Riverscape genetics defines population connectivity in Golden (*Tor putitora*) and Chocolate Mahseer (*Neolissochilus hexagonolepis*) (Cyprininae: Torini) in Bhutan

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Golden Mahseer in Bhutan:

What is known?

- Migrate (spawning?)
- Aggregate at tributaries
- Site-fidelity

Fish Migrations

Synchronized movements of thousands of fish

- Predictable
  - When
  - Where
- Hypotheses
  - Causes
  - Consequences

Fish Dispersal

Movement of individuals to new areas (populations)

= gene flow

= connectivity

- Opportunistic
  - Unpredictable
  - Environmental response
- Hypotheses

Fish Movements: How to Measure?

Telemetry

= Fish Migration

- Tracks individuals
- Predictable movements

Genetic Analyses

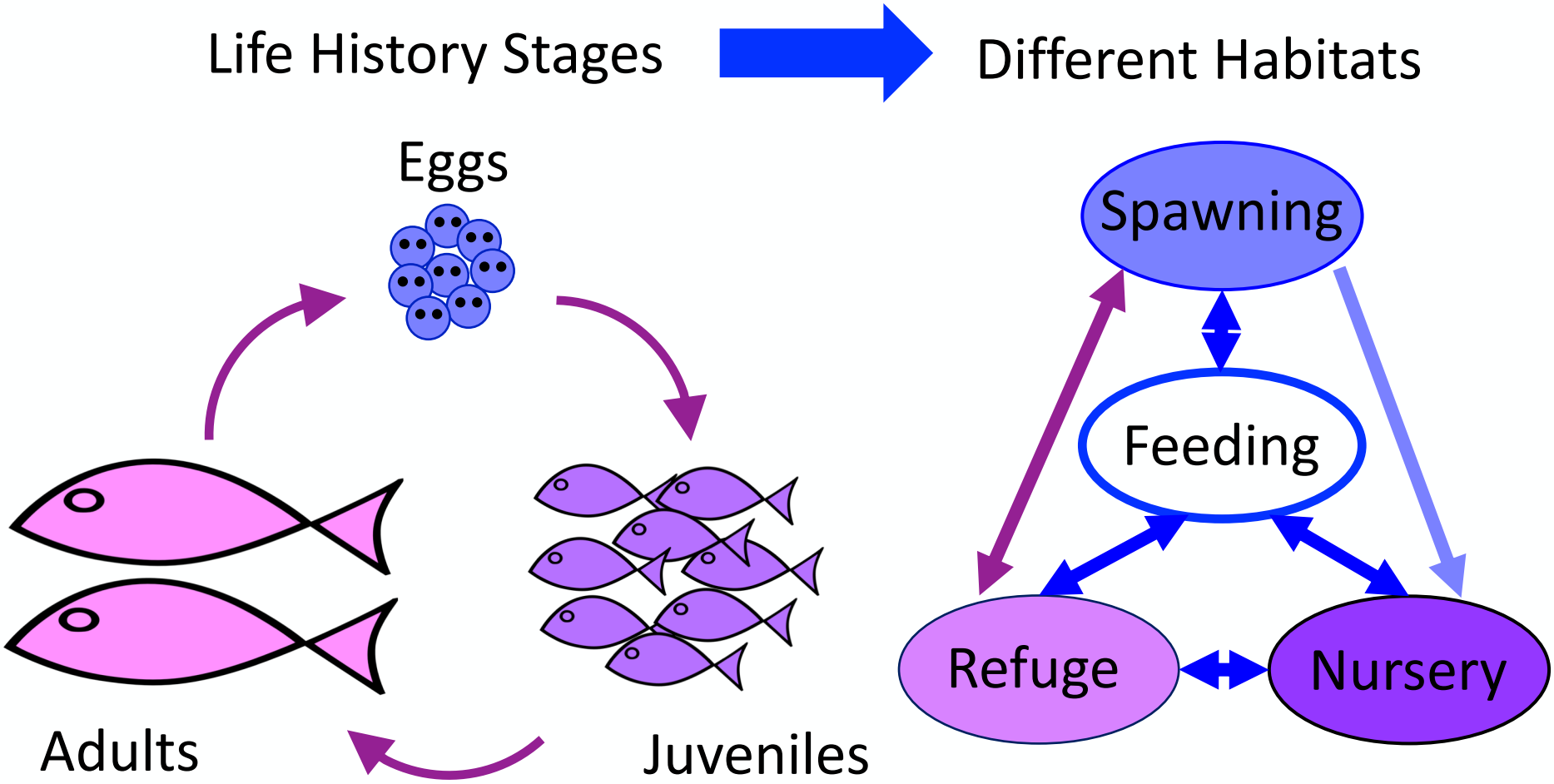
= Fish Dispersal + Migration

- Tracks populations
- Over many generations

Radio Tracking

DNA

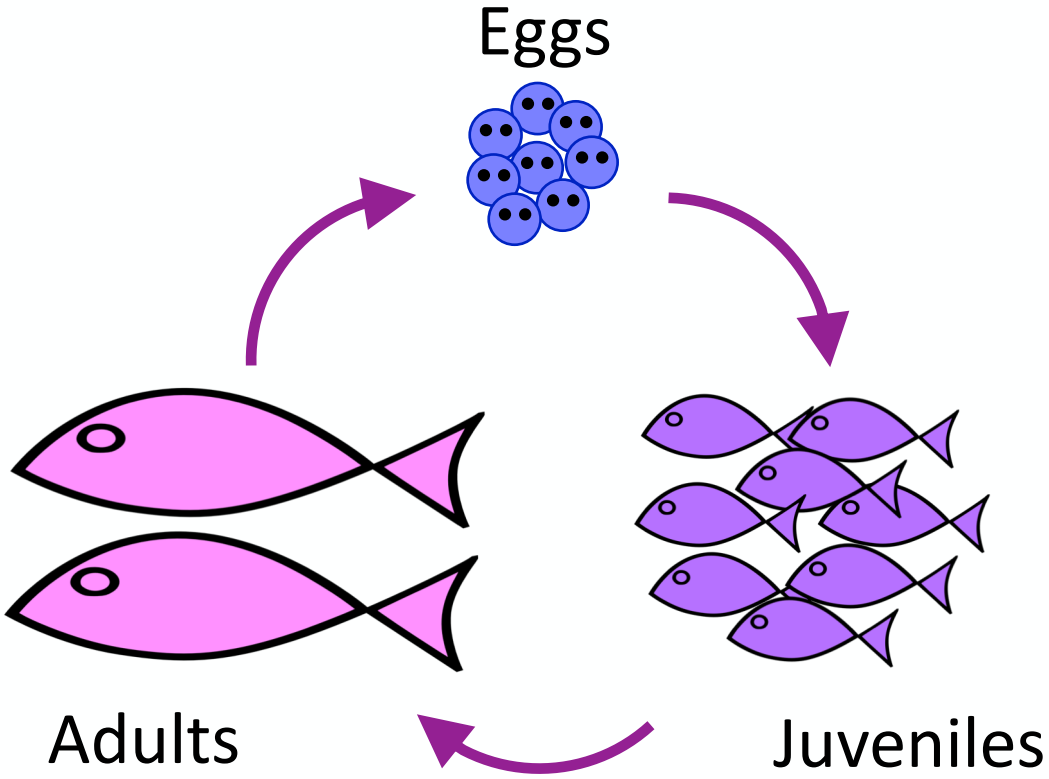
Fish Movements: Why is this Important?

