

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

Travis Hinkelman and Bradley Cavallo



# Model Overview

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## Individual-Based Delta Passage Model

- Individual-based, discrete event simulation model

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- Individual-based, discrete event simulation model
- Written in R with web-based GUI

# Individual-Based Delta Passage Model

Load new routing data

Click button after changing barriers, inflow, or exports

Show barriers and inflow

**Delta Cross Channel**

Closed

**Head of Old River**

Out

**Sacramento River at Freeport (cfs)**

90000

**San Joaquin River at Vernalis (cfs)**

20000

Show exports

**Total exports (cfs)**

10000

**State Water Project (cfs)**

6000

Central Valley Project: 4000 cfs

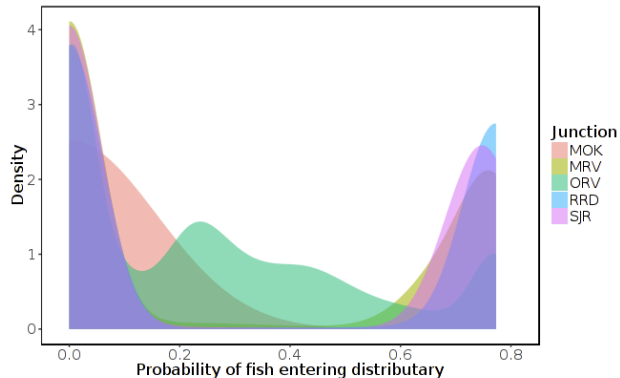
Reaches Routing Simulation References

Show more information about this tab

Show routing probability plot

Select junctions for probability plot

MOK MRV ORV RRD SJR



Kernel density estimates for the probability of fish entering distributary (or moving towards export facilities) at each junction for the selected combination of barriers, inflow, and exports. The density estimates are based on routing probabilities calculated at 15-min intervals over a 62-day period.

Show junction map

# Model Overview

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

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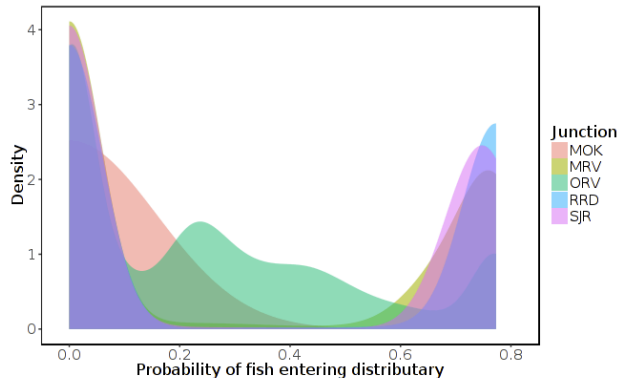
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- Effects of water project operations, barriers, predation risk, etc.

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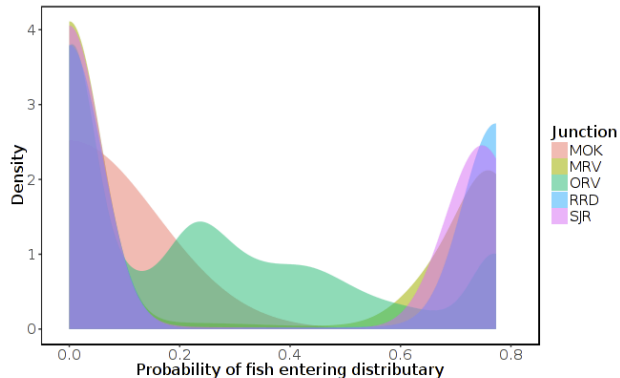
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# Model Overview

- 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

# Individual-Based Delta Passage Model

Load new routing data

Click button after changing barriers, inflow, or exports

Show barriers and inflow

Delta Cross Channel  
Closed

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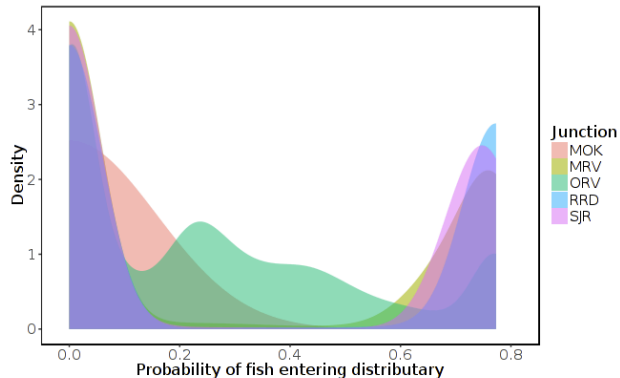
Reaches Routing Simulation References

Show more information about this tab

Show routing probability plot

Select junctions for probability plot

MOK MRV ORV RRD SJR



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

# Reaches

- 34 reaches representing key migratory routes
- Starting reaches

## Starting reaches for migrating fish

SAC1 SJR1 |

COL

DCC

GEO

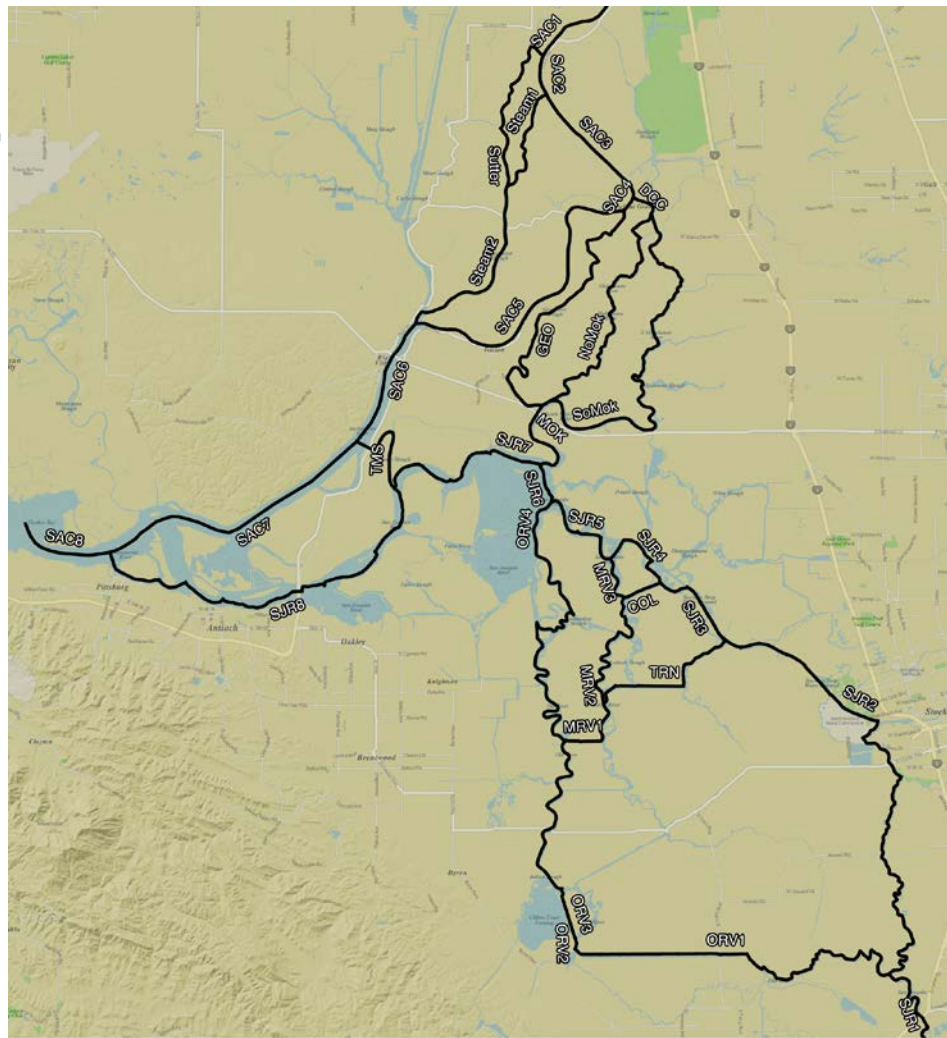
MOK

MRV1

MRV2

MRV3

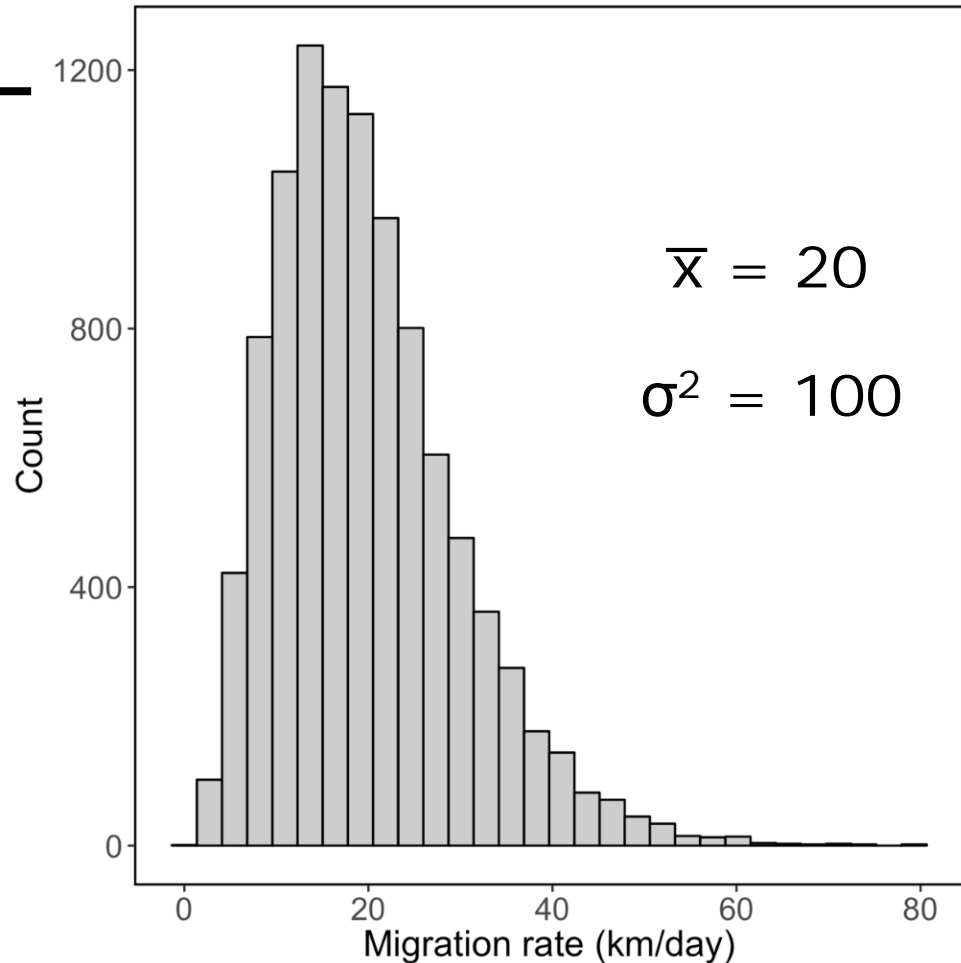
NoMok



# Migration Rate

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





# Survival

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## XT Model

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

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

# Survival

---

## XT Model

- Distance (gauntlet)
  - Reach length
- Time (exposure)
  - Reach length/migration rate
- Omega ( $\omega = 1.8$ )
  - Random encounter velocity

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

# Survival

---

## XT Model

- Distance (gauntlet)
  - Reach length
- Time (exposure)
  - Reach length/migration rate
- Omega ( $\omega = 1.8$ )
  - Random encounter velocity
- Lambda ( $\lambda = 31-188$ )
  - Distance between predator encounters

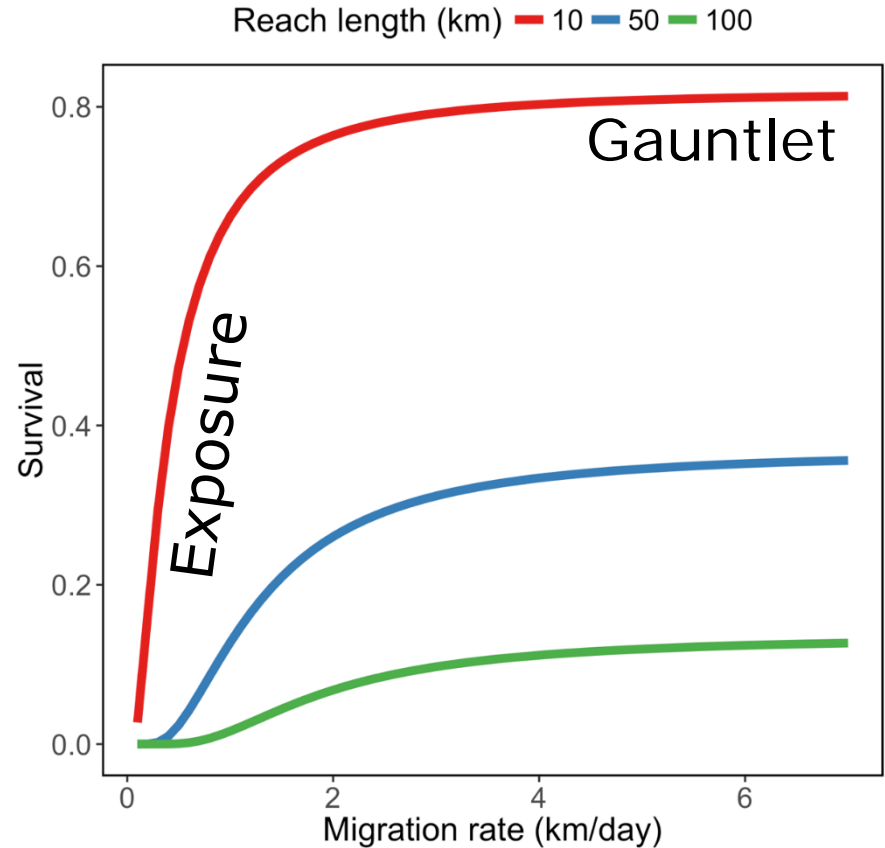
$$S = \exp \left( -\frac{1}{\lambda} \sqrt{x^2 + \omega^2 t^2} \right)$$

# Survival

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

$$\omega = 1.8$$

$$\lambda = 50$$



# Reach Properties

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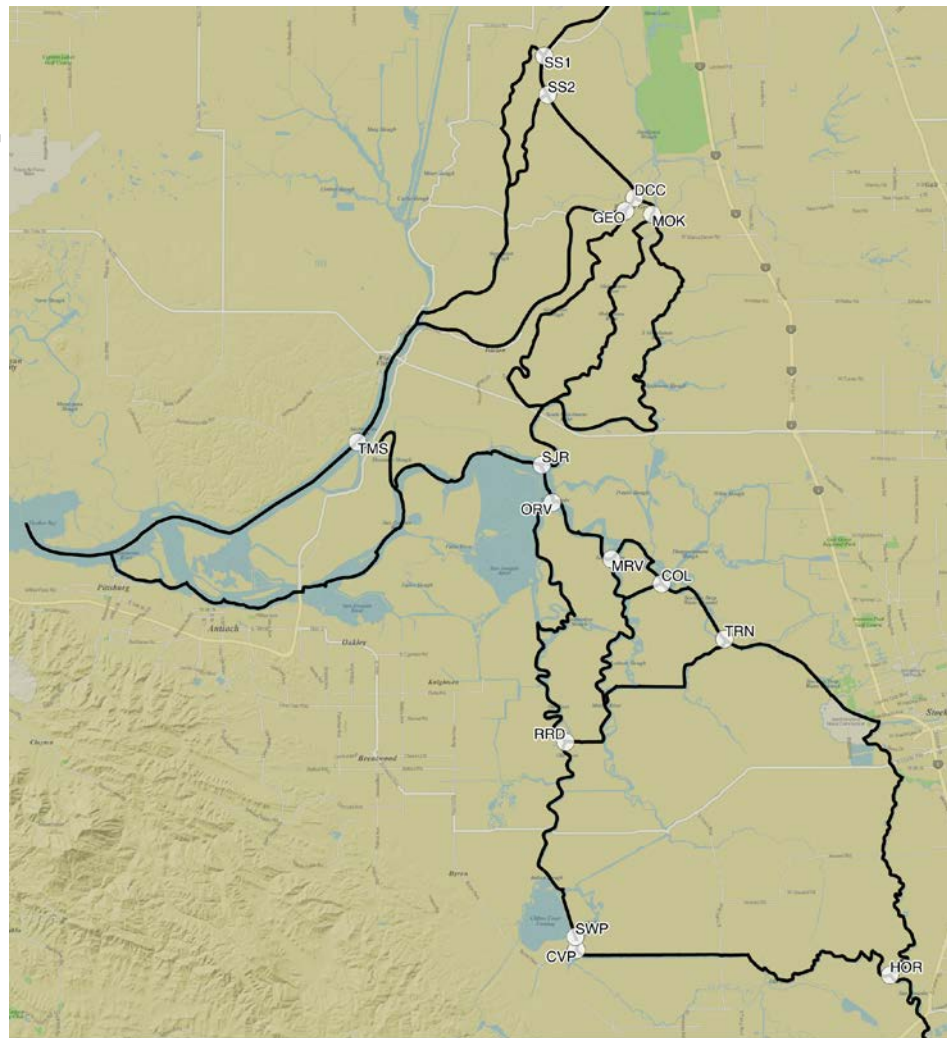
- Migration rate (km/day) mean and variance
- Distance between predator encounters (lambda; km)
- Random encounter velocity (omega; km/day)
- Reach length (km)

