Using an individual-based model to explore survival of emigrating salmonids in the South Delta

Travis Hinkelman and Bradley Cavallo

Model Overview

Individual-Based
Delta Passage Model

- Individual-based, discrete event simulation model

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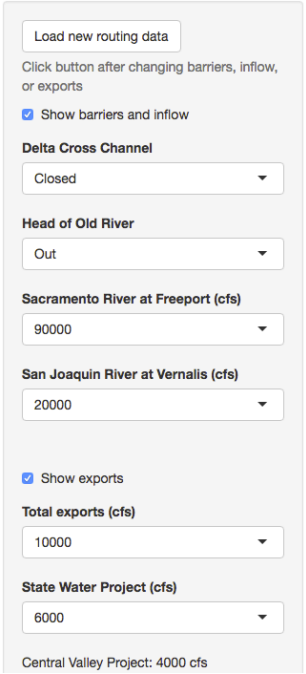
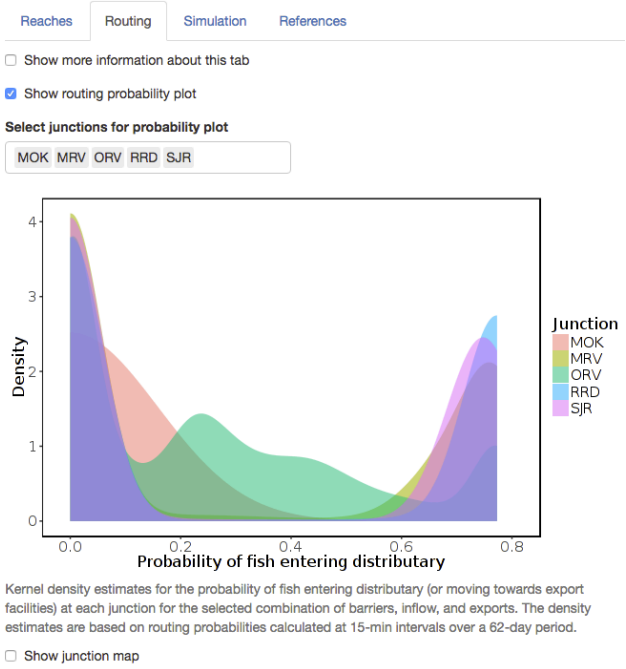
- Written in R with web-based GUI



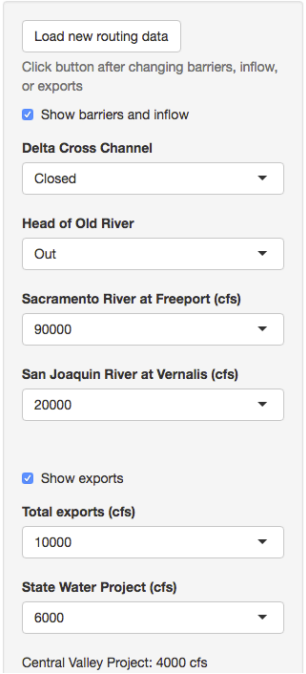


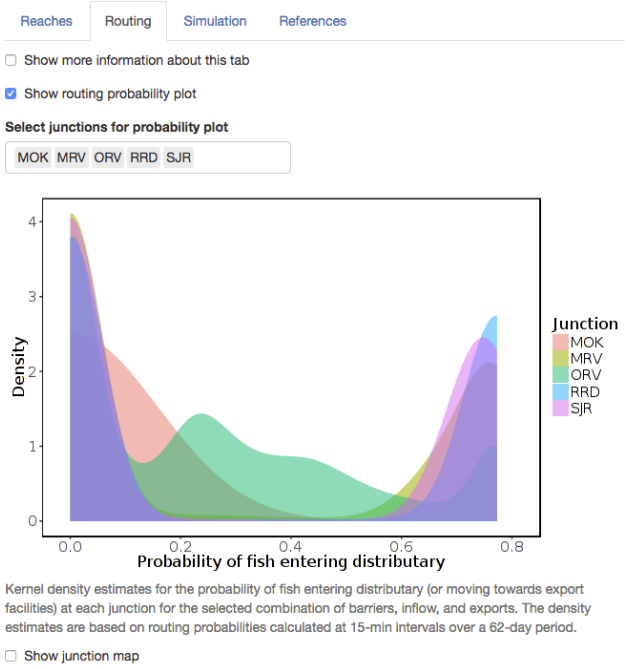
https://fishsciences.shinyapps.io/ibdpm/

Model Overview

Individual-Based Delta Passage Model

- Individual-based, discrete event simulation model
- Written in R with web-based GUI
- Practical tool for simulation experiments





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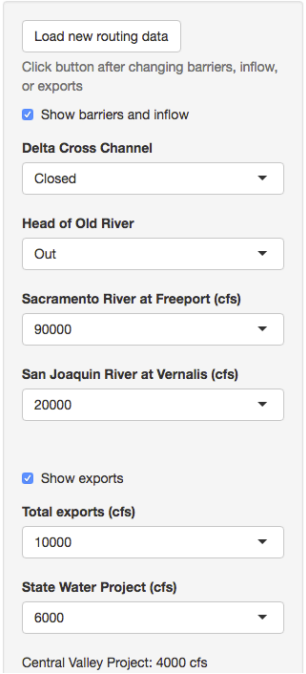
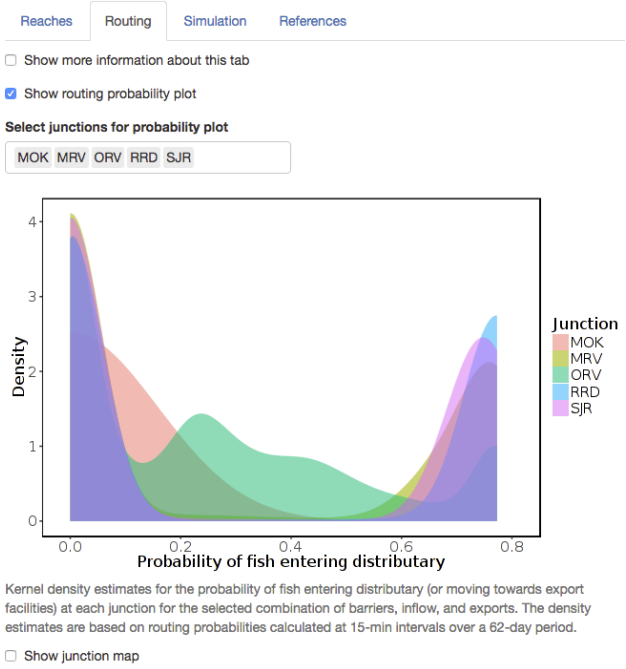
- Effects of water project operations, barriers, predation risk, etc.





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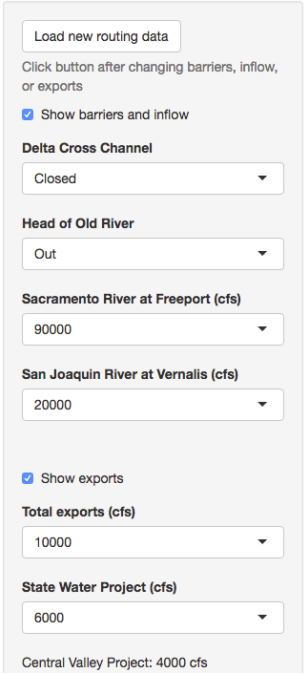
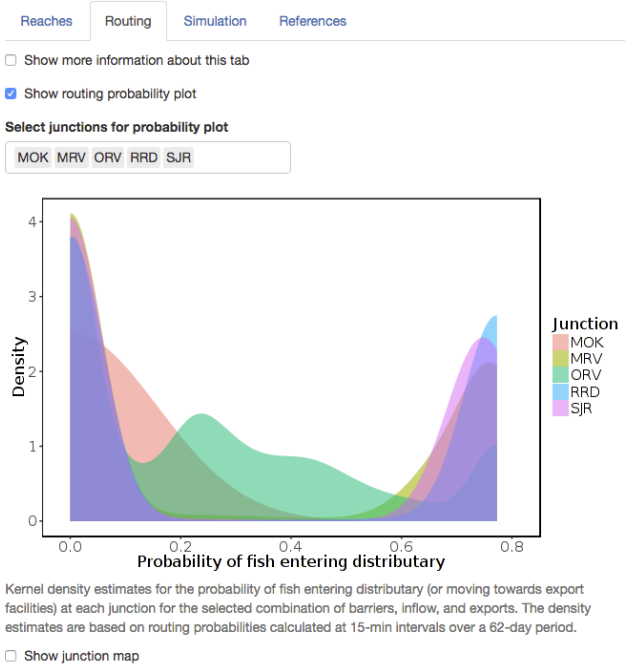
Model Overview

Individual-Based Delta Passage Model

- Individual-based, discrete event simulation model
- Written in R with web-based GUI
- Practical tool for simulation experiments
- Effects of water project operations, barriers, predation risk, etc.
- Number of juvenile salmonids arriving at Chipps Island or export facilities





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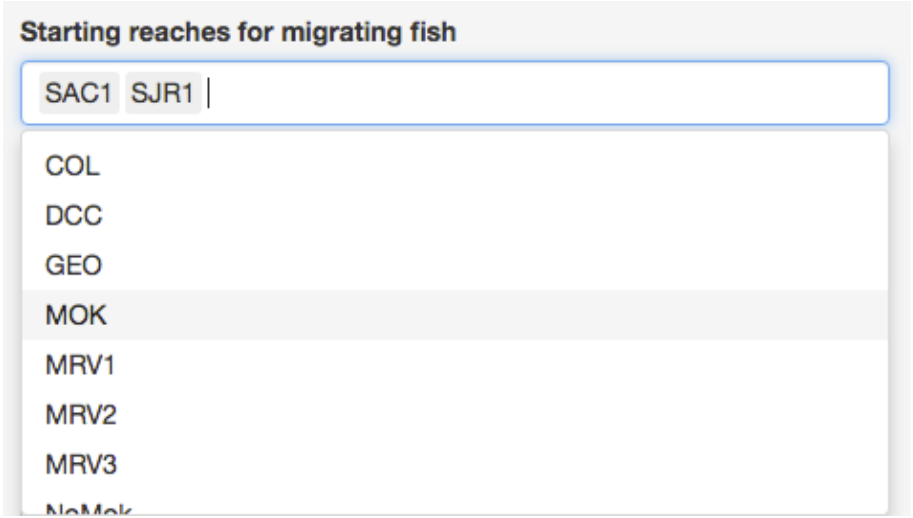
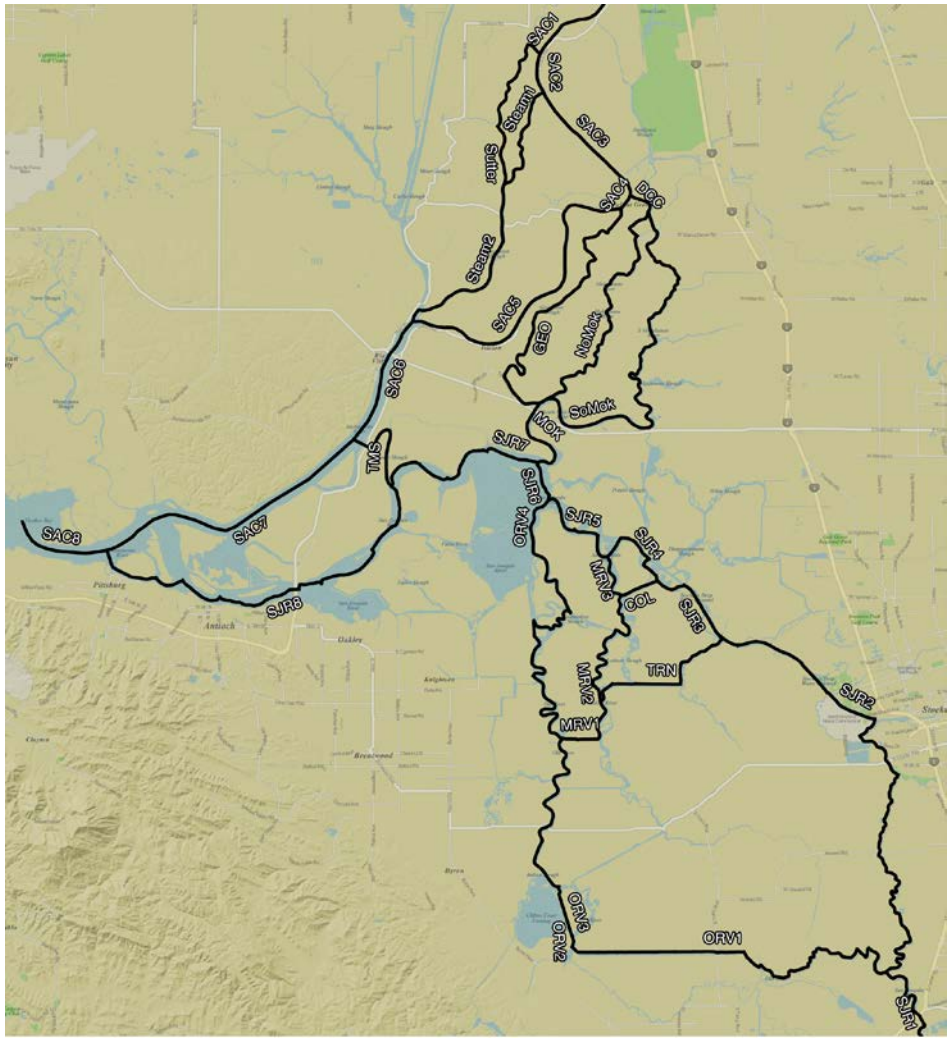
Reaches

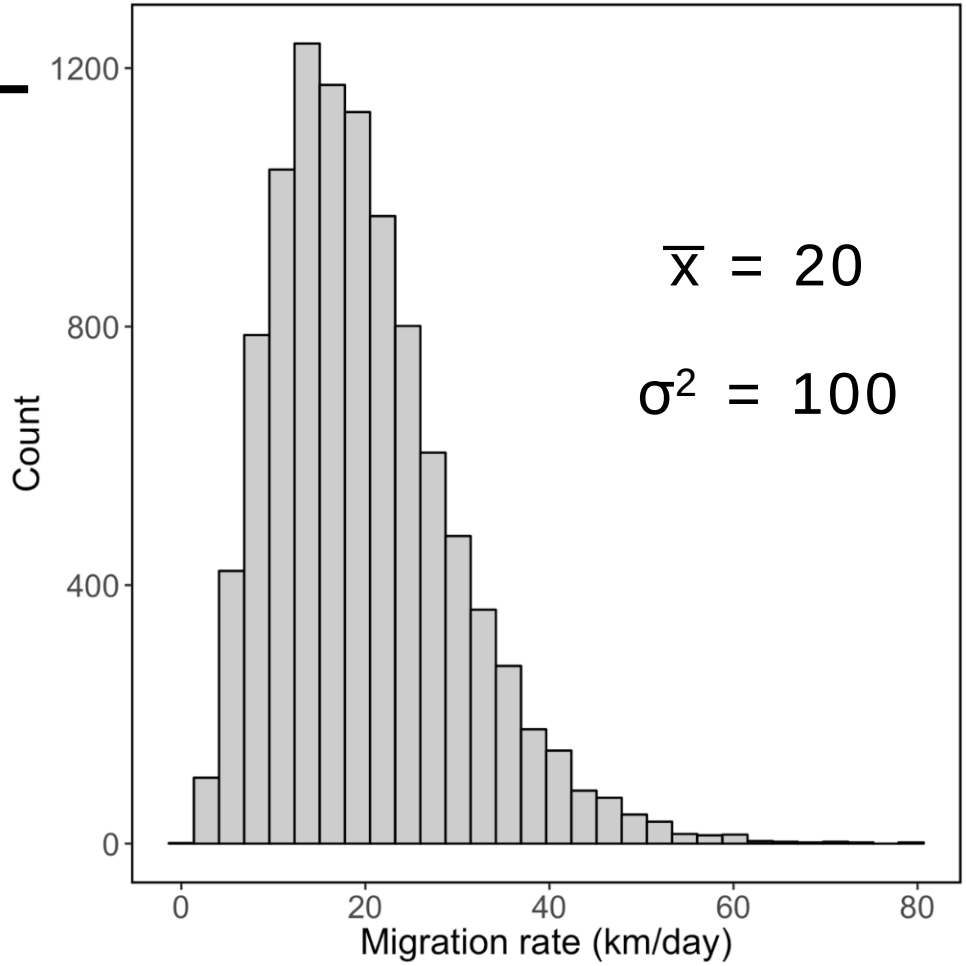
- 34 reaches representing key migratory routes
- Starting reaches





Migration Rate

- Migration rates drawn from Gamma distribution
  - Value drawn when fish enters new reach
- Gamma distribution defined by mean and variance
  - Properties of reach



Survival

XT Model

- Distance (gauntlet)
  - Reach length
- Time (exposure)
  - Reach length/migration rate

$$S = \exp\left(-\frac{1}{\lambda}\sqrt{x^2 + \omega^2 t^2}\right)$$

Anderson et al. 2005. Ecological Modelling

Survival

XT Model

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  - Reach length
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- Omega (ω = 1.8)
  - Random encounter velocity

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Anderson et al. 2005. Ecological Modelling

Survival

XT Model

- Distance (gauntlet)
  - Reach length
- Time (exposure)
  - Reach length/migration rate

- Omega (ω = 1.8)
  - Random encounter velocity
- Lambda (λ = 31-188)
  - Distance between predator encounters