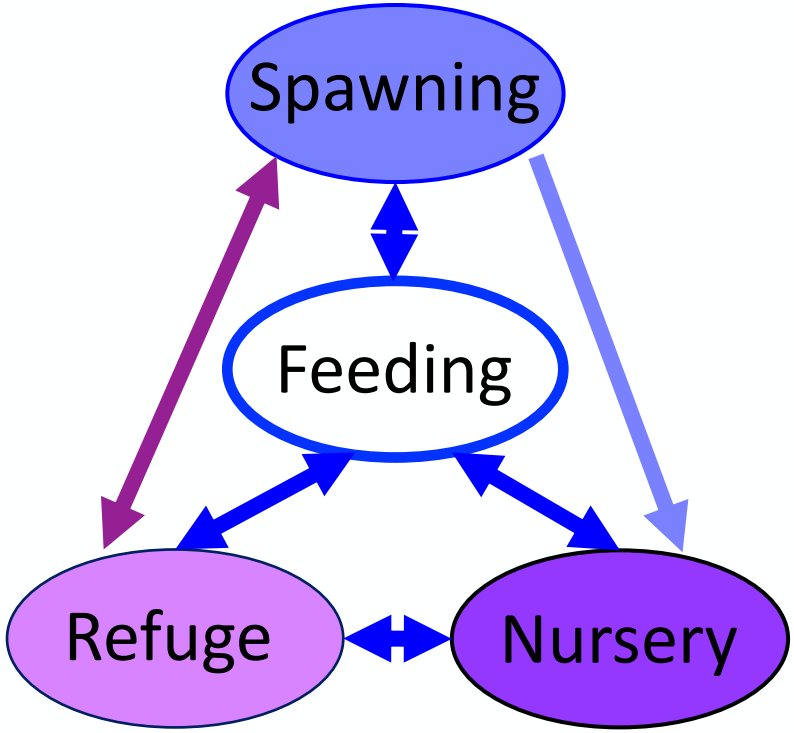


Fish Movements: Why is this Important?

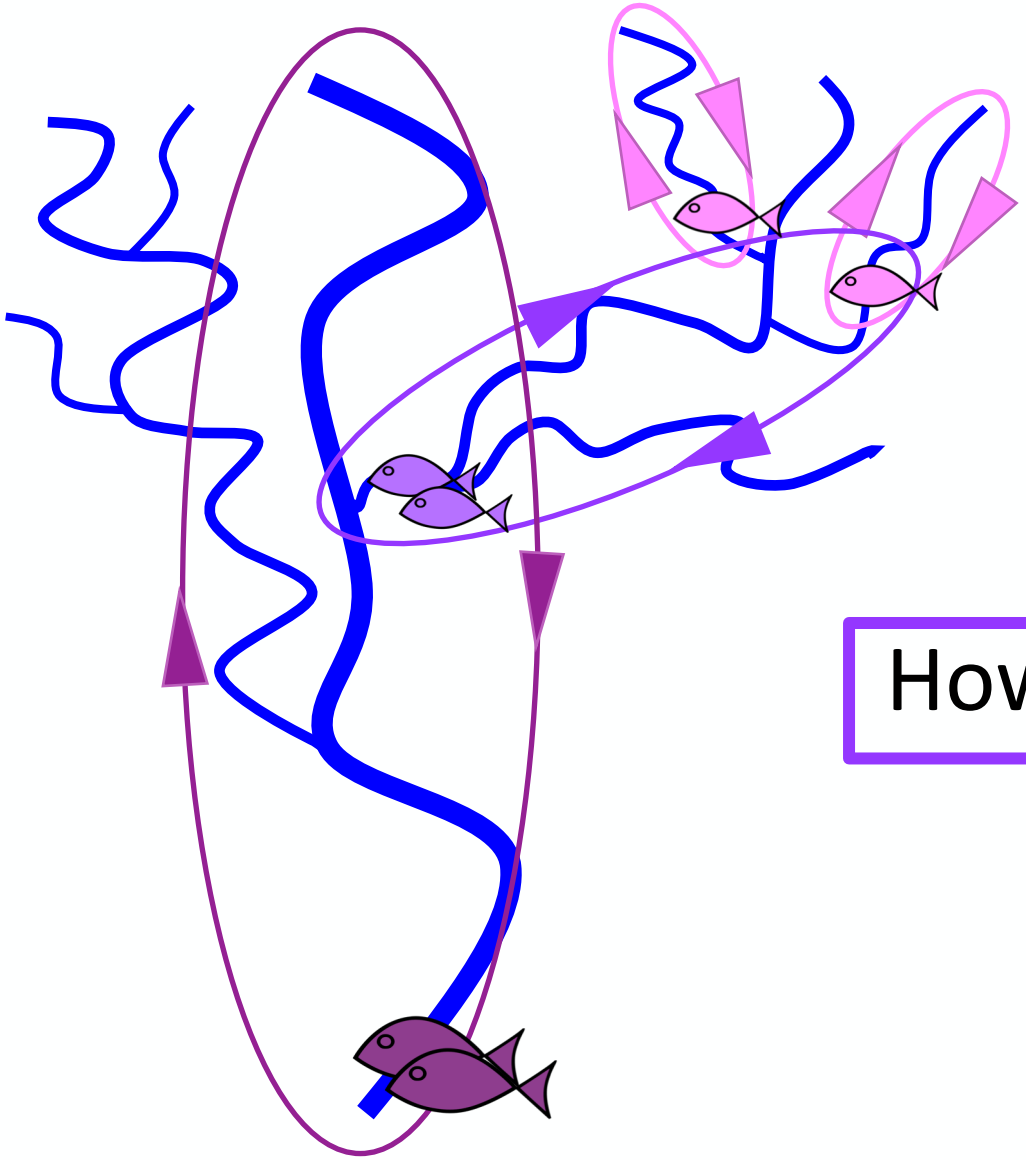
Life cycle requires all habitats + connectivity