	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

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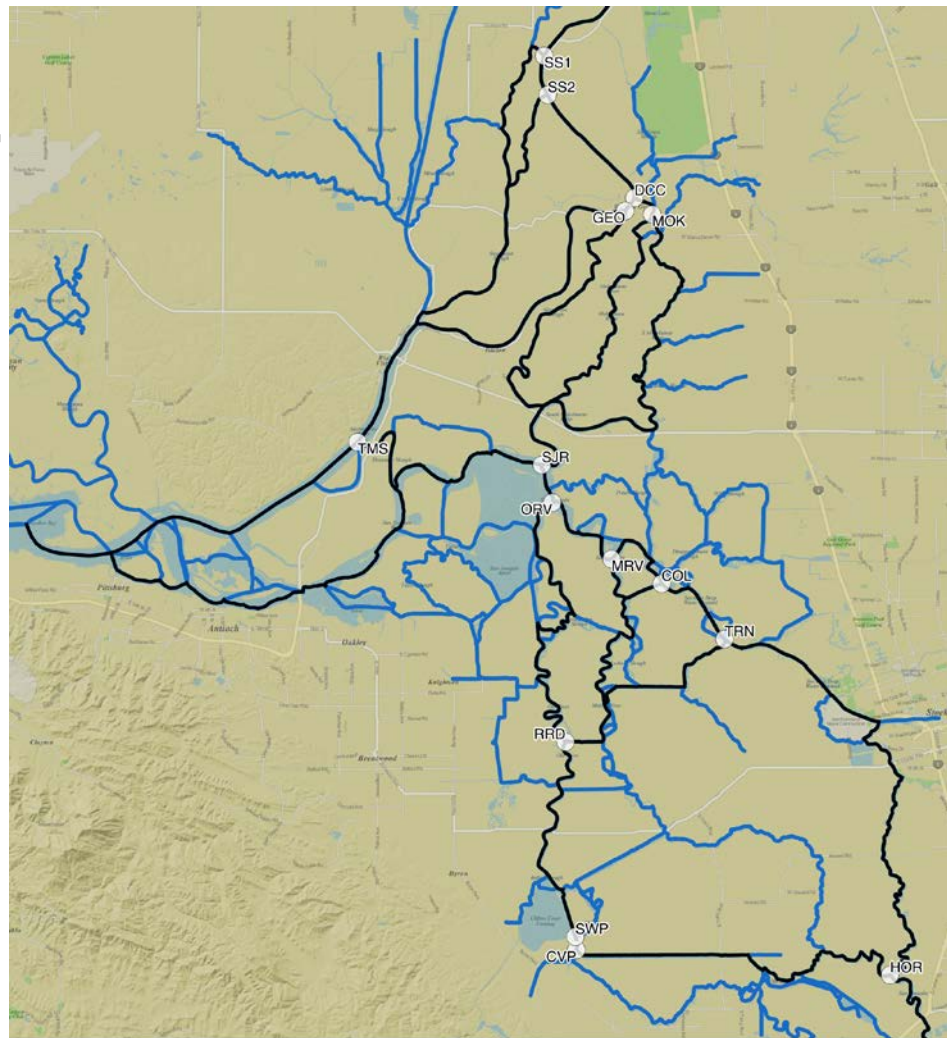
- 15 junctions on key migratory routes



# Routing

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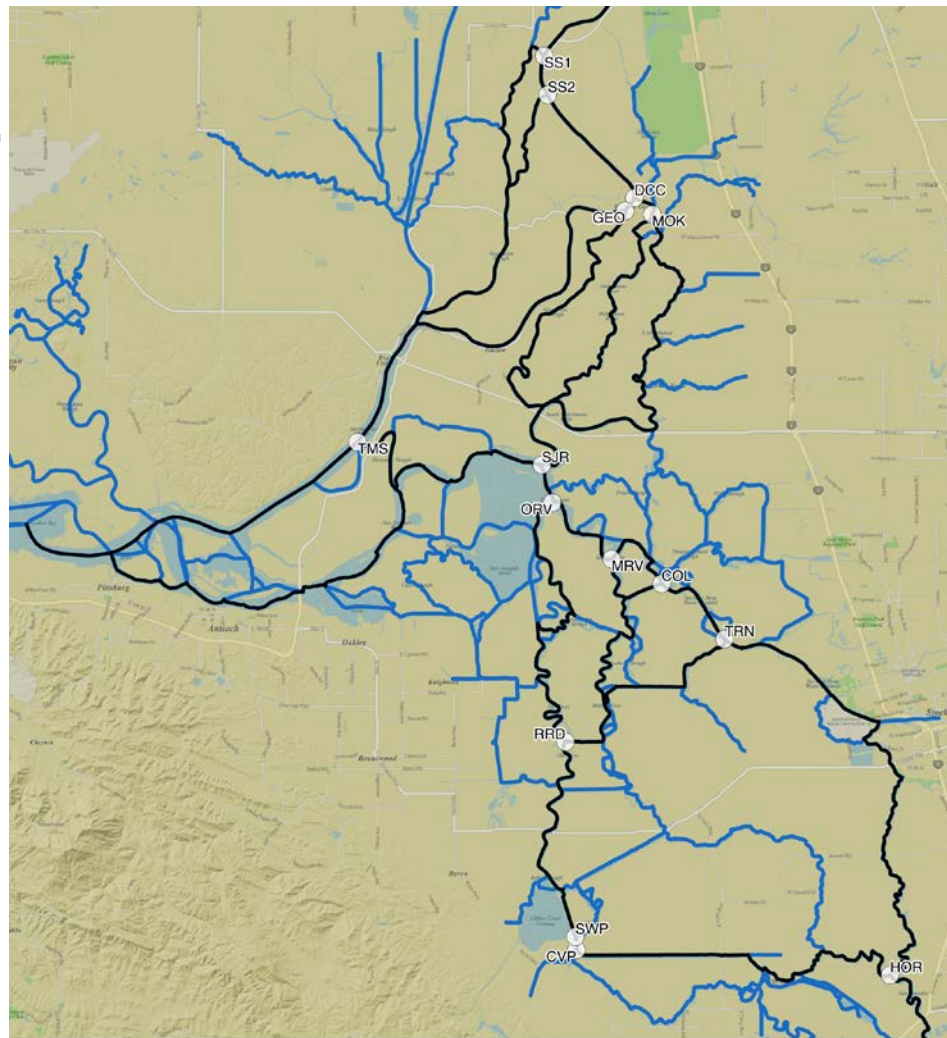
- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)



# 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

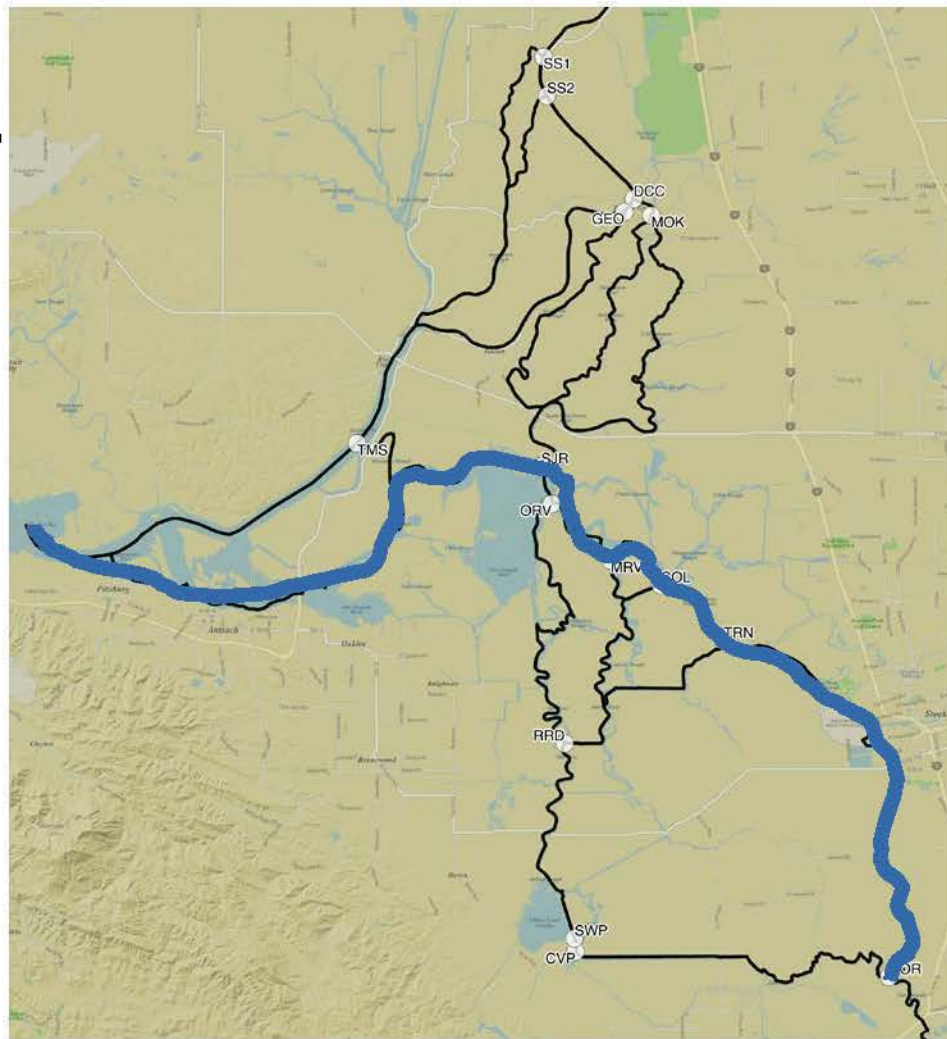
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- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)
  - 15-min flow values
  - 61 days of representative tides
  - 3,978 combinations of barriers, inflow, and exports
- Override flow-based routing

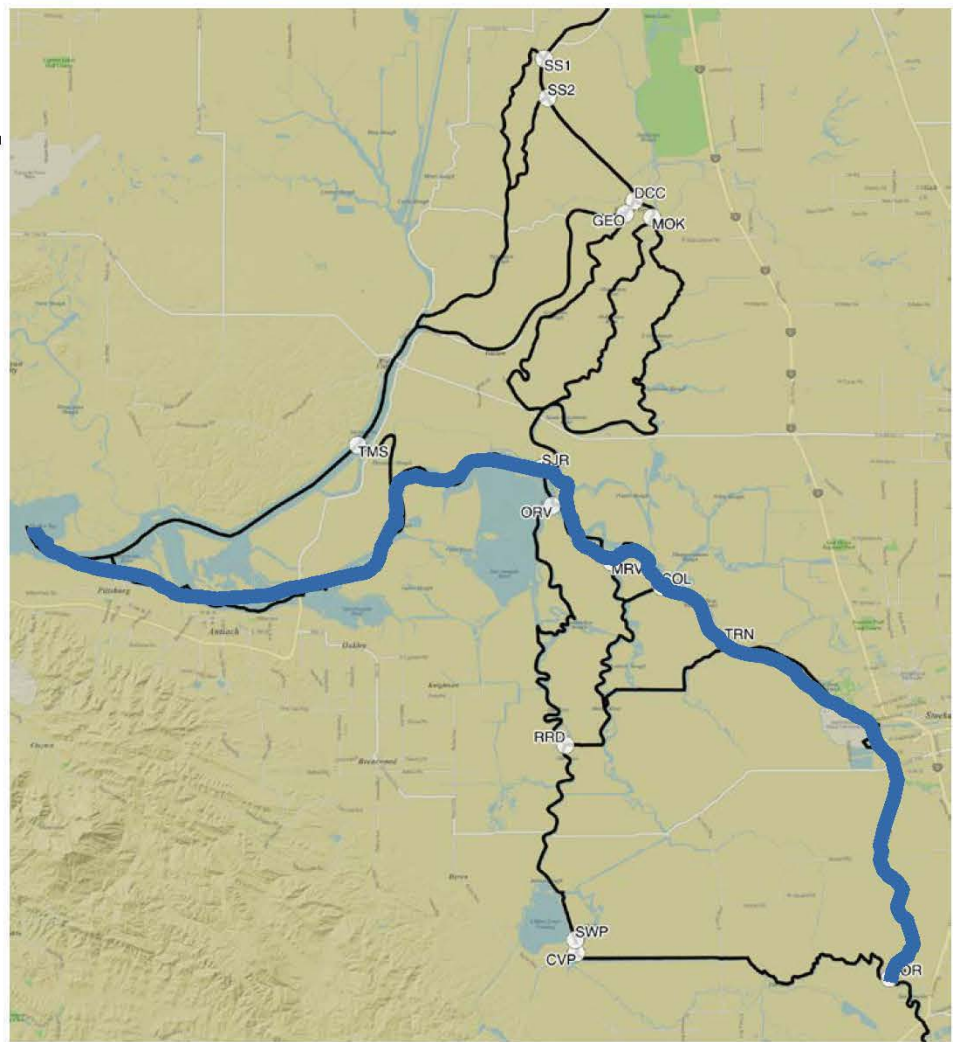
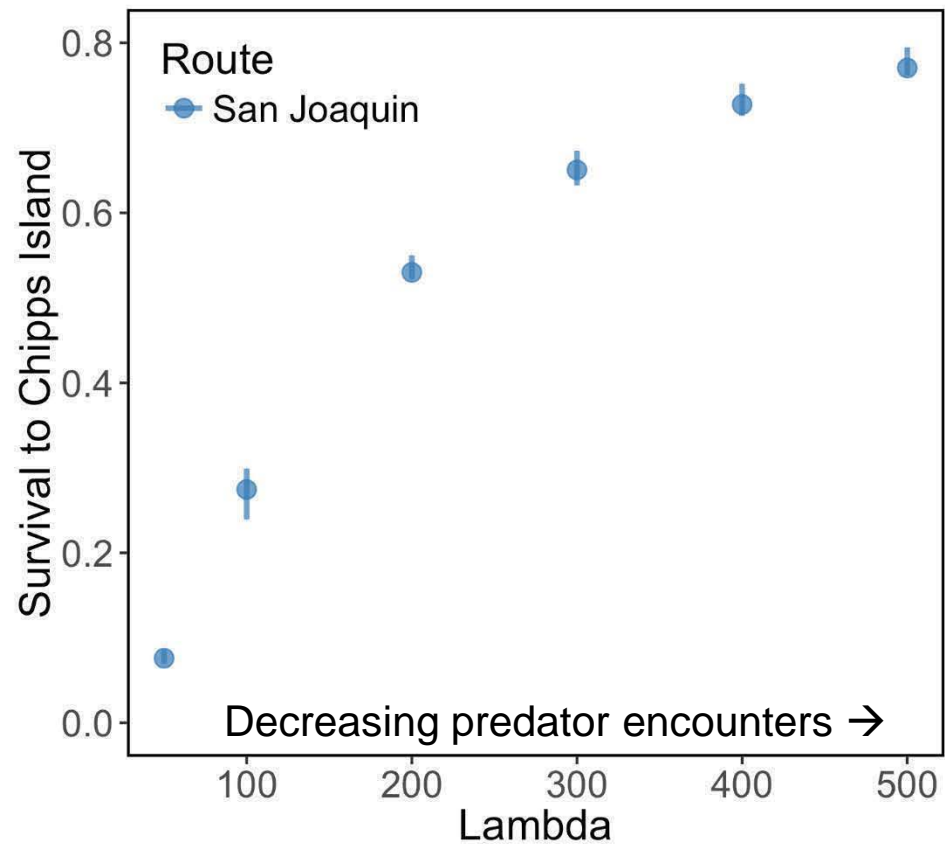
	Junction	Override	Probability
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2	CVP	<input checked="" type="checkbox"/>	1.00
3	DCC	<input type="checkbox"/>	0.00
4	GEO	<input type="checkbox"/>	0.00
5	HOR	<input checked="" type="checkbox"/>	1.00
6	MOK	<input type="checkbox"/>	0.00
7	MRV	<input type="checkbox"/>	0.00
8	ORV	<input type="checkbox"/>	0.00
9	RRD	<input type="checkbox"/>	0.00
10	SJR	<input type="checkbox"/>	0.00
11	SS1	<input type="checkbox"/>	0.00
12	SS2	<input type="checkbox"/>	0.00
13	SWP	<input type="checkbox"/>	0.00
14	TMS	<input type="checkbox"/>	0.00
15	TRN	<input type="checkbox"/>	0.00

