Enhanced Particle Tracking Model (ePTM)

Model update: motivation, concepts and status

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Agenda

- What is the best available science on juvenile salmon migration in the Delta?
- What are we actually modeling?
- What was in ePTM v.0?
- What are we changing in v.1.0?
- Next steps ...

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What we know about typical migrating juvenile salmon

River/Upper estuary:

- Strong urge to migrate away from natal streams
- Spatial and temporal distribution of migration rates
- Migration rate faster with oceanward flow, and slower with landward flow
- Holding position during flood tides and oceanward swimming during ebb tides. Drifting when landward flow becomes very strong
- Swimming orientation based on sensory inputs
- Diel migration pattern, with holding during daylight hours

Lower estuary:

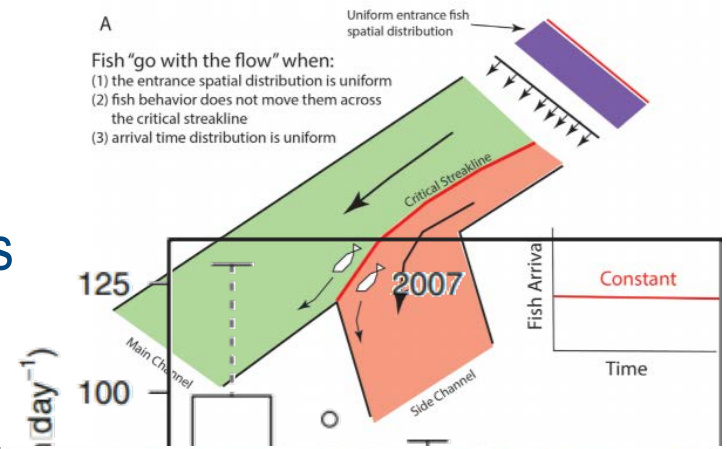
- More uniform daily migration pattern
- Swimming orientation potentially due to several hydrodynamic and water quality cues

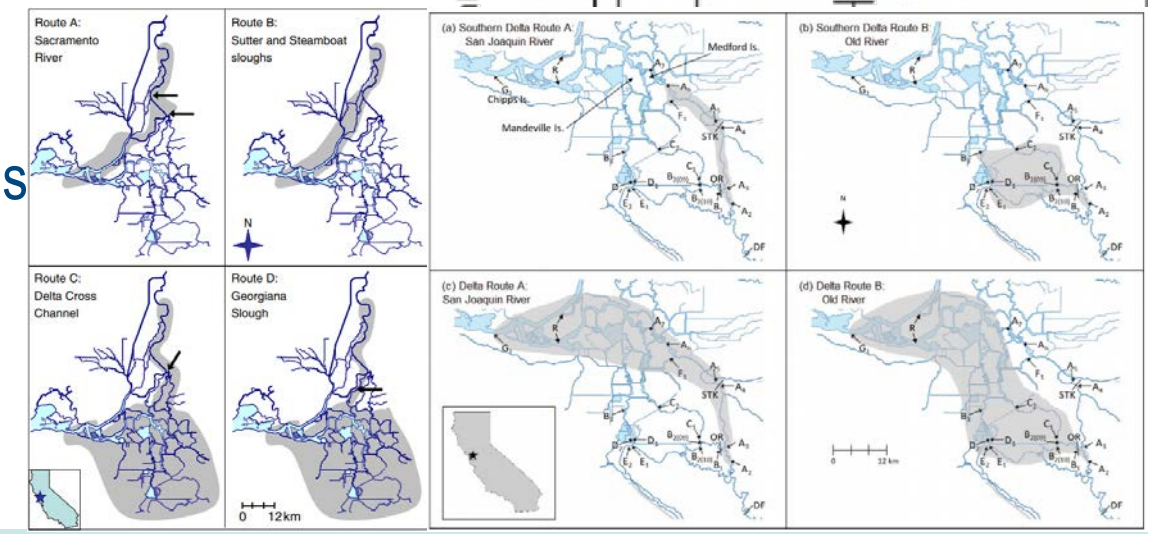
In the Delta

- Migration mechanics vary between runs
- Migration mechanics vary between hatchery and wild salmon
- Migration mechanics and survival vary between life stages (migrating vs. rearing fry vs. smolts)
- Predator avoidance, migration mechanics, route selection and survival vary by fork length
- Covariates could affect swimming speeds, migration rates, predation, and survival
- Various studies highlight effects of different covariates