Life History Stages → Different Habitats





Fish Movements: Habitat Connectivity



Need to know spatial extent

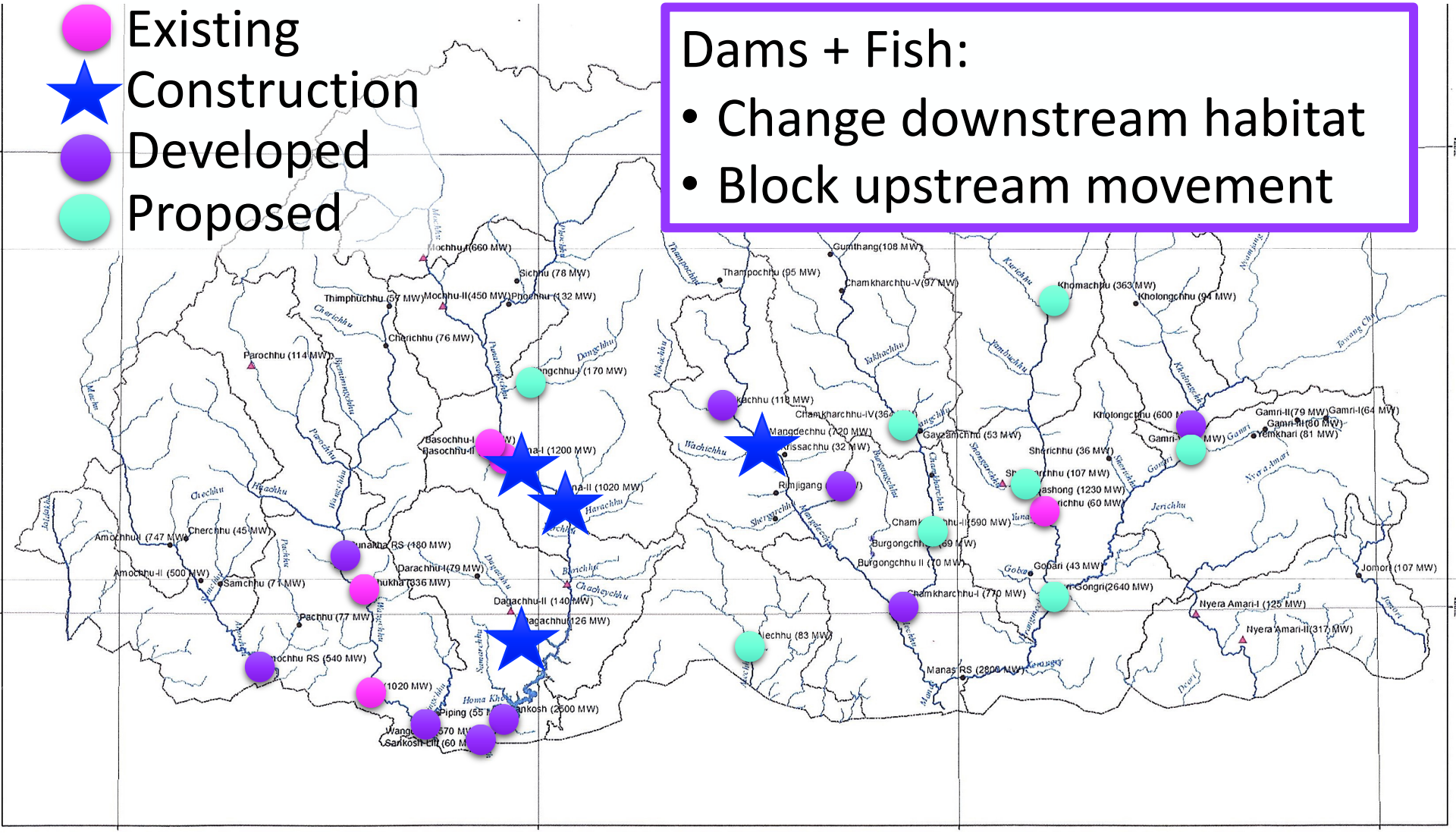
How far do fish move?

Bhutan: Hydropower Potential Sites (> 25 MW)

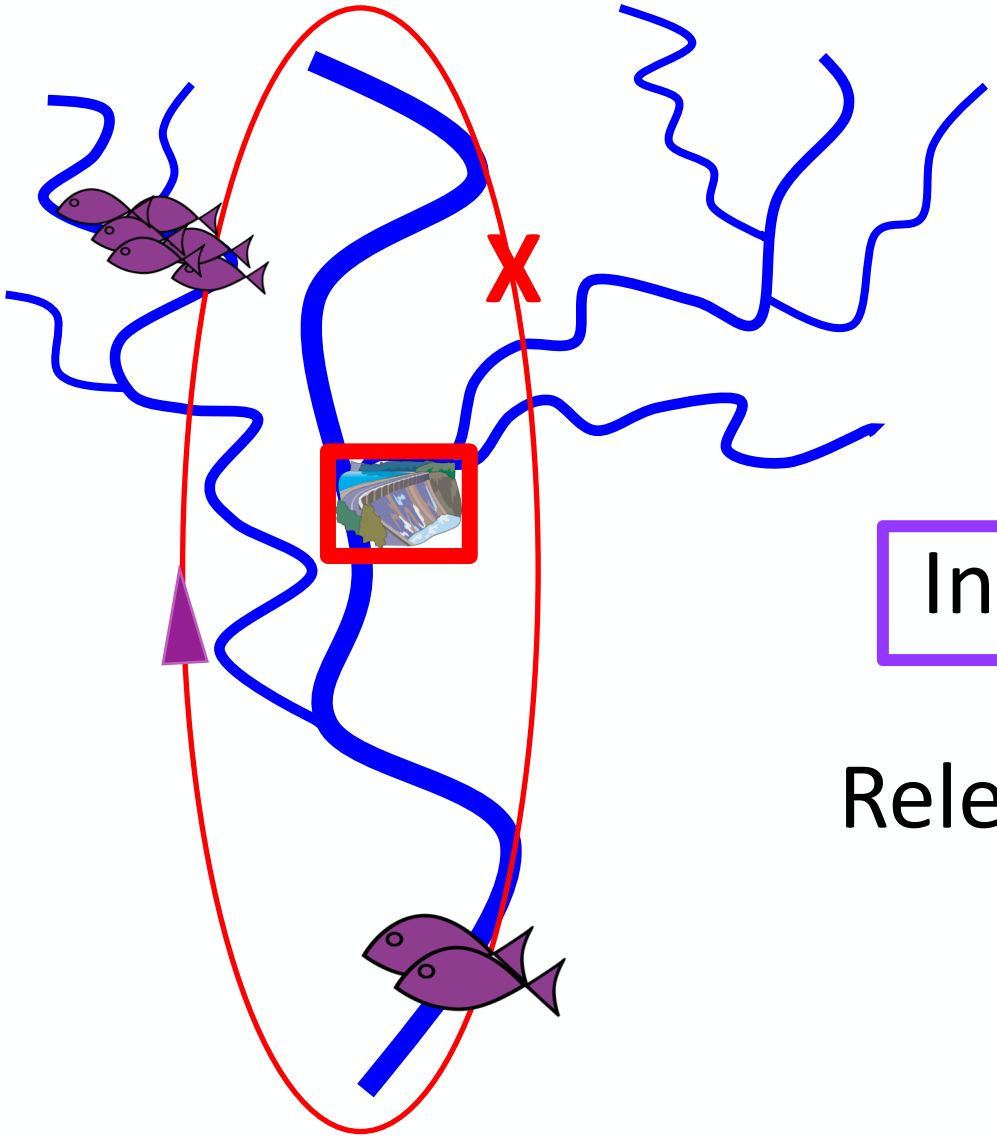
- Existing
- Construction
- Developed
- Proposed

Dams + Fish:

