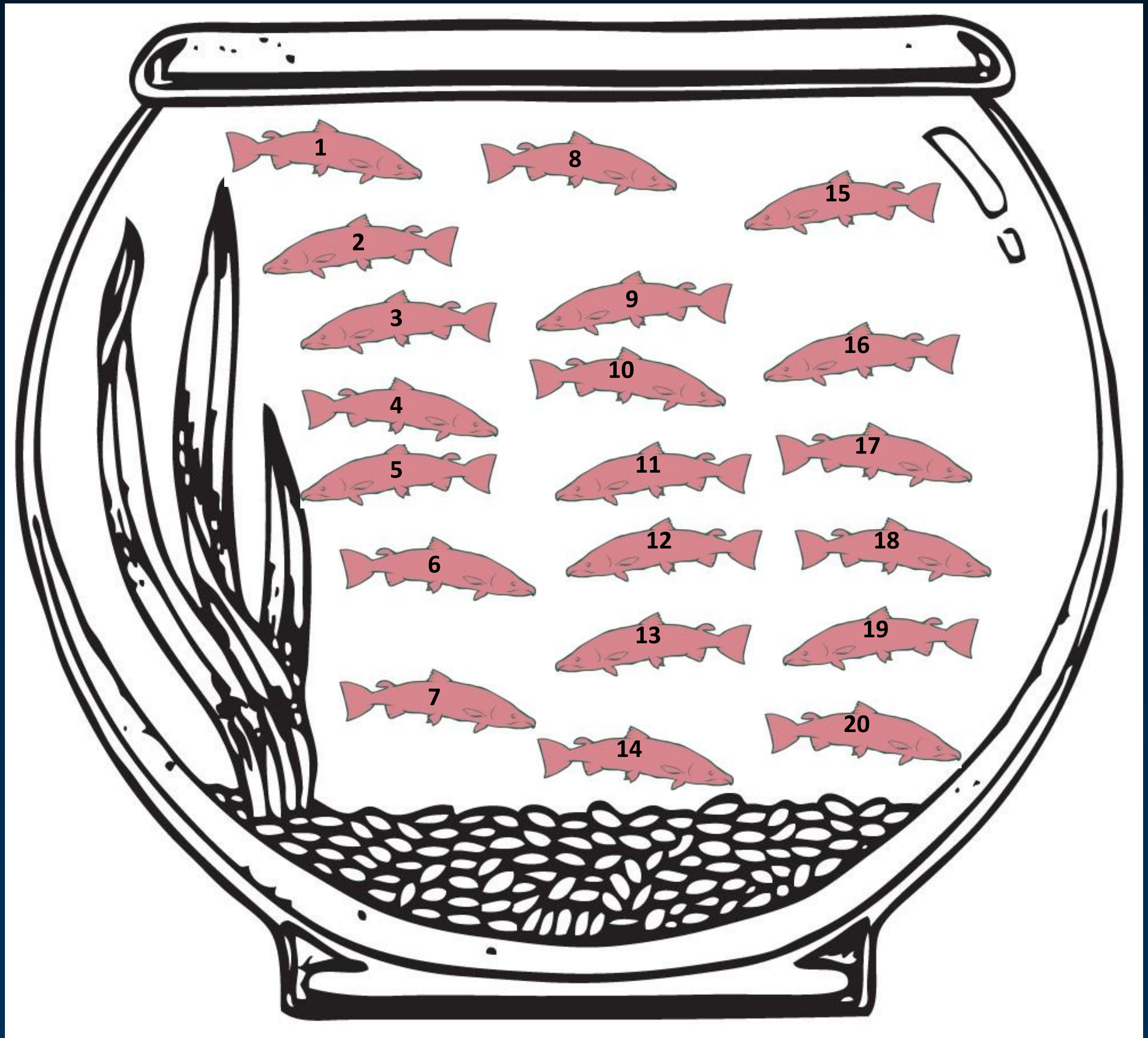


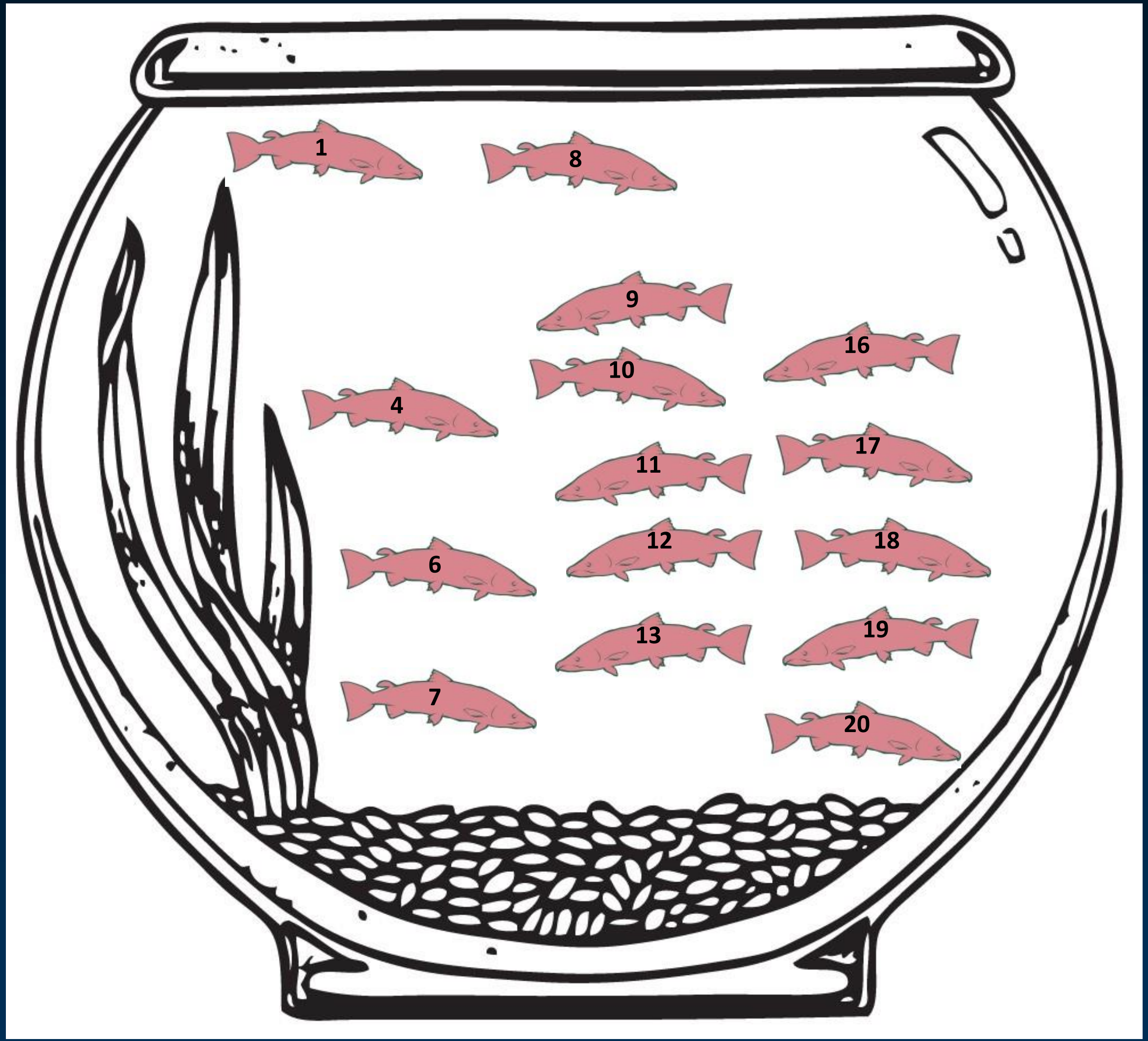
Time 0 (t = 0), $R = 20$

$\hat{\phi} = {}^{13}/_{20} = 0.65$

Time 1 (t = 1), $m_1 = 13$

One more time.