# Survival by Route

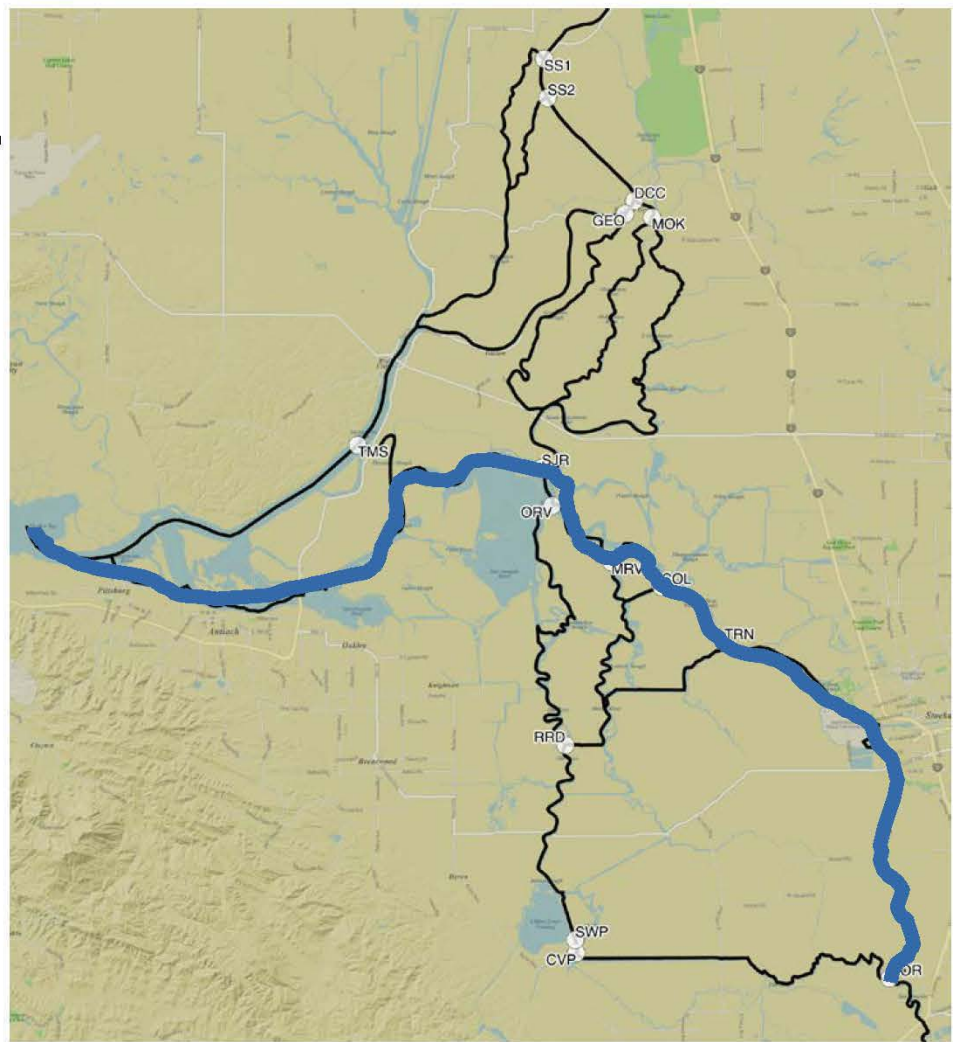
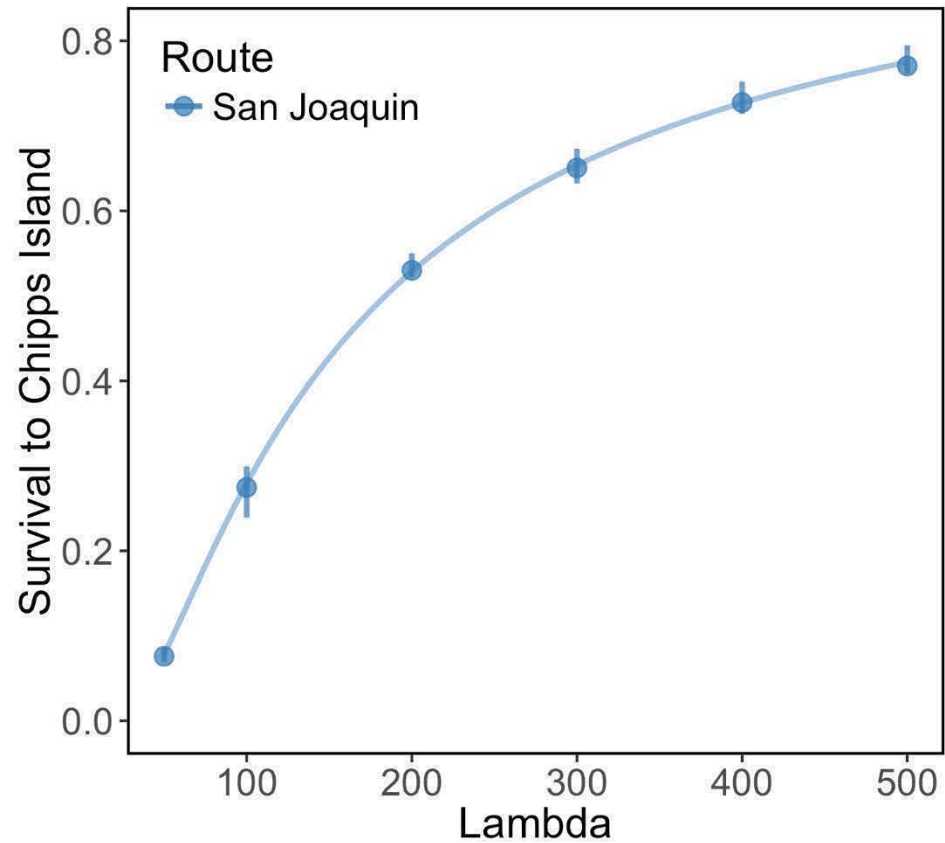
	Junction	Override	Probability
1	COL	<input checked="" type="checkbox"/>	0.00
2	CVP	<input type="checkbox"/>	0.00
3	DCC	<input type="checkbox"/>	0.00
4	GEO	<input type="checkbox"/>	0.00
5	HOR	<input checked="" type="checkbox"/>	0.00
6	MOK	<input type="checkbox"/>	0.00
7	MRV	<input checked="" type="checkbox"/>	0.00
8	ORV	<input type="checkbox"/>	0.00
9	RRD	<input type="checkbox"/>	0.00
10	SJR	<input type="checkbox"/>	0.00
11	SS1	<input type="checkbox"/>	0.00
12	SS2	<input type="checkbox"/>	0.00
13	SWP	<input type="checkbox"/>	0.00
14	TMS	<input type="checkbox"/>	0.00
15	TRN	<input checked="" type="checkbox"/>	0.00



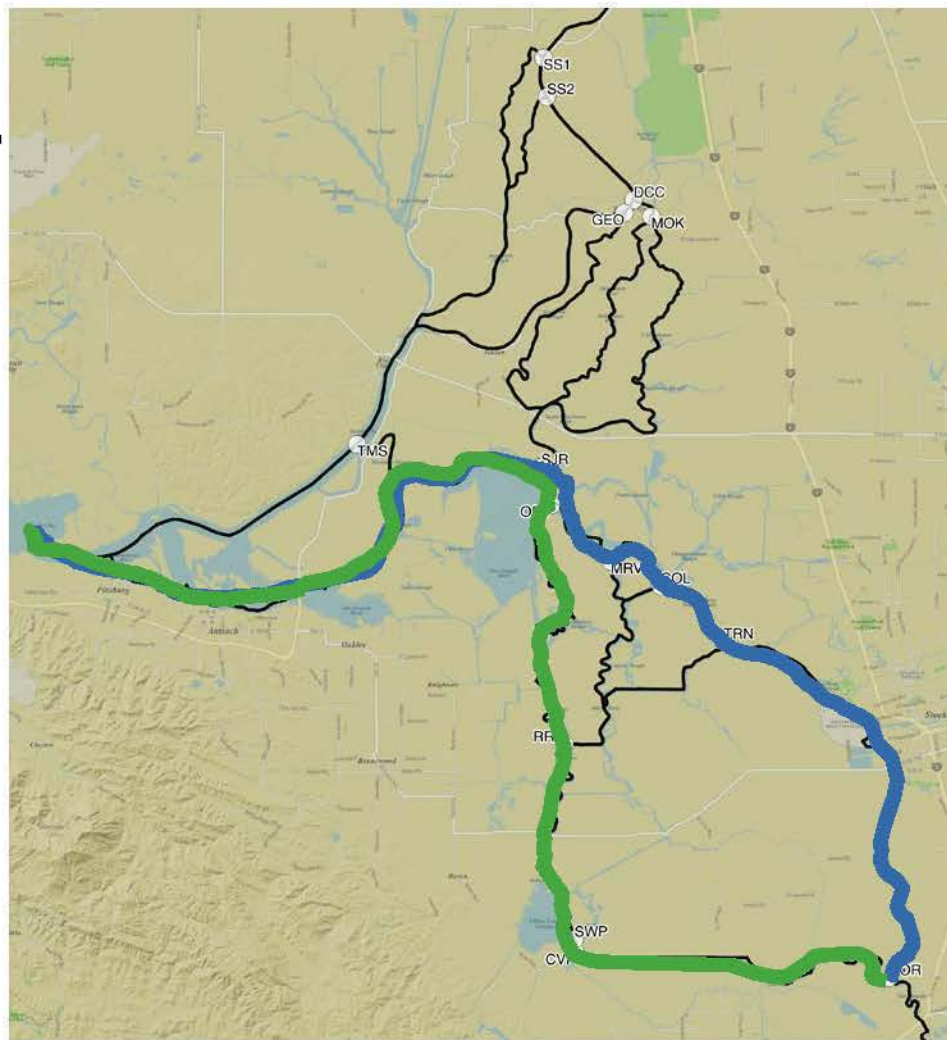
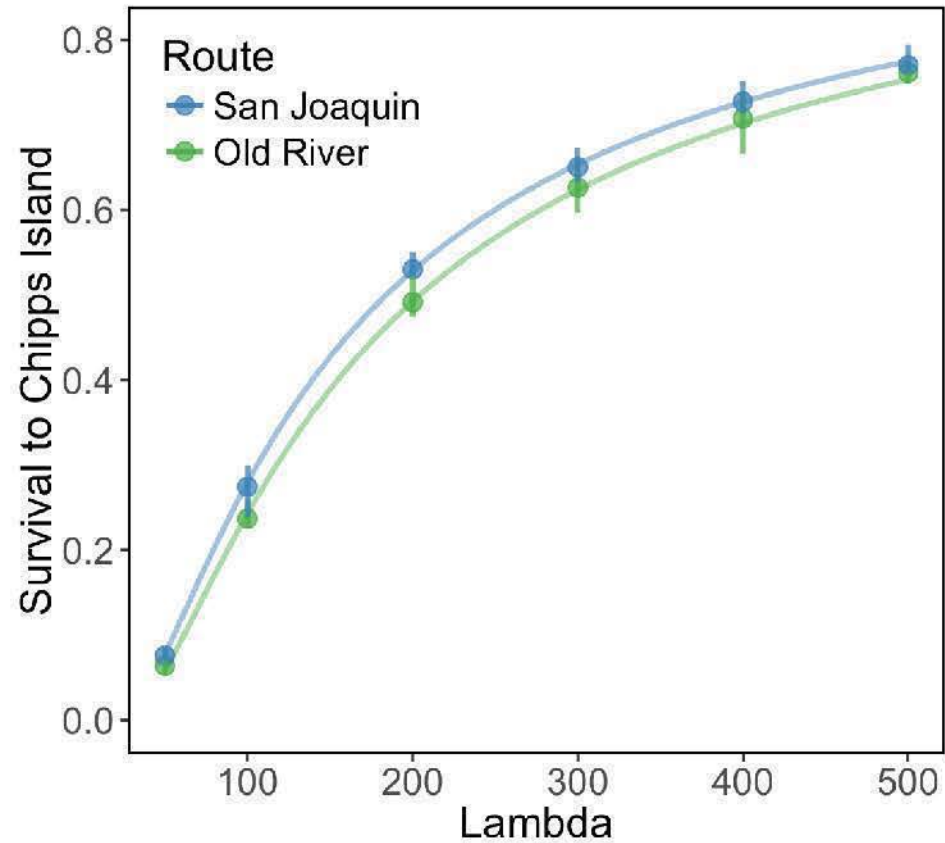
# Survival by Route