Migration mechanics

- Diel migration predominantly at night, and increasingly during day as well oceanward
- Increased bi-directional diel detections during high flows
- Possible flood-tide holding occurring
- Durations typically less than 30 days
- Migration rate is slowest in Delta
- Fish don't obey flow splits at junctions
- North Delta, South Delta routes
- Delta routes have lower survival





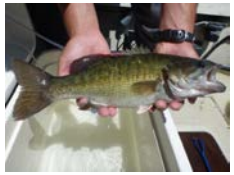
Predation

- Complex assemblages of predators depending on environmental covariates
- Predation knowledge driven by expert opinion
- Predators behave differently and sample different parts of water column
- Only beginning to address predation events and differentiate predators from salmon smolts

Largemouth Bass

Striped Bass

Smallmouth Bass



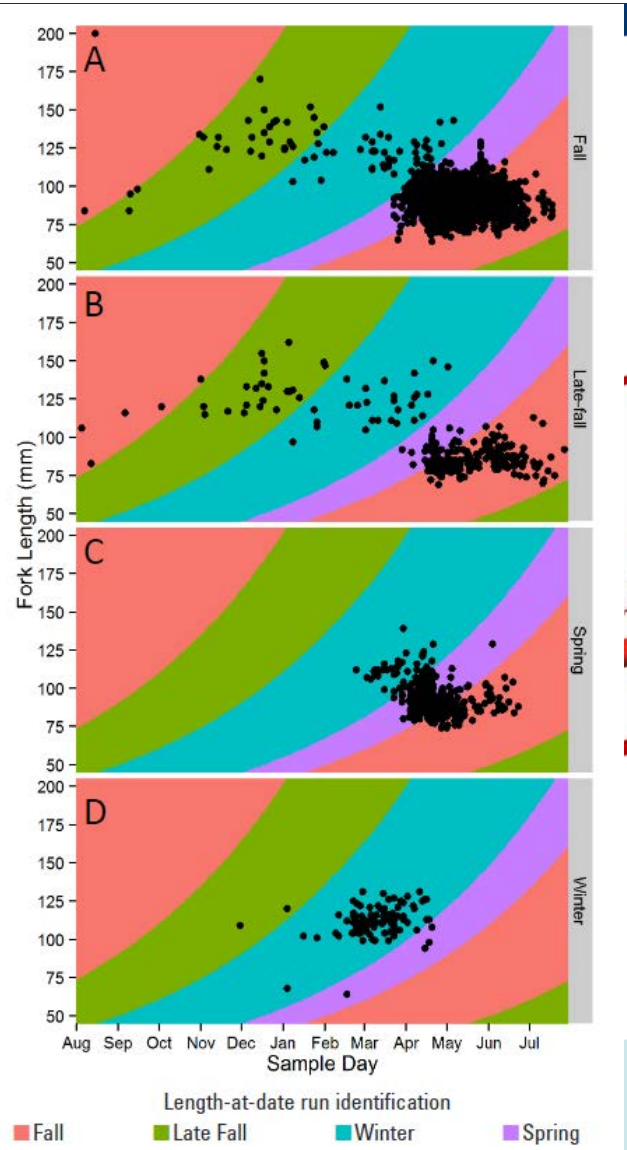
Green Sunfish

Sacramento Pikeminnow

Crappie

Channel Catfish

White Catfish


A
B
C
D
Fall
Late-fall
Spring
Winter
Fork Length (mm)
200
175
150
125
100
75
50
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
Sample Day
Length-at-date run identification
Fall
Late Fall
Winter
Spring

ePTM v.0: a first attempt at modeling migration

- Represented behaviors based on representative hydrodynamics
- Represented swimming behavior based on lab studies
- Multiple models representing complex biophysical processes
- Calibration, validation, and application steps continuously updated

ePTM v1.0: a more streamlined model

- Developing the simplest possible model that integrates various scientific results from different studies
- Fish now making decisions based on the local hydrodynamics they experience
- Definition and parametrization of swimming velocity now different, so that migration rates are comparable to those observed
- Swimming, directional orientation, and memory now decoupled
- Presenting an aligned calibration, validation and application pathway
- Improved hydrodynamics and water quality co-variate response