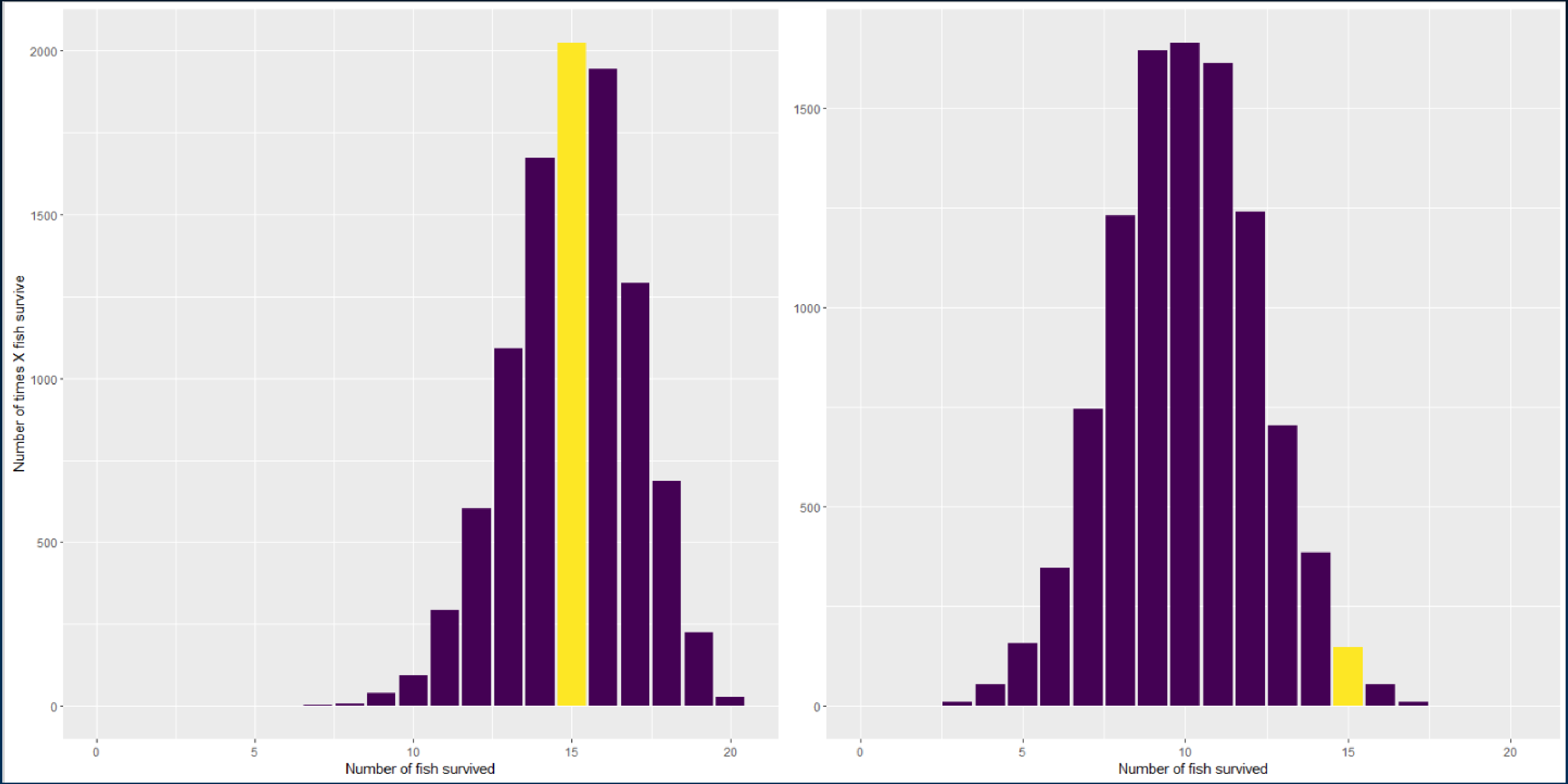


Time 0 (t = 0), $R = 20$

$$\hat{\phi} = {}^{17}/_{20} = 0.85$$

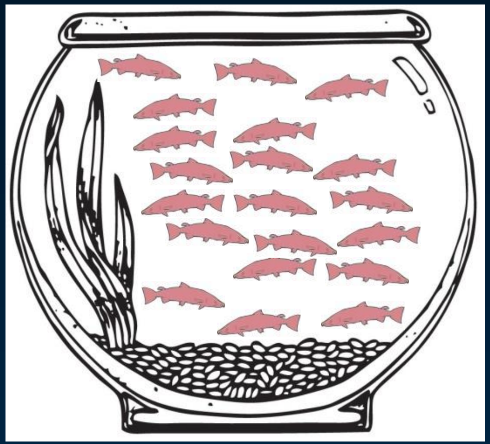
Time 1 (t = 1), $m_1 = 17$

This is why you need us pesky statisticians

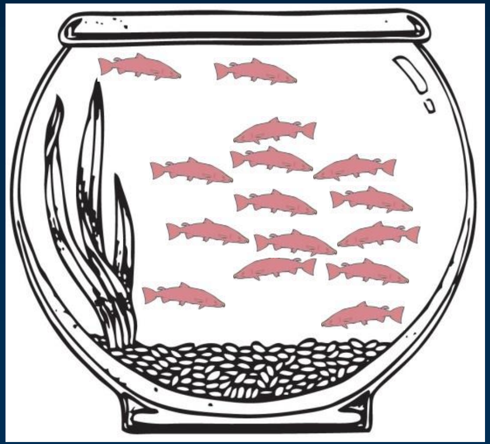


rbinom(n = 10000, size = 20, prob = 0.75)   rbinom(n = 10000, size = 20, prob = 0.50)

A Reasonable Probability Model for Survival: ϕ



Time 0 (t = 0), $R = 20$



Time 1 (t = 1), $m_1 = 15$

$$L(\phi|R, m_1) = \binom{R}{m_1} \phi^{m_1}(1-\phi)^{R-m_1}$$

- A *probability model* maps the *data* (R, m_1) to the *parameter* we care about: the probability of survival (ϕ)
- We use this probability model to ***estimate*** ϕ

$\hat{\phi} = 0.75$, 95% CI: [0.56, 0.94]

- Basic statistical strategy:
  1. Define a probability model for the data
  2. Solve for the thing we care about ("parameters")
  3. **Quantify uncertainty**

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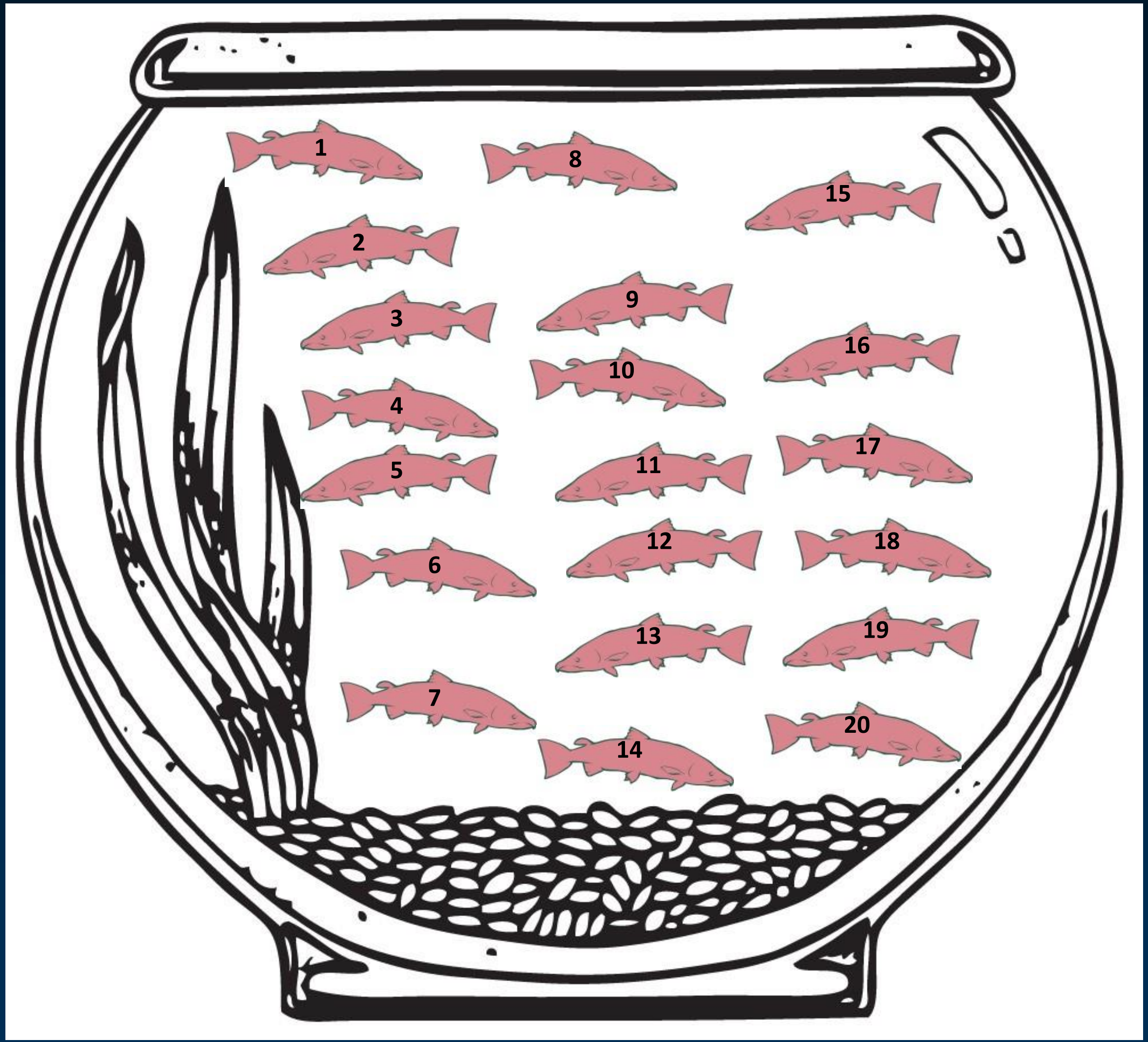
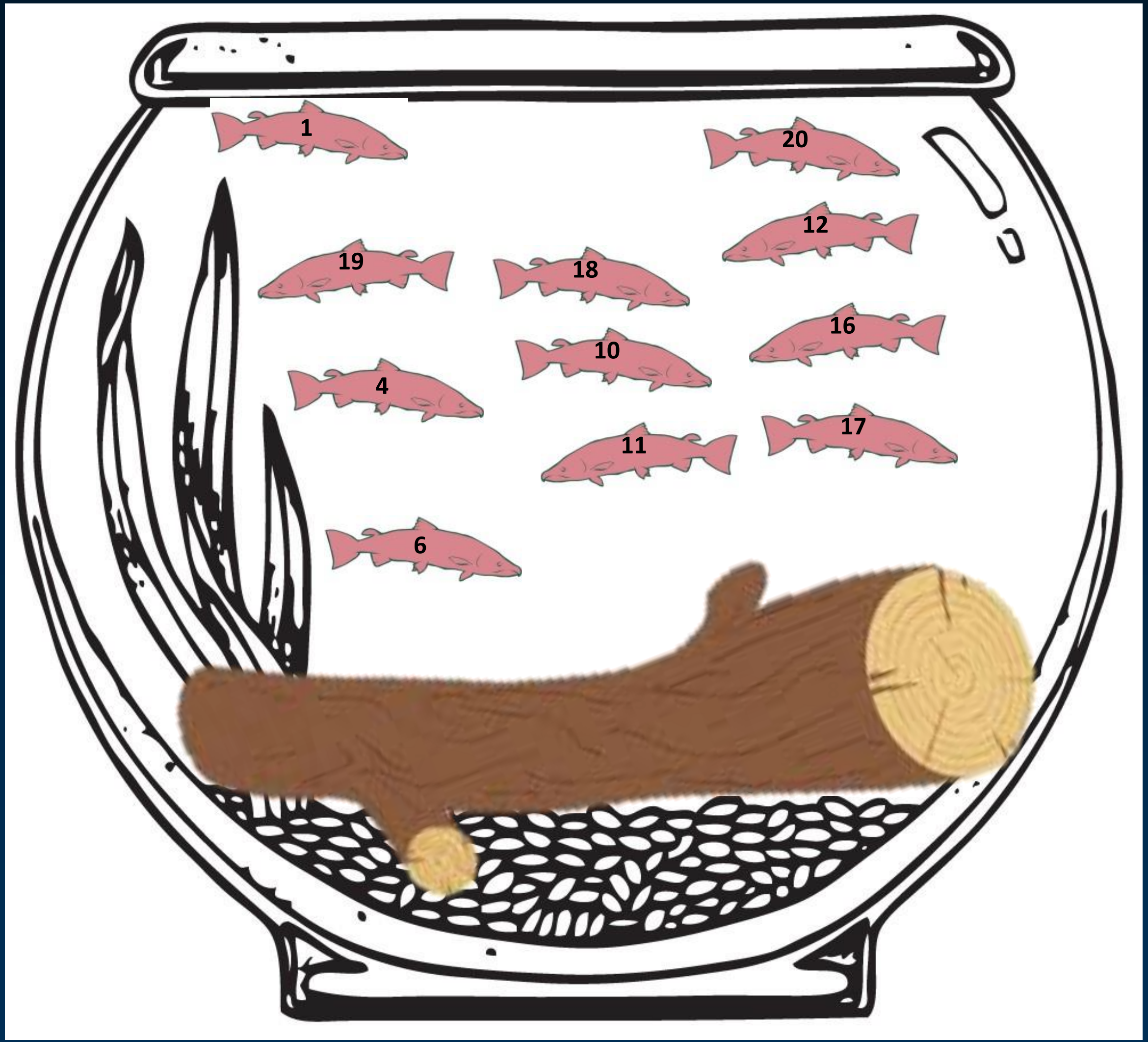
Back to the Fishbowl: Imperfect Detection