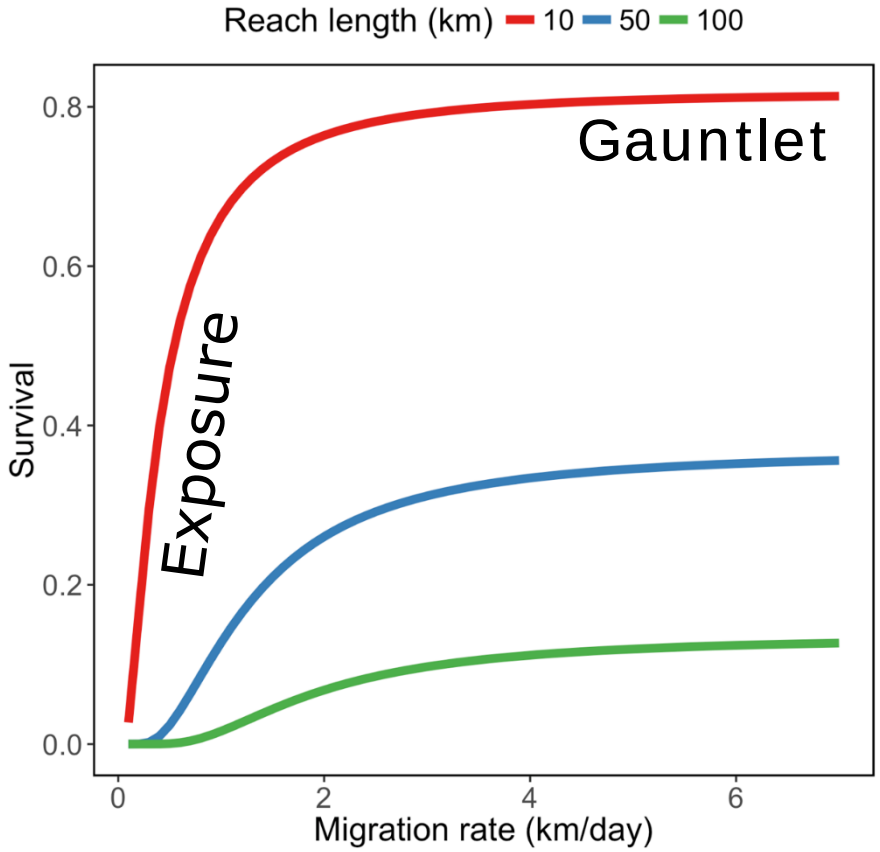
$$S = \exp\left(-\frac{1}{\lambda}\sqrt{x^2 + \omega^2 t^2}\right)$$

Anderson et al. 2005. Ecological Modelling

Survival

- XT model
  - Distance (reach length)
  - Time (reach length/migration rate)
  - Omega (random encounter velocity)
  - Lambda (distance between predator encounters)

ω = 1.8 λ = 50



Anderson et al. 2005. Ecological Modelling

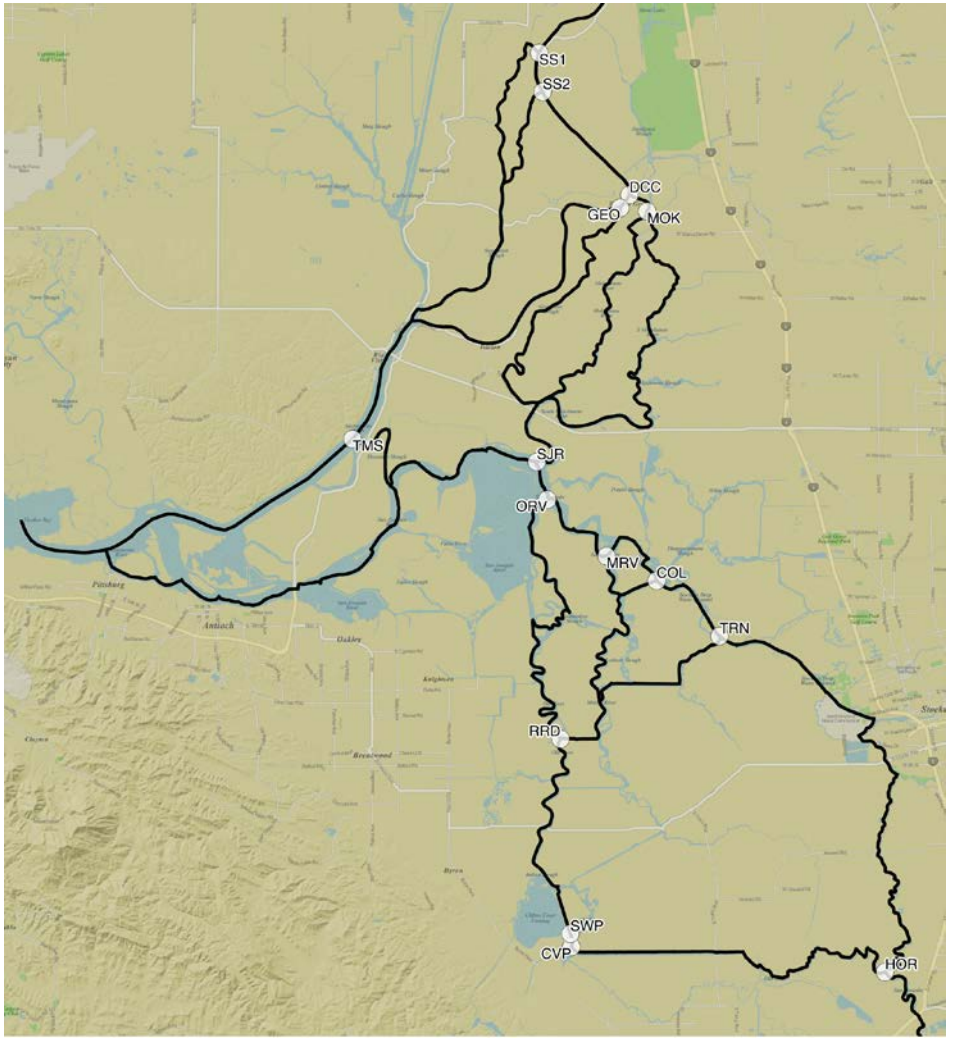
Reach Properties

- Migration rate (km/day) mean and variance
- Distance between predator encounters (lambda; km)
- Random encounter velocity (omega; km/day)
- Reach length (km)

	Reach	Mean	Variance	Lambda	Omega	Length
1	SAC1	20	100	188	1.80	41.00
2	SAC2	20	100	188	1.80	2.60
3	SAC3	20	100	188	1.80	8.60
4	Steam1	20	100	101	1.80	7.20
5	Steam2	20	100	101	1.80	12.20
6	SAC4	20	100	96	1.80	1.00
7	SAC5	20	100	96	1.80	19.80
8	SAC6	20	100	84	1.80	8.50
9	SAC7	20	100	84	1.80	18.20
10	SAC8	20	100	84	1.80	6.20
11	GEO	20	100	66	1.80	20.30
12	MOK	20	100	66	1.80	6.10
13	COL	20	100	36	1.80	2.50
14	MRV1	20	100	36	1.80	5.00
15	MRV2	20	100	36	1.80	10.20
16	MRV3	20	100	36	1.80	3.10
17	ORV1	20	100	36	1.80	24.70
18	ORV2	20	100	36	1.80	0.80
19	ORV3	20	100	36	1.80	15.60
20	ORV4	20	100	36	1.80	24.90

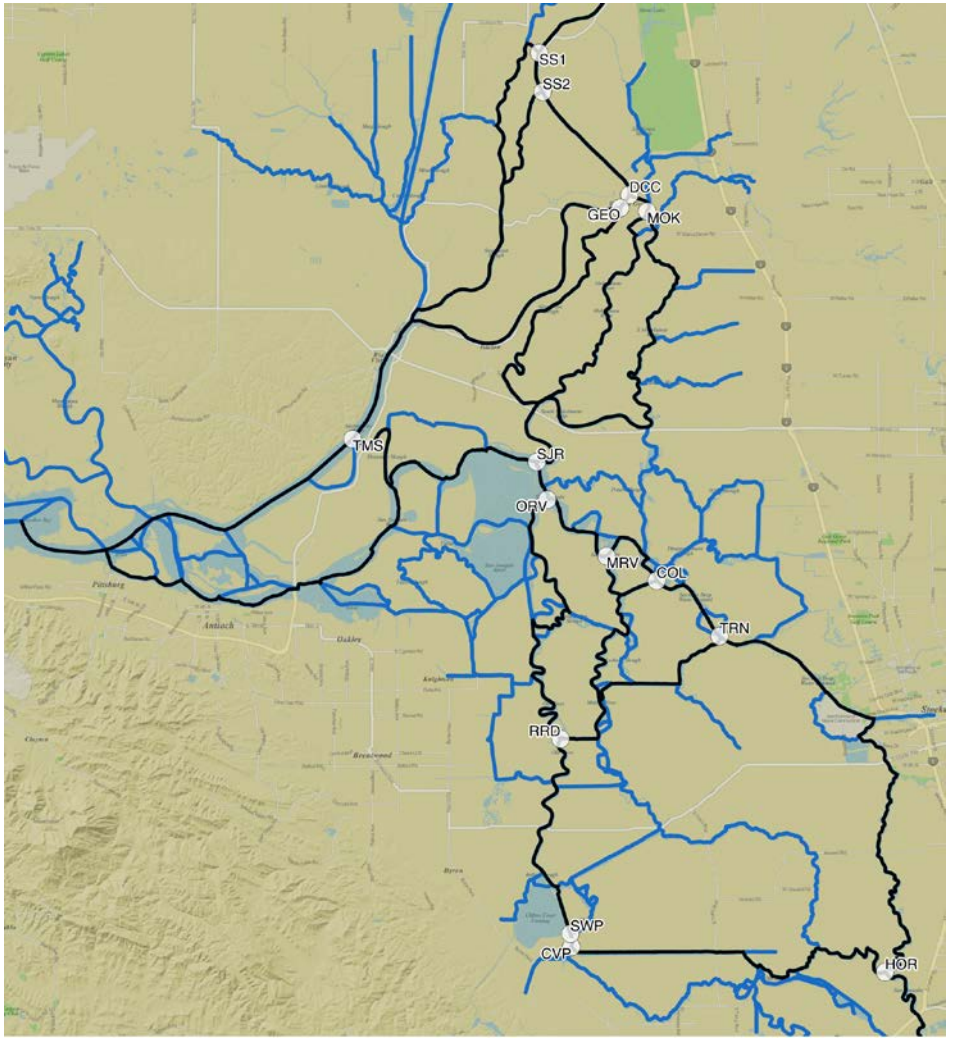
Routing

- 15 junctions on key migratory routes



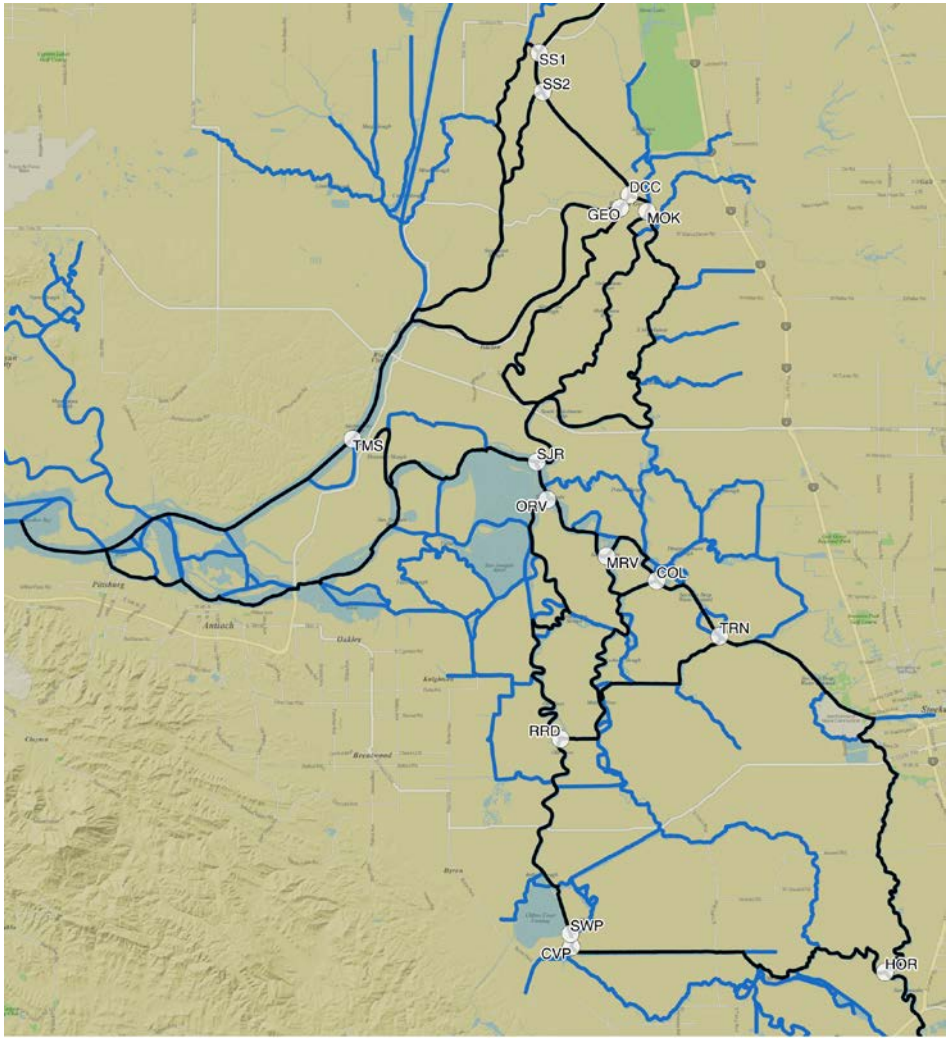
Routing

- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)



Routing

- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)
  - 15-min flow values
  - 61 days of representative tides
  - 3,978 combinations of barriers, inflow, and exports



Routing

- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)
  - 15-min flow values
  - 61 days of representative tides
  - 3,978 combinations of barriers, inflow, and exports
- Override flow-based routing

	Junction	Override	Probability
1	COL	☐	0.00
2	CVP	☑	1.00
3	DCC	☐	0.00
4	GEO	☐	0.00
5	HOR	☑	1.00
6	MOK	☐	0.00
7	MRV	☐	0.00
8	ORV	☐	0.00
9	RRD	☐	0.00
10	SJR	☐	0.00
11	SS1	☐	0.00
12	SS2	☐	0.00
13	SWP	☐	0.00
14	TMS	☐	0.00
15	TRN	☐	0.00

Survival by Route

	Junction	Override	Probability
1	COL	☑	0.00
2	CVP	☐	0.00
3	DCC	☐	0.00
4	GEO	☐	0.00
5	HOR	☑	0.00
6	MOK	☐	0.00
7	MRV	☑	0.00
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10	SJR	☐	0.00
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13	SWP	☐	0.00
14	TMS	☐	0.00
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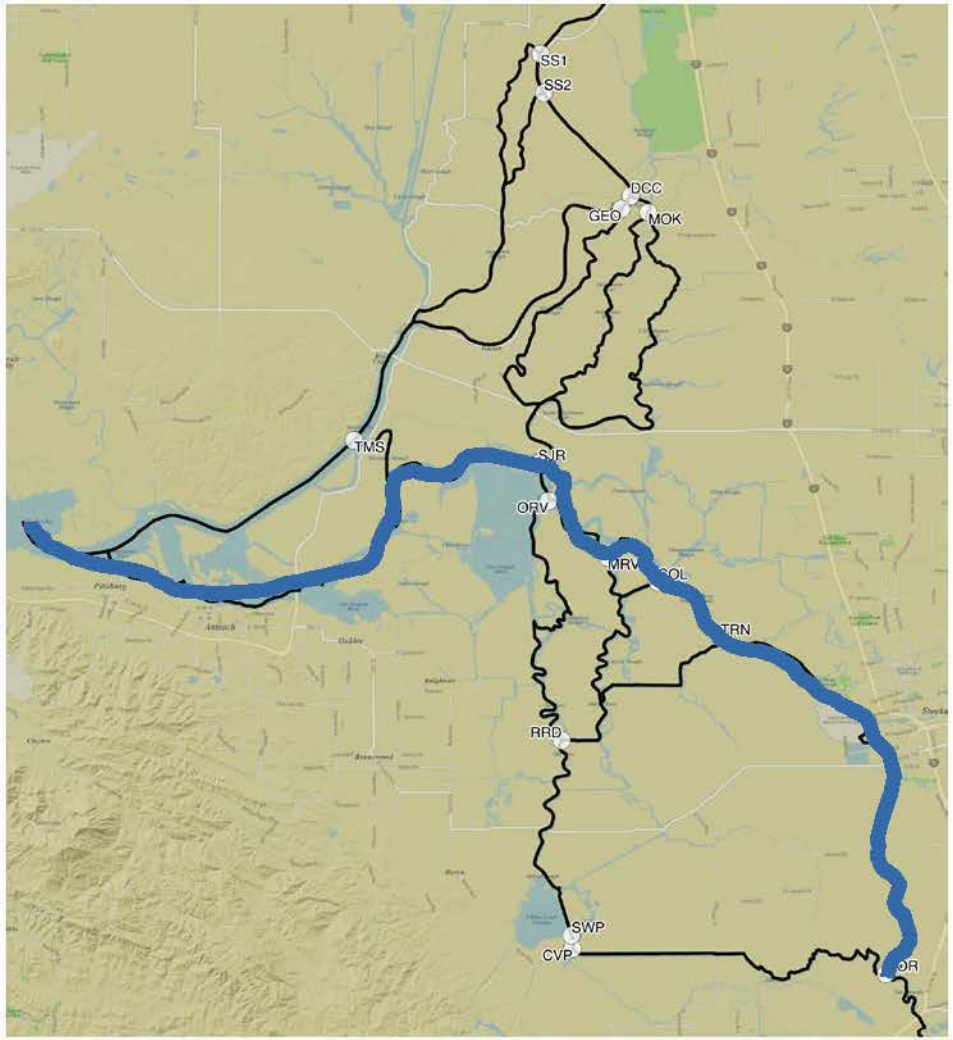