- Change downstream habitat
- Block upstream movement



Fish Movements: Habitat Connectivity

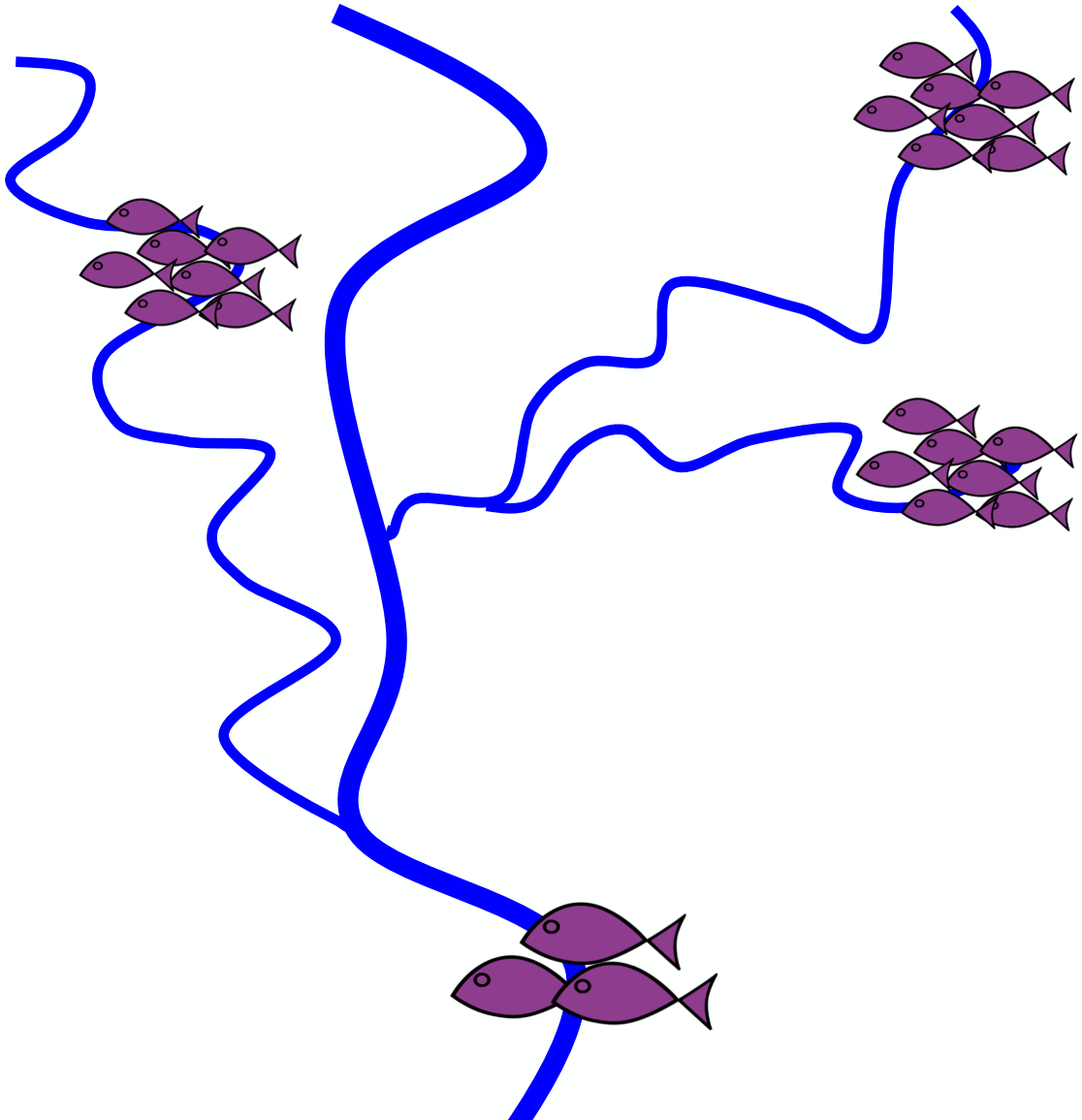


Need to know spatial extent

Inform Policy Decisions

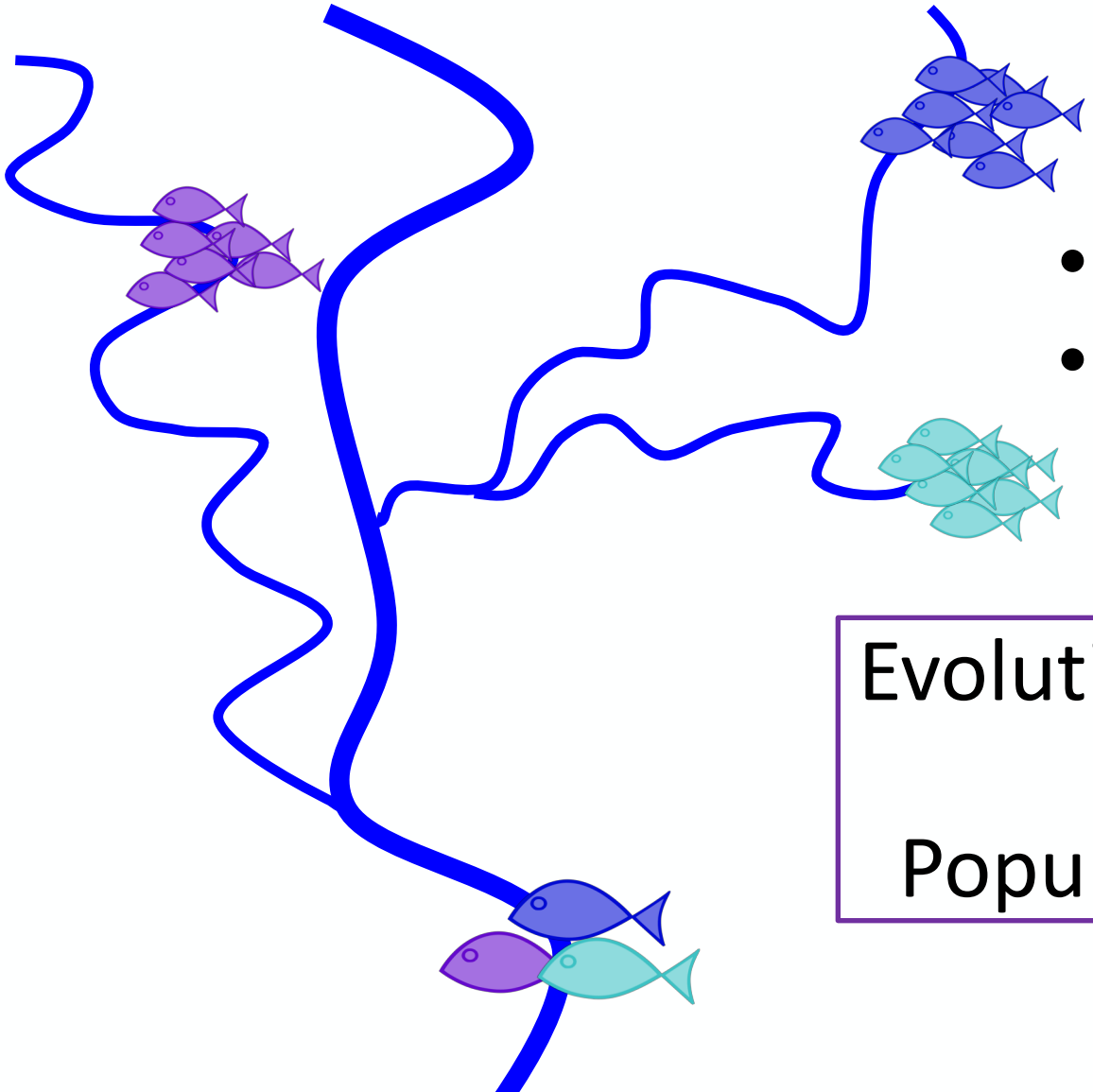
Relevant for conservation + management

Mahseer Movements: Site fidelity



Philopatry
Homing