Time 0 (t = 0), $R = 20$



Time 1 (t = 1), $m_1 = 11$

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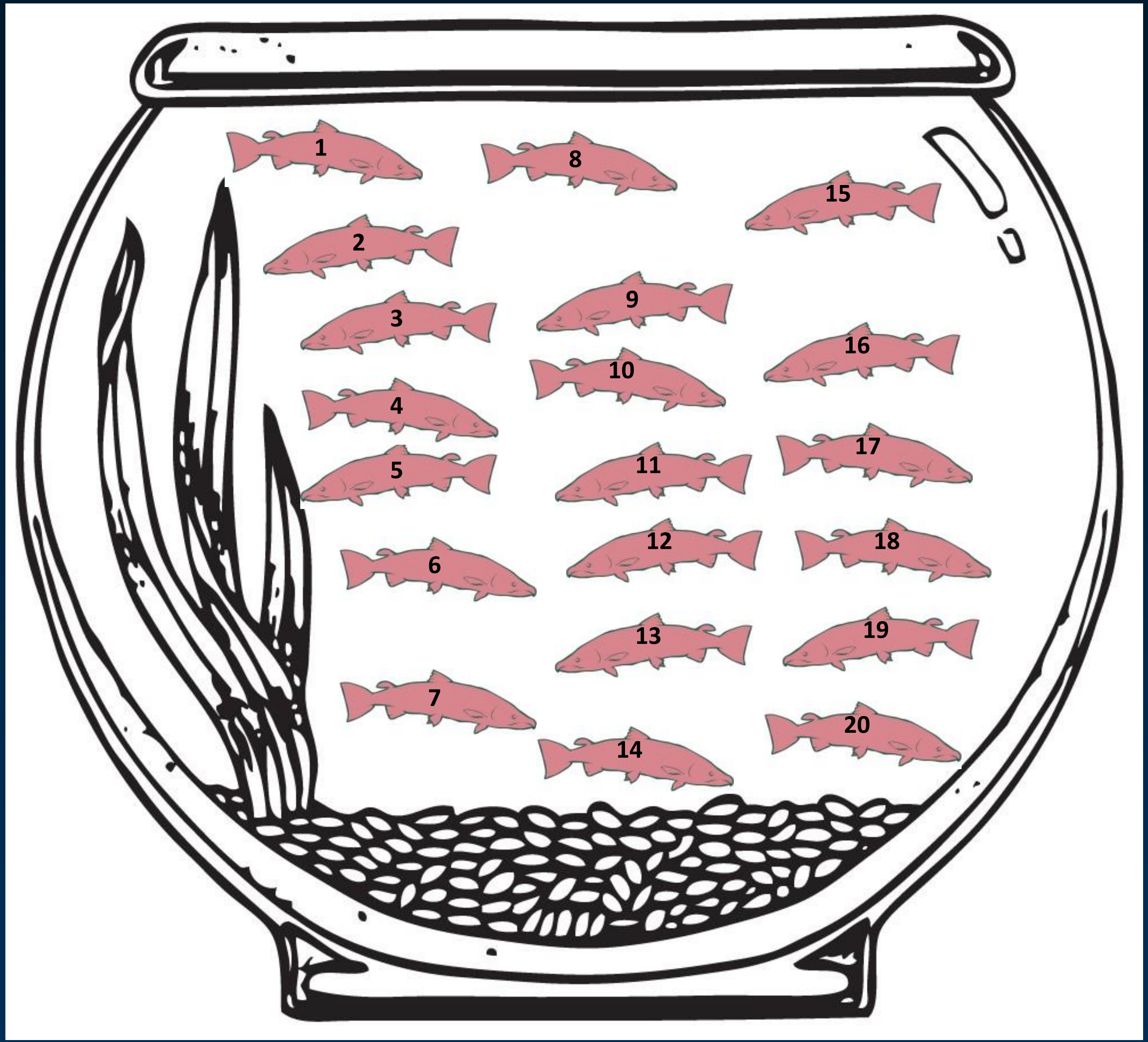
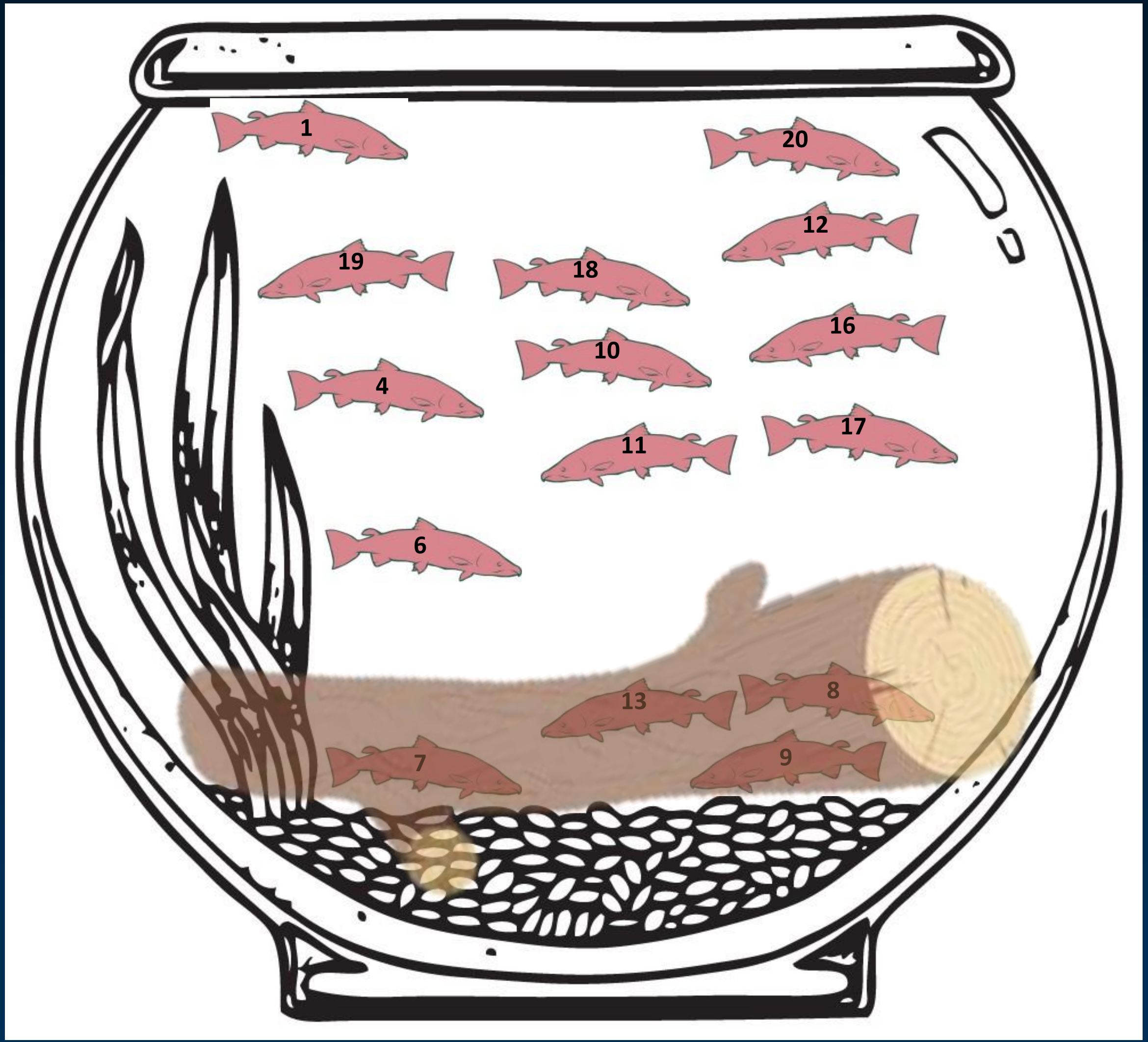
Is our probability model still reasonable?



Time 0 (t = 0), $R = 20$



Time 1 (t = 1), $m_1 = 11$?