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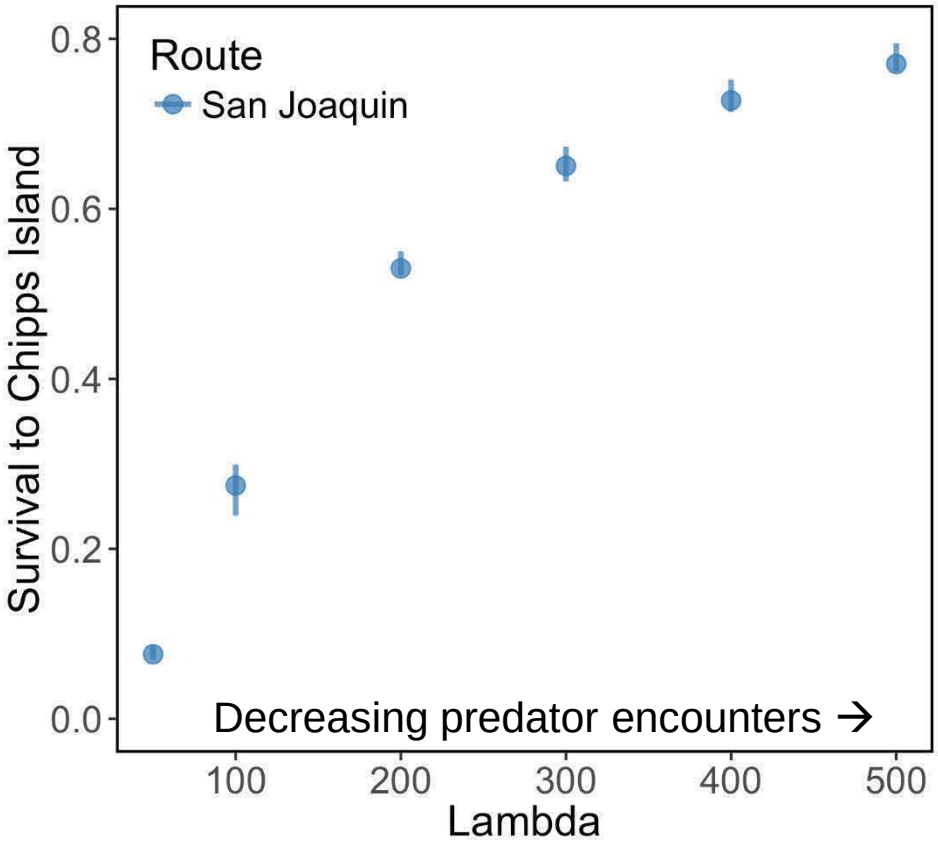

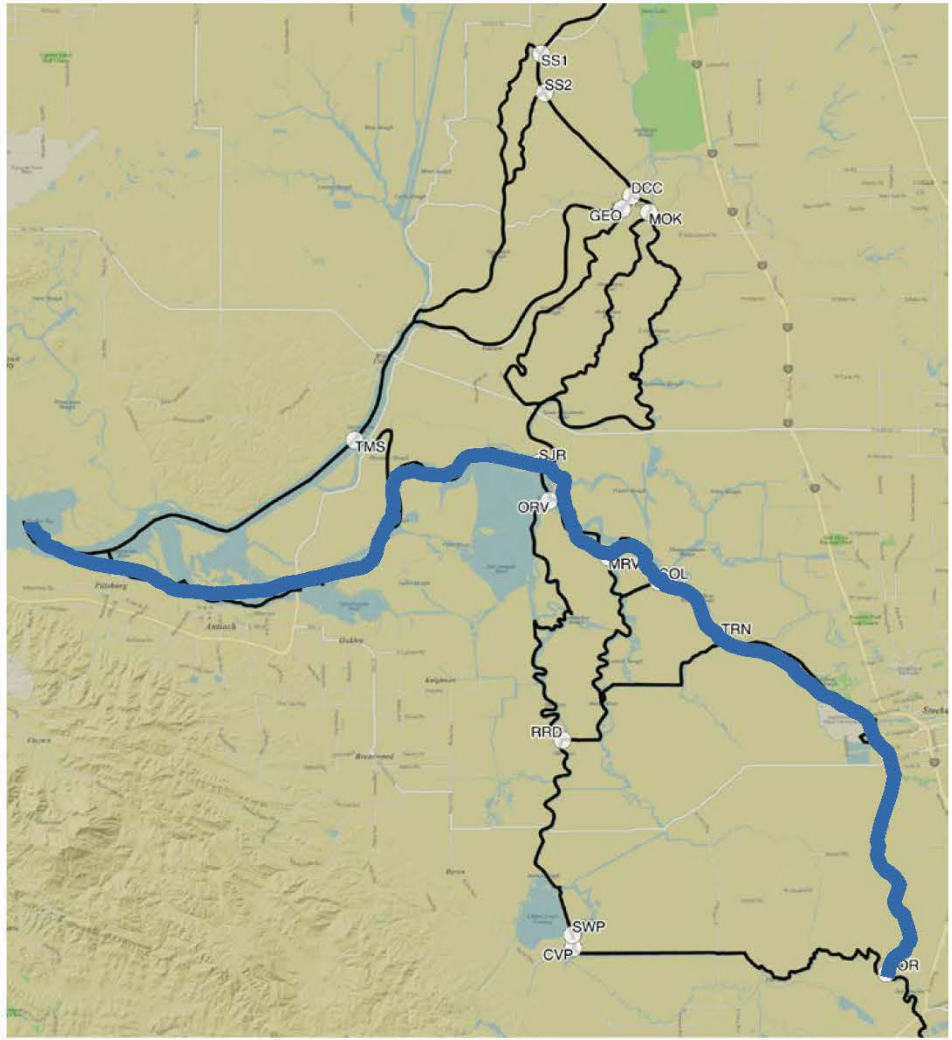

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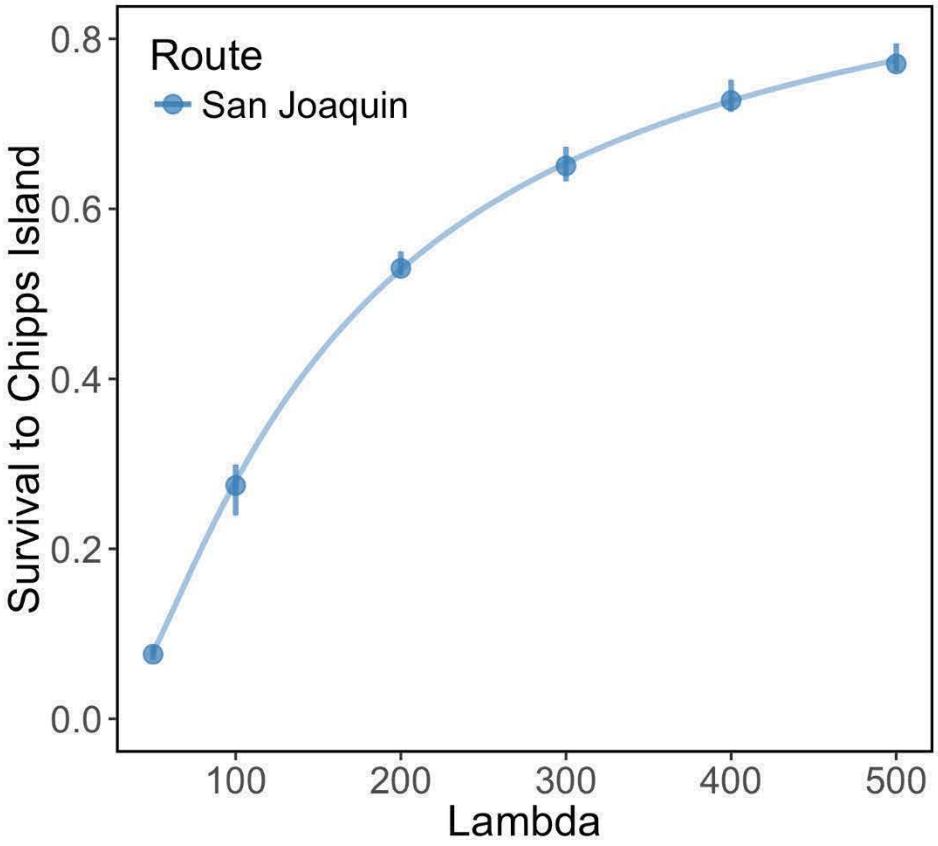

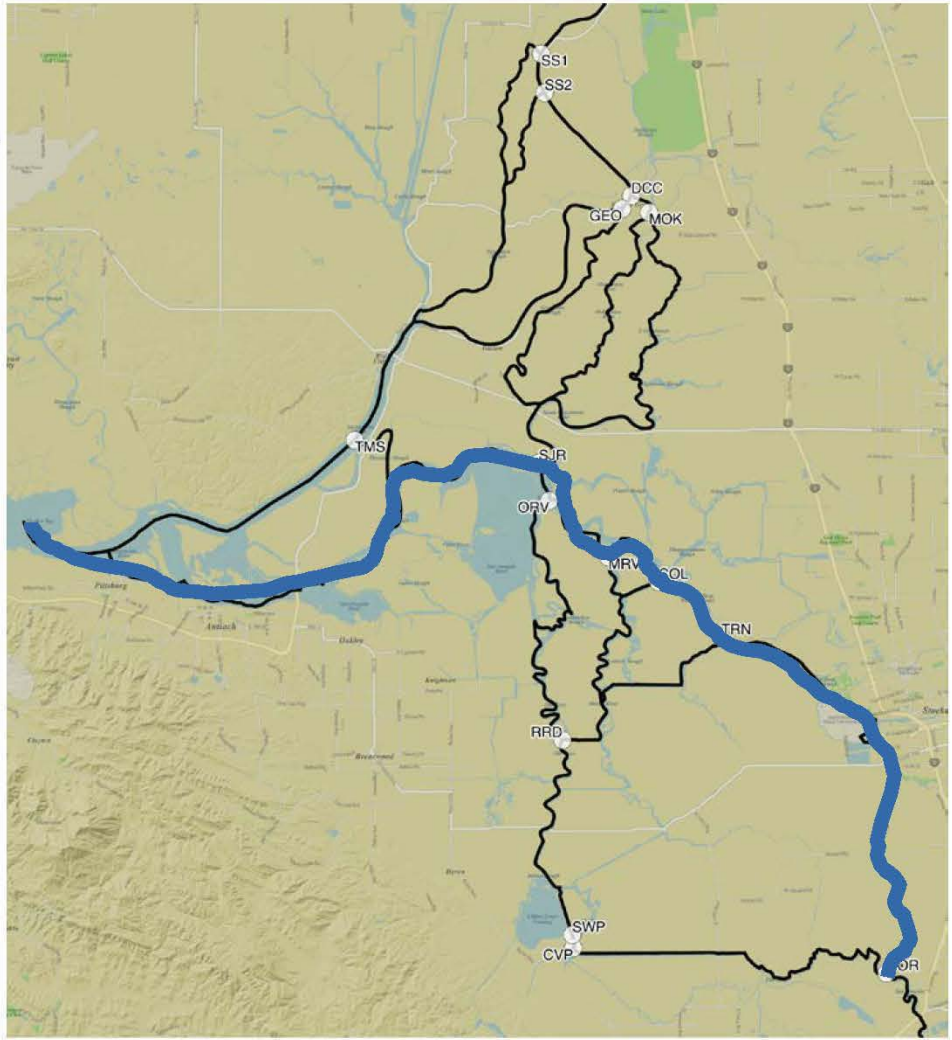

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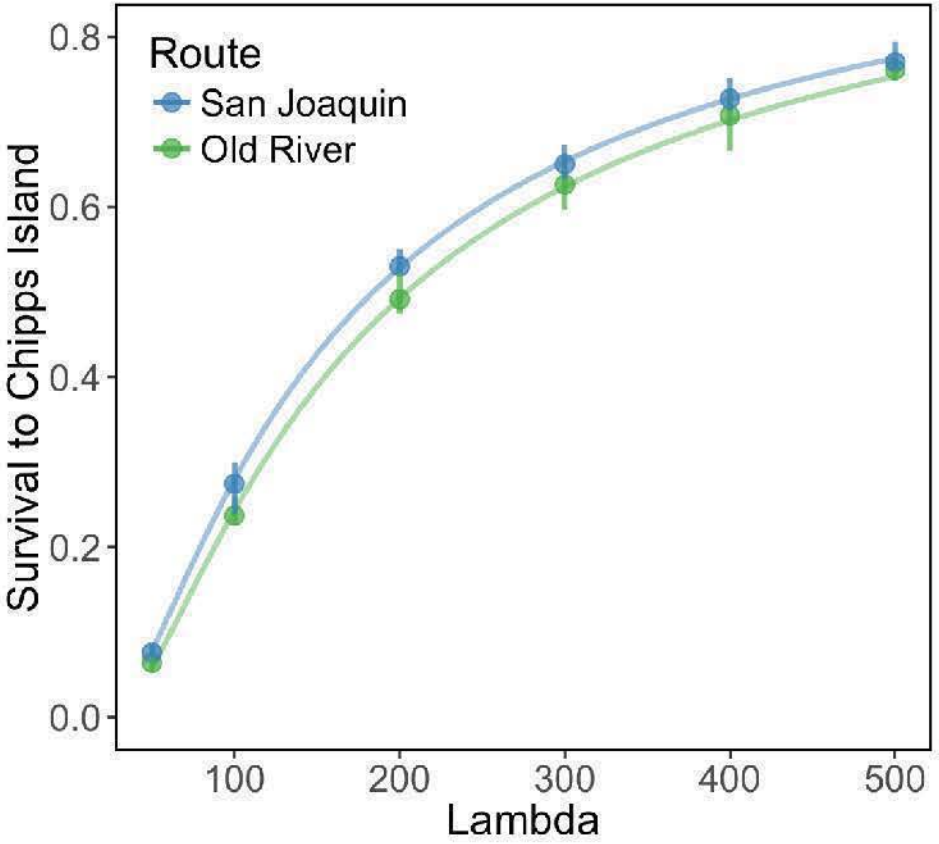