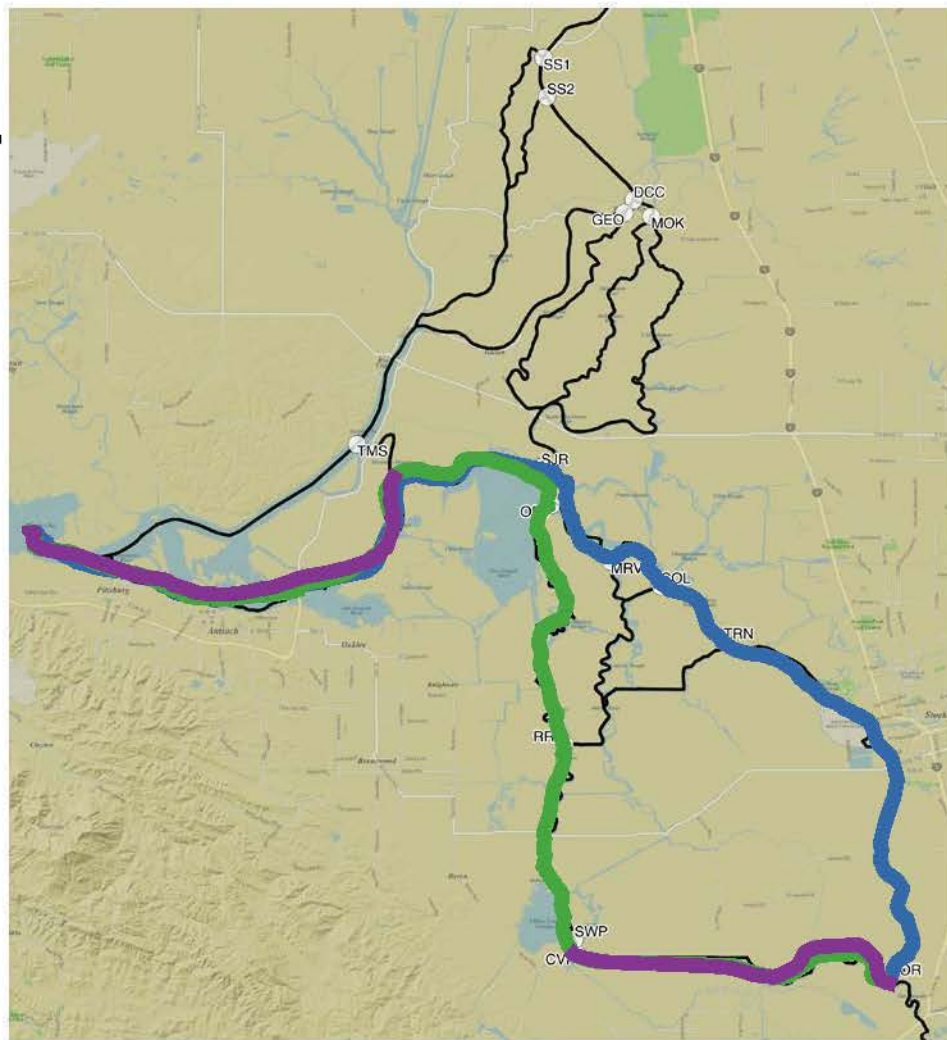
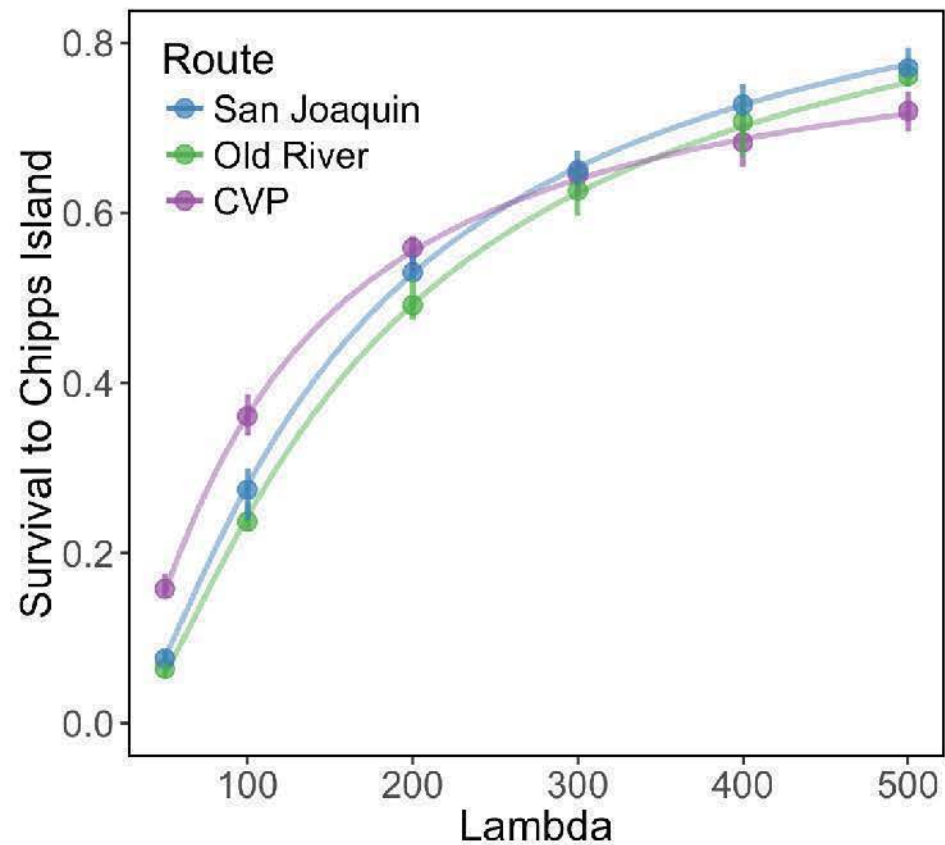
# Survival by Route



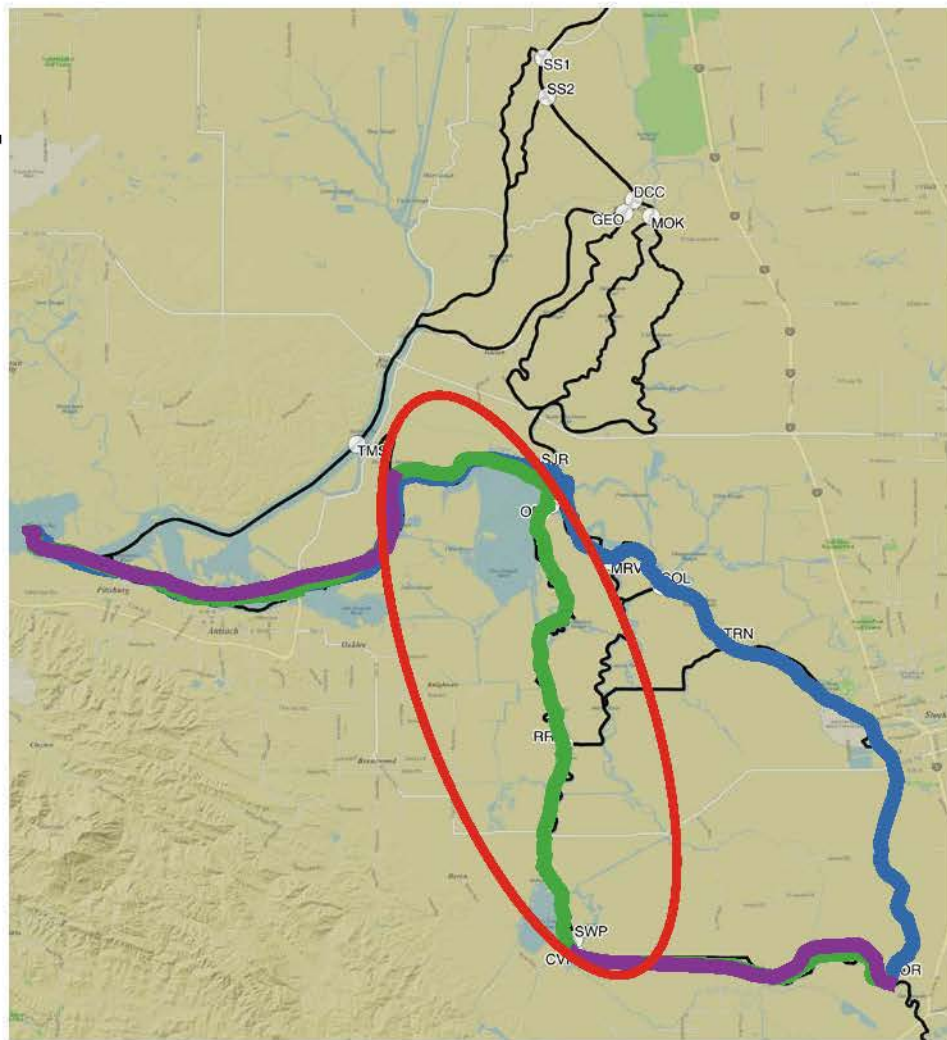
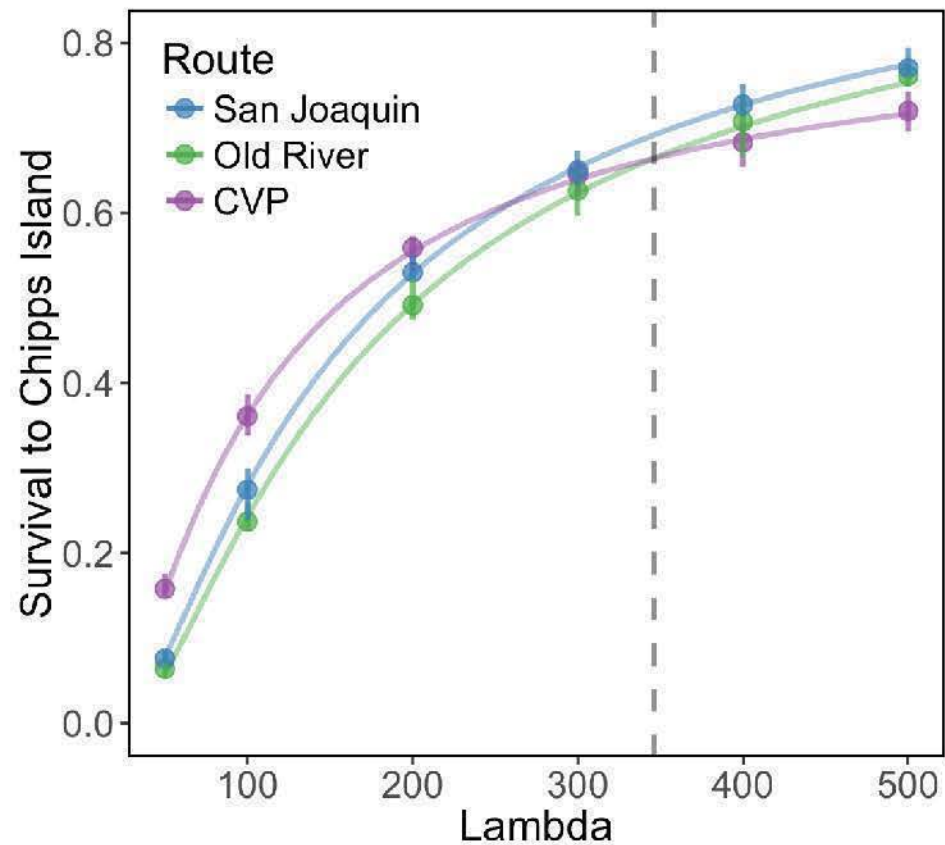
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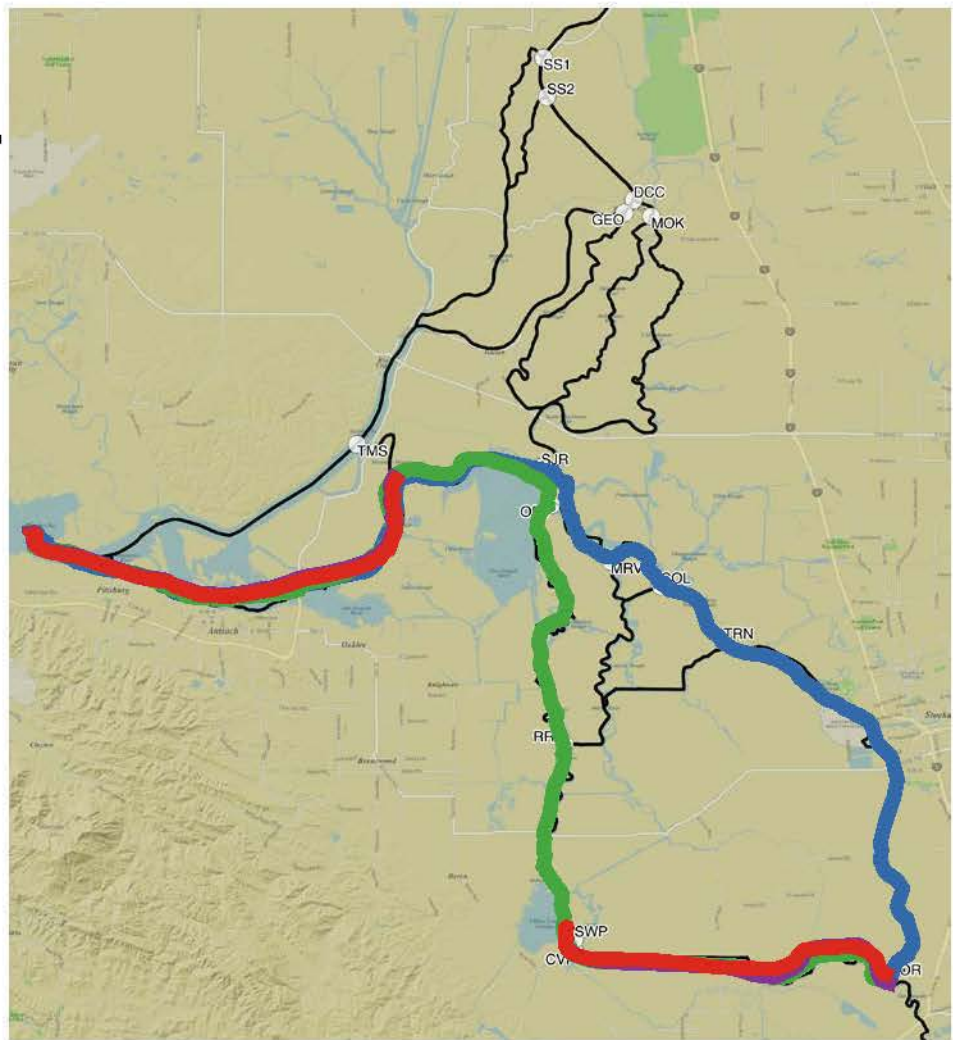
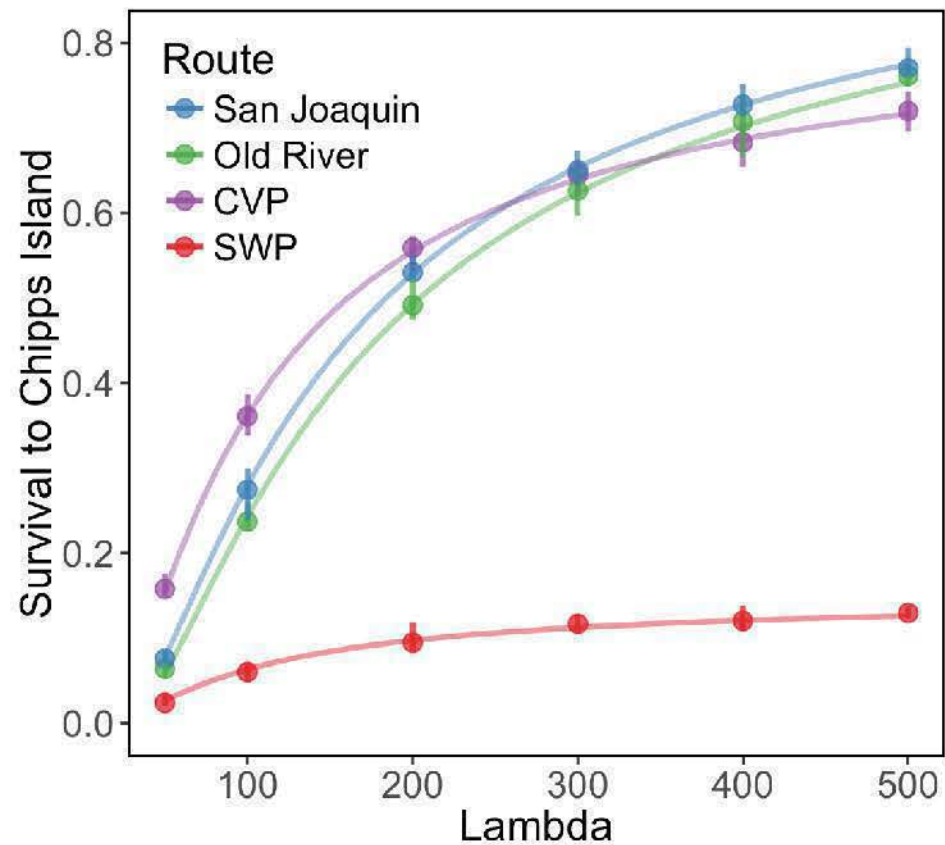
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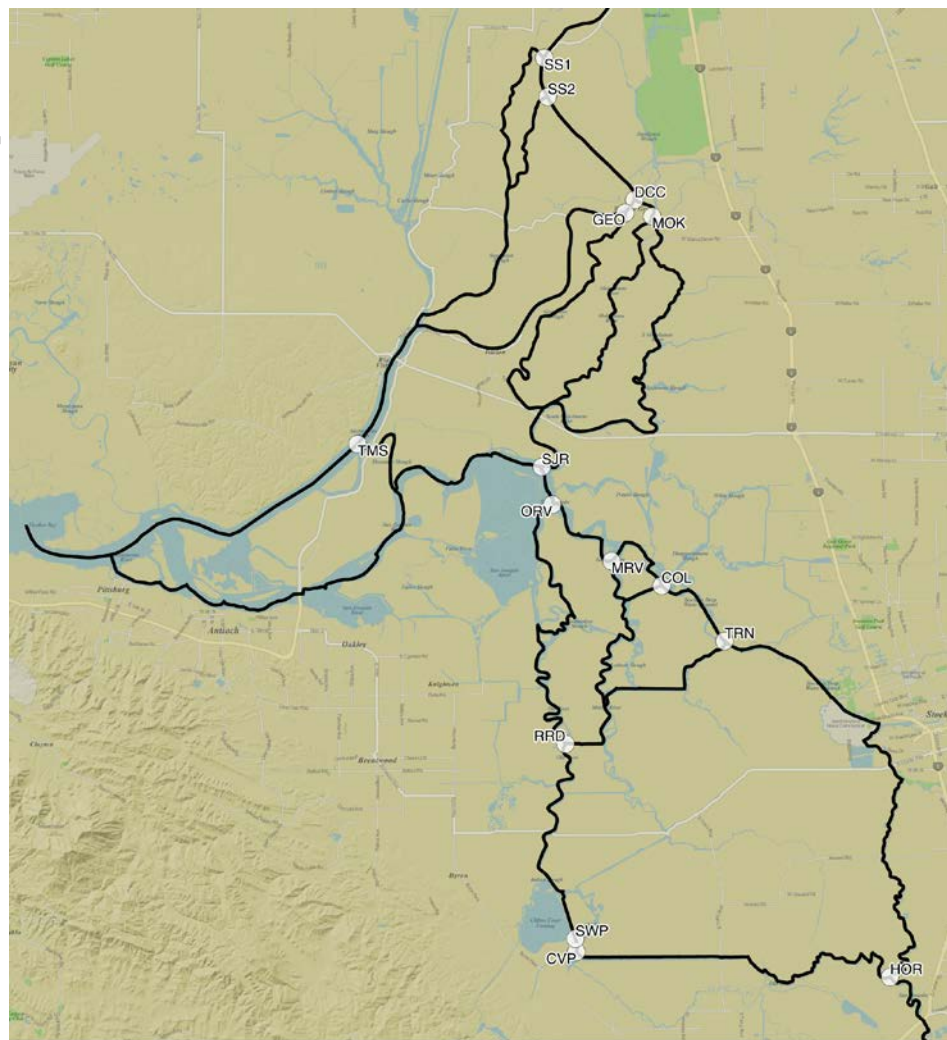
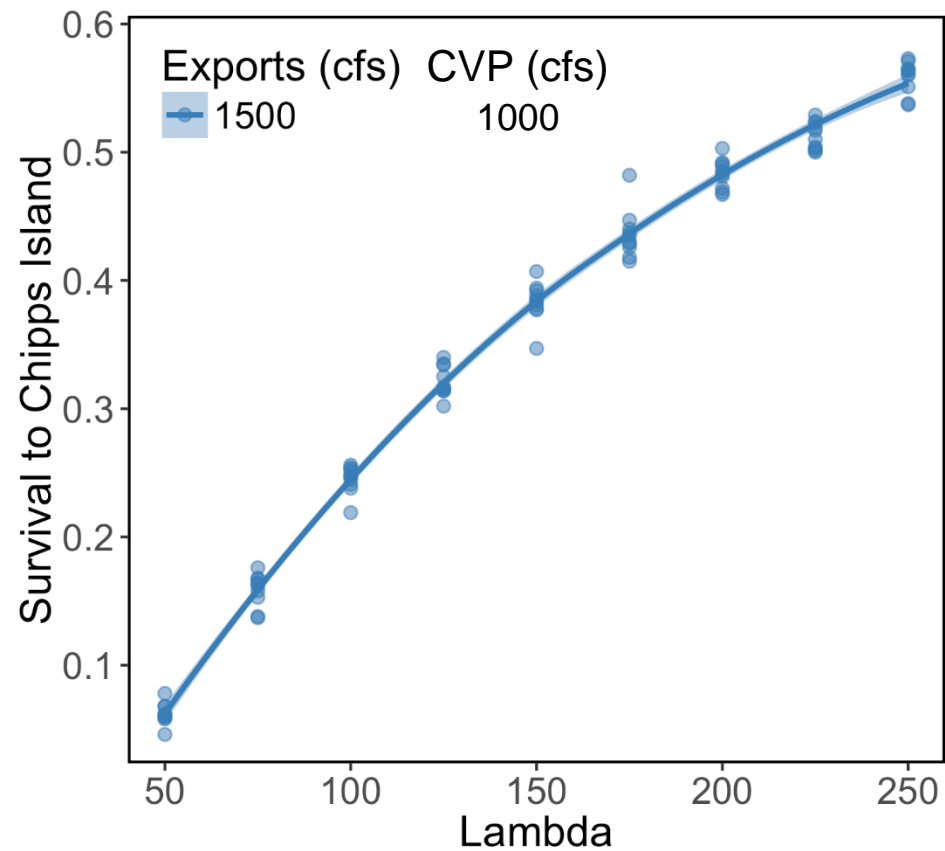