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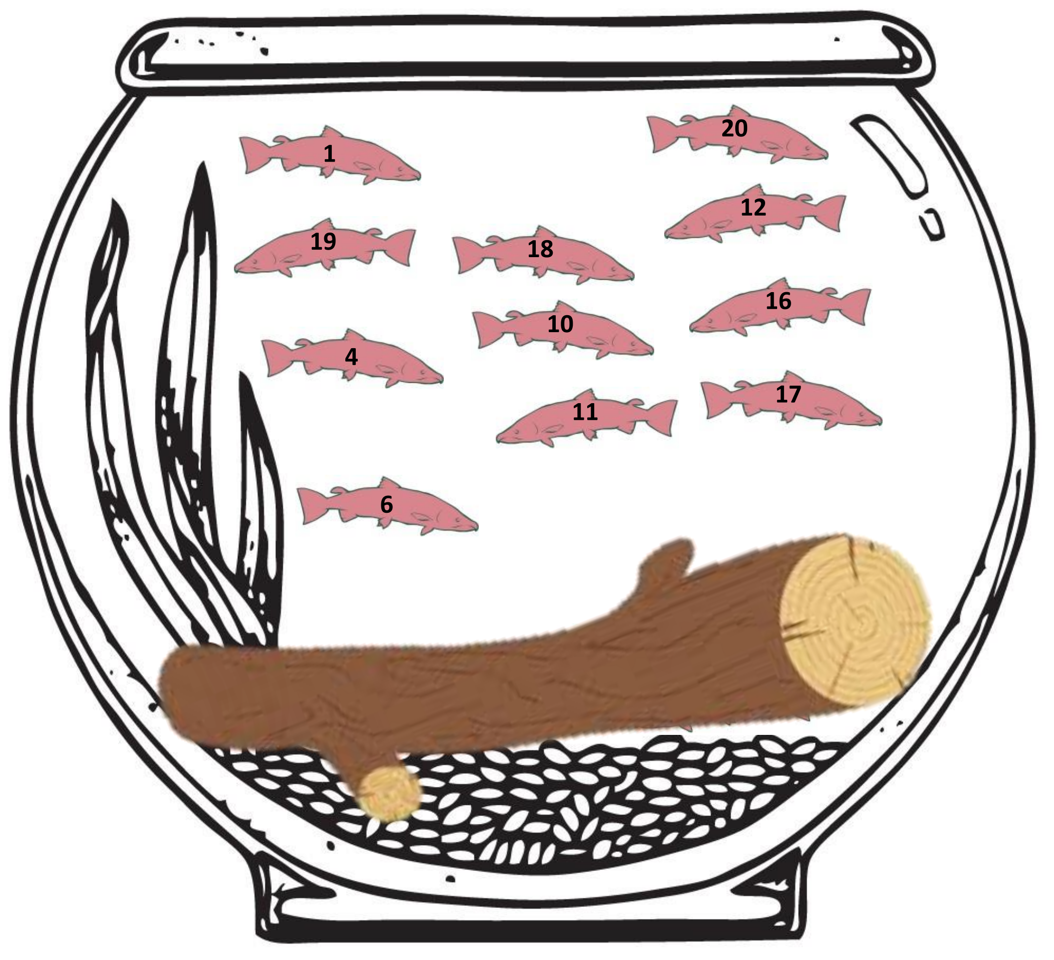
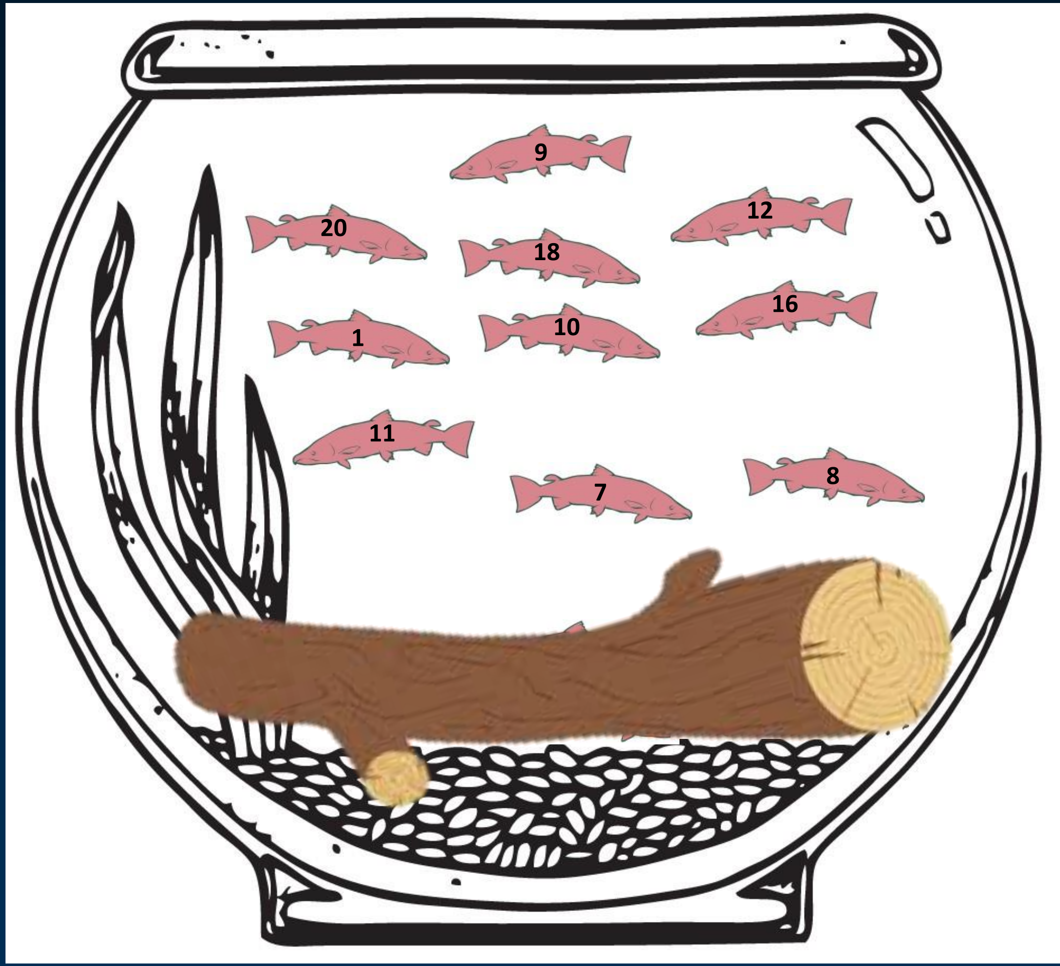
Enter the Cormack-Jolly-Seber model