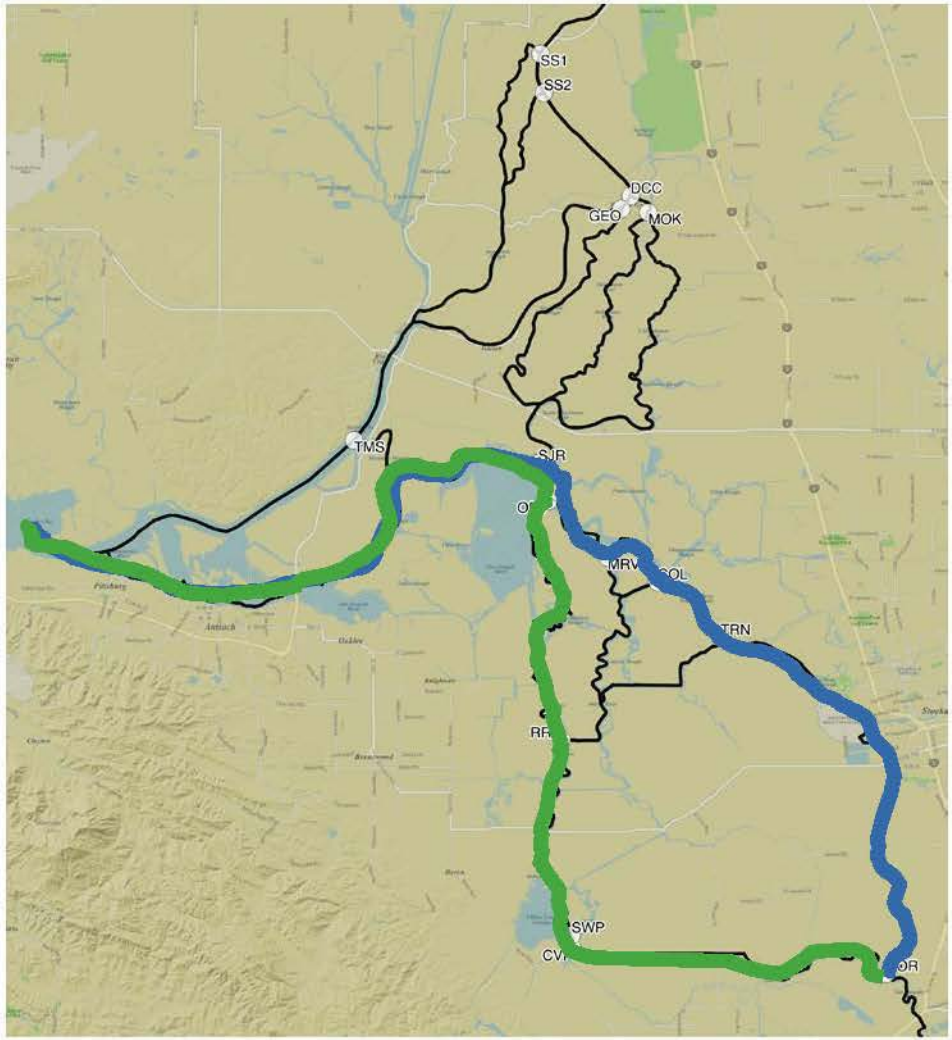

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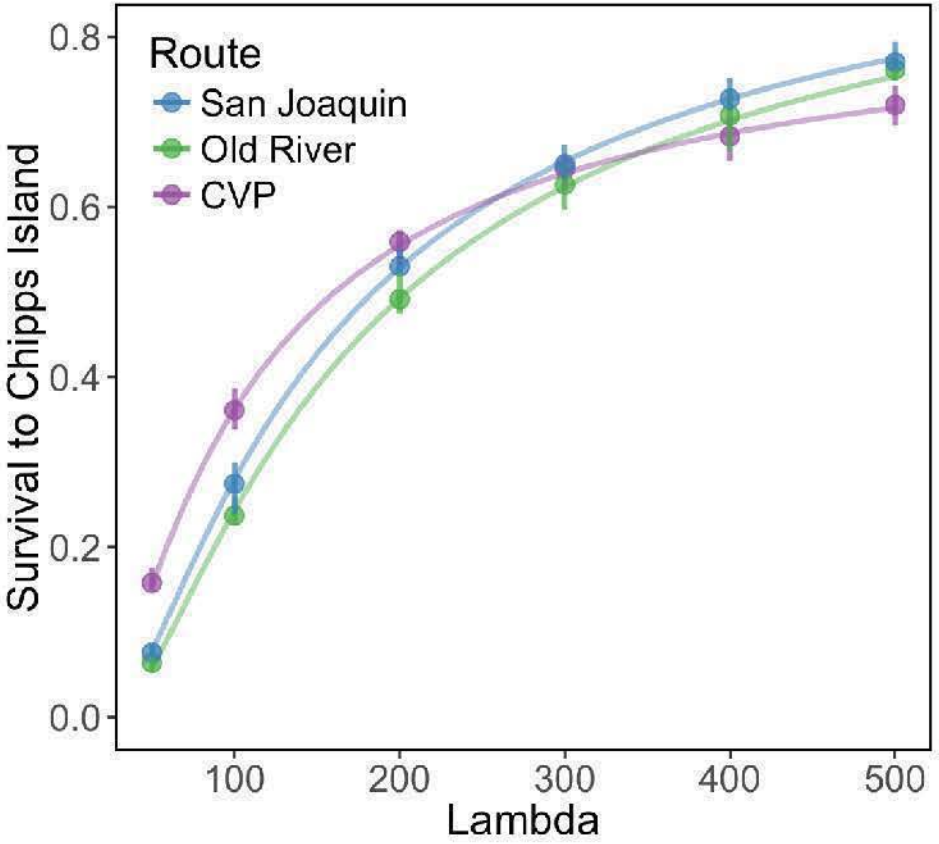

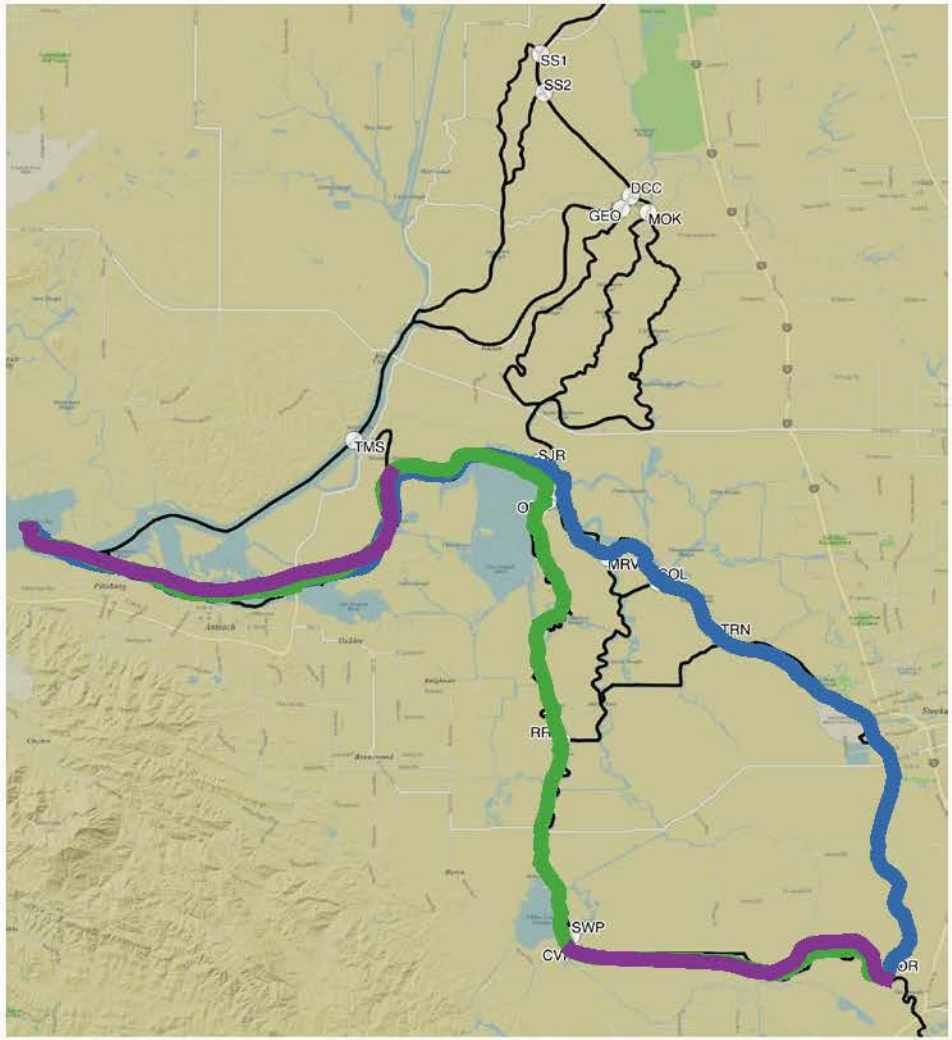

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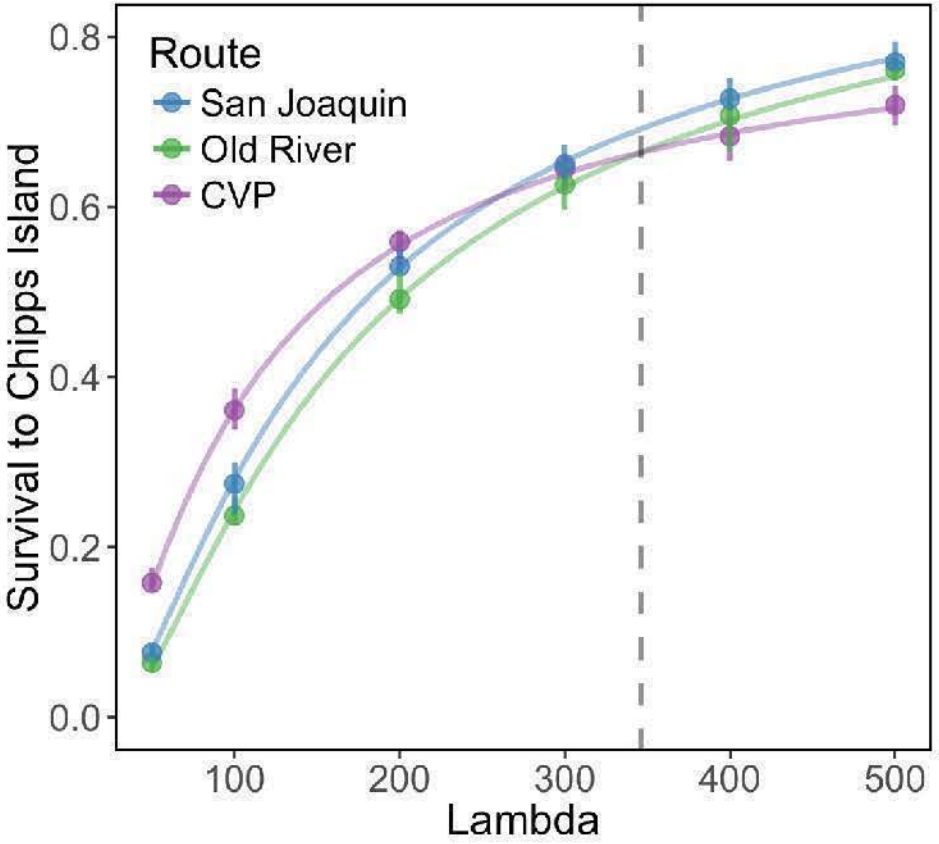

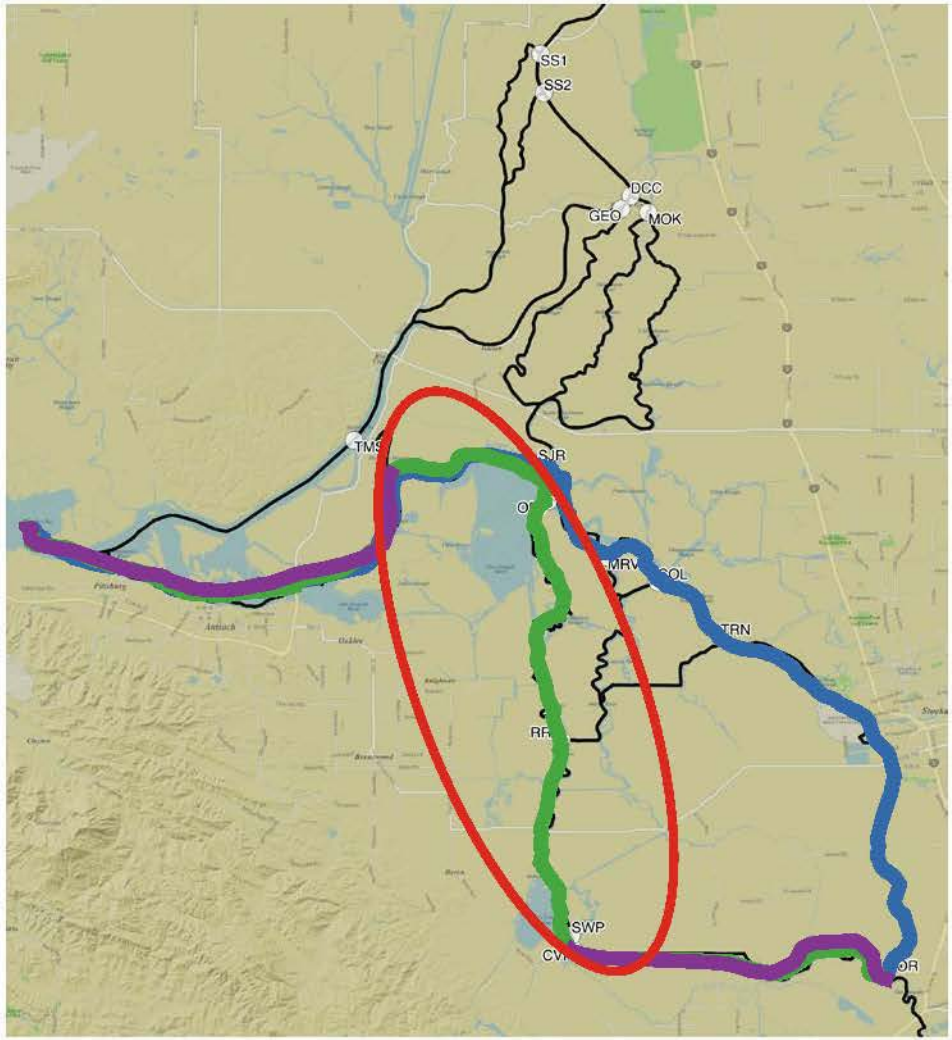

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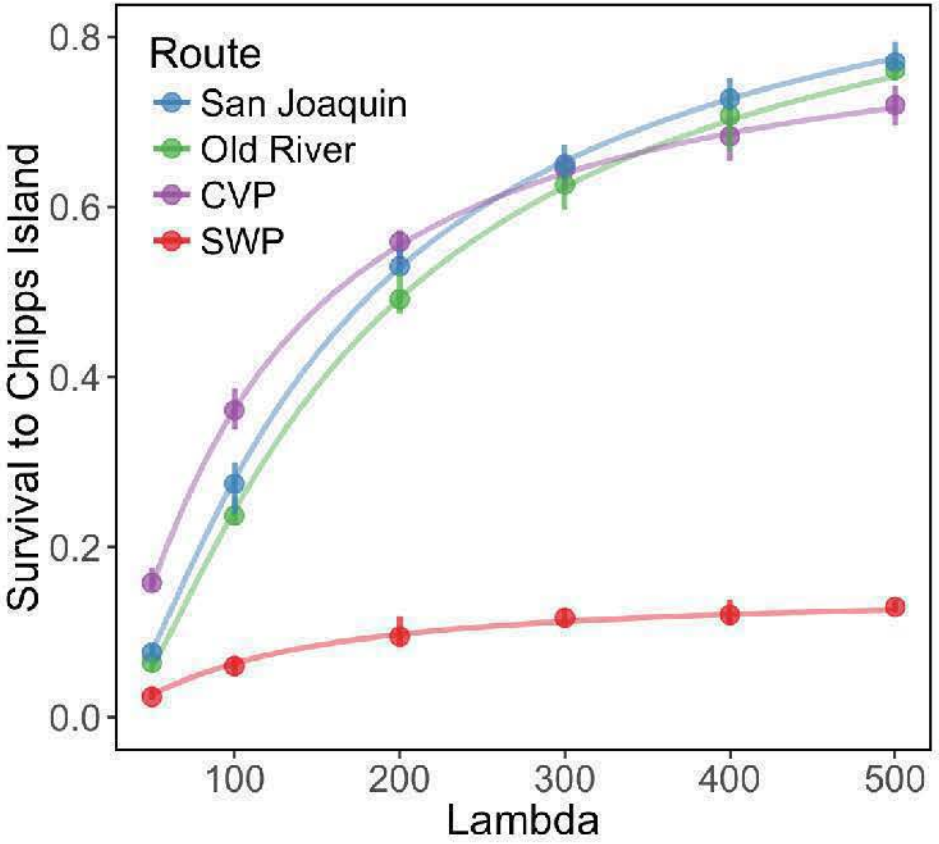
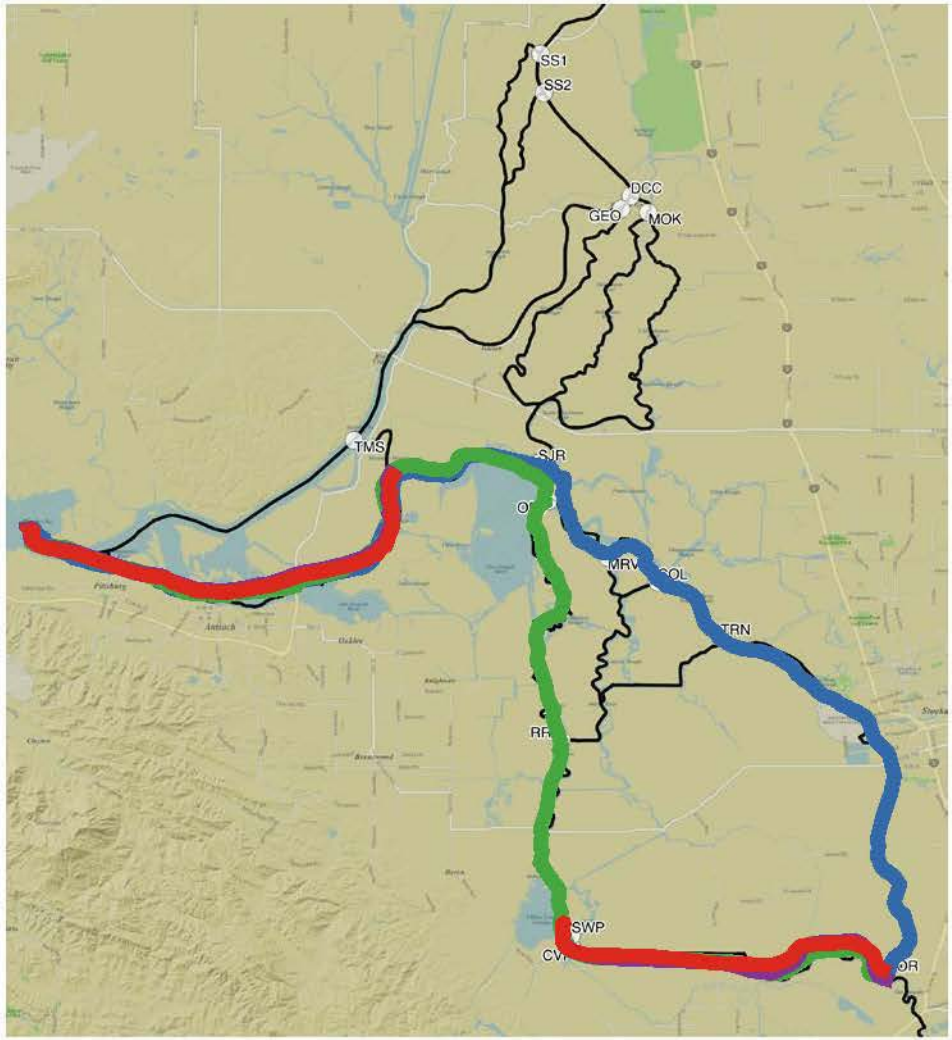
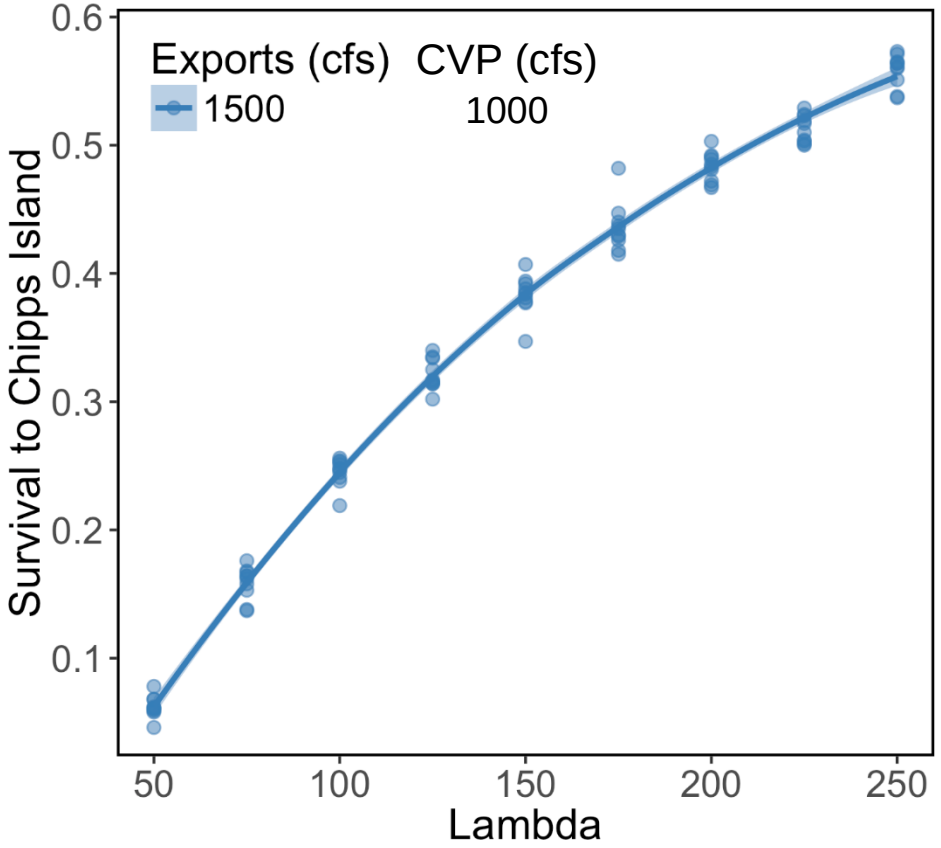
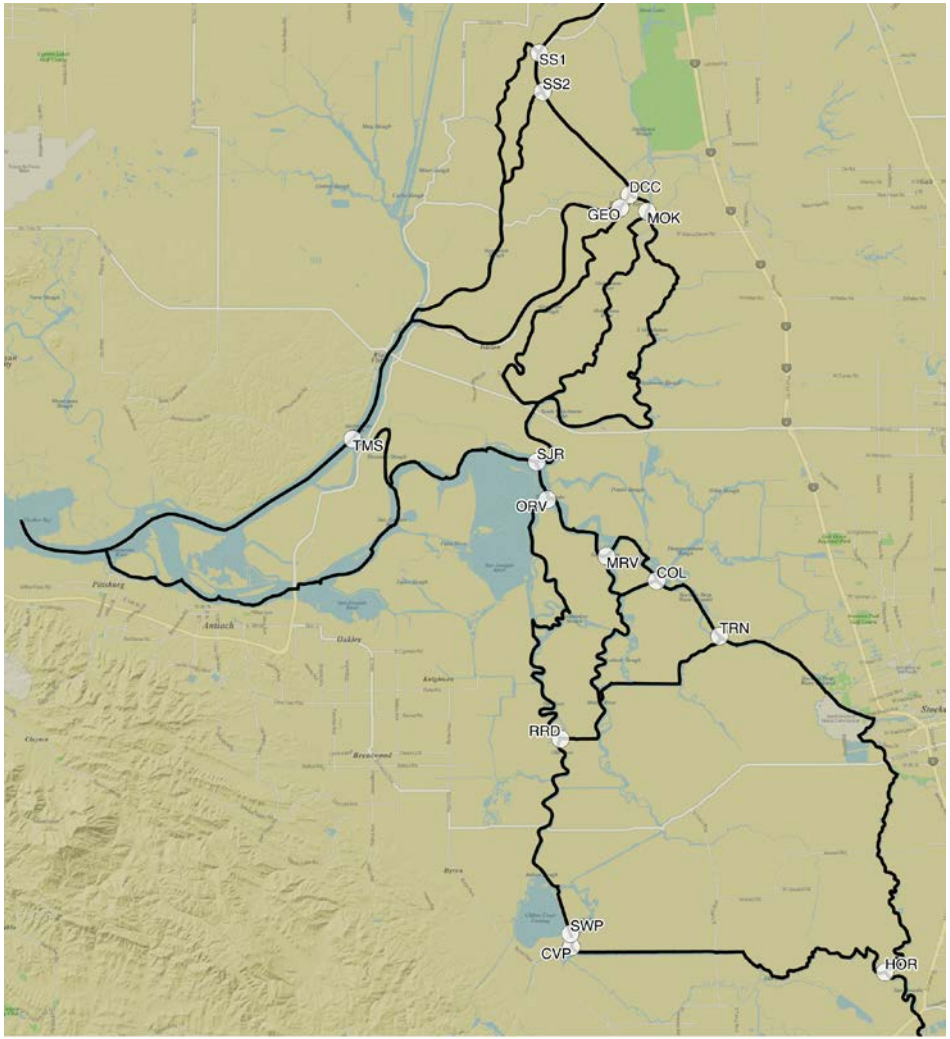