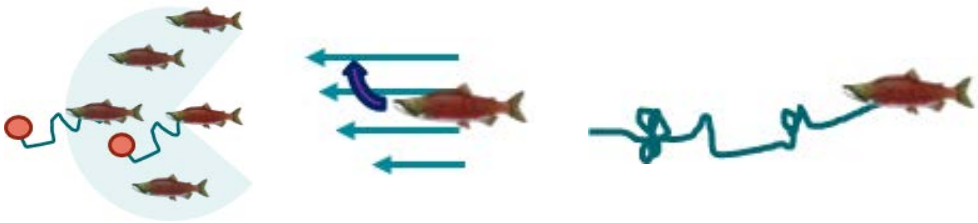
We are simulating migration, not movement

All the fine-scale behaviors below are averaged into a 15 minute – 1 hour average migration rate:

• Individual swimming patterns – rheotaxis, foraging, feeding, predator evasion, bioenergetic holding, etc.	Milliseconds to seconds
• Response to local thermal variability, turbulence, coherent structures, obstacles, etc.	Seconds to minutes
• Endurance runs, bursts of speed, recovery times, resting, etc.	Seconds to minutes
• Group dynamics: individual response to stimuli, group contagion, etc.	Microseconds to seconds

Big takeaway

During each model timestep, fish are doing their thing…



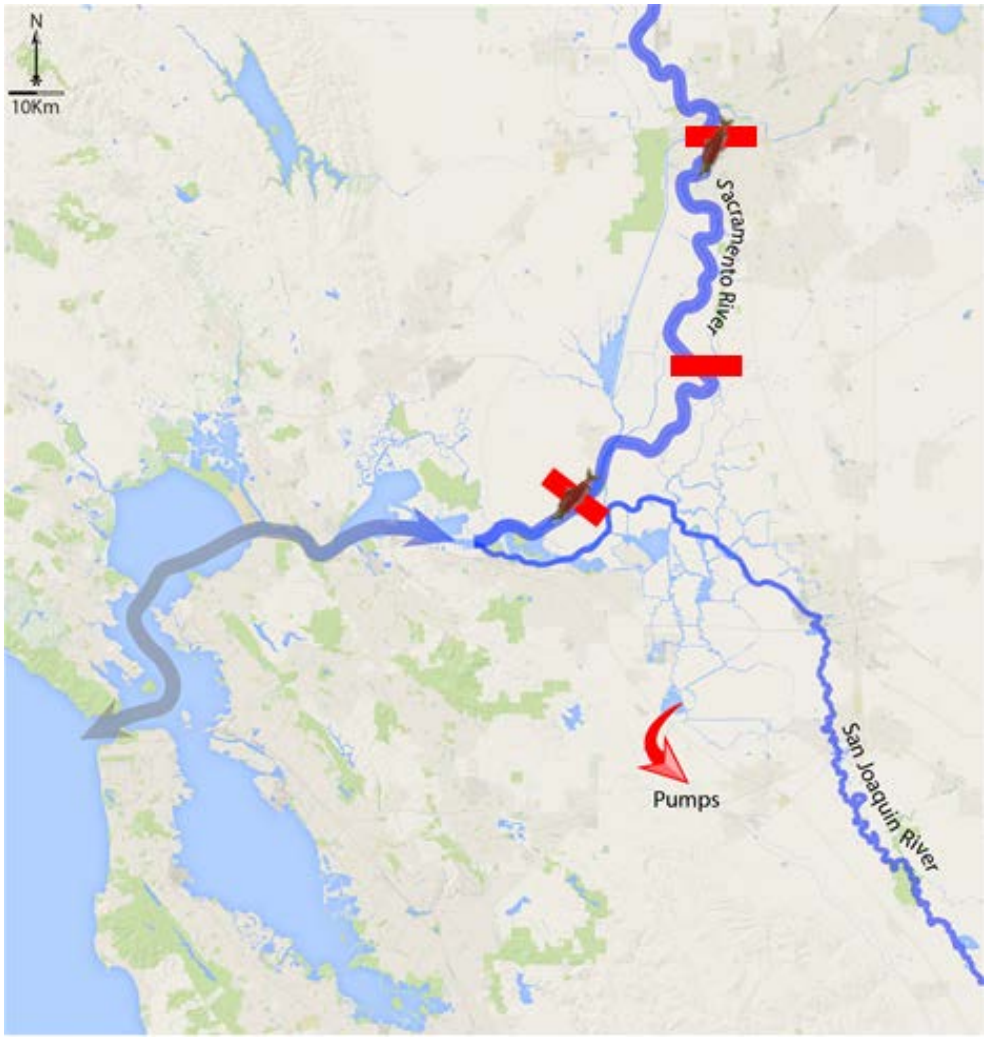
We take snapshots at the beginning and at the end of the timestep