Still: Time 0 (t = 0), $R = 20$



Time 1 (t = 1), $m_1 = 11$



Time 2 (t = 2), $m_2 = 10$

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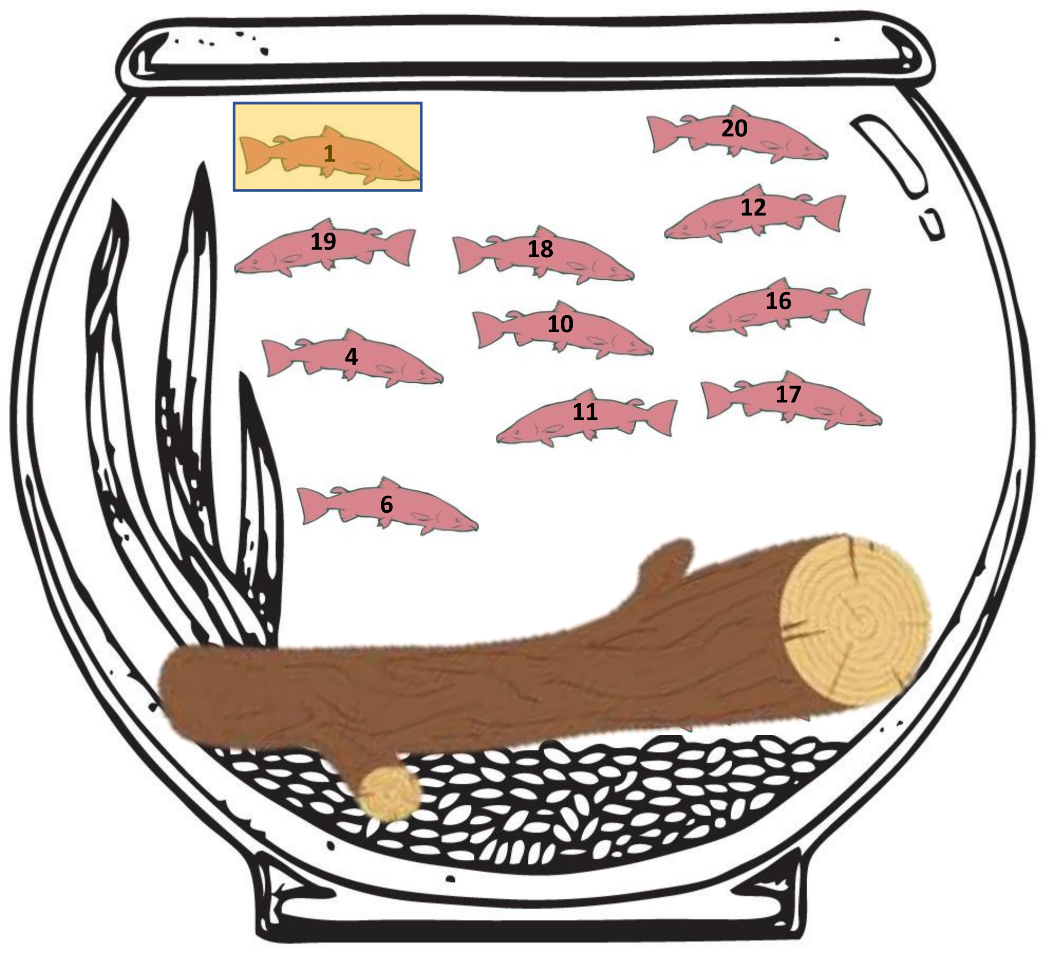
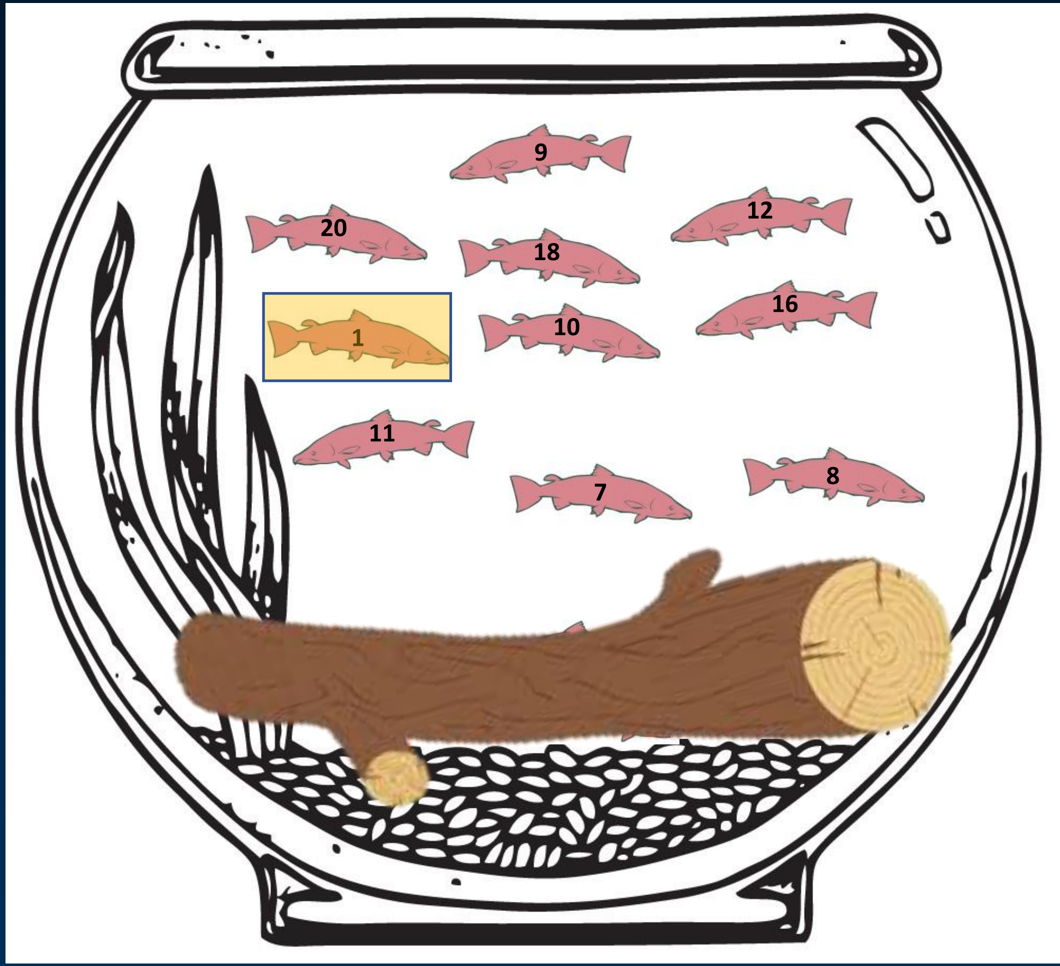
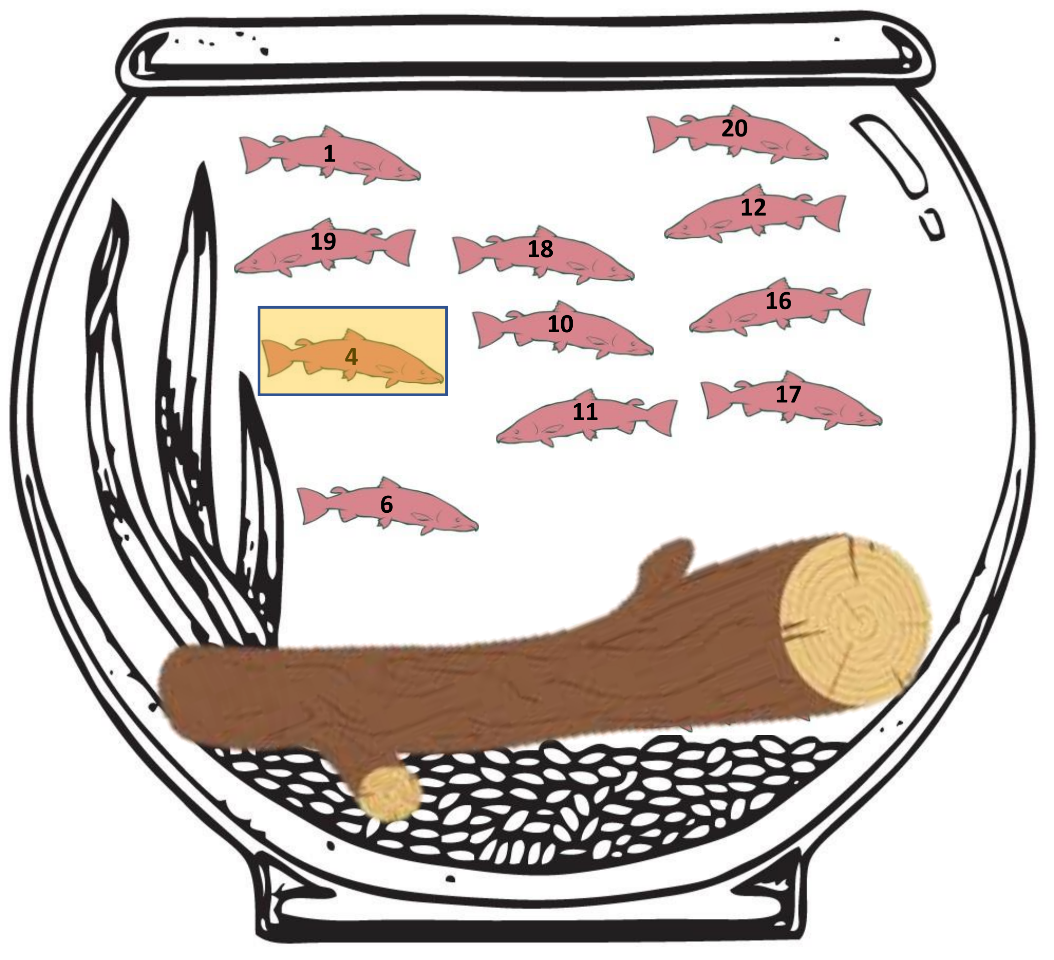
CJS Data: *Capture Histories*