Survival and Exports





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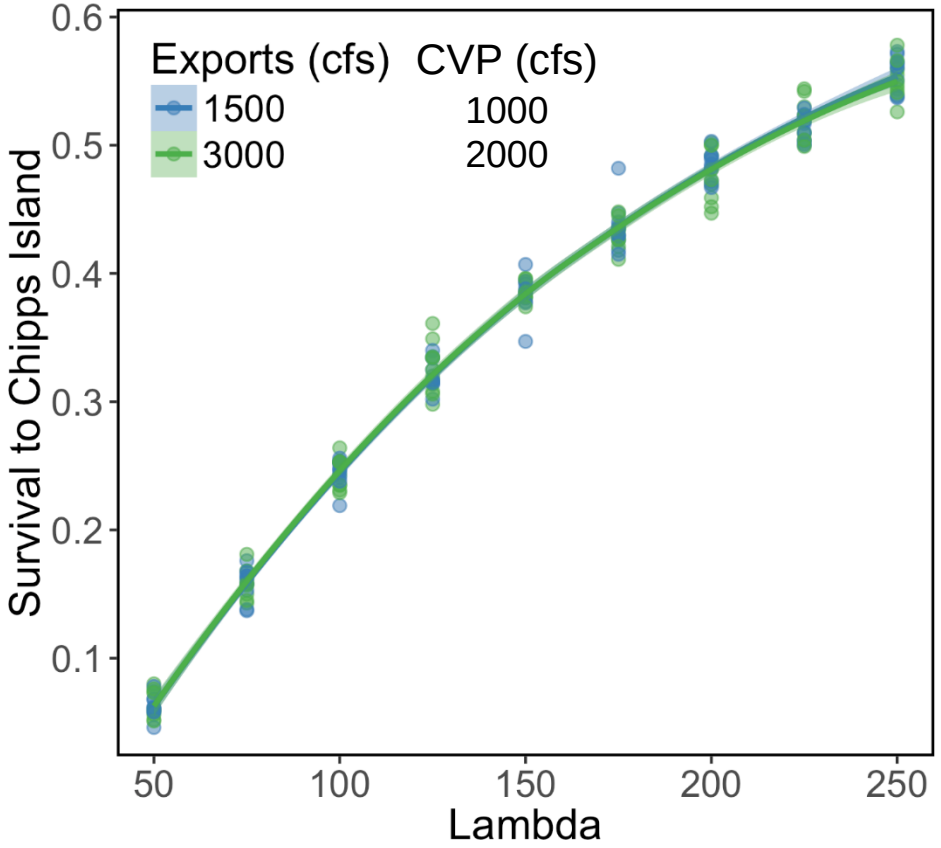

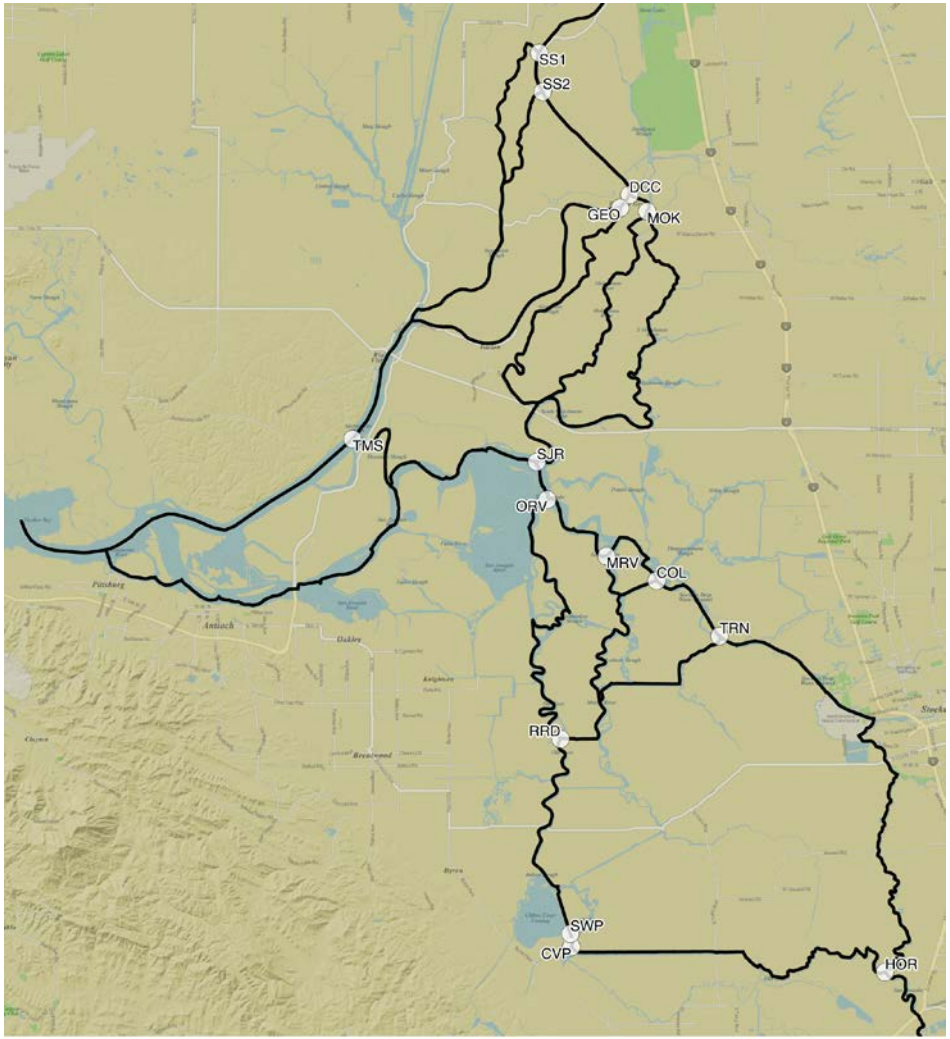

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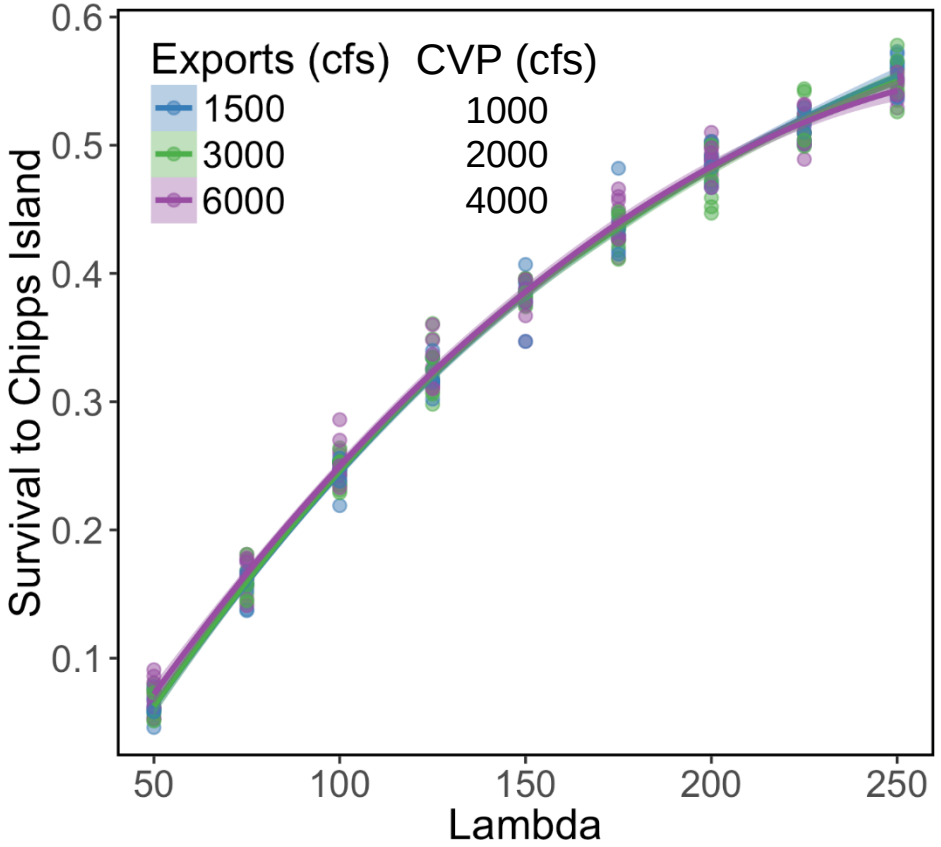

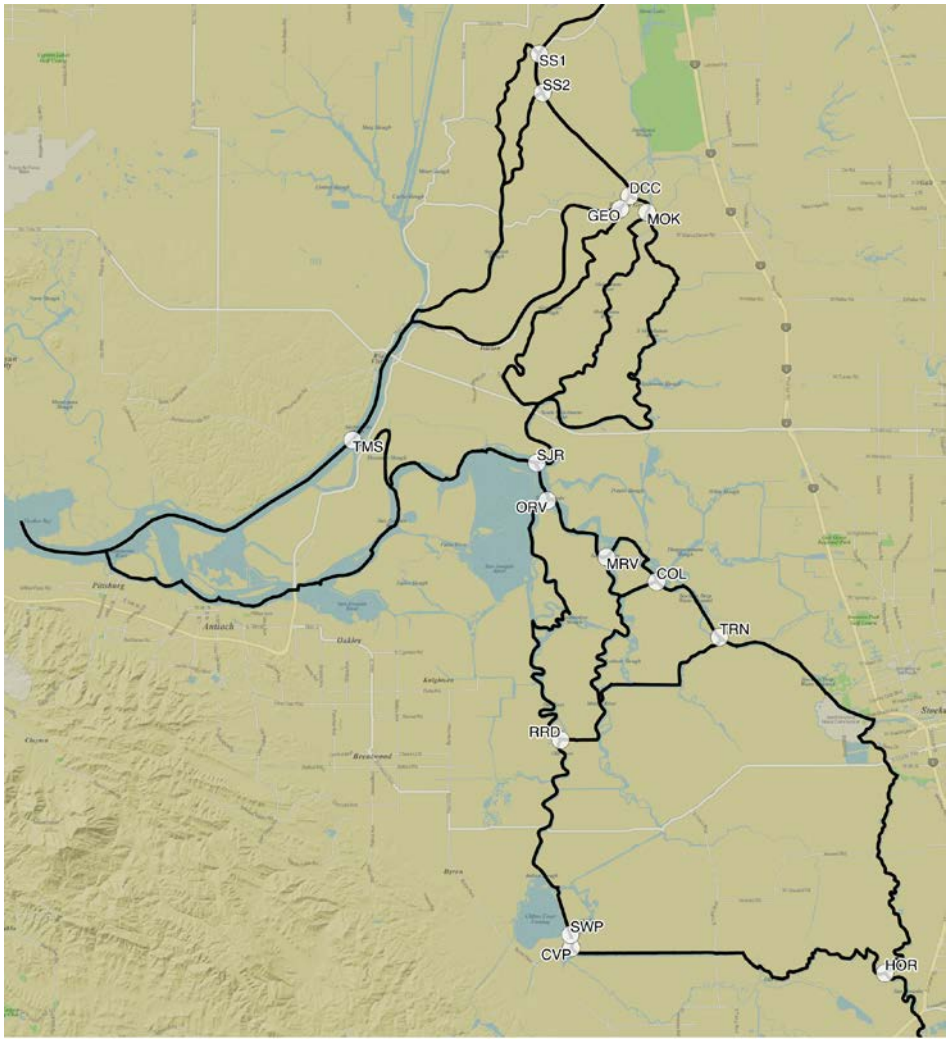

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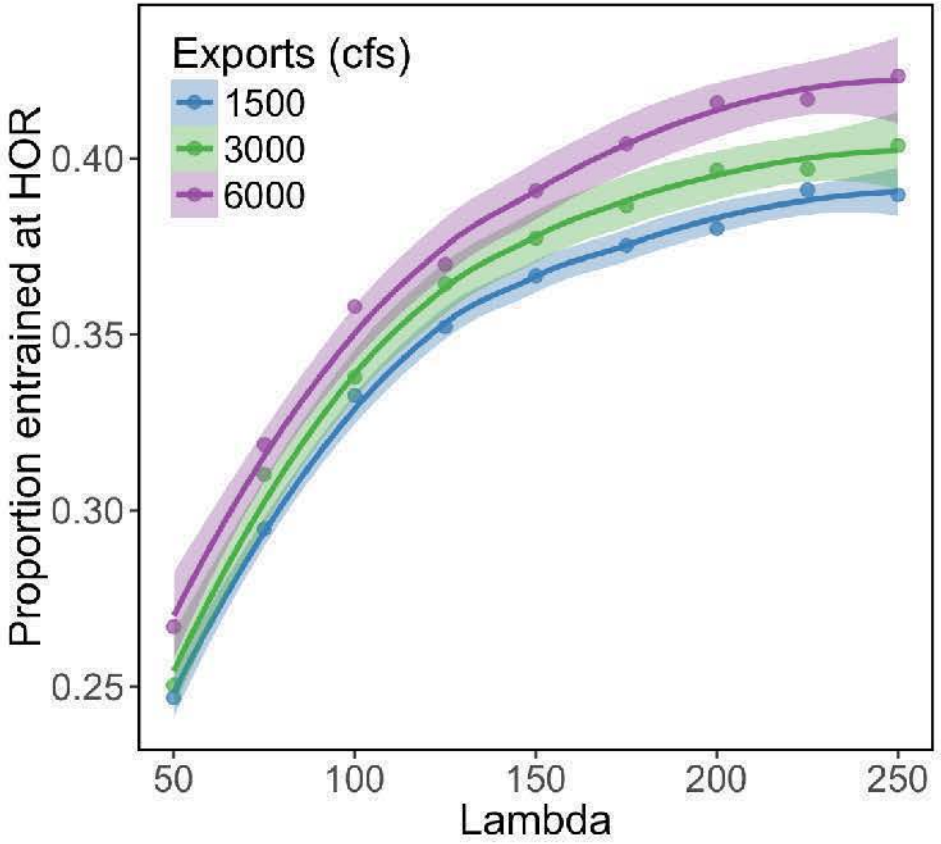