At the scale of motion we have information on…

• Migration rates through reaches	First acoustic-tag detection histories
• Travel time distributions through reaches	First acoustic-tag detection histories
• Survival statistics through reaches	Mark-recapture inferences
• Diel detection patterns	Acoustic-tag detections
• Tidal detection patterns	Acoustic-tag detections
• Predation hotspots	Autopsies, acoustic-tag detection filtering, predator surveys

Big takeaway

We are inferring macro-scale migratory patterns from very coarse scale records of fish passage.



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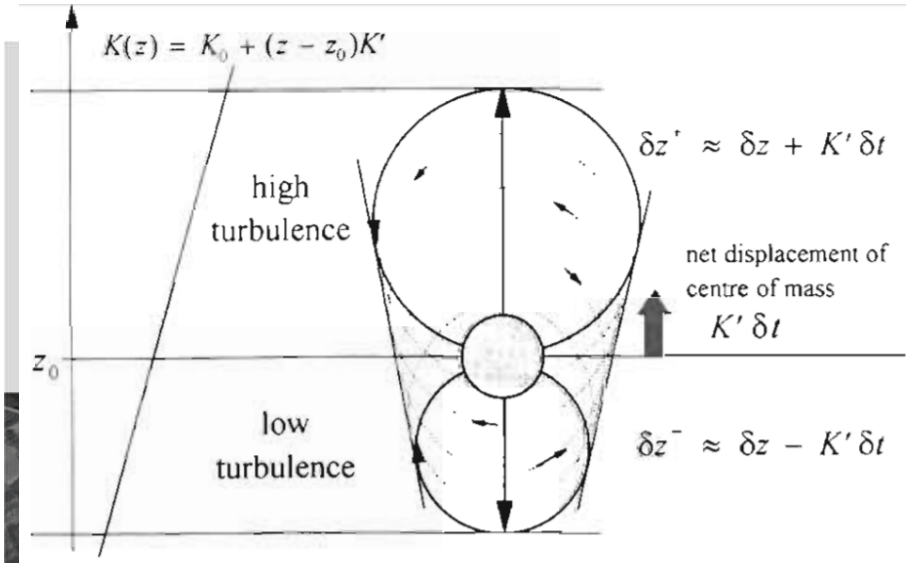
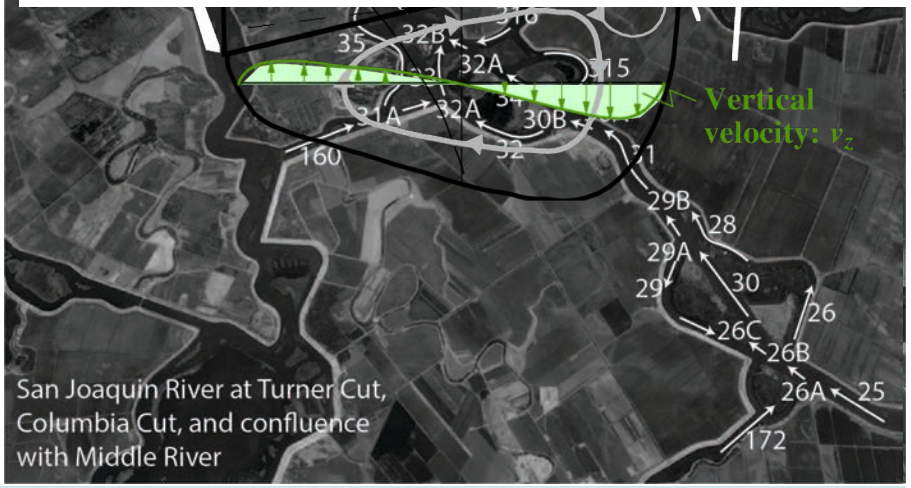
Hydrodynamics