Mahseer Philopatry: Genetic Stocks



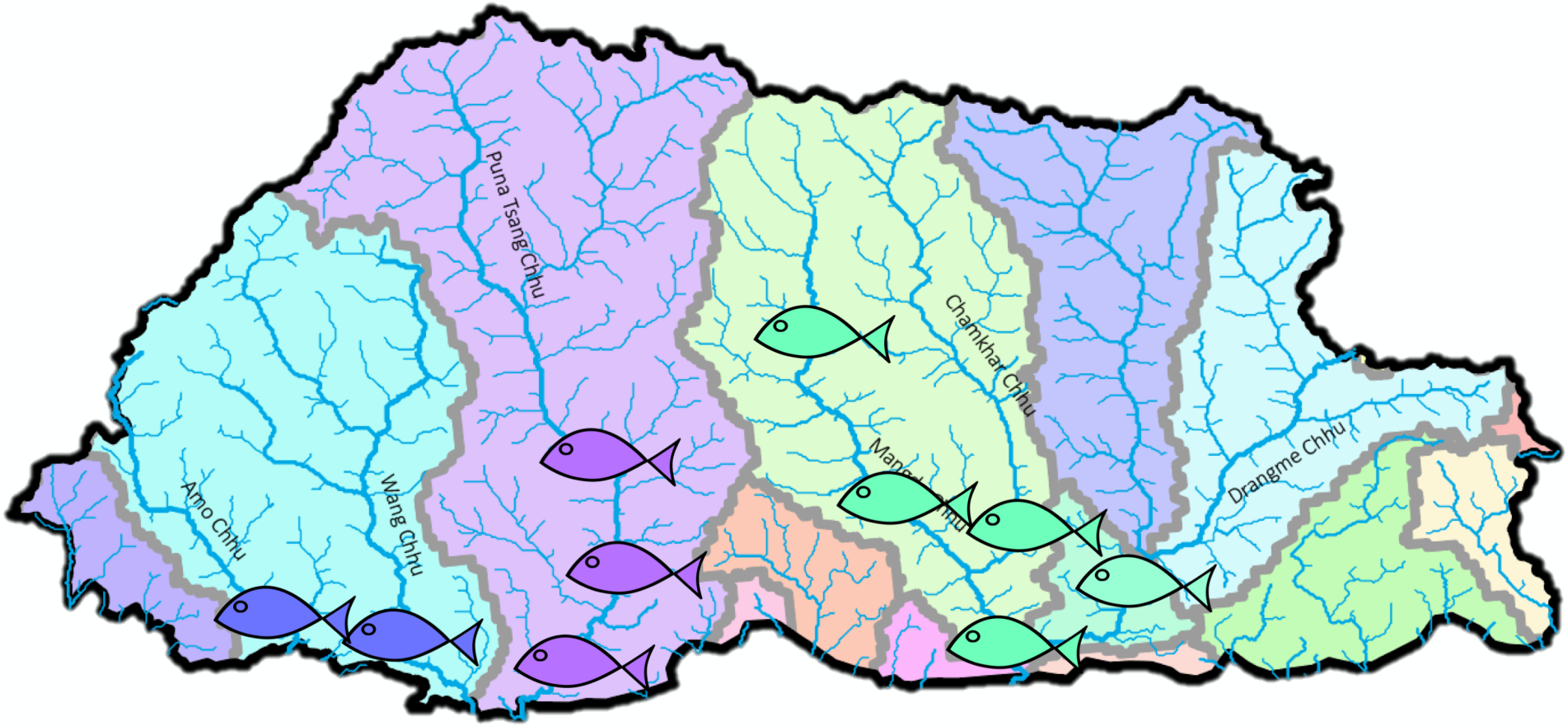
- Genetic drift
- Local adaptation

Evolutionary Processes

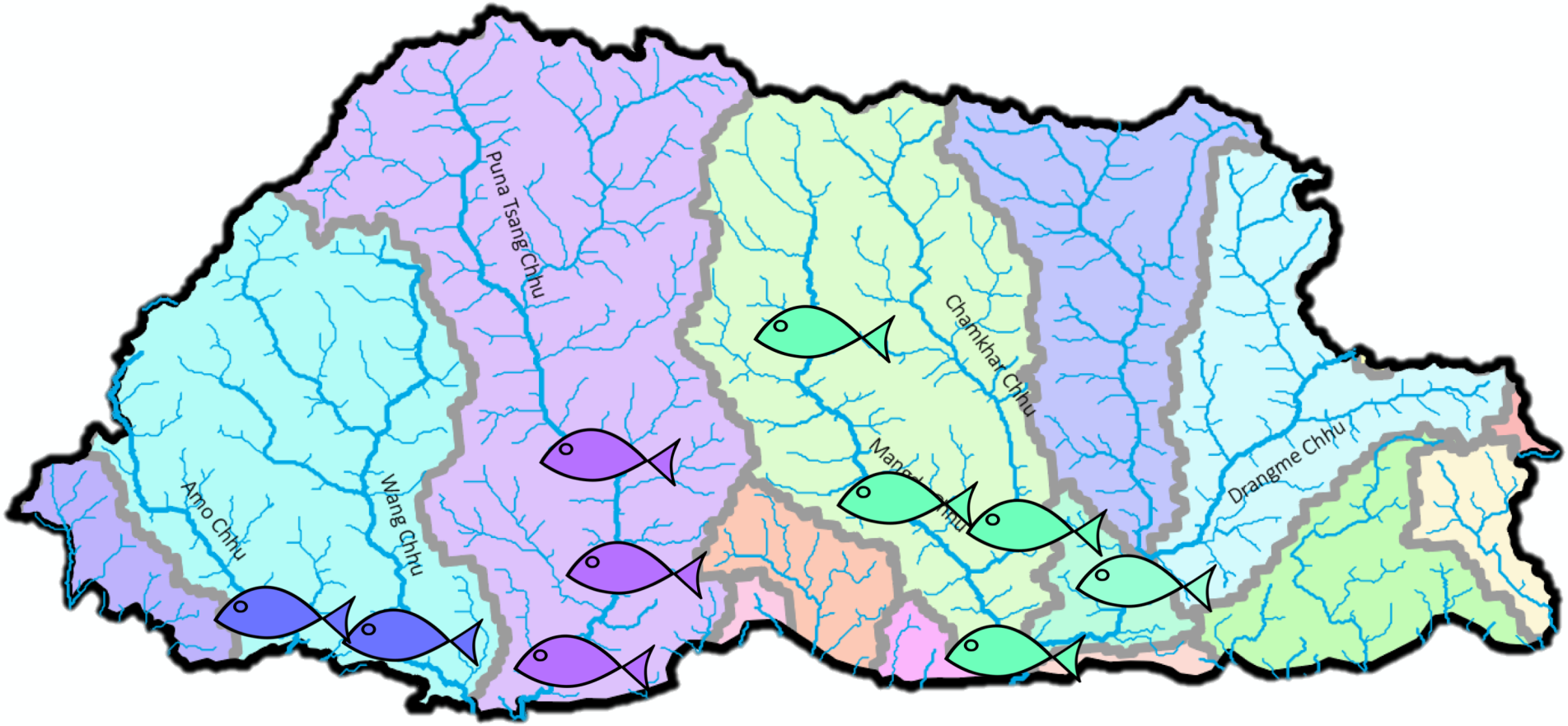
↓

Population Structure

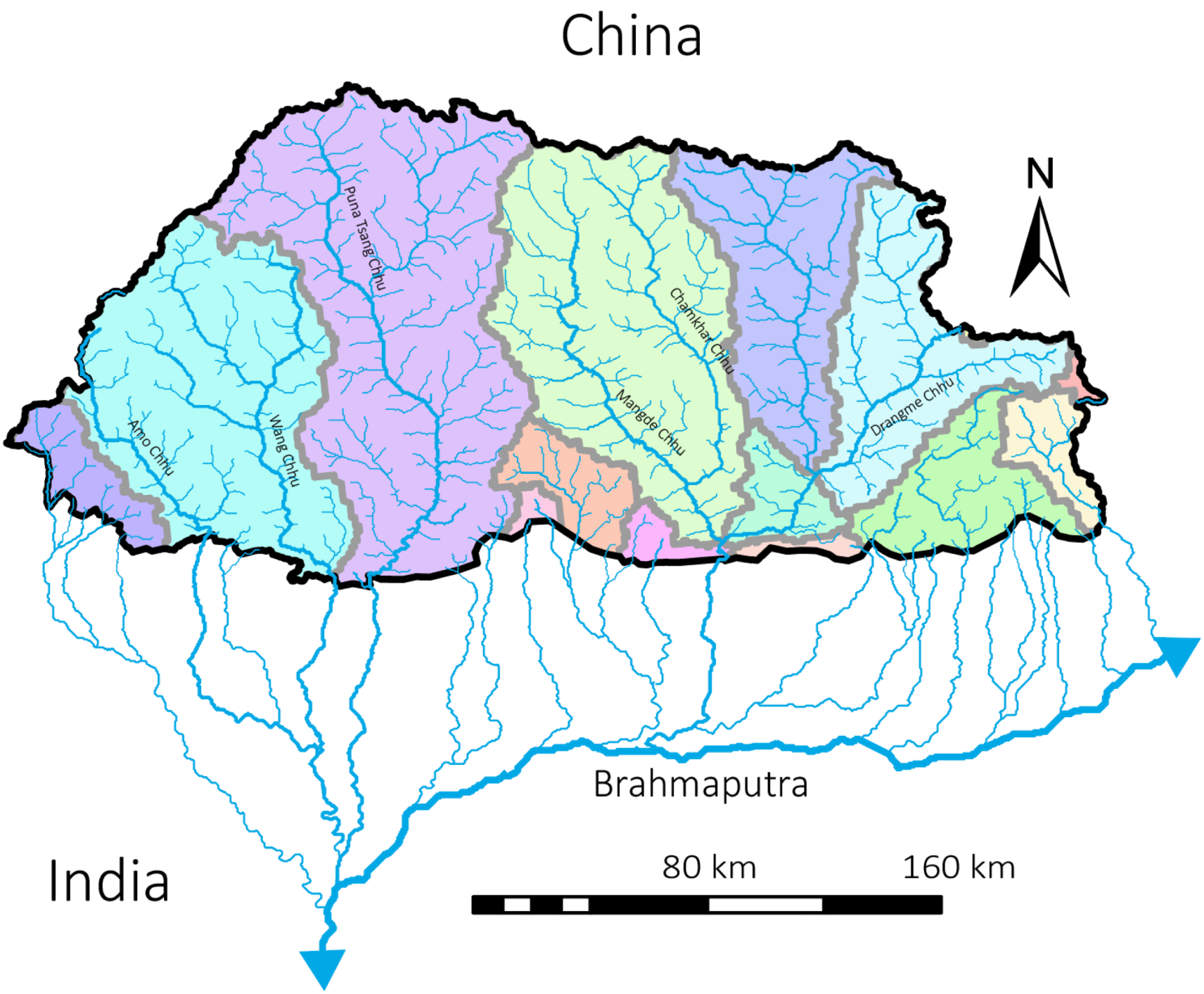
Mahseer in Bhutan: Genetic Stocks?



Mahseer in Bhutan: Population Connectivity?

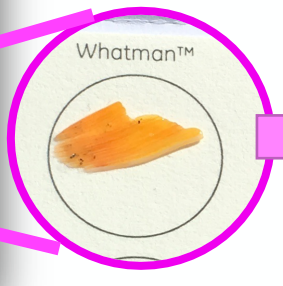


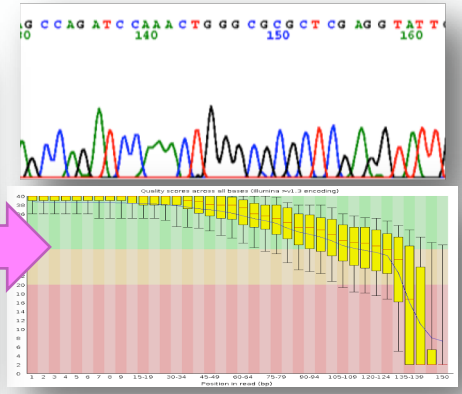
Evolutionary Processes = a very long time


China
N
Puna Tsang Chhu
Chamkhar Chhu
Mangde Chhu
Drangme Chhu
Amo Chhu
Wang Chhu
Brahmaputra
India
80 km
160 km

Genetic Approaches

- Sample fish
- Collect fin clips
- Extract DNA from fin clips
- Genotype each sample
- Analyze genetic variation