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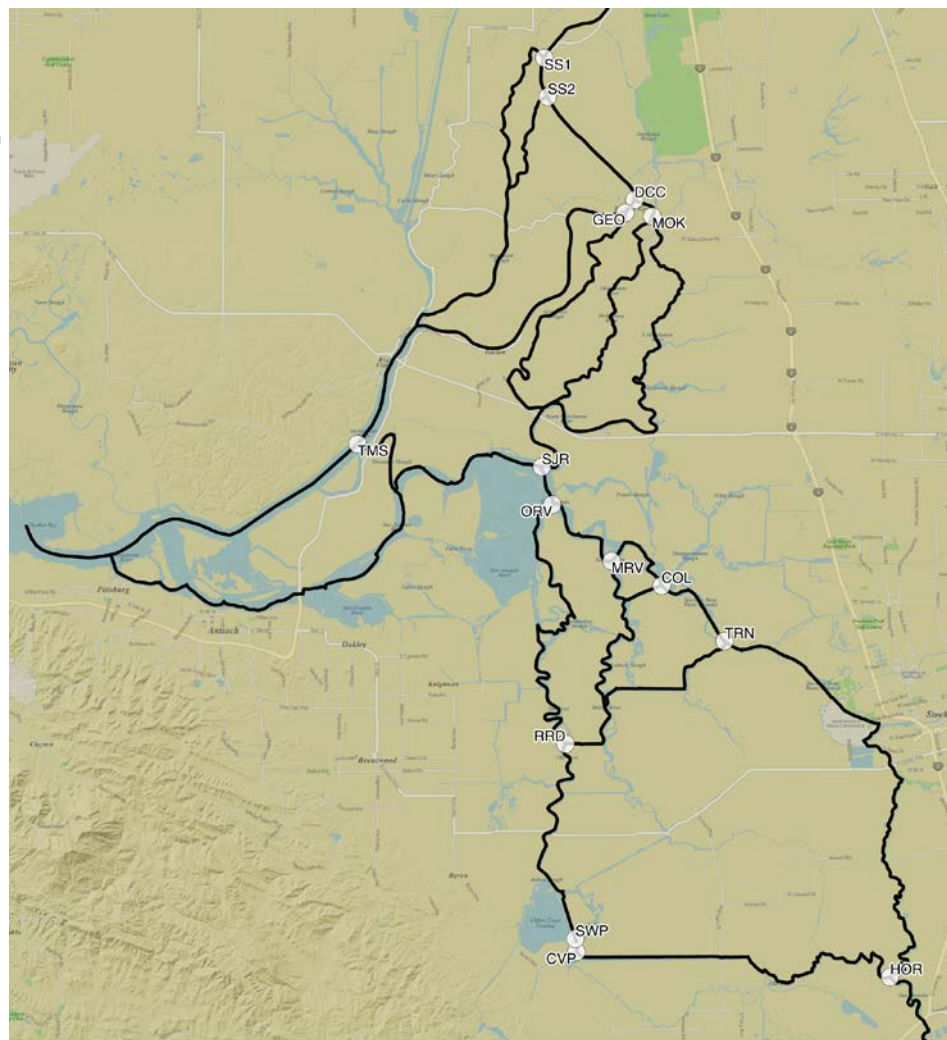
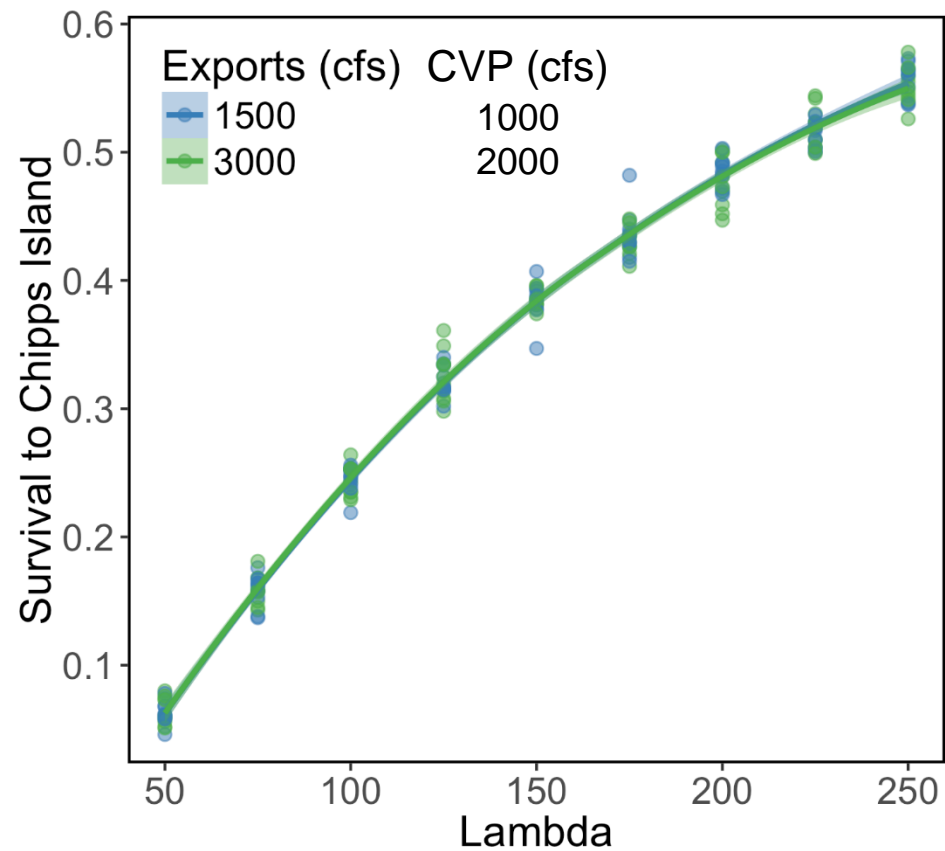




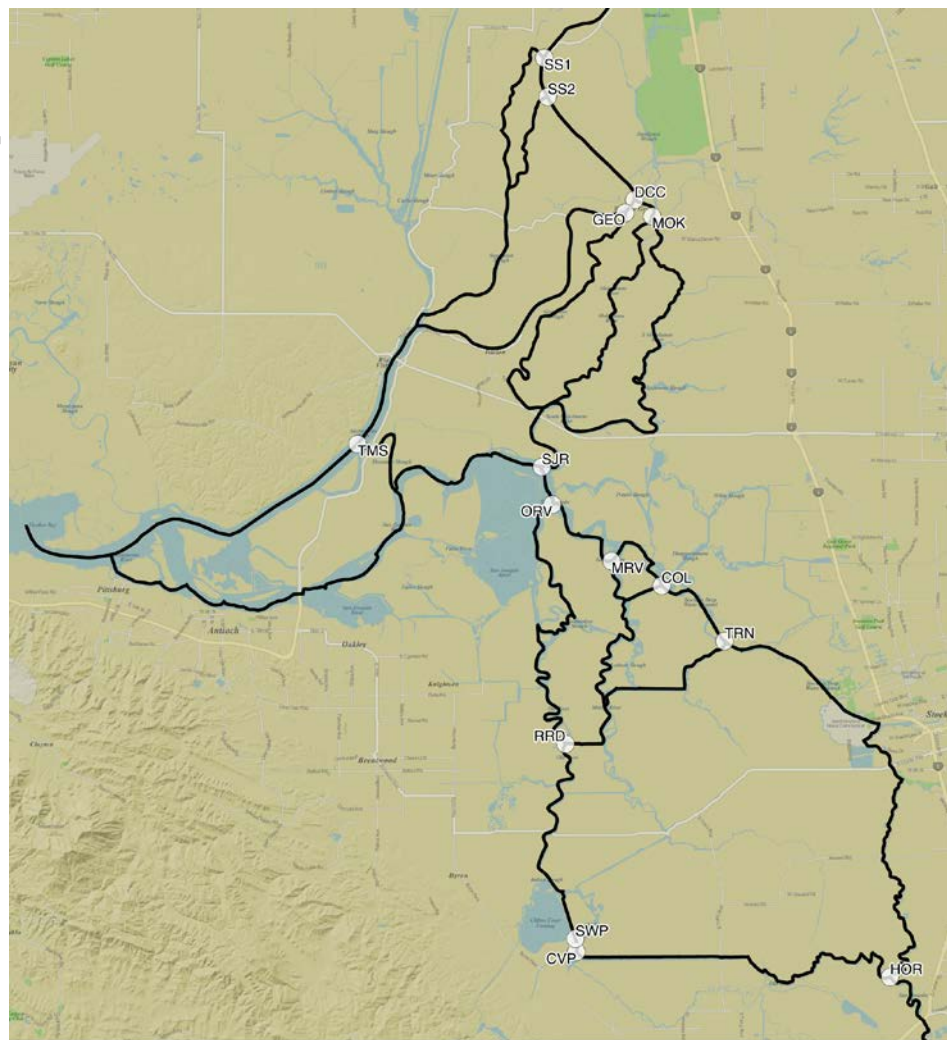
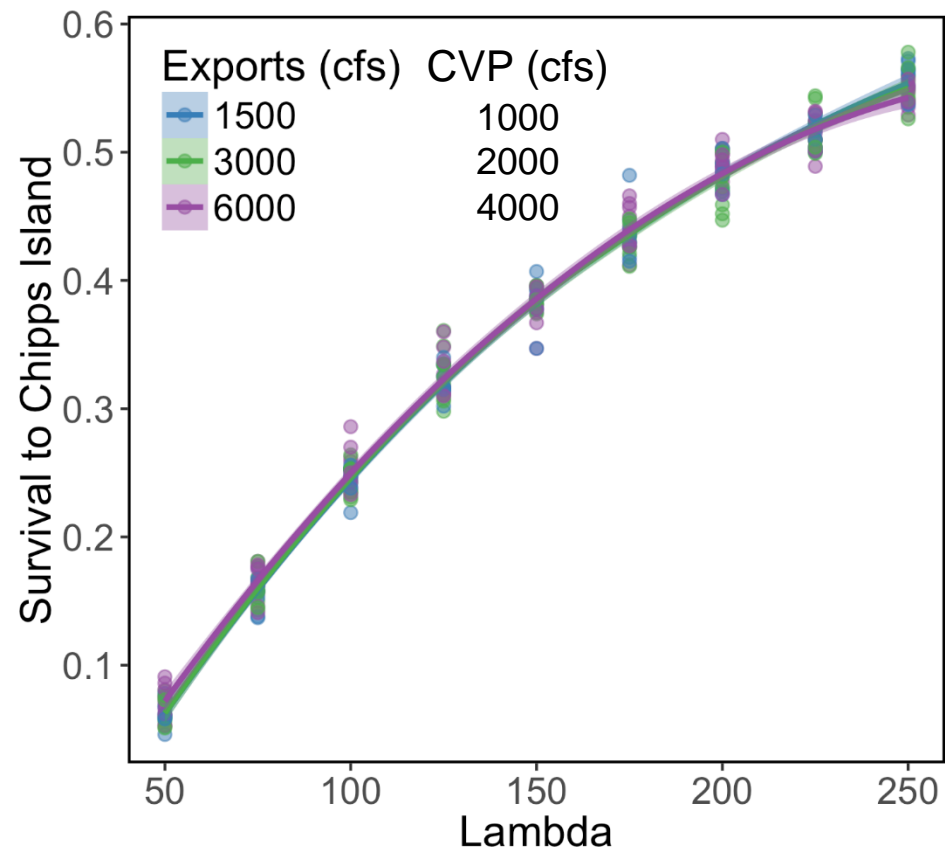
# Survival and Exports