- **Cross-sectional mixing:** diffusivity structure, vertical movement mechanism, and what happens near water column boundaries
- **Bends:** implementing a simplified lateral momentum balance
- **Junctions:** implementing the critical streakline based partitioning of simulated juvenile salmon
- **Prop 1** work addresses more fundamental scientific questions





Biology

- Diel swimming (a probability)
- Predation (one or more generic predators via the X-T model)
- Migration rate from a log-normal distribution
- Migration direction based on memory, as well as local flows (still logistic)
- Flood phase holding based on local velocity (and a general sense of the oceanward direction)

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Next steps

- Debugging and testing
- Calibrating and validating (potentially with CWT data)
- Reporting: 2 papers by the end of the year
- Producing a robust, useful, and accessible tool

Thank you

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Supplemental material

Biology of chinook salmon migrating through the Delta

Swimming behavior

Migration rate

Migration routes

Migration duration

Survival

Predation

Effect of environmental covariates

Size and condition effects

Life history trajectory

Source variegation

Inter-species effects

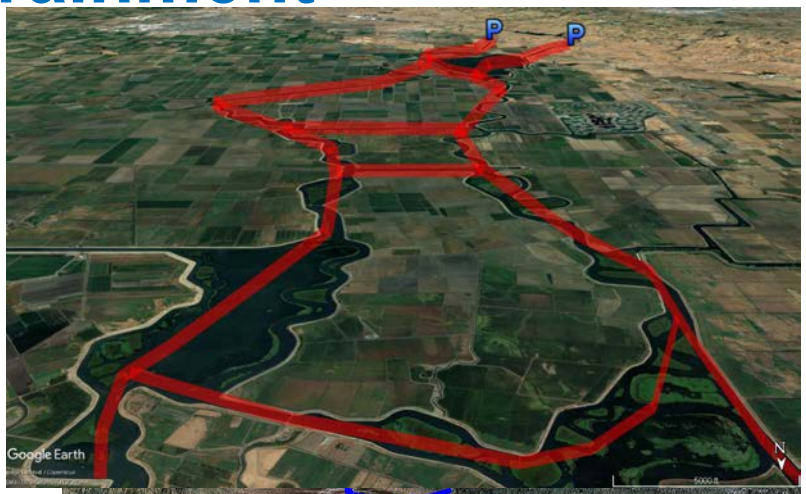
Swimming speeds

- Respirometers and race track flumes: Sustained swimming speeds under stress can be about 4.3-11 body lengths per second

- In the rivers: swimming speeds are typically 1.5-2 body lengths per second

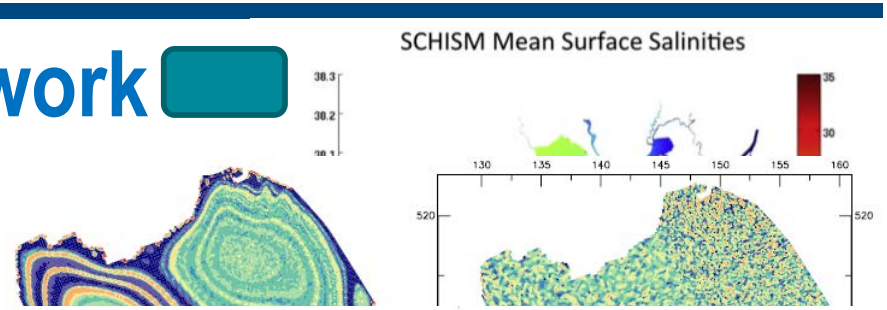
Water operations, exports and entrainment