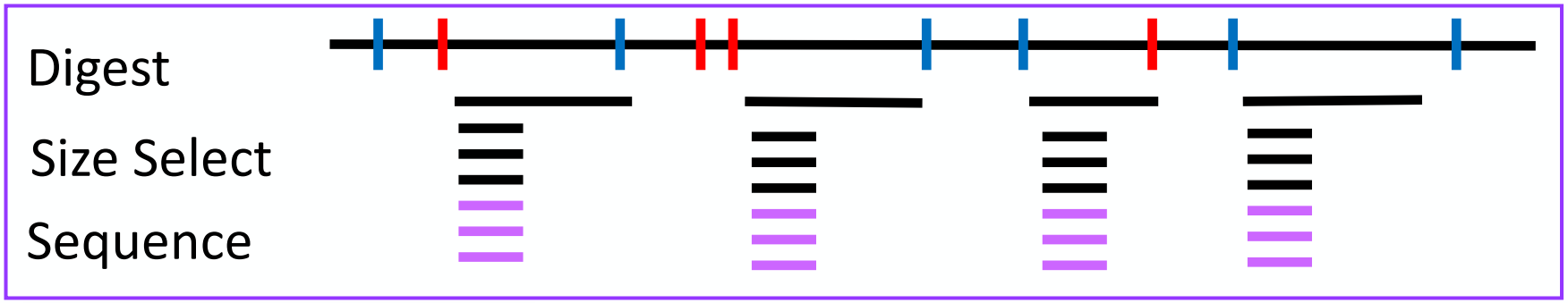


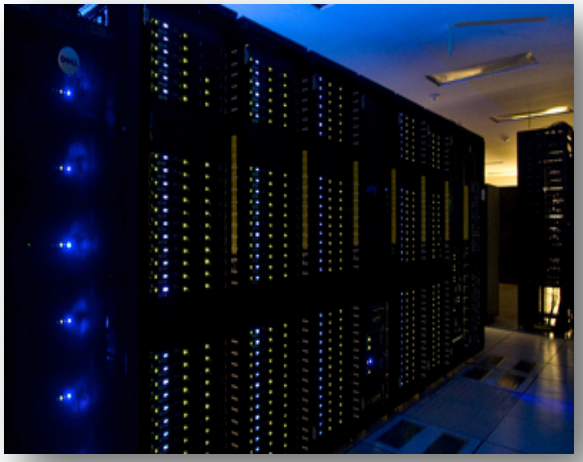


Methods: SNP Genotyping (ddRAD)

- SNPs: Single Nucleotide Polymorphism (variation)
- ddRAD: double-digest Restriction-site Associated DNA

→ reduced genomic representation





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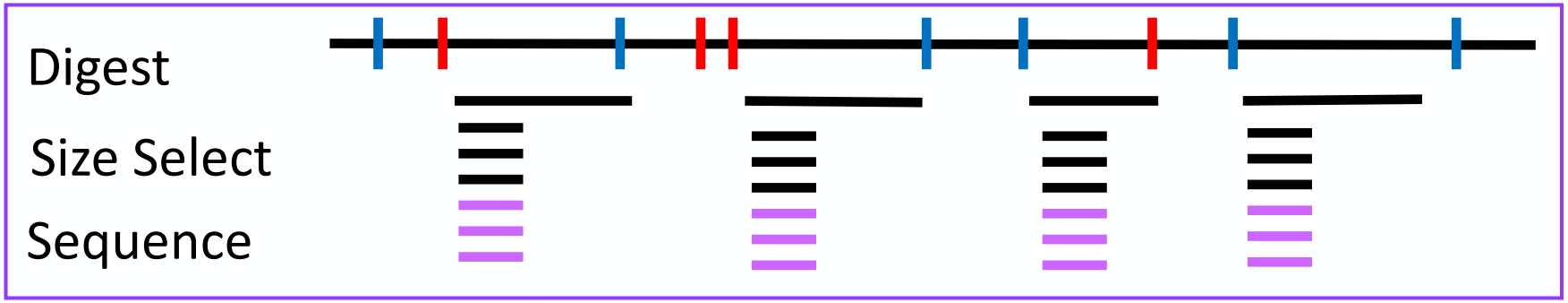
Arkansas High Performance Computing Center

Jetstream

Methods: SNP Genotyping (ddRAD)

- Thousands of loci, hundreds of individuals
- Subsampling genome consistently
- Massive amount of data > computationally demanding



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Jetstream

Golden Mahseer

Tor putitora

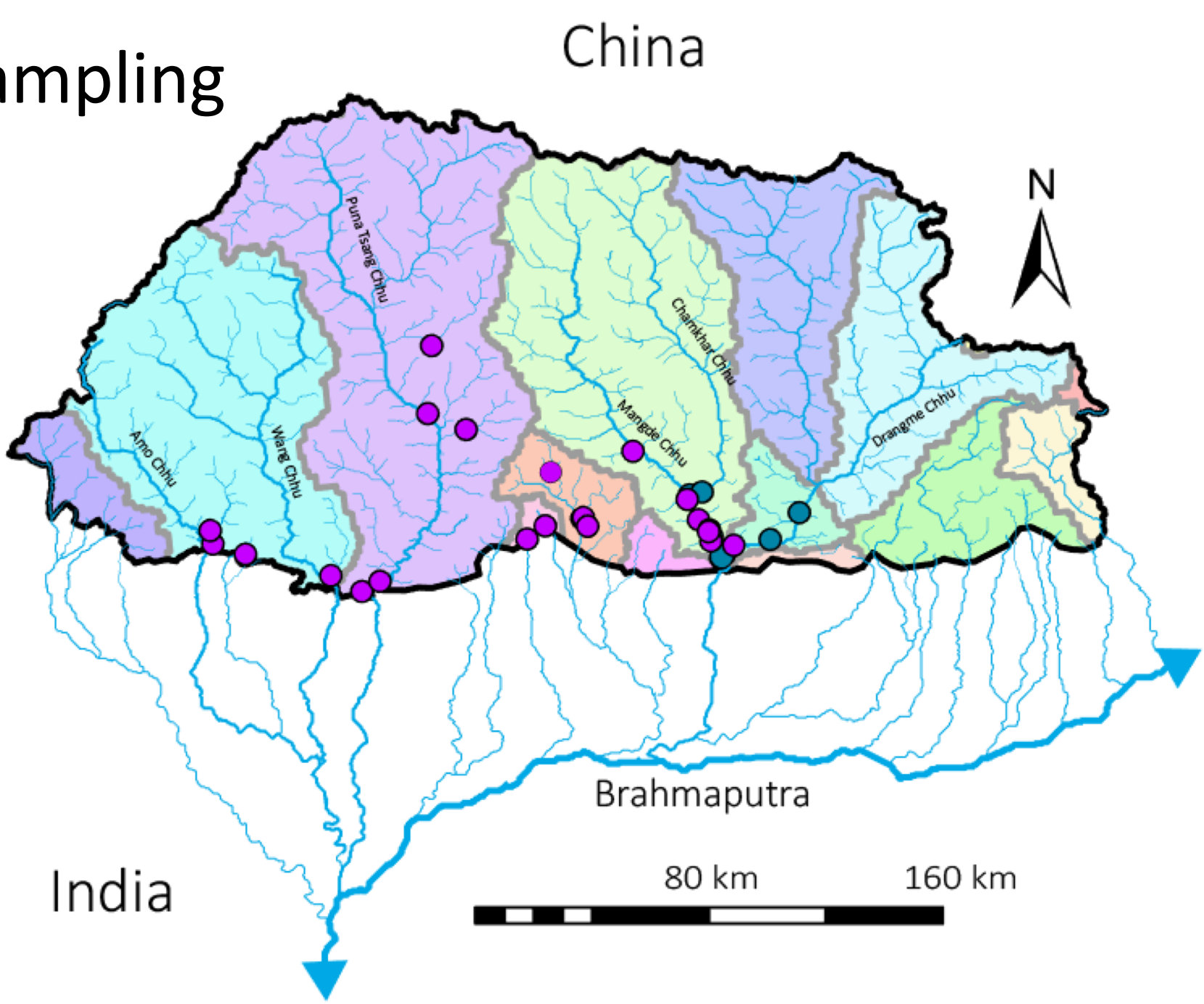
rare

Chocolate Mahseer

Neolissochilus hexagonolepis

common > surrogate

Sampling


China
N
Puna Tsang Chhu
Amo Chhu
Wang Chhu
Mangde Chhu
Chamkhar Chhu
Drangme Chhu
Brahmaputra
India
80 km
160 km