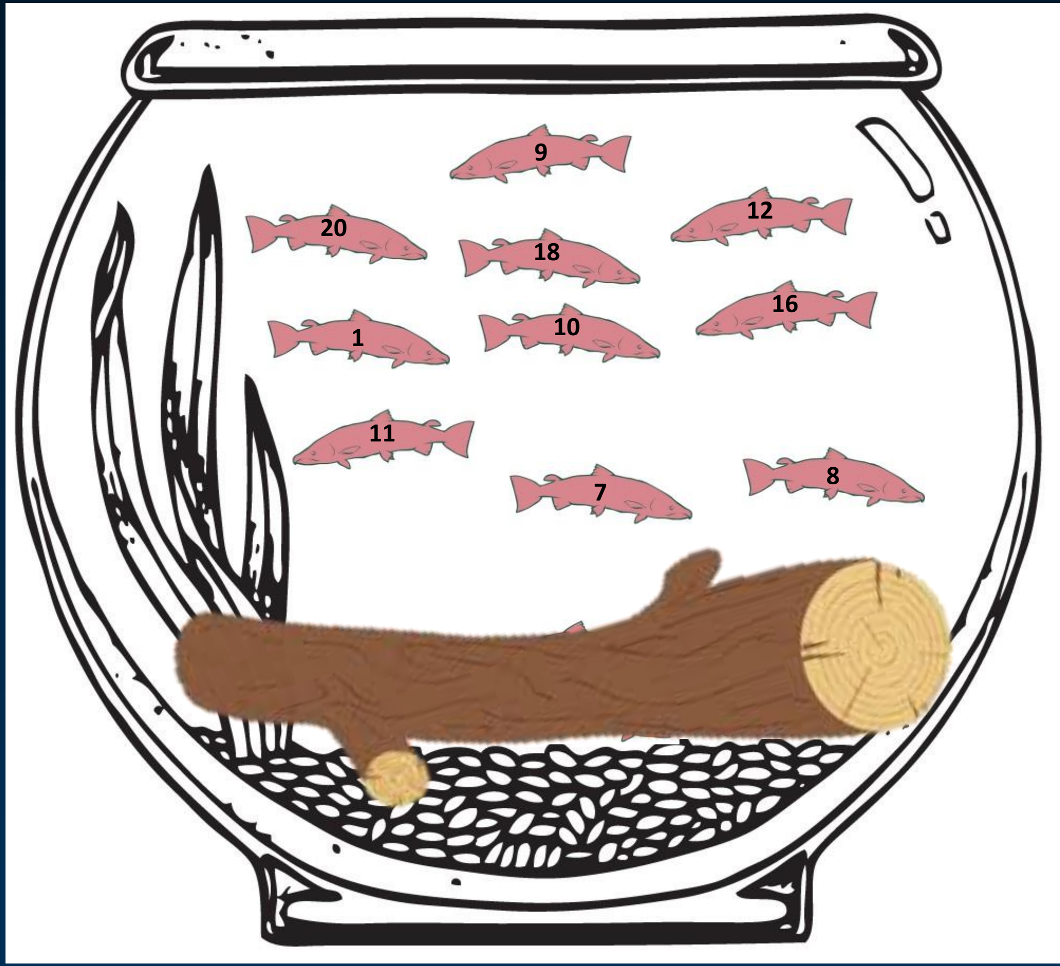




Fish 1 Capture History: 1,1,1

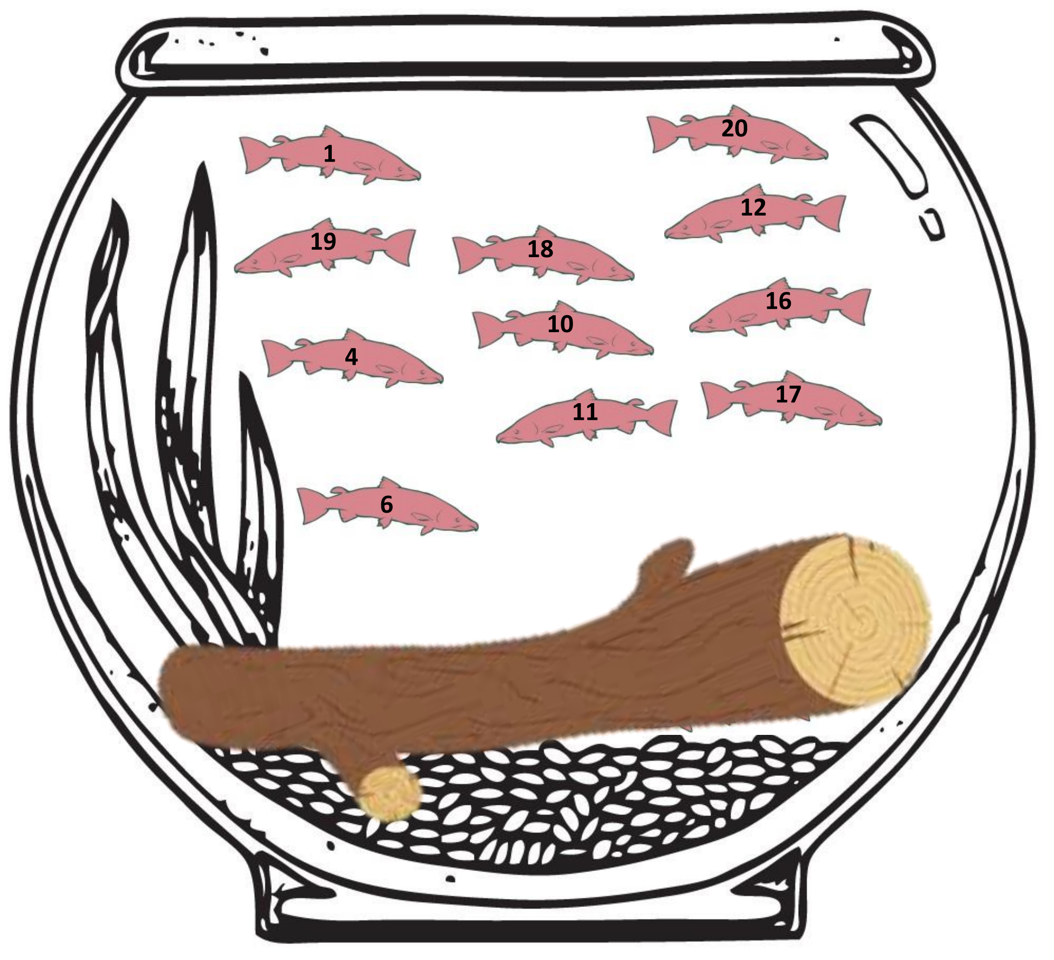
CJS Data: *Capture Histories*

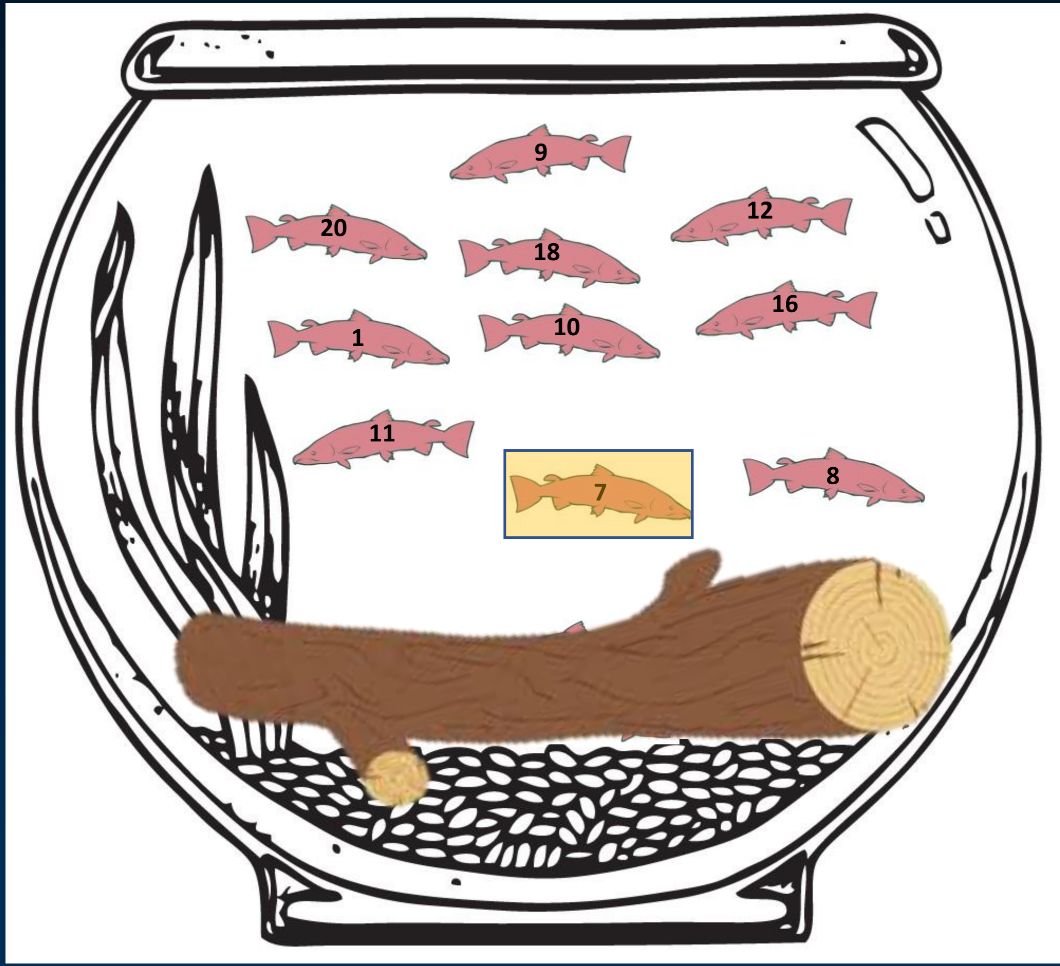




Fish 4 Capture History: 1,1,0

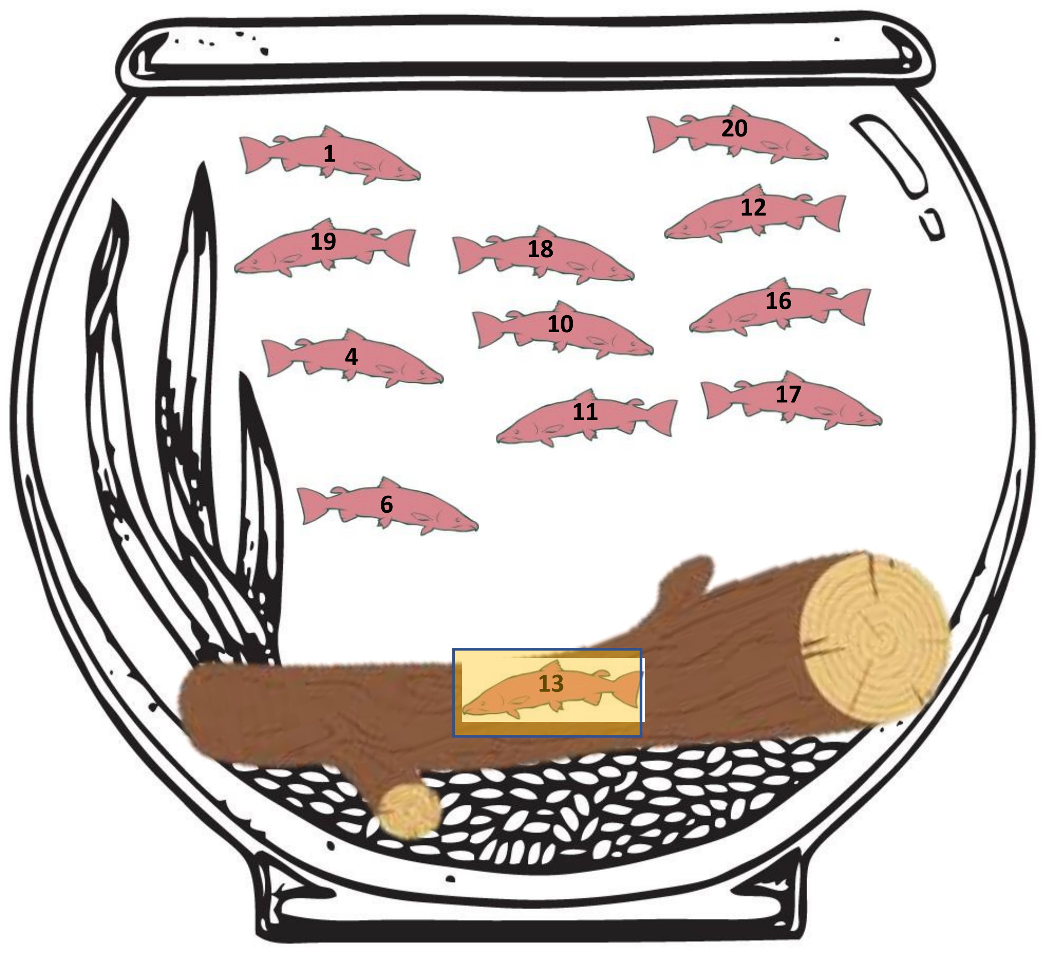
CJS Data: *Capture Histories*

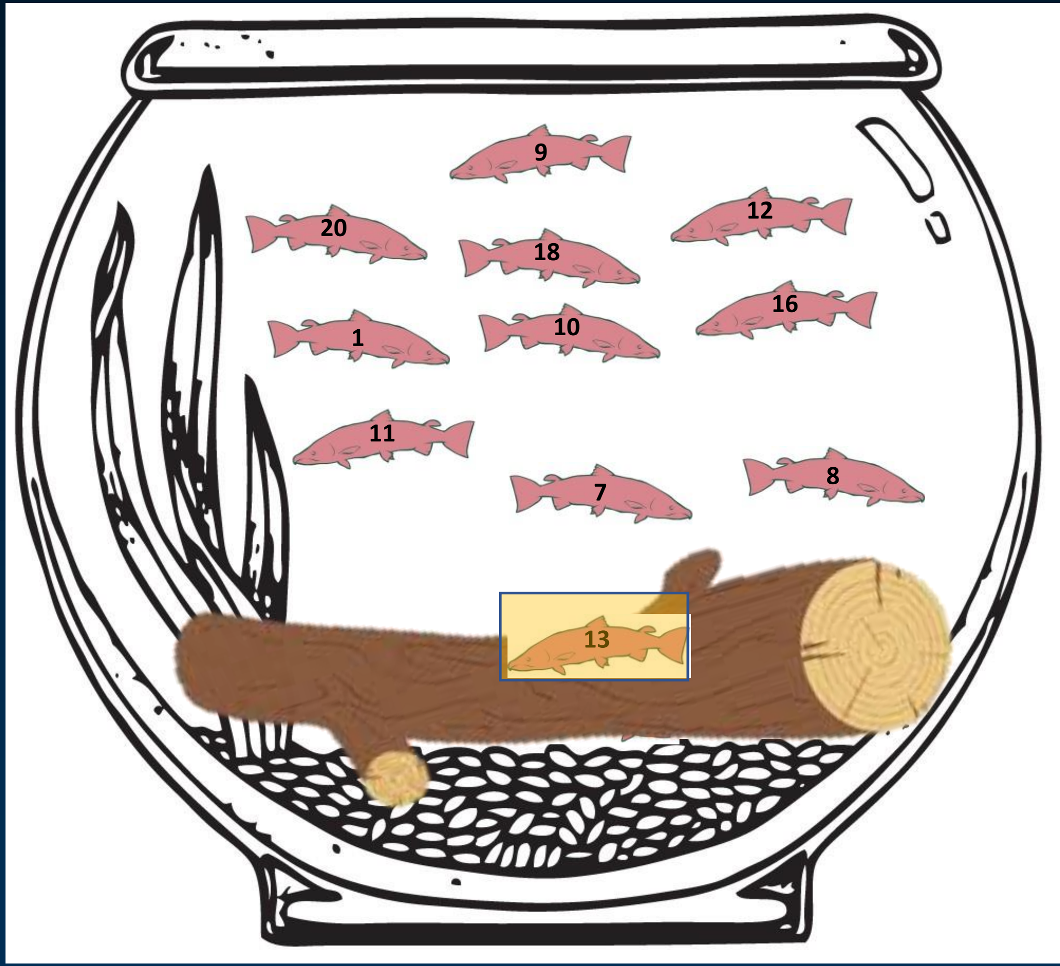