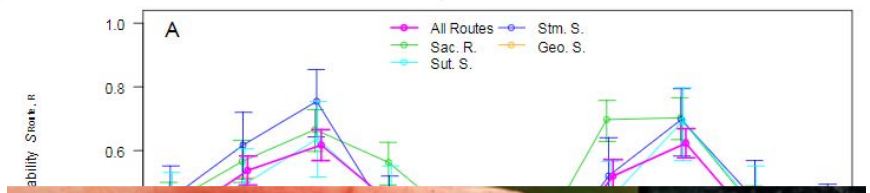
- Exports confuse fish about migration direction
- Exports decrease survival due to entrainment into pumps
- Lower flow in conjunction with exports reduces survival
- Entrainment zone depends on export levels and barrier placements
- Effect can extend to North and West Delta as well, particularly when Delta Cross Channel is in operation



CDFW Proposition 1 proposed work

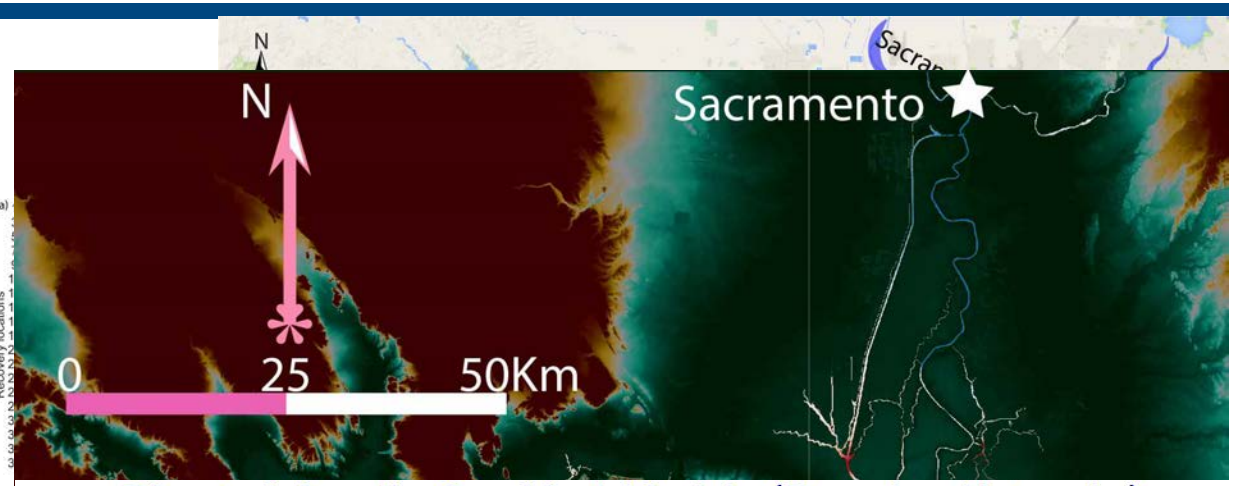
- **Cross-sectional mixing:** becomes more complicated with 2D and 3D
- **Submerged islands:** implementing simulated salmon residences using reactor theory
- **Open water processes:** parametrization from SCHISM
- **Hydraulic controls and predation hotspots:** parametrization from 2D hydroacoustic datasets
- **Navigation and predation:** more data driven using ML
- **Response to covariates:** temperature, turbidity, salinity
- **Repurposing CWT data:** rich validation dataset, and allows us to go much farther back than AT datasets



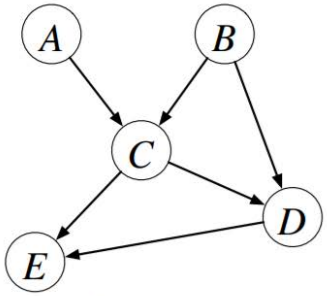


Coded wire tag data

- Graph of CWT release locations and beach seine and trawl locations
- Trellis diagrams useful for Bayesian analysis of hidden models
- Stitching together survivals from CWT and AT datasets using flow and path lengths
- A unified survival map
- Probability graphical model to determine likely migration routes/ rearing times



Directed Acyclic Graphical Models (Bayesian Networks)