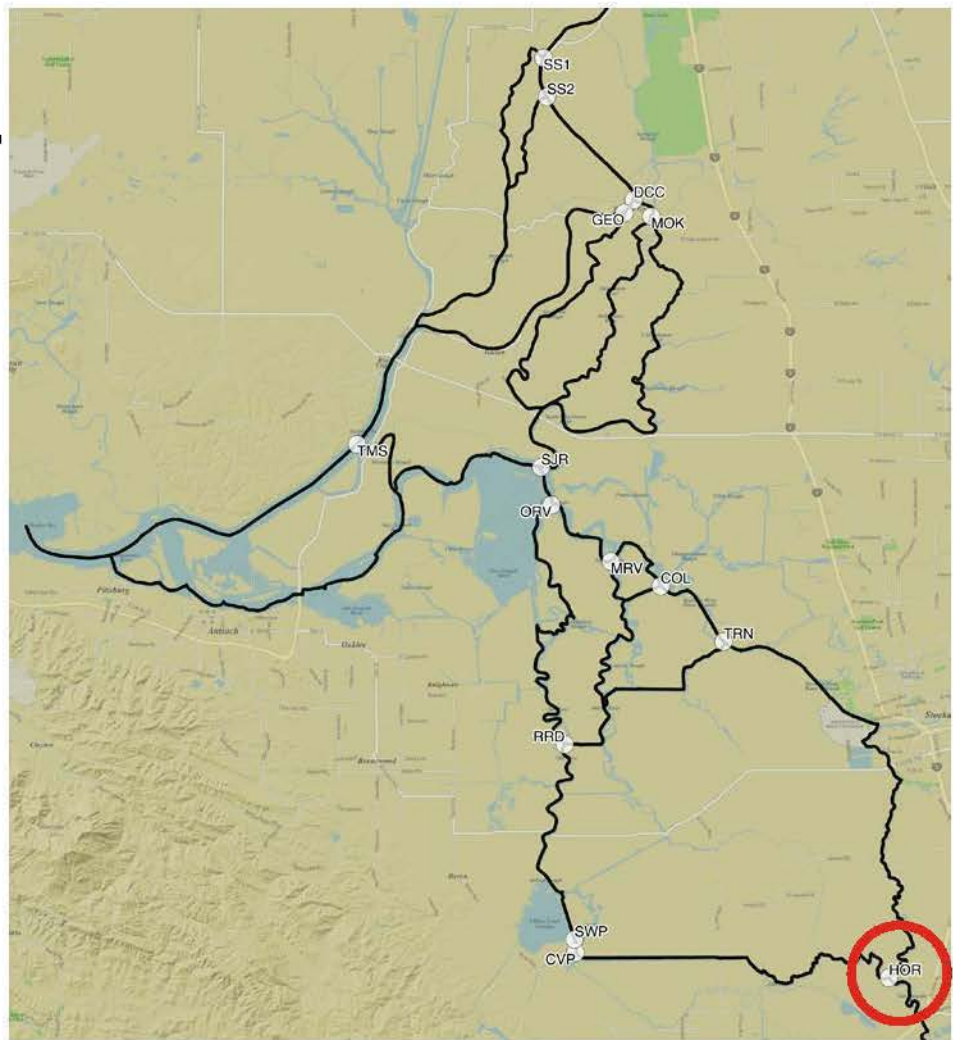
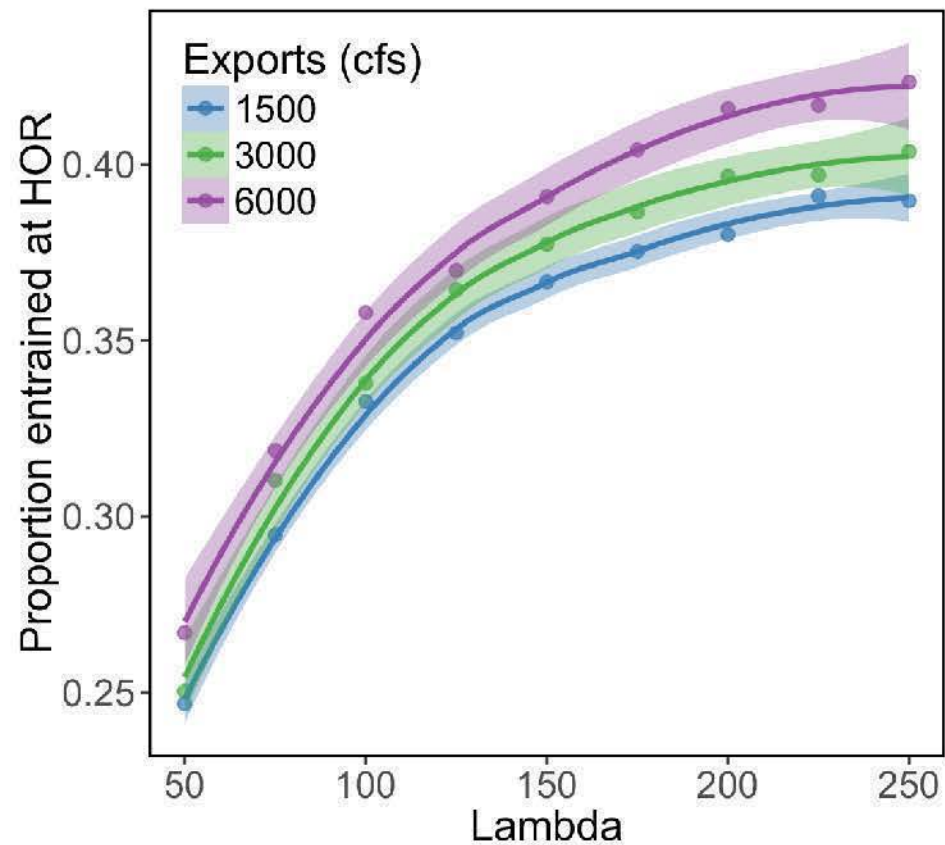
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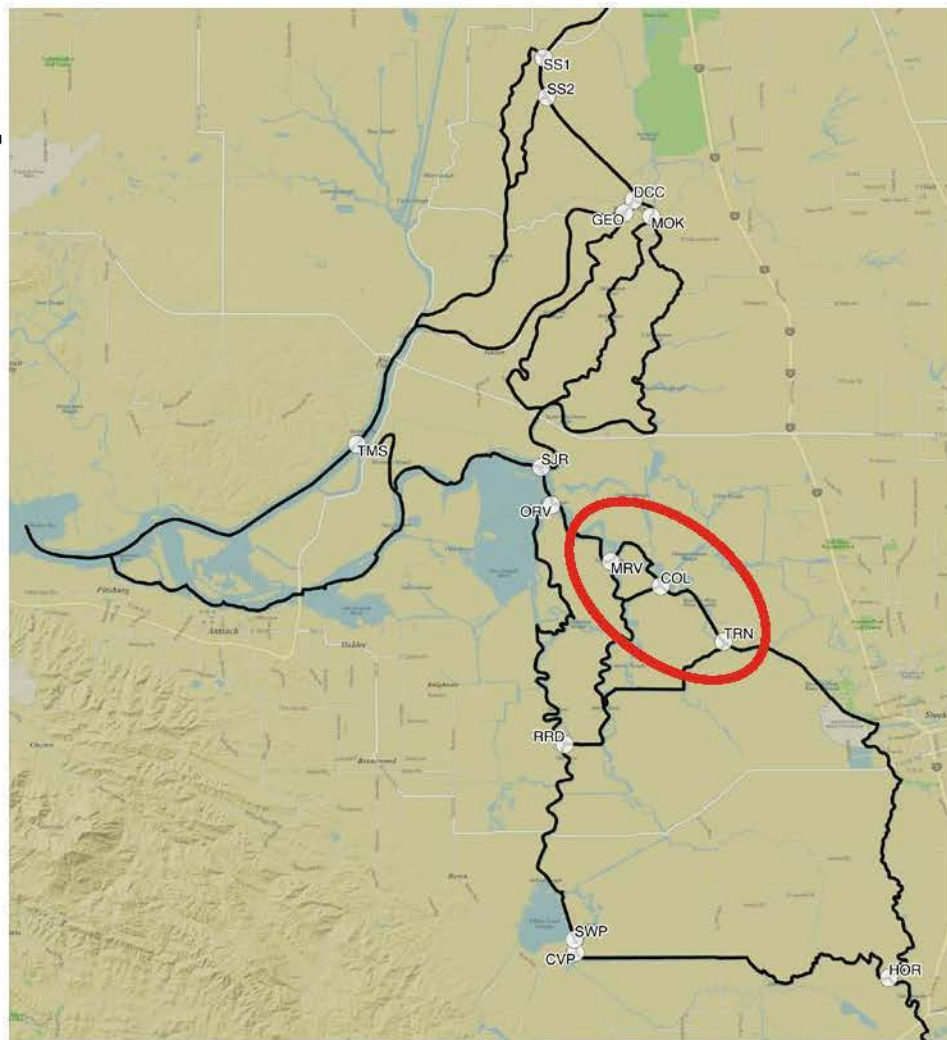
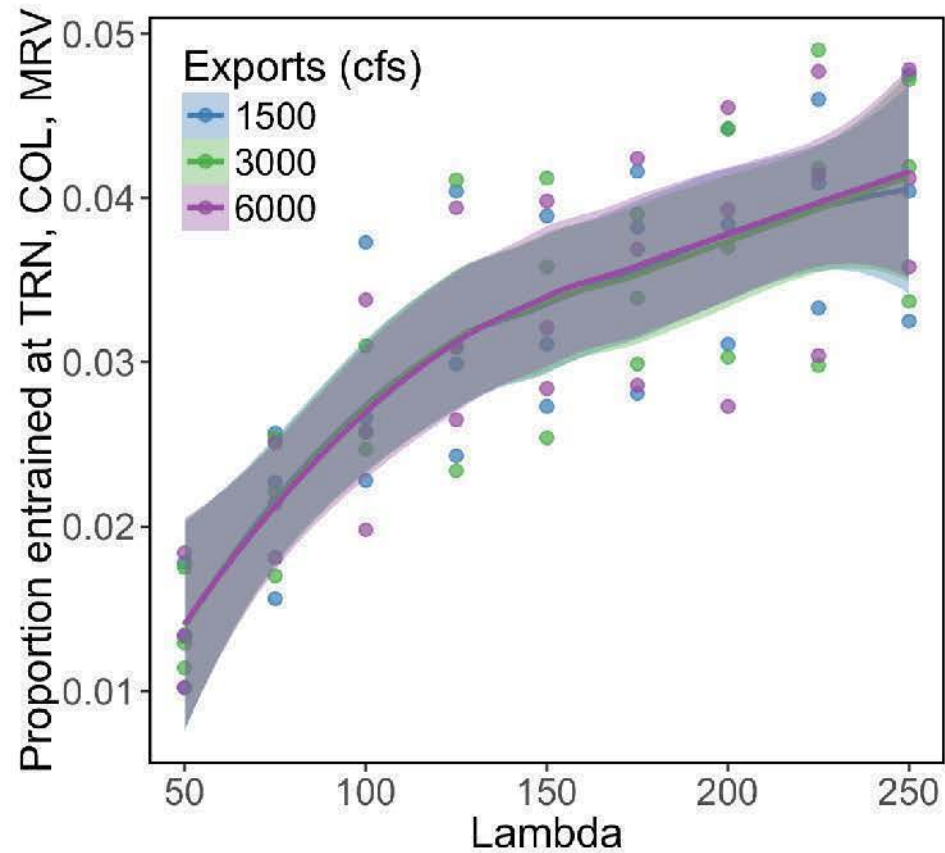
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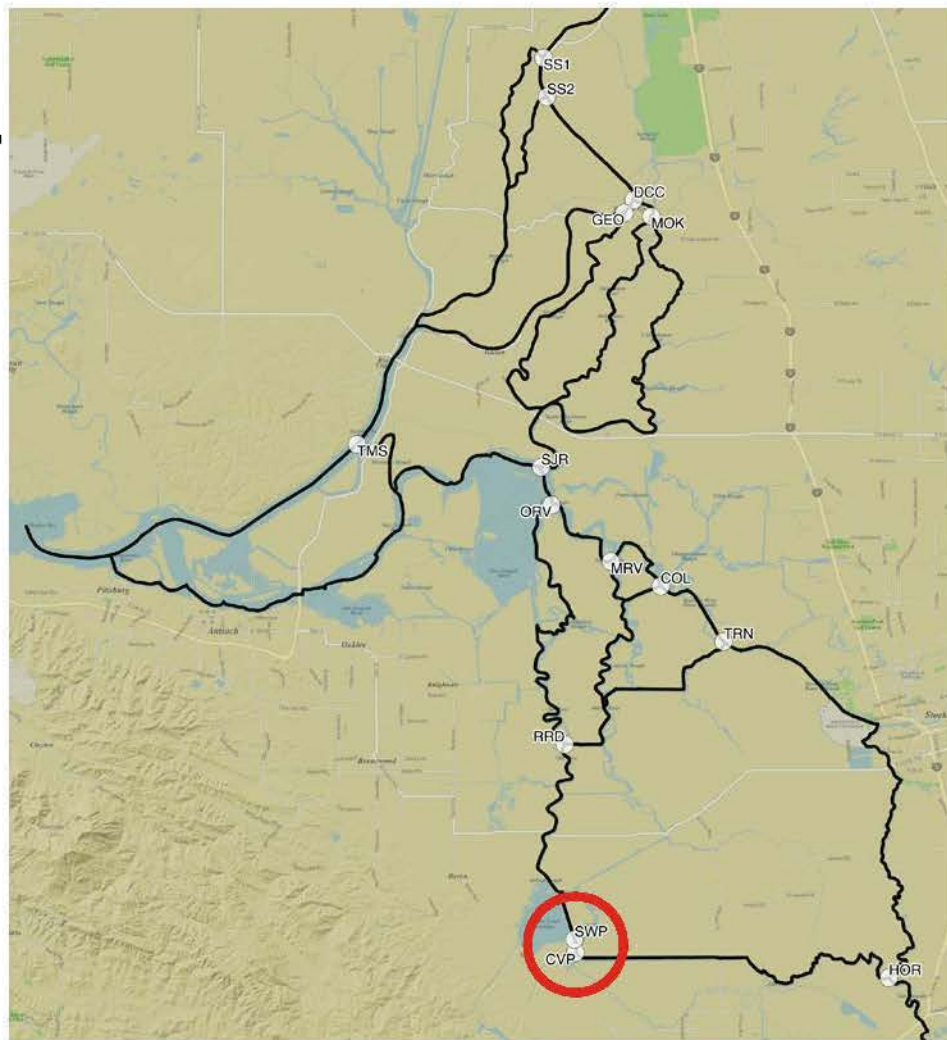
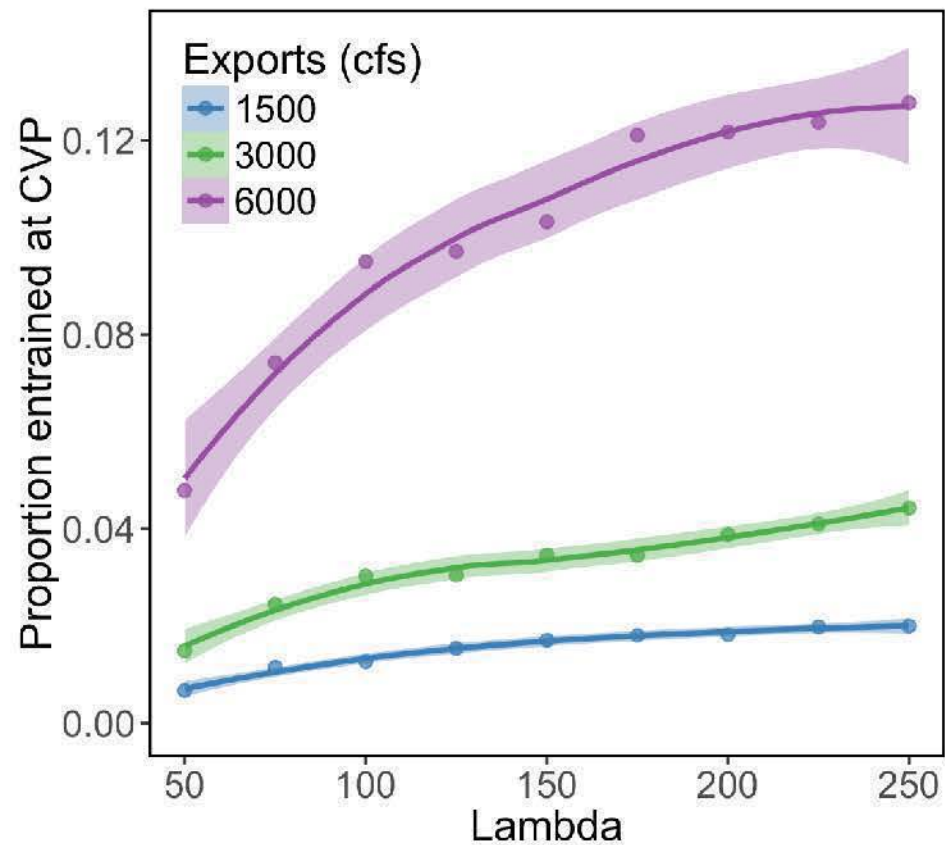
# Routing and Exports