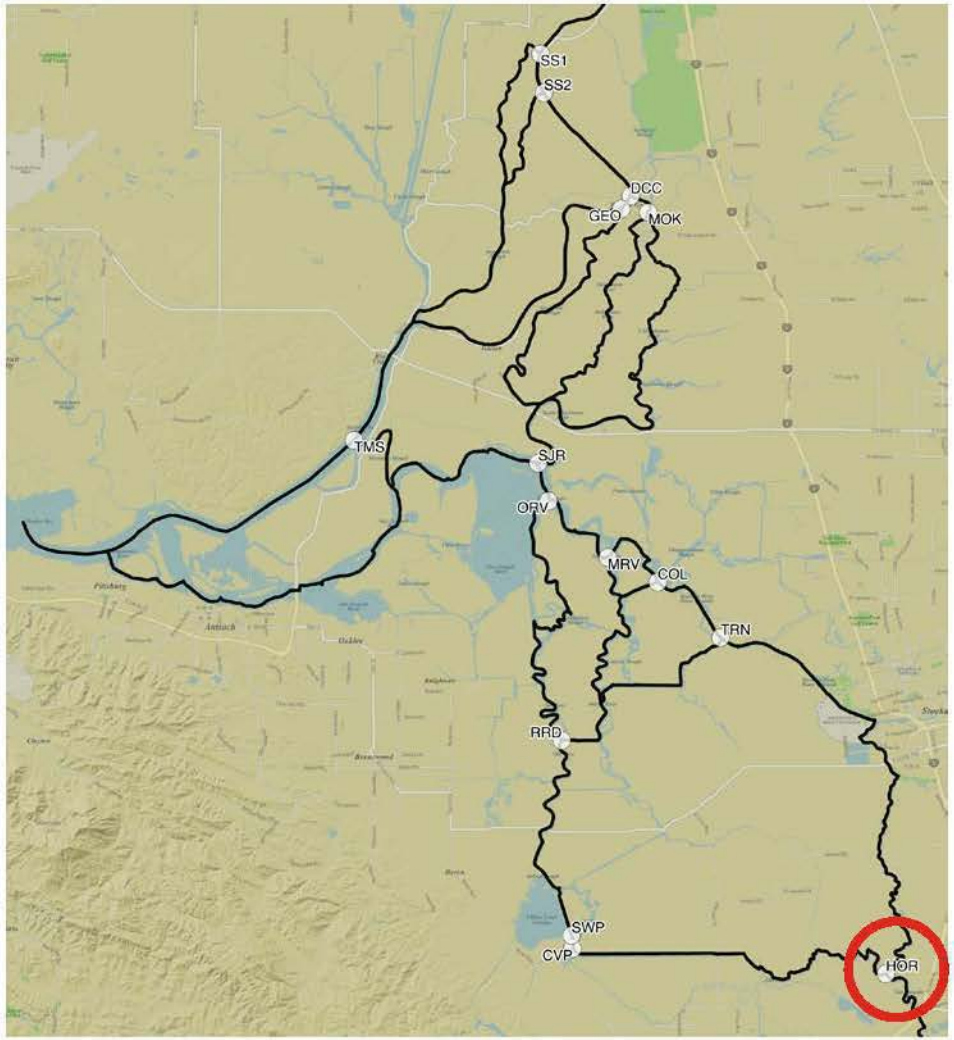

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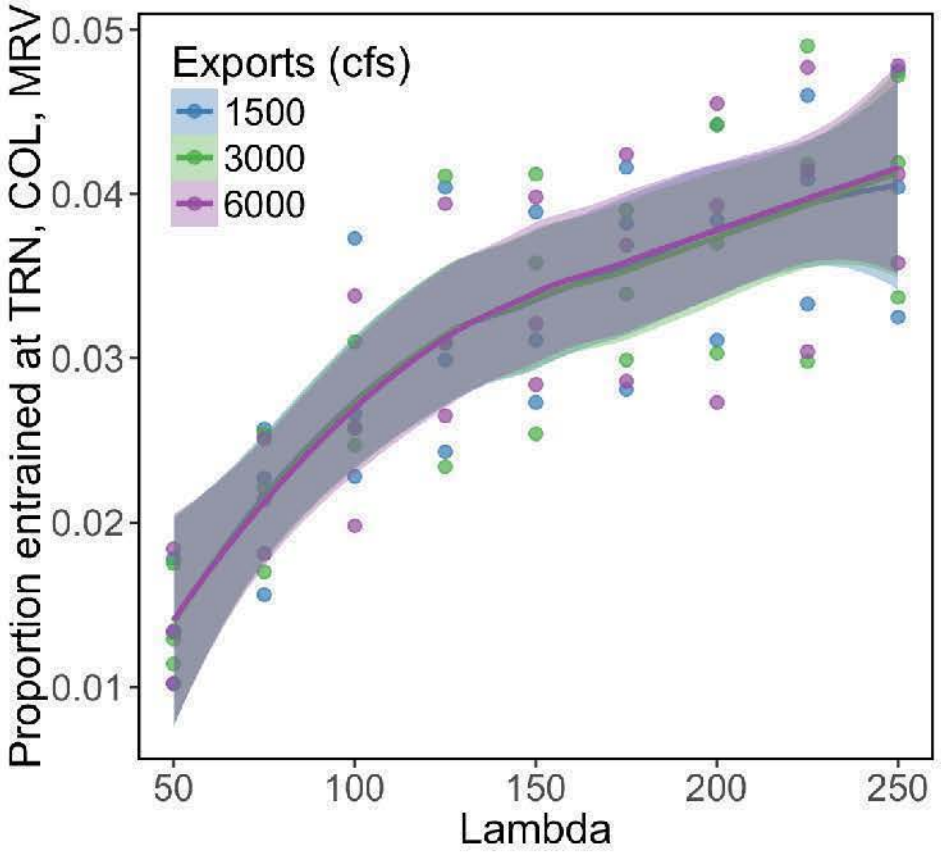

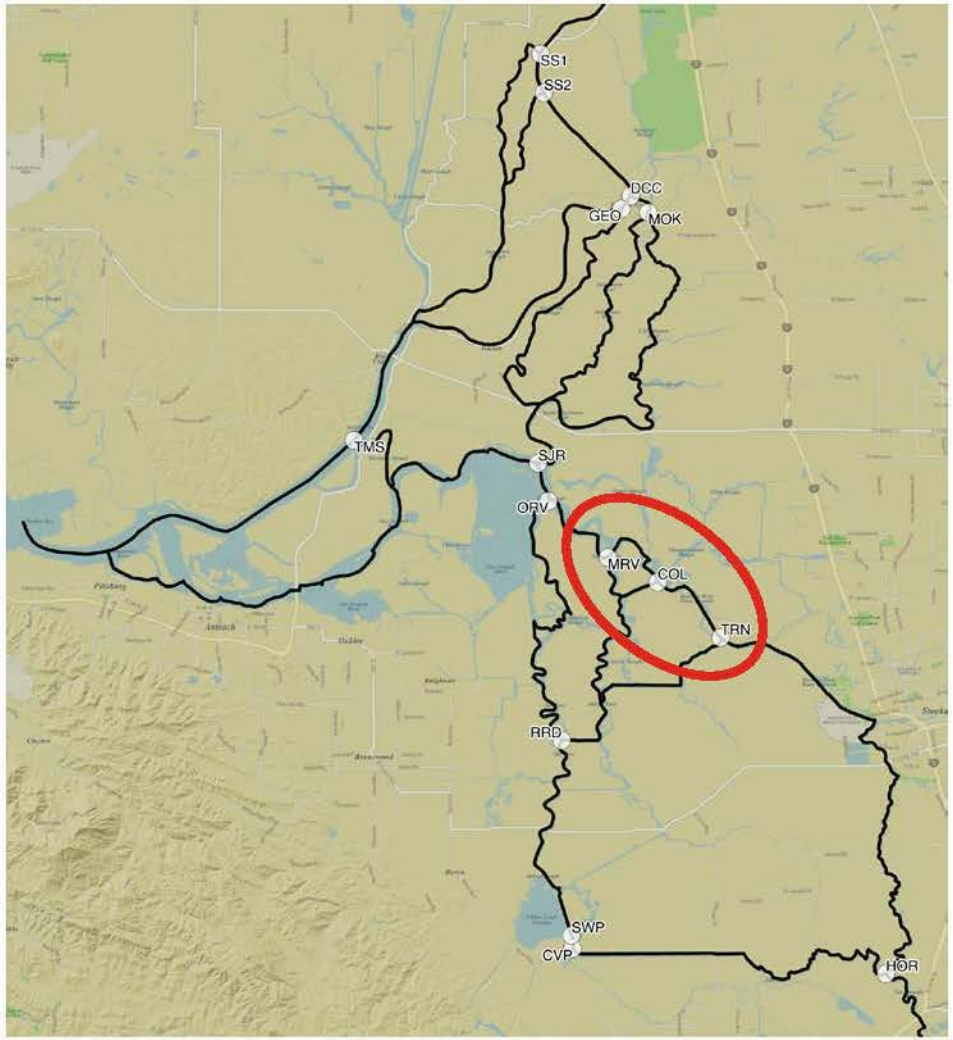

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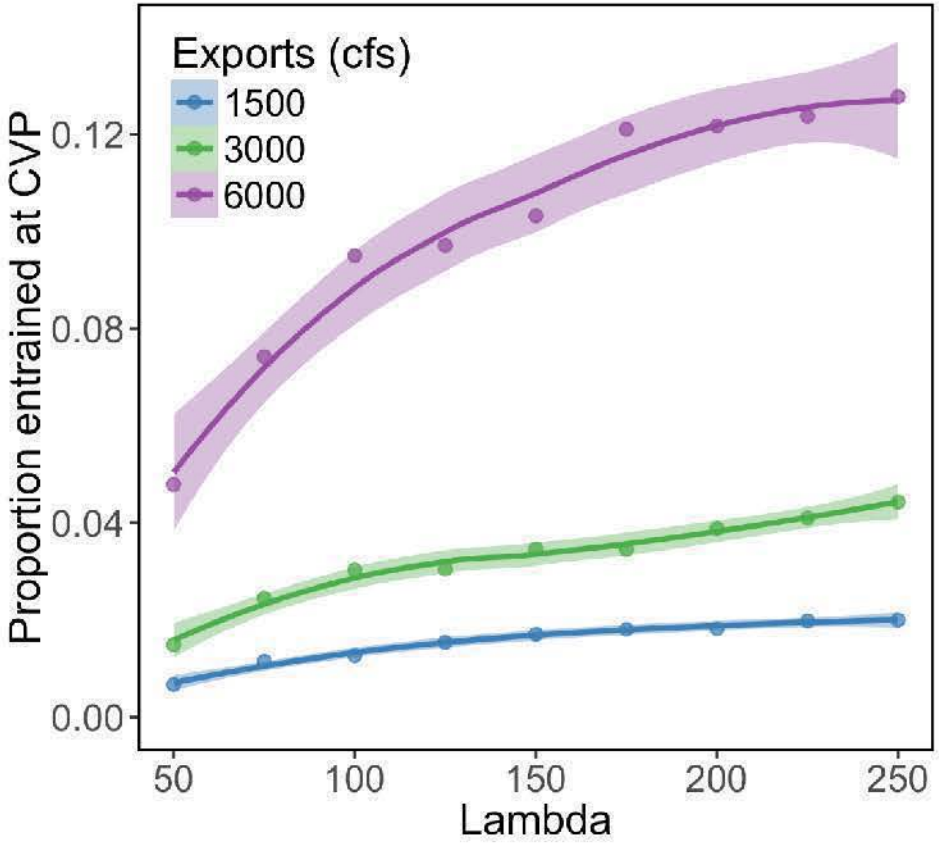