Fish 7 Capture History: 1,0,1

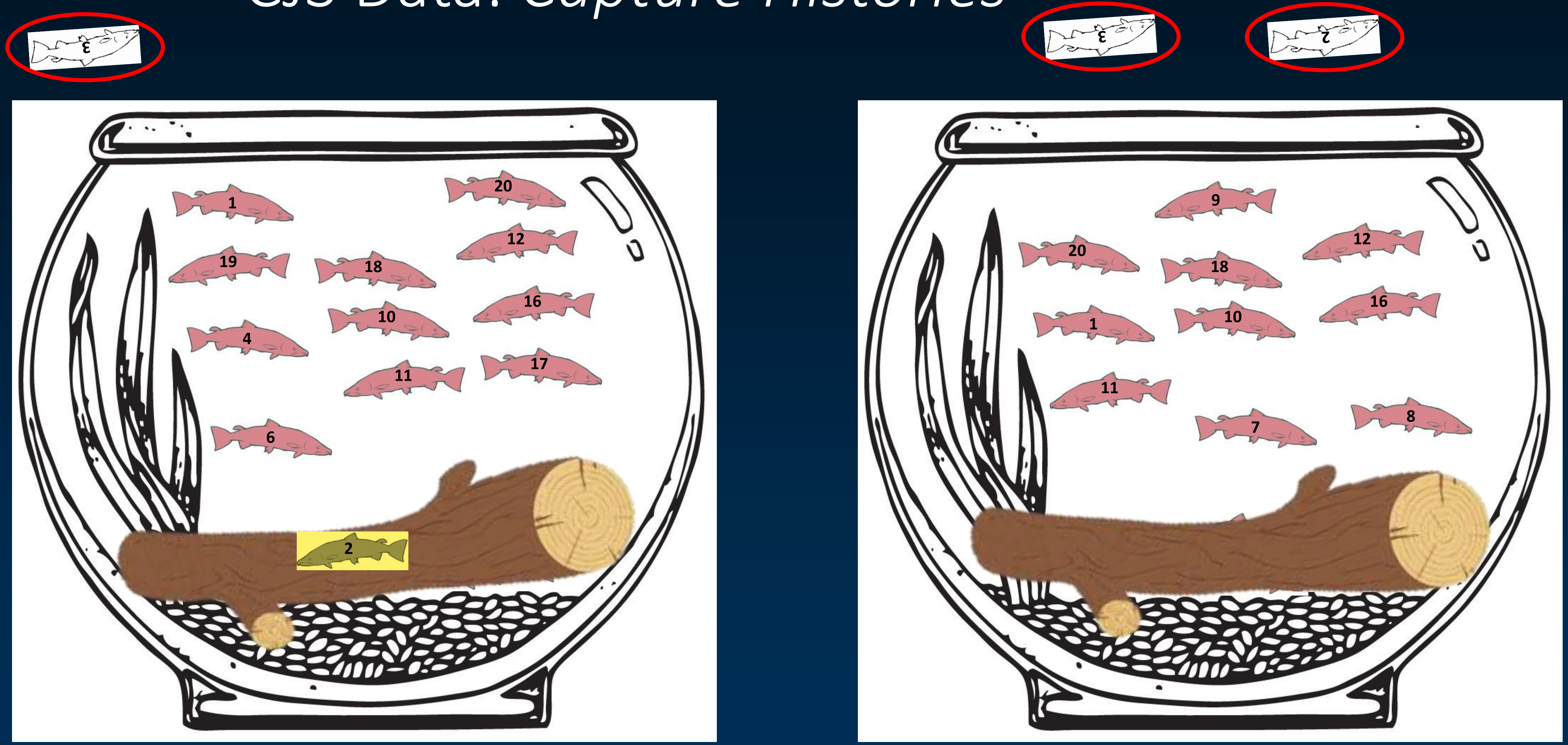
CJS Data: *Capture Histories*





Fish 13 Capture History: 1,0,0

CJS Data: *Capture Histories*



Fish 2 & 3 Capture History: 1,0,0

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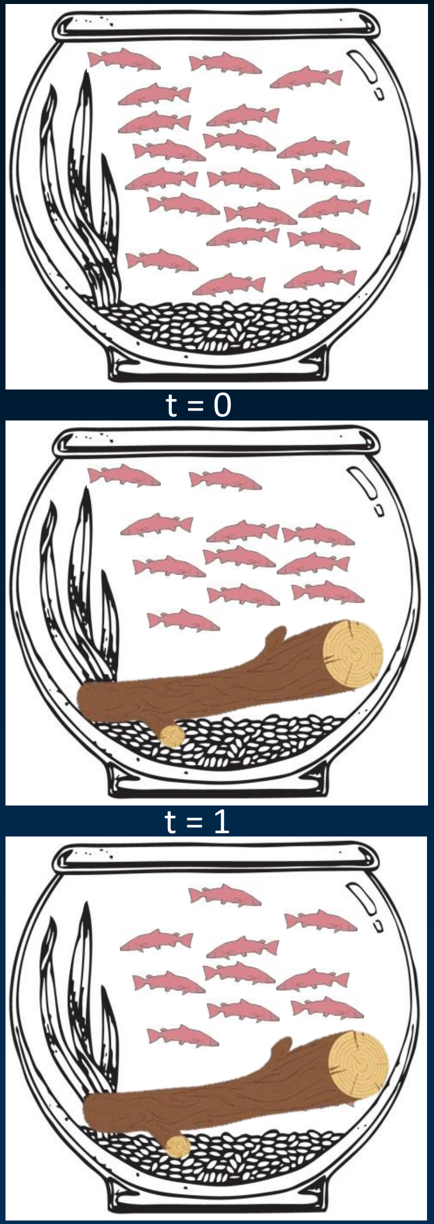
The CJS Probability Model