A DAG Model / Bayesian network[1] corresponds to a factorization of the joint probability distribution:

$$p(A, B, C, D, E) = p(A)p(B)p(C|A, B)p(D|B, C)p(E|C, D)$$

Putting it all together: predation, the habitat layer, and net survival

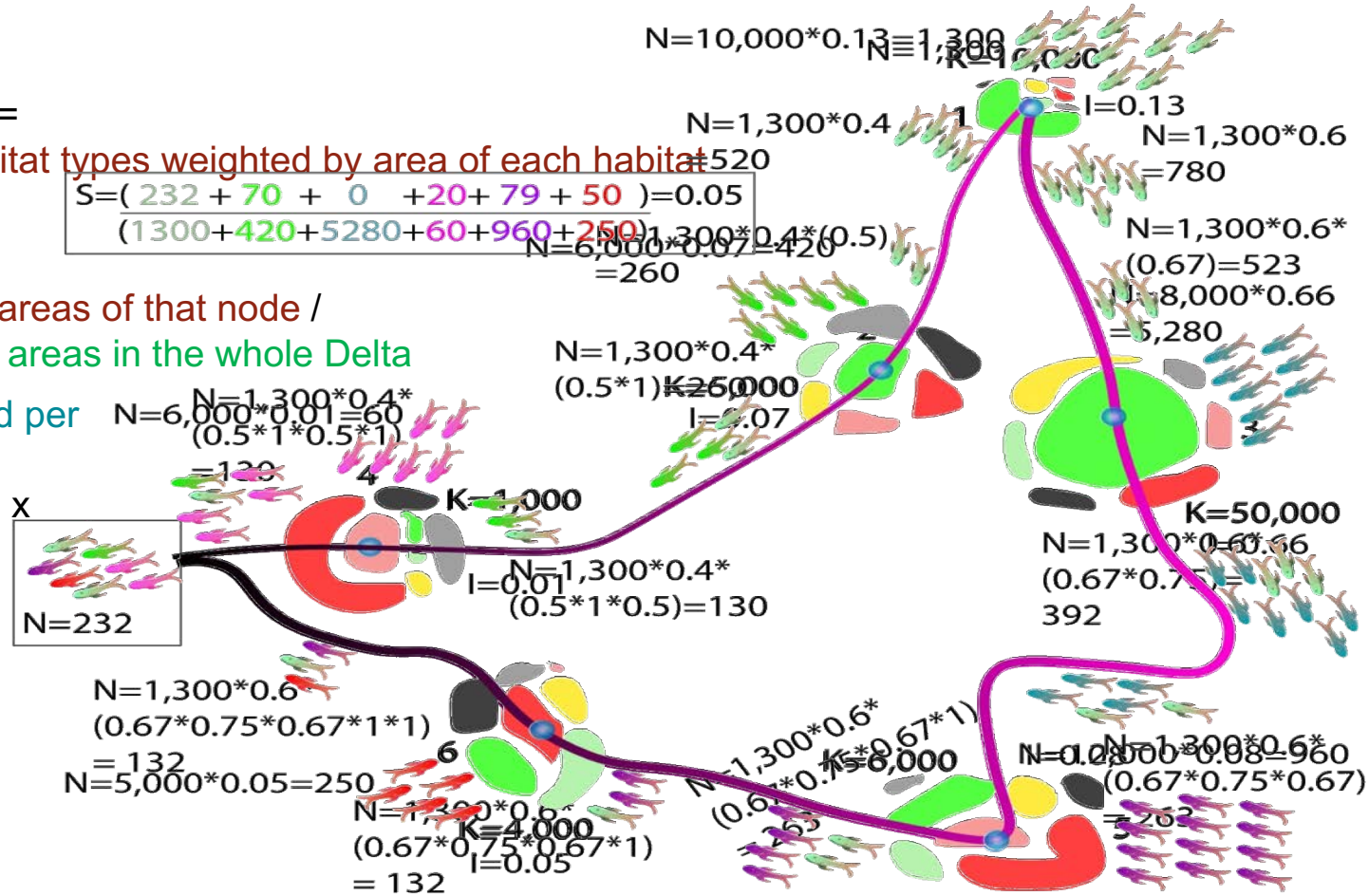
Total carrying capacity of a node =
Sum of carrying capacities of habitat types weighted by area of each habitat type at that node

$$S=\frac{(232+70+0+20+79+50)}{(1300+420+5280+60+960+250)}=0.05$$

Importance of each node =
Total carrying capacity of habitat areas of that node /
Total carrying capacity of habitat areas in the whole Delta

Scaled up number of fish released per node =
Number of fish released per node x importance of each node

Through Delta survival =
Average survival of fish released from each node weighted by scaled up number of fish released per node



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