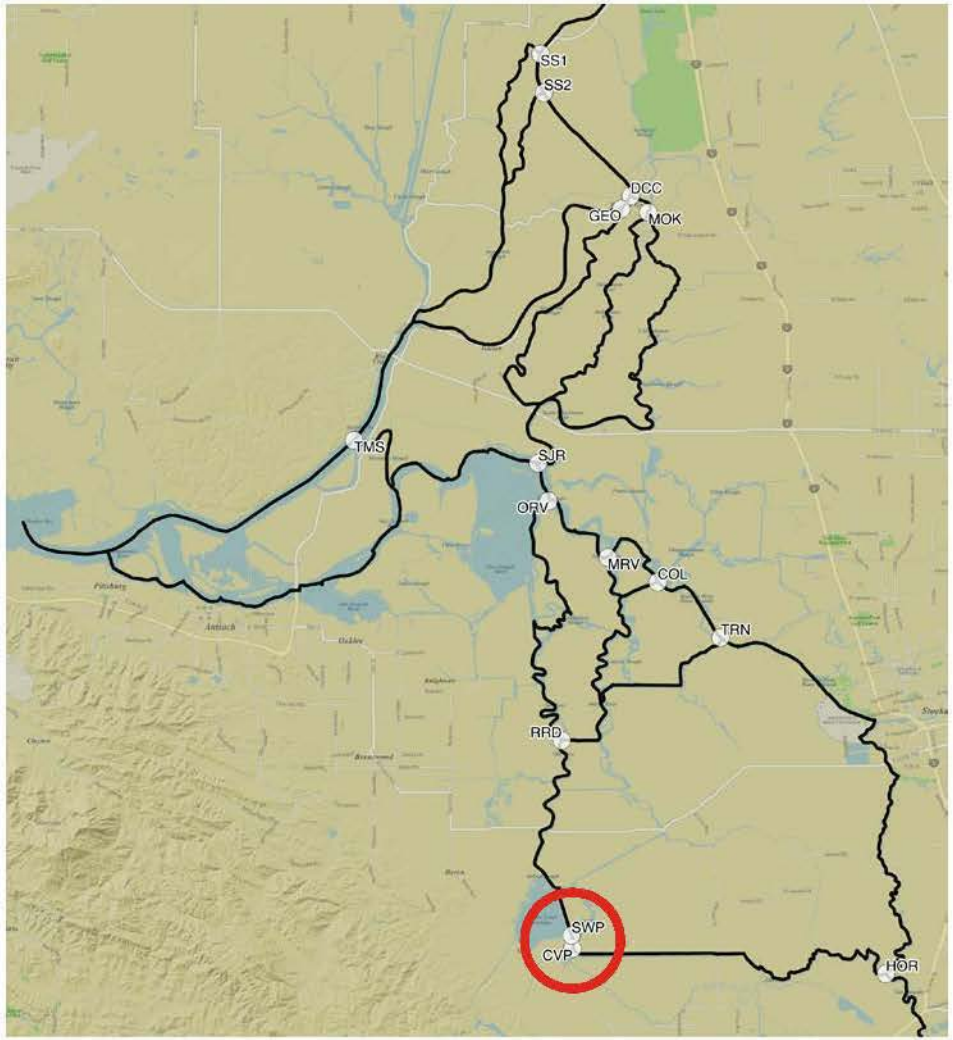

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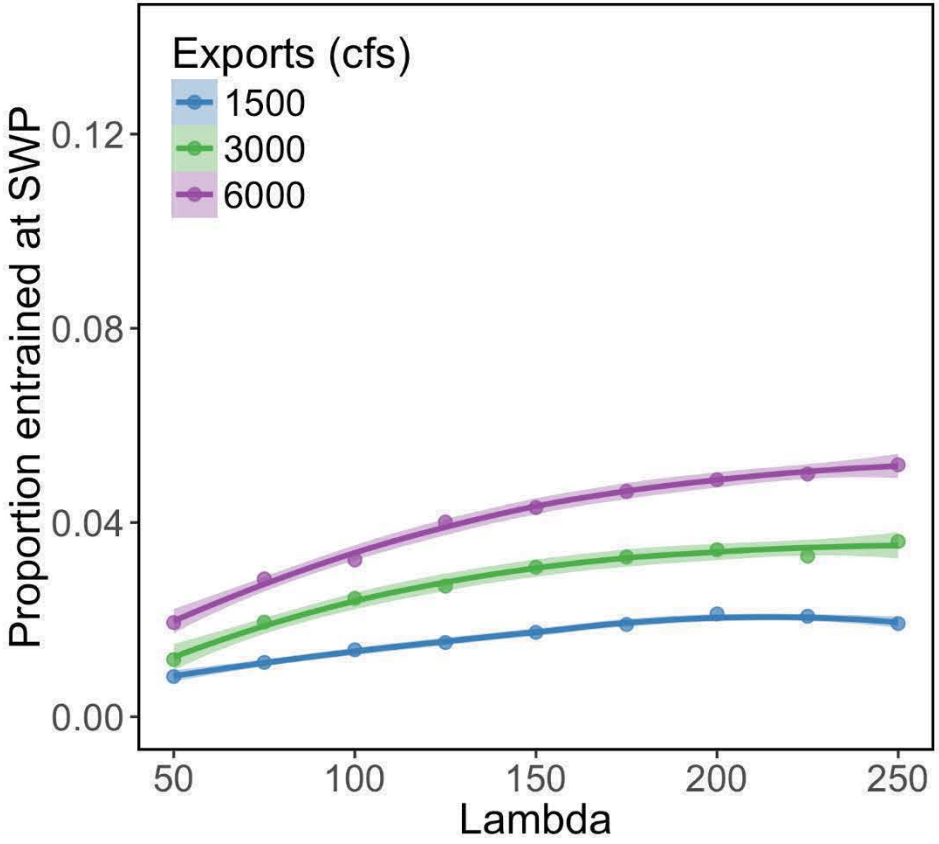
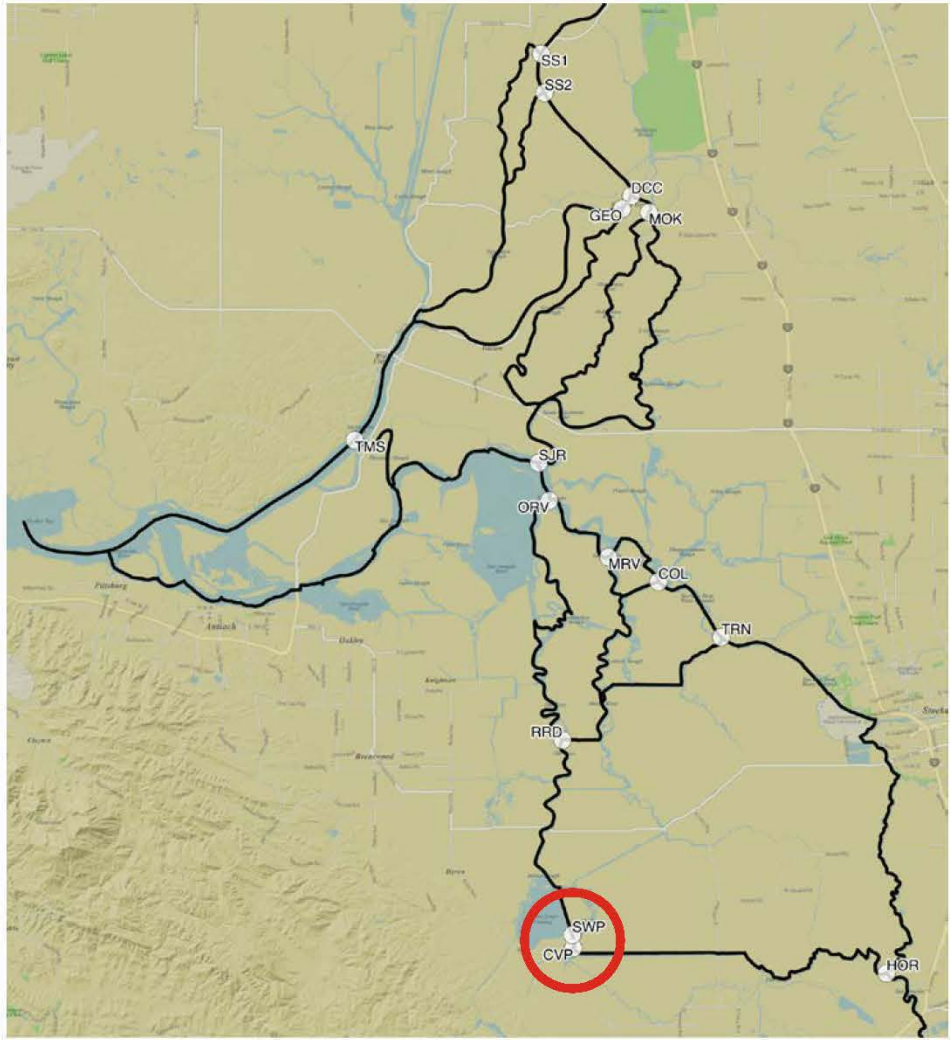
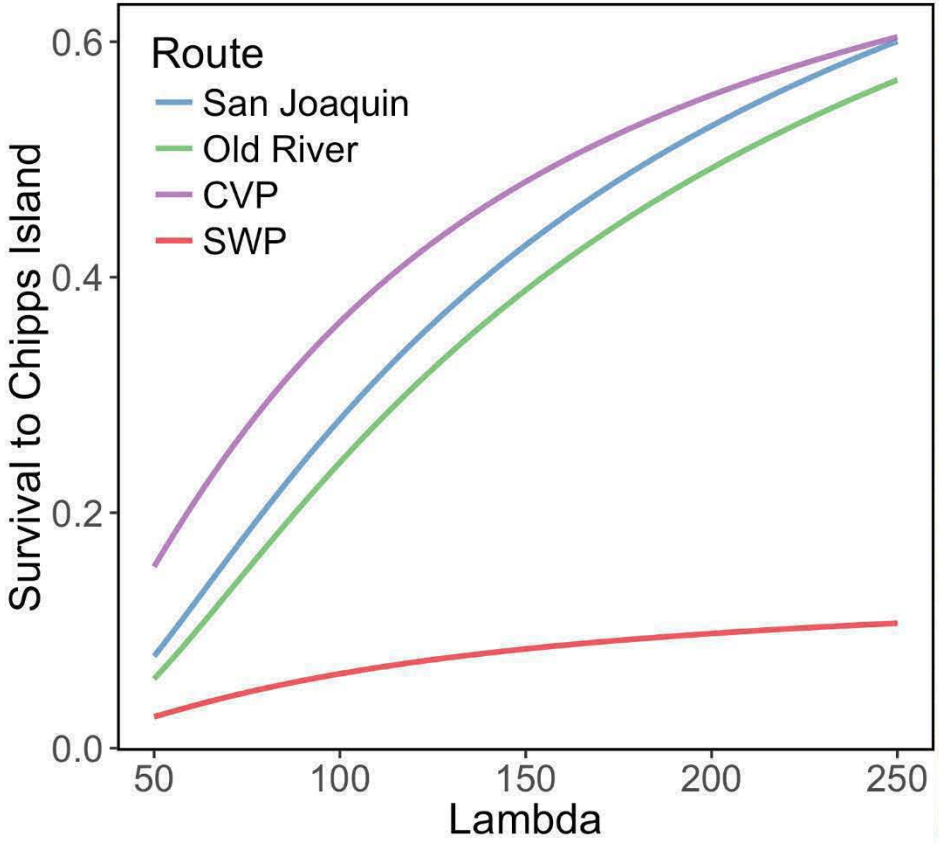
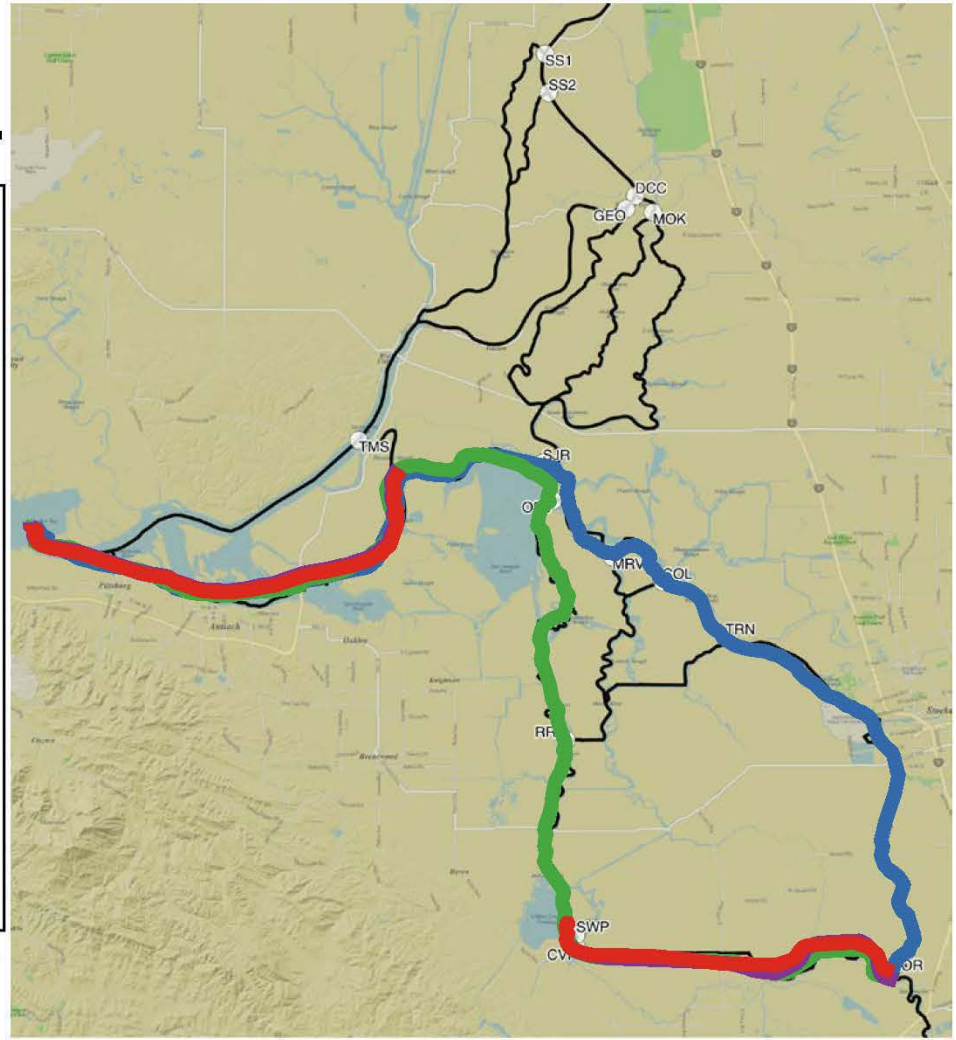


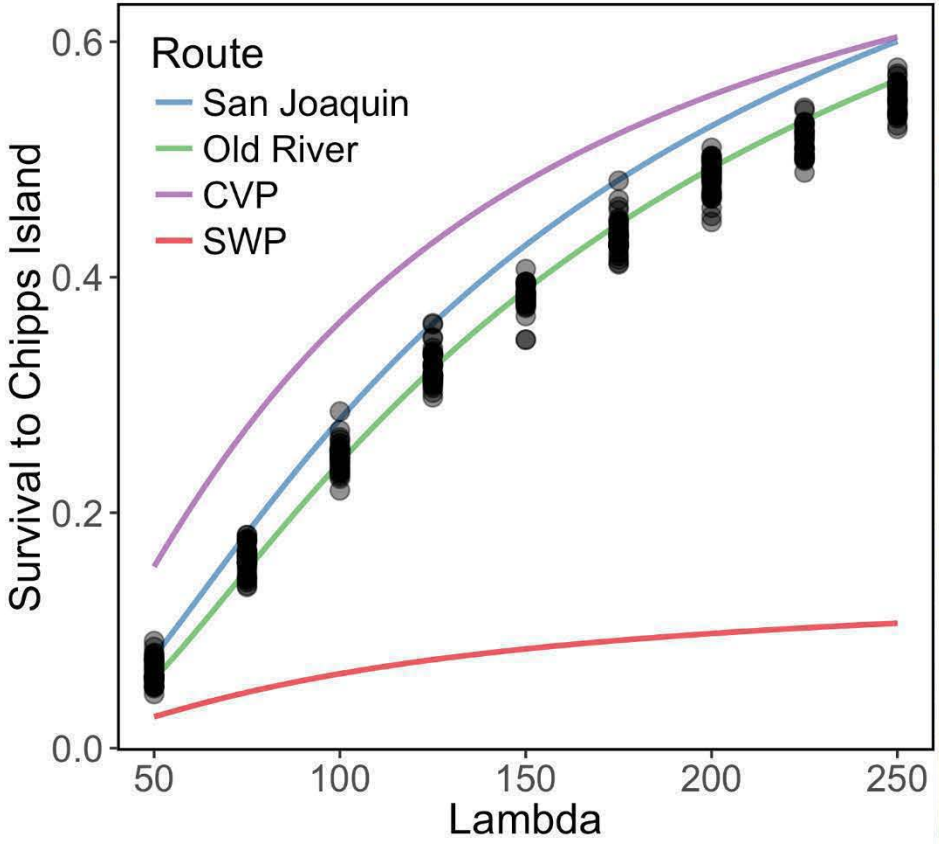


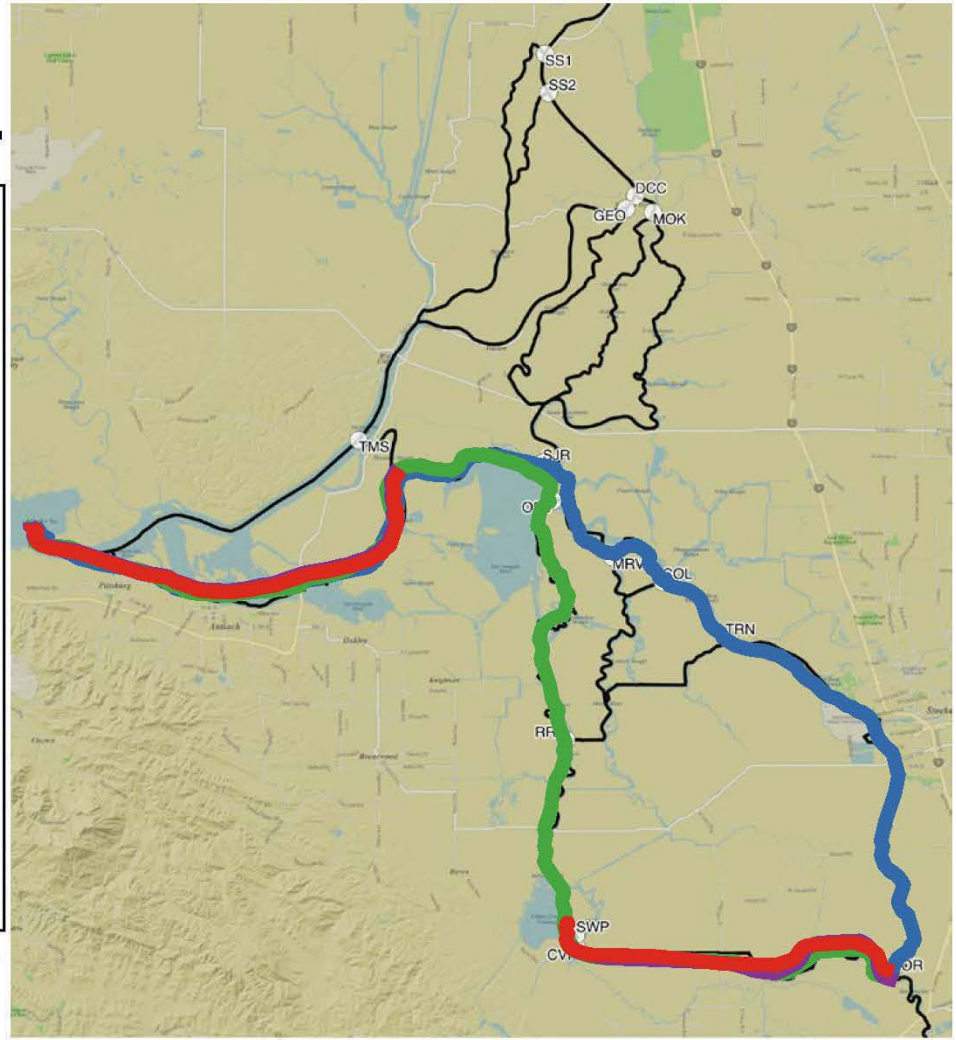
Conclusion


Route
San Joaquin
Old River
CVP
SWP
Survival to Chipps Island
0.0
0.2
0.4
0.6
50
100
150
200
250
Lambda


SS1
SS2
DCC
GEO
MOK
TMS
SJR
MRV
COL
TRN
SWP

Conclusion


Route
San Joaquin
Old River
CVP
SWP
Survival to Chipps Island
0.0
0.2
0.4
0.6
50
100
150
200
250
Lambda