t = 0

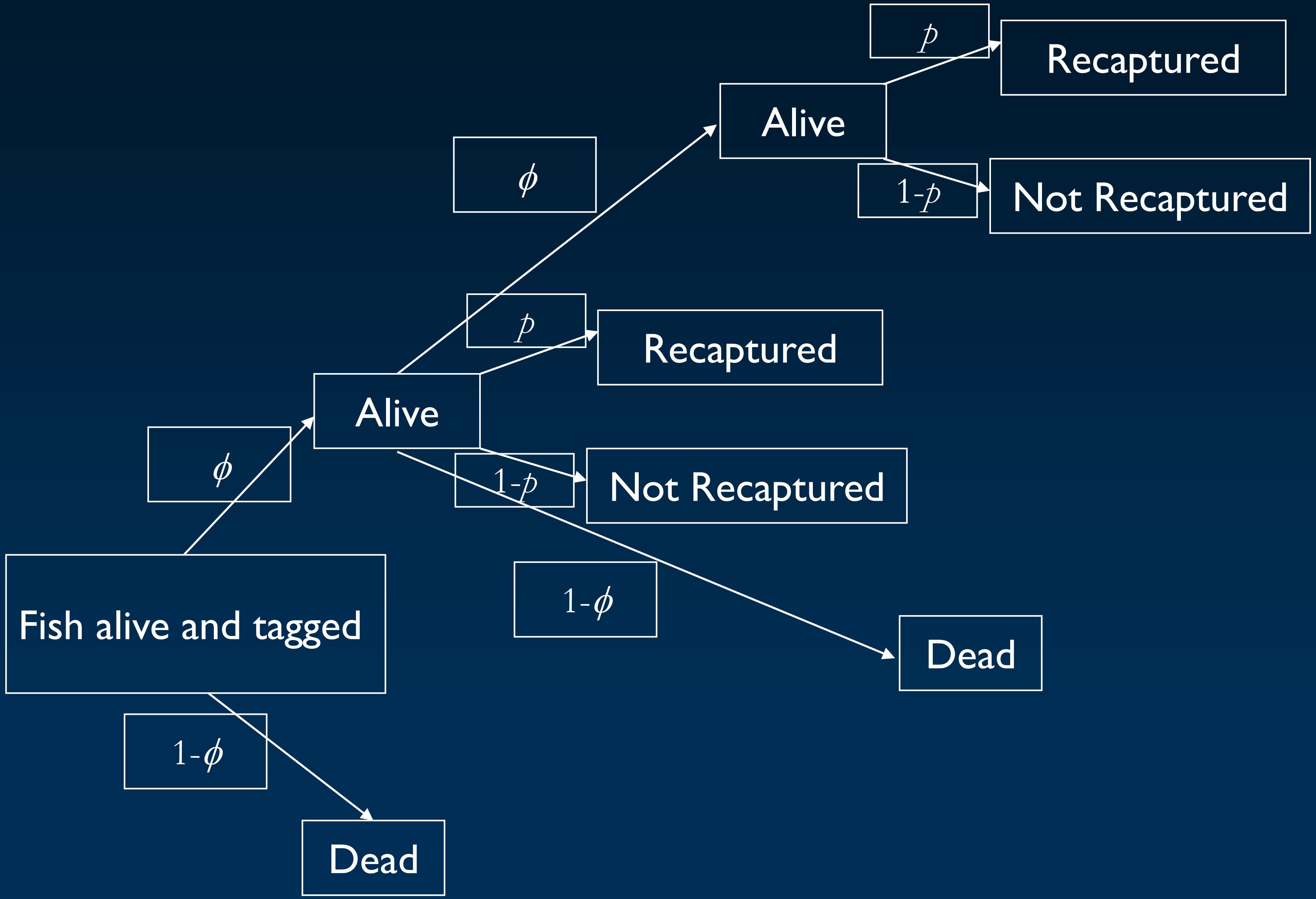
t = 1

t = 2

ϕ_1

p_1

$\lambda = \phi_2 \, p_2$



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Estimation of CJS Models

Assumptions:

- Test fish are *representative*
- Test *conditions* are representative
- No lost marks or false positives
- Statistical independence of individual fish and release groups
- All fish in a release group have equal survival and detection probabilities
- Capture/detection events have no effect on subsequent survival and detection probabilities

Multiple Software Options:

- MARK
- R: marked, RMark
- SURPH/PITPRO
- R/STAN/JAGS: Bayesian

$\hat{\phi}_{1,marked}$ = 0.786, 95% CI: [0.434, 0.946]

$\hat{\phi}_{1,SURPH}$ = 0.786, 95% CI: [0.532, 1.147]

$\hat{\phi}_{1,Bayes}$ = 0.793, 95% CI: [0.588, 0.999]

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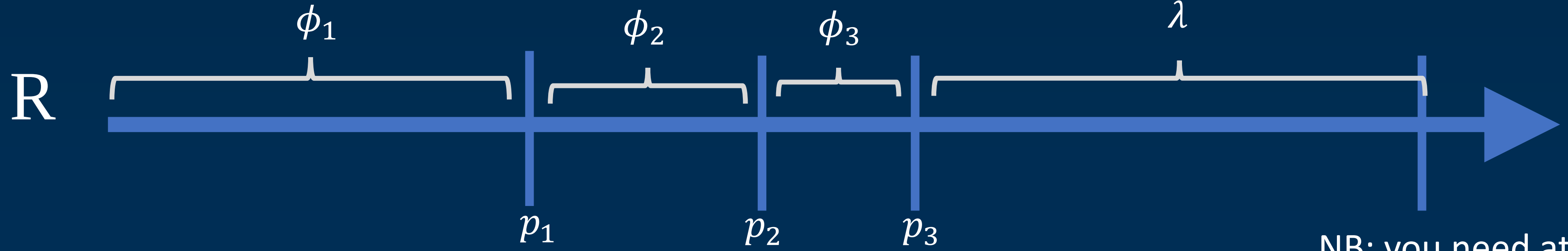
The Space For Time CJS Probability Model



NB: you need at least one detection event past the last reach for survival estimation.

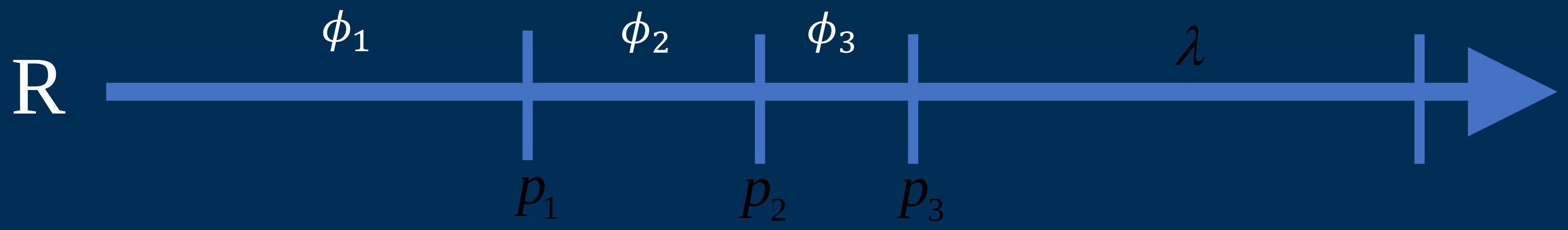
Cormack-Jolly-Seber Model

Assumptions

1. No tag failure or tag loss.
2. Tagged population is migrating.
3. Every fish has equal and independent probability of success.
4. Every fish has equal and independent probability of detection, given it survives to detection location.
5. Upstream detection history has no effect on downstream survival and detection.
6. Tagging has no effect on survival.
7. Detection is instantaneous.
   - No mortality during detection
8. Tags are read correctly.
9. Tagged sampled is representative of the population.
10. All detections come from live study fish.
    - No drifting of dead fish/tags
    - No predator detections

Design Issues: Final Detection Site

- Need at least one detection site past the last reach for survival estimation.
  - Downstream survival: extra array downstream of last reach
  - Upstream survival: extra array upstream of last reach
- Placed close enough that you expect fish to get from last reach to last site
- Very small λ → unable to estimate ϕ



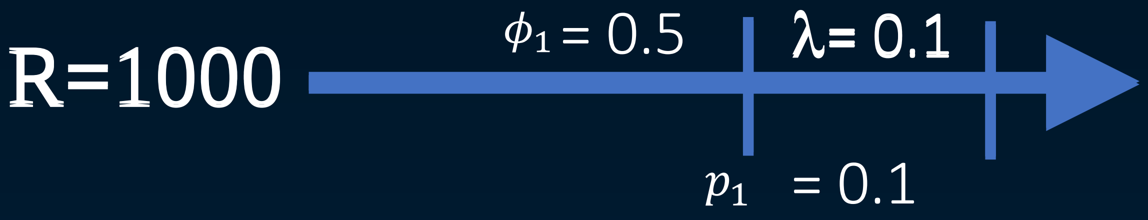
Sample Size

- The number of tagged fish you release
- Affects the expected number of tags observed with each detection history
  - Affects ability to estimate parameters
- Affects standard error: measure of sampling variability (precision)
  - If you repeated experiment many times under same conditions, how much would estimates vary?
  - Does not include population variability
- Tools available to help you figure this out

Sparse Data

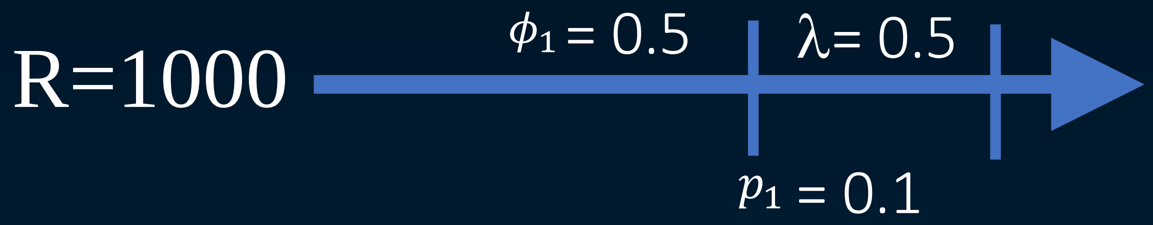
- Low release size
- Low parameter values
  - Survival: ϕ
  - Detection: p
  - "Last reach" parameter: $\lambda = \phi p$
- Estimates
  - Low precision
  - Can get large error between estimate and true value

Scenario 1:



		Count		
Detection History	Probability	Expected	Observed-1	Observed-2
n_{11}	0.005	5	3	7
n_{10}	0.045	45	45	45
n_{01}	0.045	45	47	43
n_{00}	0.905	905	905	905
	Statistic	Value		
	$m_1 = n_{11} + n_{10}$	50	48	52
	$m_2 = n_{11} + n_{01}$	50	50	50
	$r_1 = n_{11}$	5	3	7
	$\hat{p}_1$	0.1	0.06	0.14
	$\hat{\phi}_1$	0.5	0.8	0.37

Scenario 2:



		Count		
Detection History	Probability	Expected	Observed-1	Observed-2
n_{11}	0.025	25	20	30
n_{10}	0.025	25	25	25
n_{01}	0.225	225	230	220
n_{00}	0.725	725	725	725
	Statistic	Value		
	$m_1=n_{11}+n_{10}$	50	45	55
	$m_2=n_{11}+n_{01}$	250	250	250
	$r_1=n_{11}$	25	20	30
	$\hat{p}_1$	0.1	0.08	0.12
	$\hat{\phi}_1$	0.5	0.56	0.46

Sparse Data: Moral

- Even with large release group, can get sparse data
  → may get estimates that are far from true values
  → estimates not useful
- How to avoid?
  - Increase λ:
    - Move last detection site closer (increase ϕ_2)
    - Boost p_2
    - Add additional sites to form composite λ
  - Boost p_1
    - Add redundant array at p_1
    - Place site 1 more effectively
    - Maintain equipment carefully