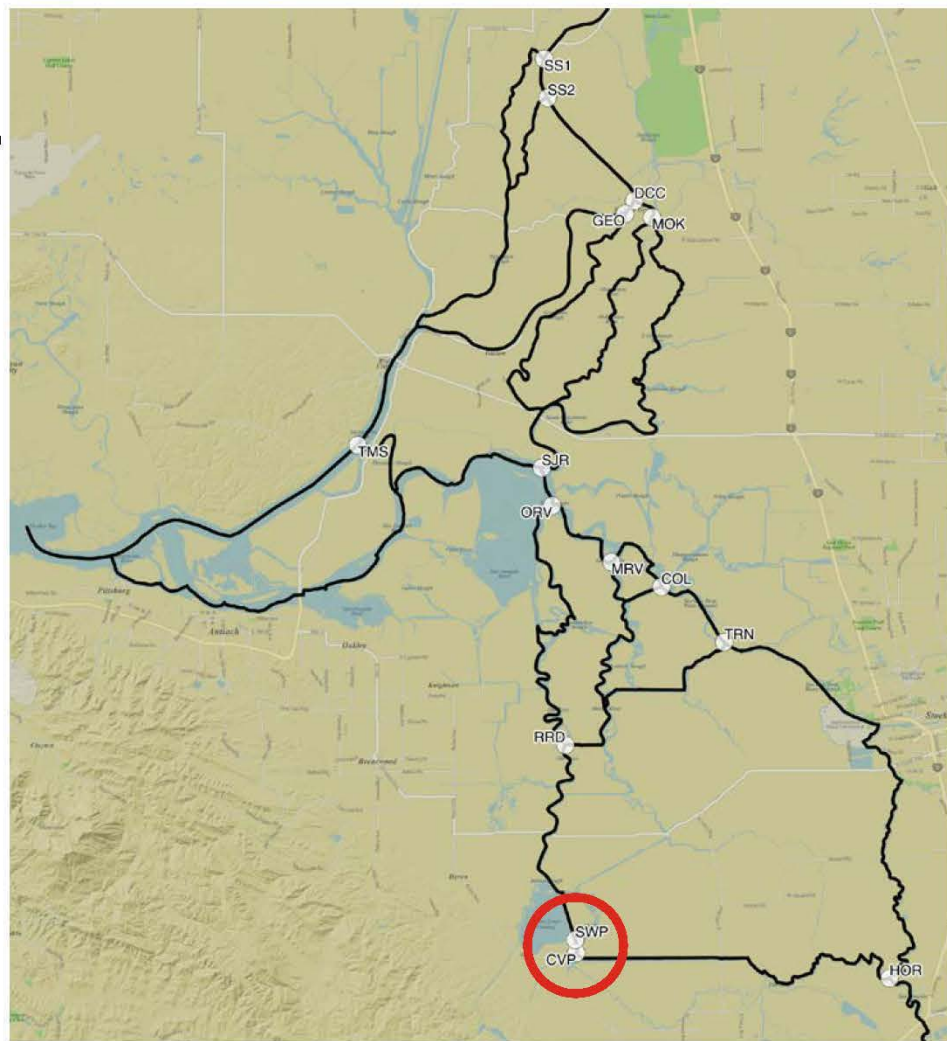
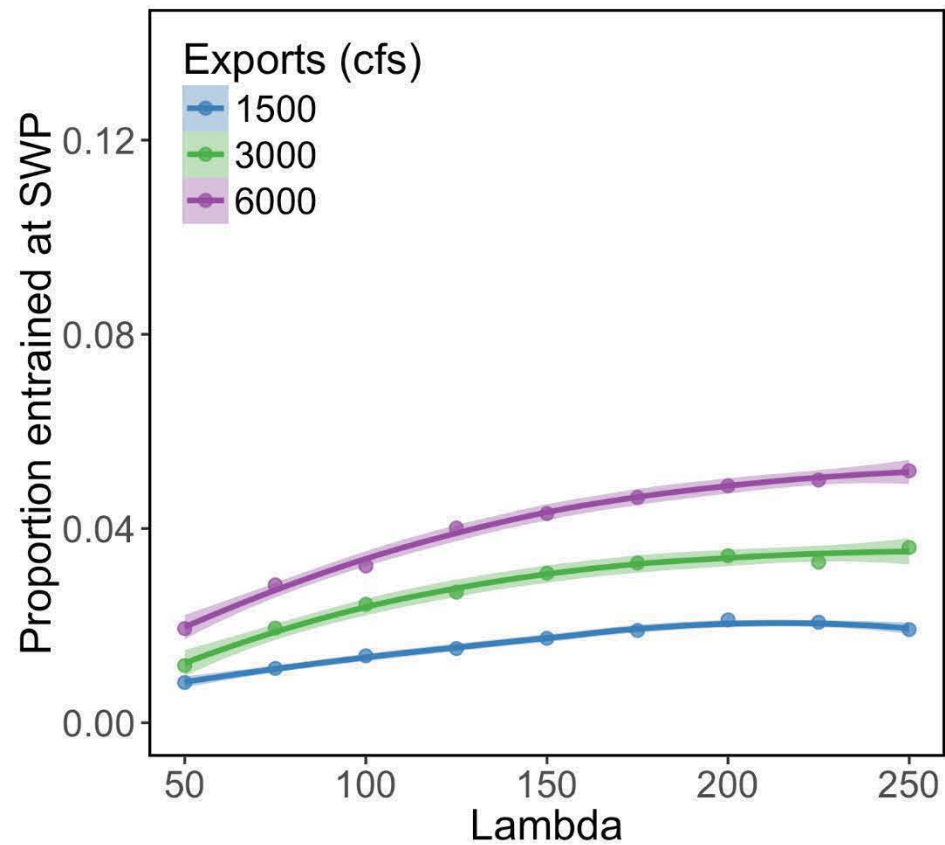
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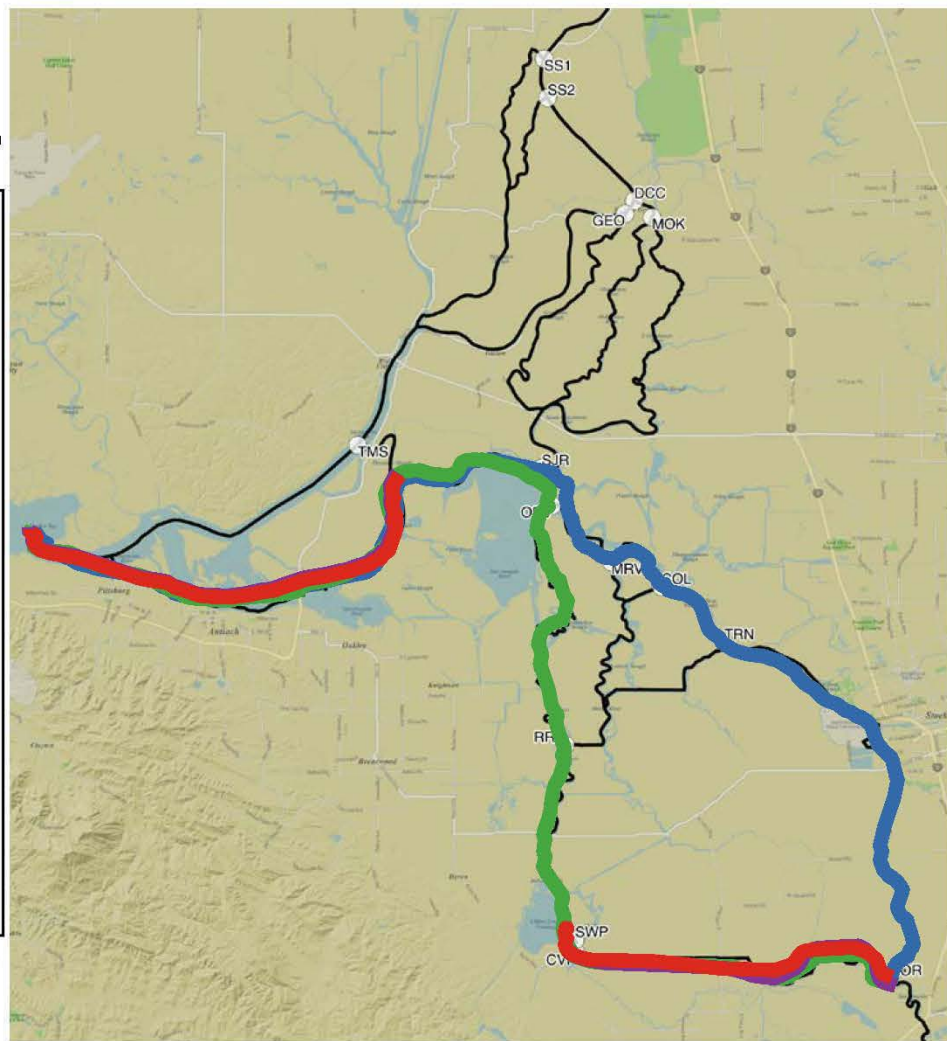
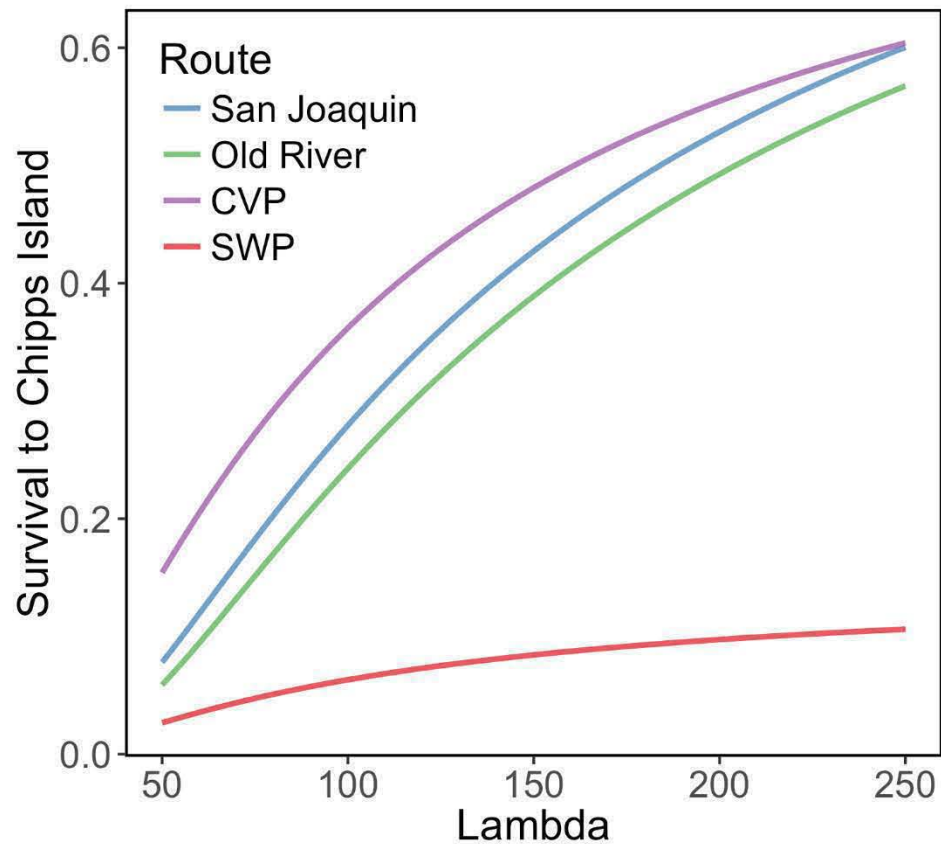
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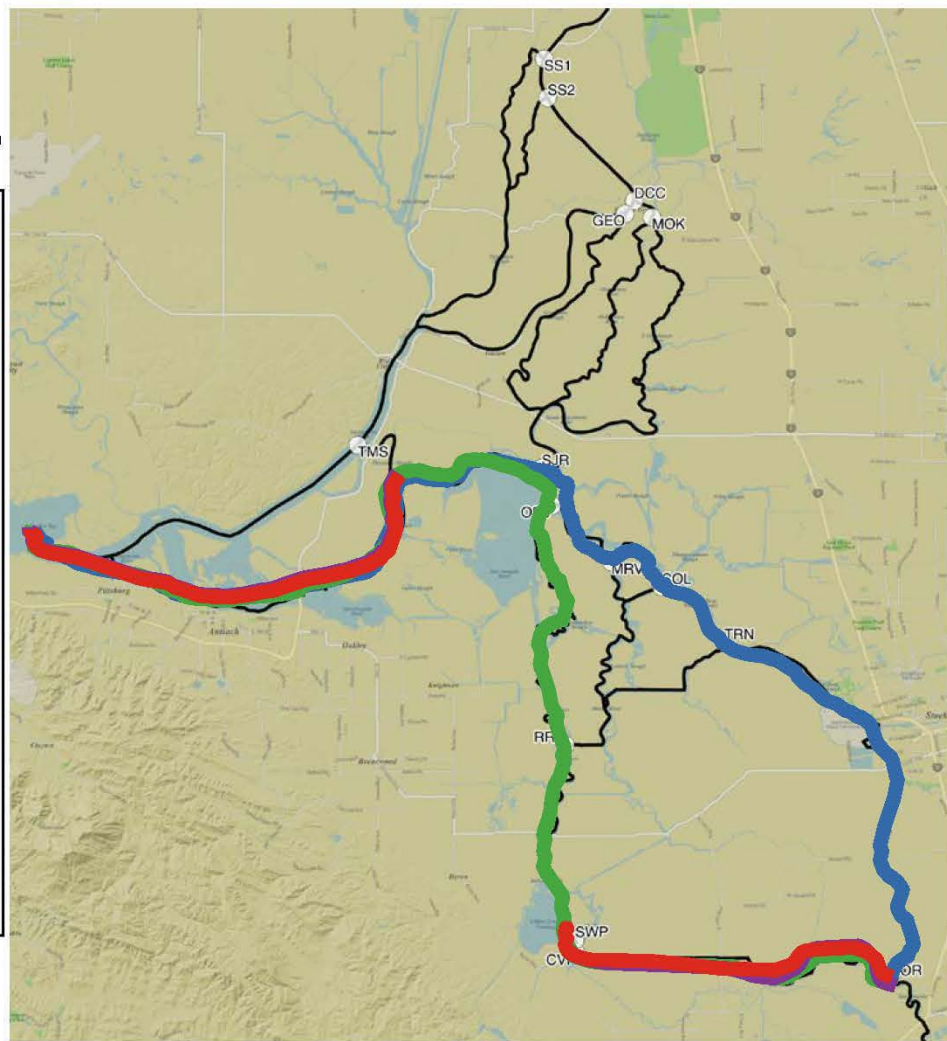
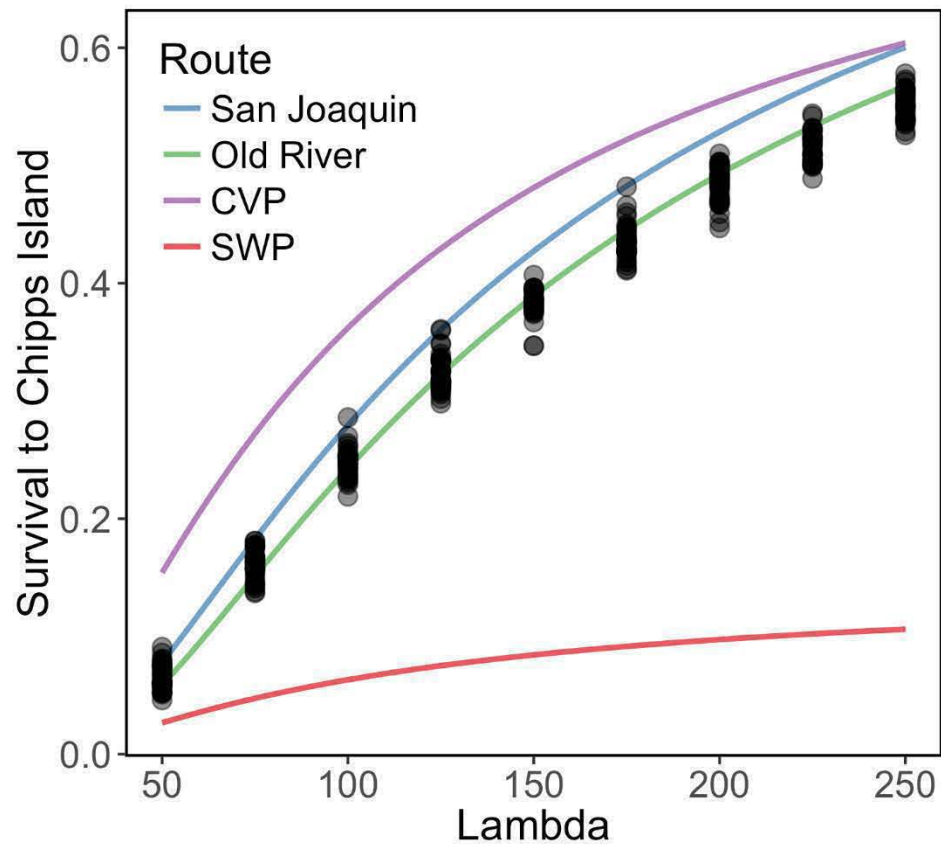