SS1
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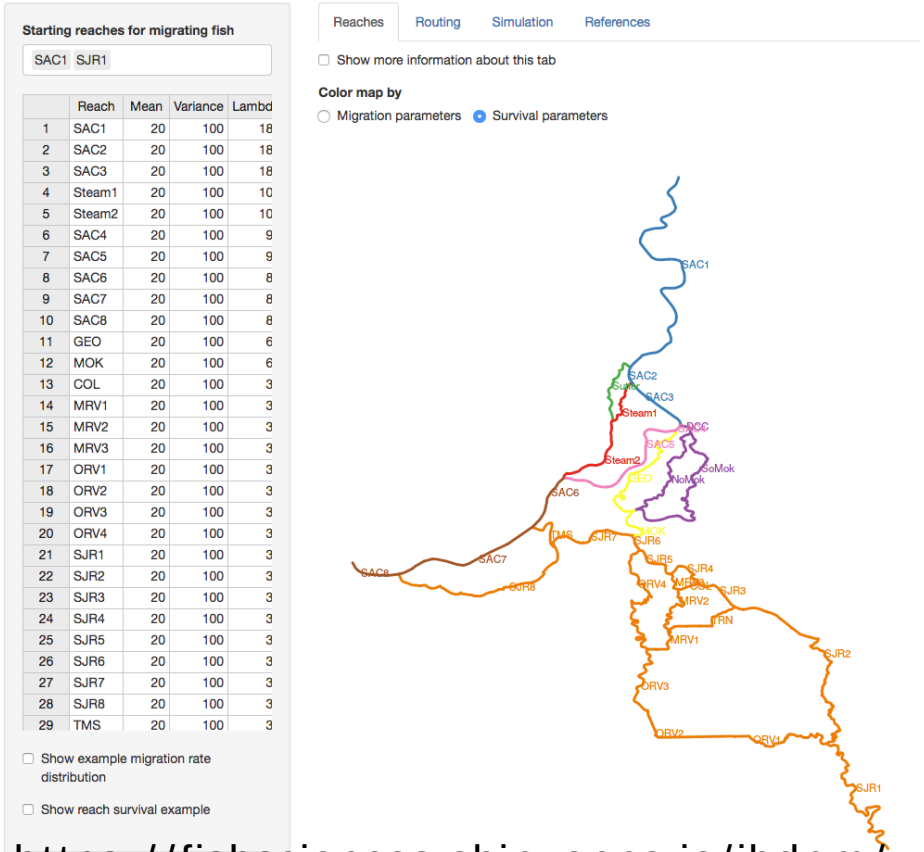
Acknowledgments

- Russell Perry
- Tara Smith
- Yu Zhou

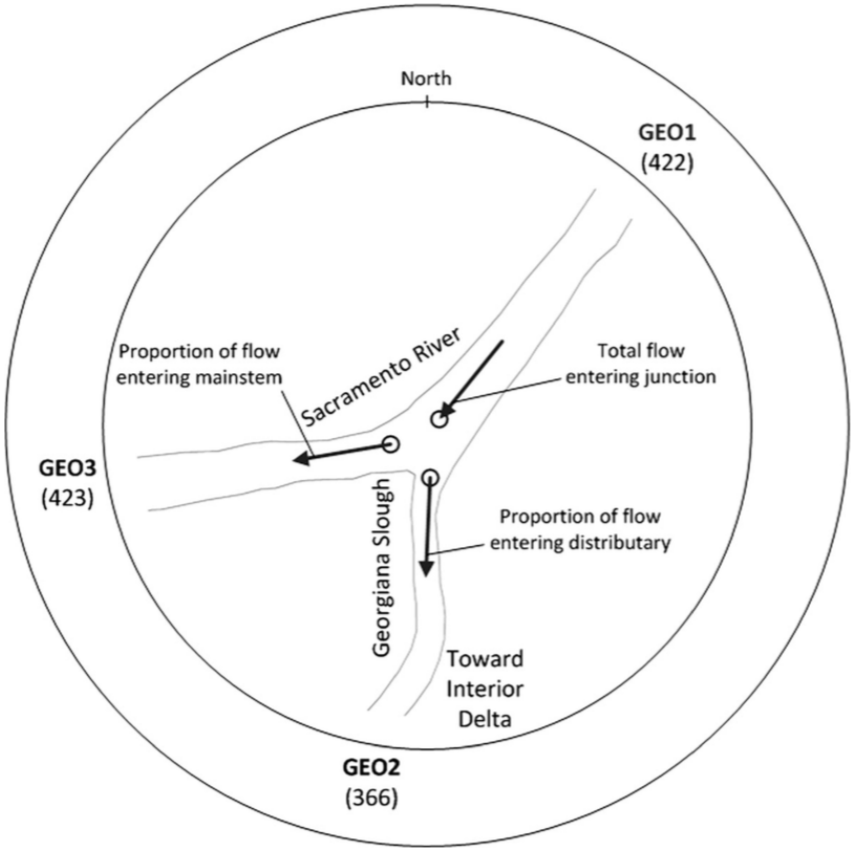
Individual-Based Delta Passage Model



https://fishsciences.shinyapps.io/ibdpm/

Routing

- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)
  - 15-min flow values
  - 61 days of representative tides
  - 3,978 combinations of barriers, inflow, and exports



Cavallo et al. 2015. Environ Biol Fish

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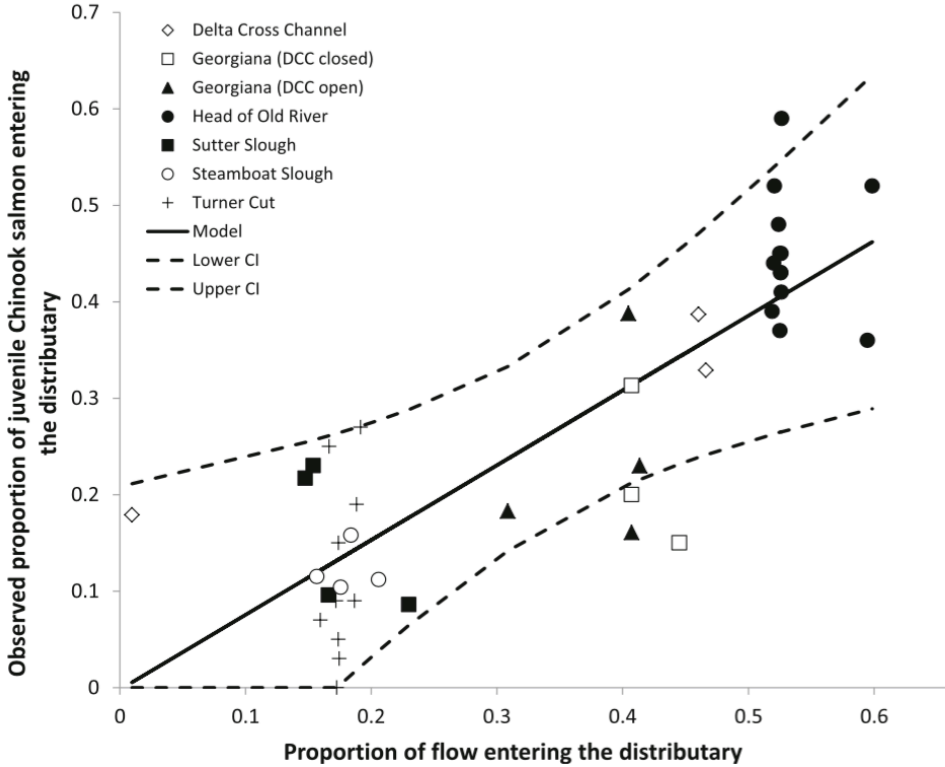
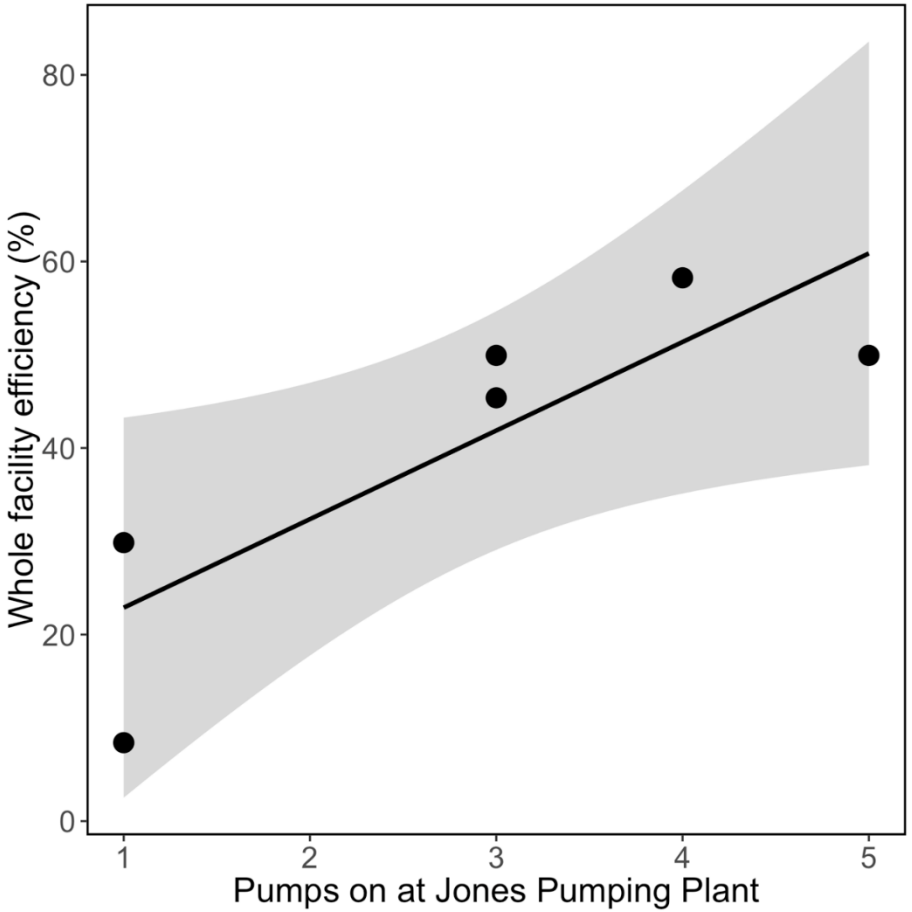


Cavallo et al. 2015. Environ Biol Fish

Routing

- Whole facility efficiency
  - CVP only
  - Applied after routing probability
  - Probability that fish entrained
  - Fish not entrained migrate north in Old River
  - If CVP routing is overridden, then relationship not used



Discrete Event Simulation

- Continuous time, discrete events
- Event queue
- Fish traits
  - Alive
  - Arrived at Chipps
  - Migration trajectory
  - Migration rates in each reach

Event queue

event.time	event.type	id
32.57920	route	46
32.58151	migrate	47
32.62865	route	41
33.13411	route	151
33.19192	migrate	54
33.19192	migrate	154
33.24126	route	38
33.40157	route	140
33.77194	route	152
33.81818	migrate	55

Fish traits

Rep	ID	Alive	Chipps
1	1	1	1
1	2	0	0
1	3	0	0
1	4	0	0
1	5	1	1
1	101	0	0
1	102	0	0
1	103	0	0
1	104	1	1
1	105	0	0

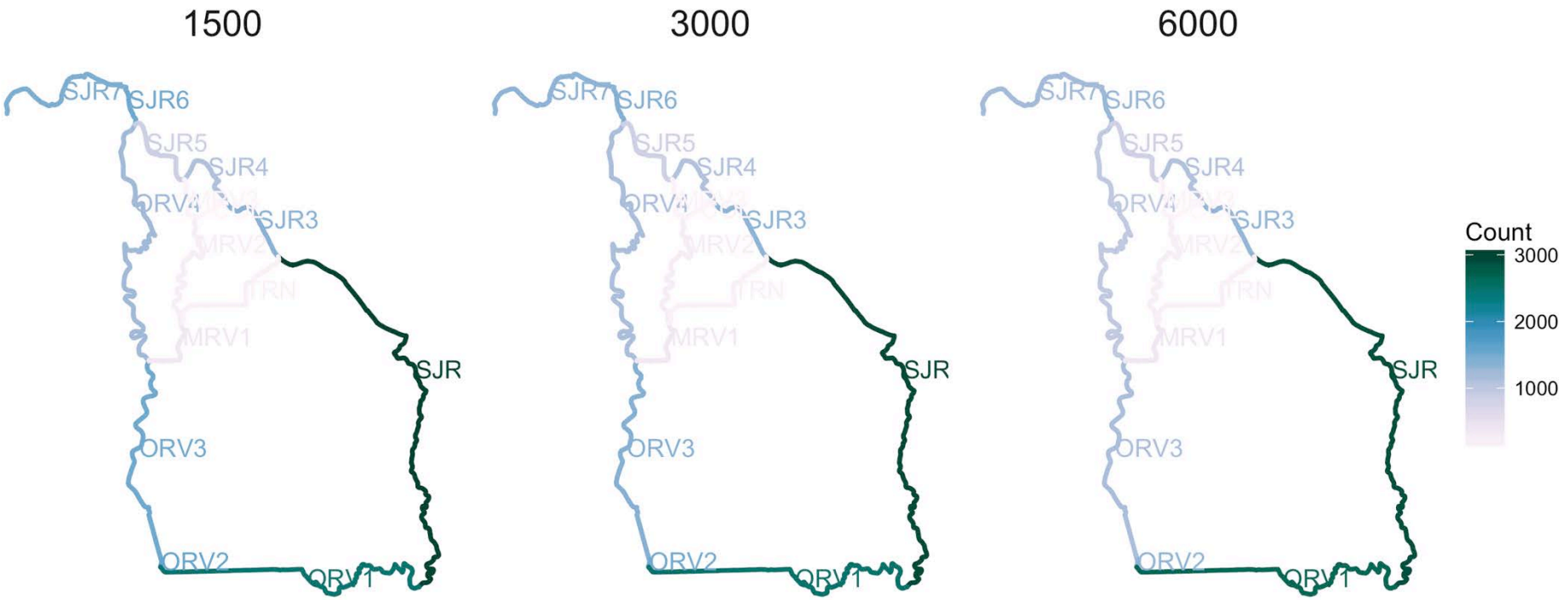
Migration trajectory

ID	Reach1	Reach2	Reach3	Reach4	Reach5	Reach6	Reach7	Reach8	Reach9
1	SAC1	SAC2	SAC3	SAC4	SAC5	SAC6	SAC7	SAC8	*NA*
2	SAC1	SAC2	SAC3	SAC4	SAC5	SAC6	*NA*	*NA*	*NA*
3	SAC1	SAC2	Steam1	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
4	SAC1	Sutter	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
5	SAC1	Sutter	Steam2	SAC6	SAC7	SAC8	*NA*	*NA*	*NA*
101	SJR1	SJR2	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
102	SJR1	SJR2	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
103	SJR1	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
104	SJR1	SJR2	SJR3	SJR4	SJR5	SJR6	SJR7	SJR8	SAC8
105	SJR1	SJR2	SJR3	SJR4	*NA*	*NA*	*NA*	*NA*	*NA*

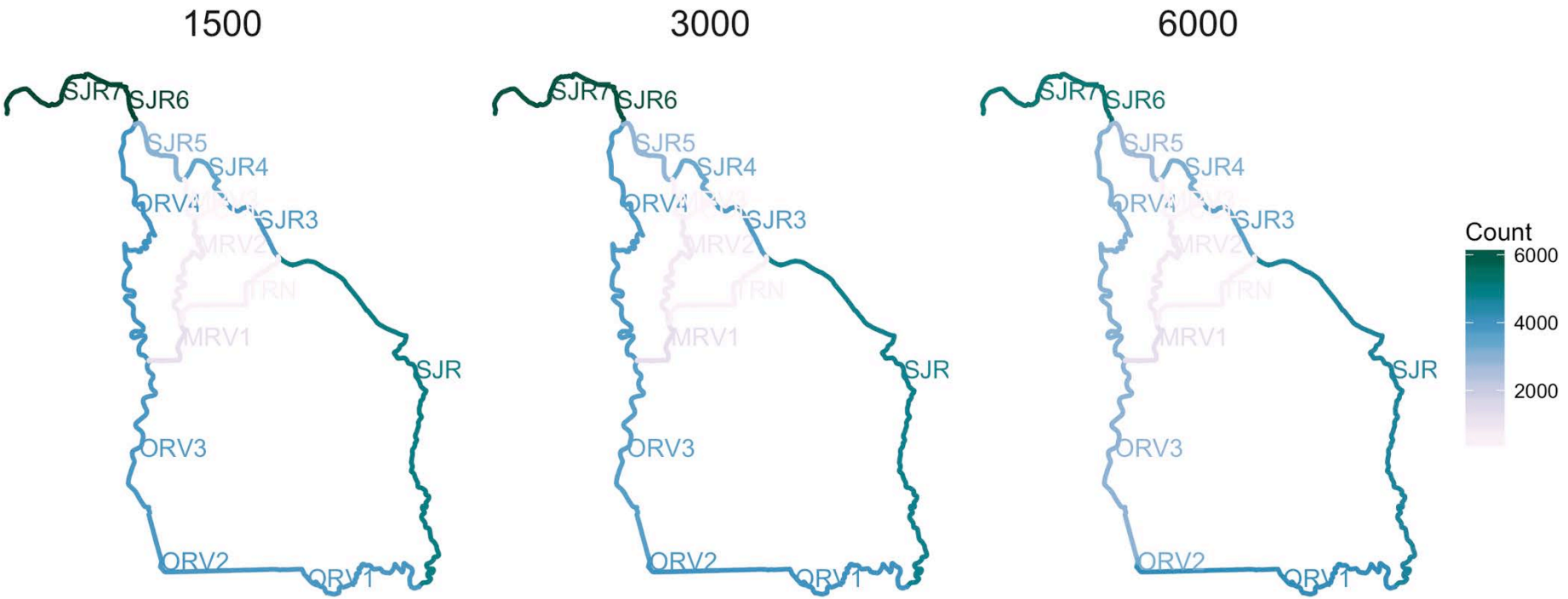
Reach Usage Map

λ = 50

Exports (cfs)



Reach Usage Map

λ = 250

Exports (cfs)