# Conclusion





# Conclusion



# Acknowledgments

- Russell Perry
- Tara Smith
- Yu Zhou



# Individual-Based Delta Passage Model

Starting reaches for migrating fish

SAC1 SJR1

	Reach	Mean	Variance	Lambd
1	SAC1	20	100	18
2	SAC2	20	100	18
3	SAC3	20	100	18
4	Steam1	20	100	10
5	Steam2	20	100	10
6	SAC4	20	100	9
7	SAC5	20	100	9
8	SAC6	20	100	8
9	SAC7	20	100	8
10	SAC8	20	100	8
11	GEO	20	100	6
12	MOK	20	100	6
13	COL	20	100	3
14	MRV1	20	100	3
15	MRV2	20	100	3
16	MRV3	20	100	3
17	ORV1	20	100	3
18	ORV2	20	100	3
19	ORV3	20	100	3
20	ORV4	20	100	3
21	SJR1	20	100	3
22	SJR2	20	100	3
23	SJR3	20	100	3
24	SJR4	20	100	3
25	SJR5	20	100	3
26	SJR6	20	100	3
27	SJR7	20	100	3
28	SJR8	20	100	3
29	TMS	20	100	3

Show example migration rate distribution

Show reach survival example

Reaches Routing Simulation References

Show more information about this tab

Color map by

Migration parameters  Survival parameters

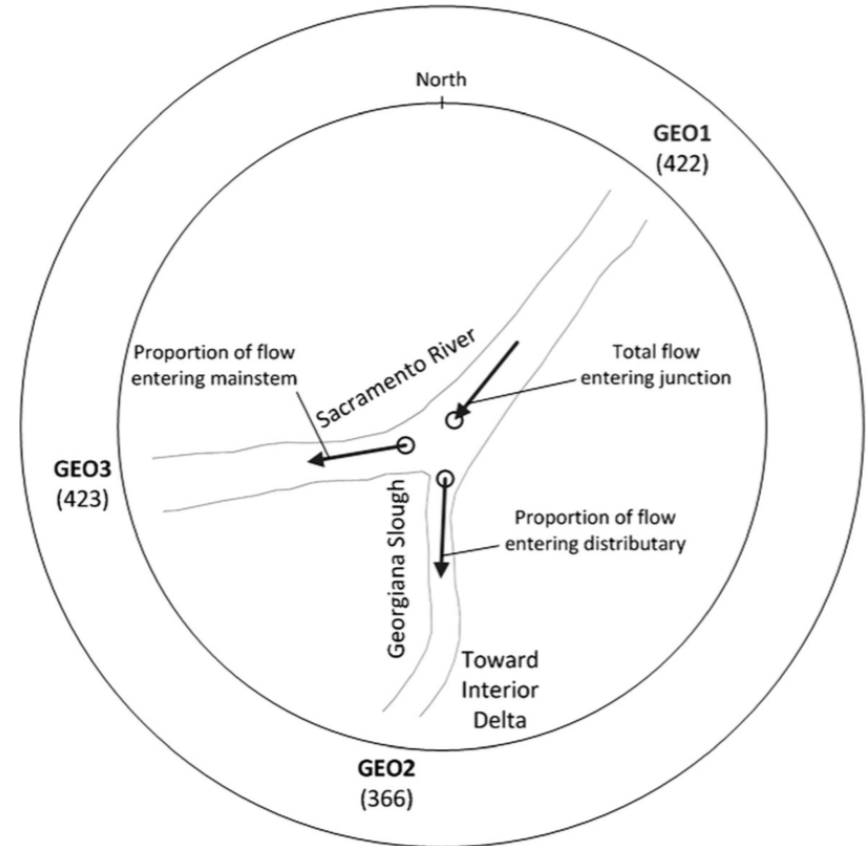
A map of the Delta region showing various reaches. The reaches are color-coded according to survival parameters. The map includes labels for various reaches such as SAC1, SAC2, SAC3, Steam1, Steam2, SAC4, SAC5, SAC6, SAC7, SAC8, GEO, MOK, COL, MRV1, MRV2, MRV3, ORV1, ORV2, ORV3, ORV4, SJR1, SJR2, SJR3, SJR4, SJR5, SJR6, SJR7, SJR8, TMS, and ORV2. The map also shows a network of waterways and a central area labeled "Mok".

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

# Routing

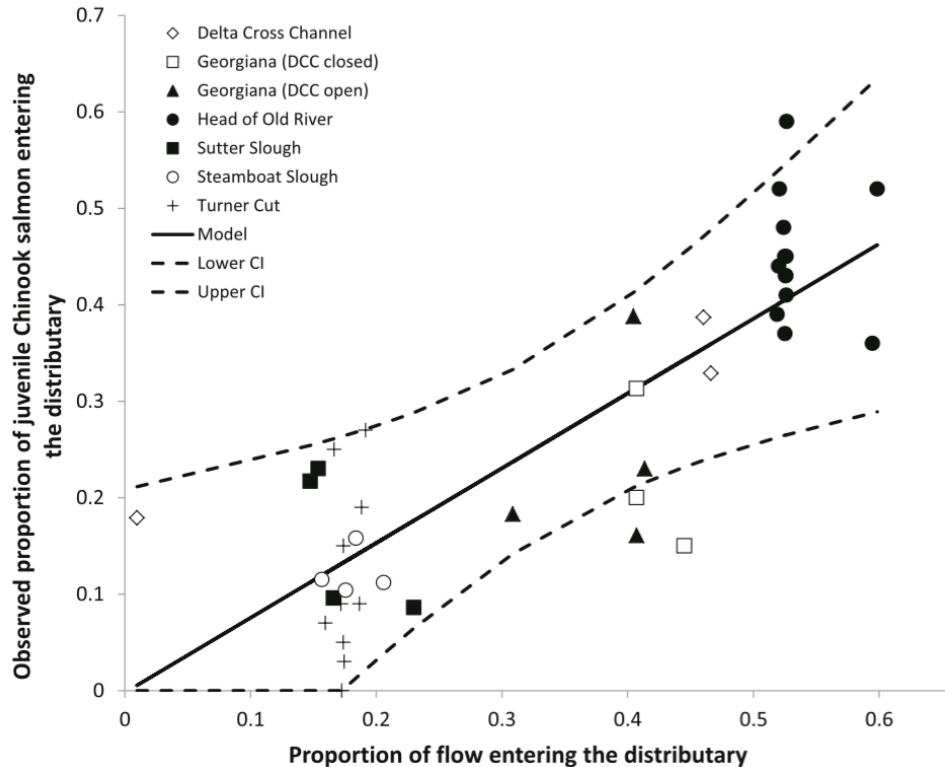
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- 15 junctions on key migratory routes
- Delta Simulation Model II (DSM2)
  - 15-min flow values
  - 61 days of representative tides
  - 3,978 combinations of barriers, inflow, and exports



# Routing

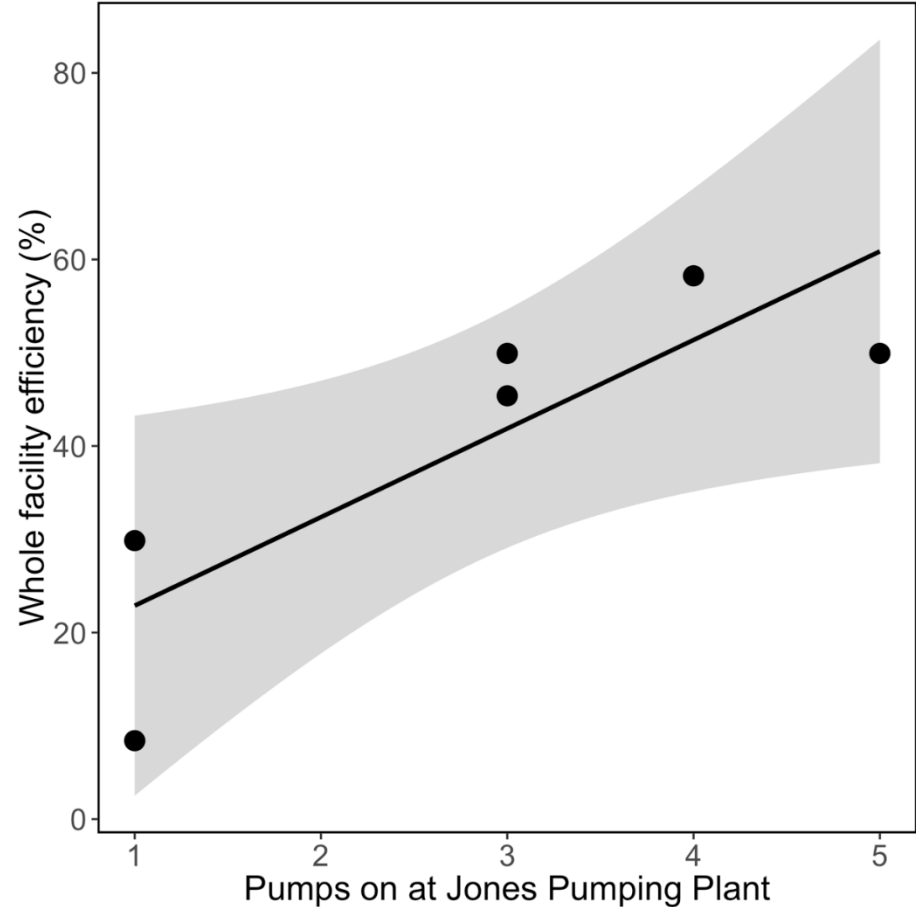
- 15 junctions on key migratory routes
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# Routing

---

- 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

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- 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

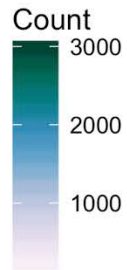
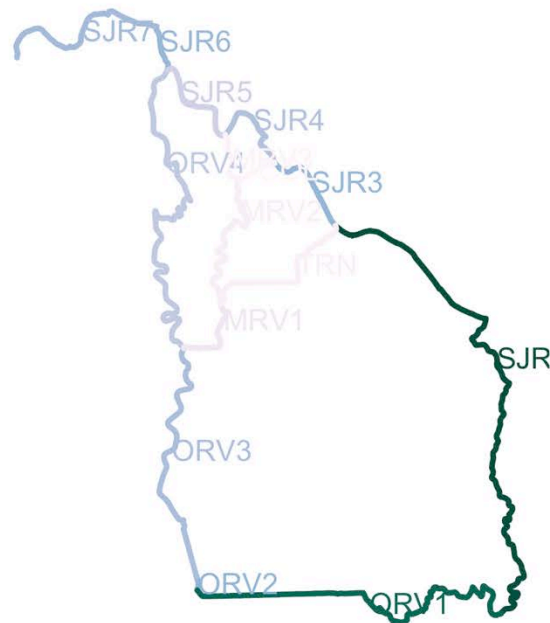
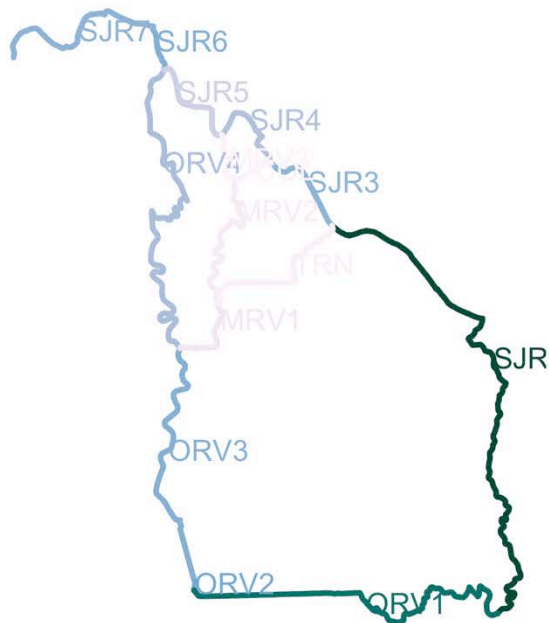
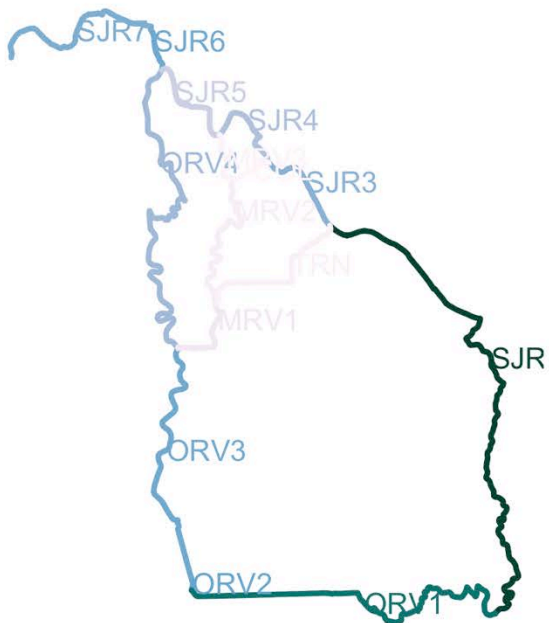
$\lambda = 50$

Exports (cfs)

1500

3000

6000



# Reach Usage Map

$\lambda = 250$

Exports (cfs)

1500

3000

6000