Genetic Data

Golden Mahseer

N = 37 individuals

Chocolate Mahseer

N = 144 individuals

Data: ~22,400 loci

- 2,241,478 total nucleotides
- 123,662 polymorphic
- 80,114 parsimony informative

A lot of data

Single-gene Sanger sequencing

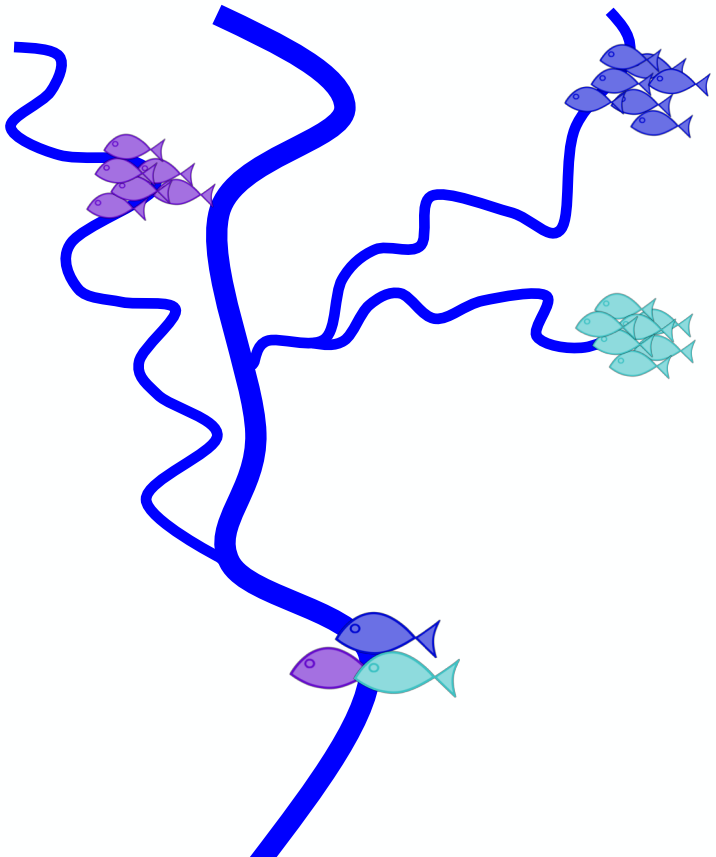
- 1-4 loci
- 1,000-6,000 nucleotides

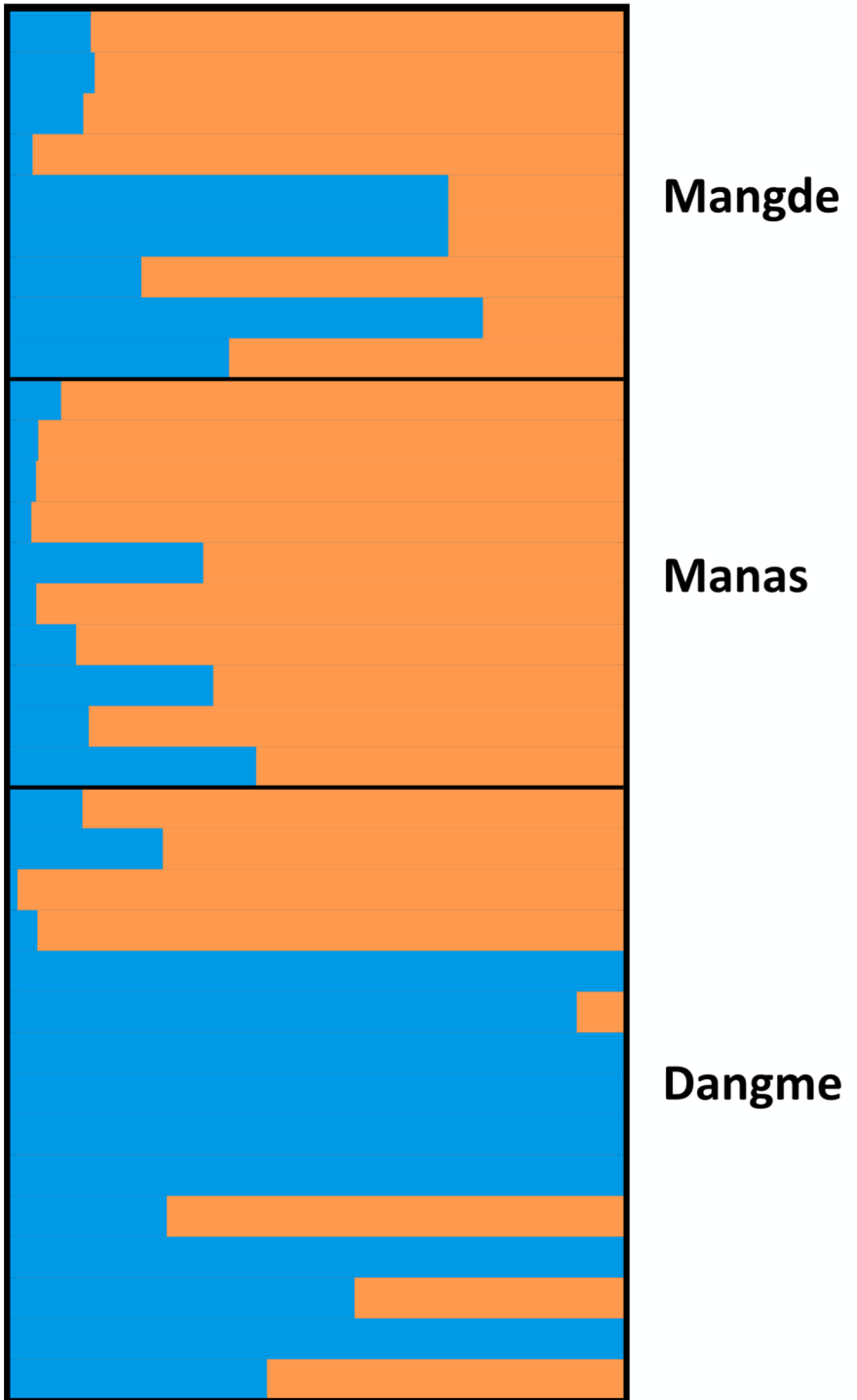
Variation among individuals requires large sample sizes to statistically infer patterns

How many genetically distinct populations?

= Gene pools

Bayesian Assignment Test

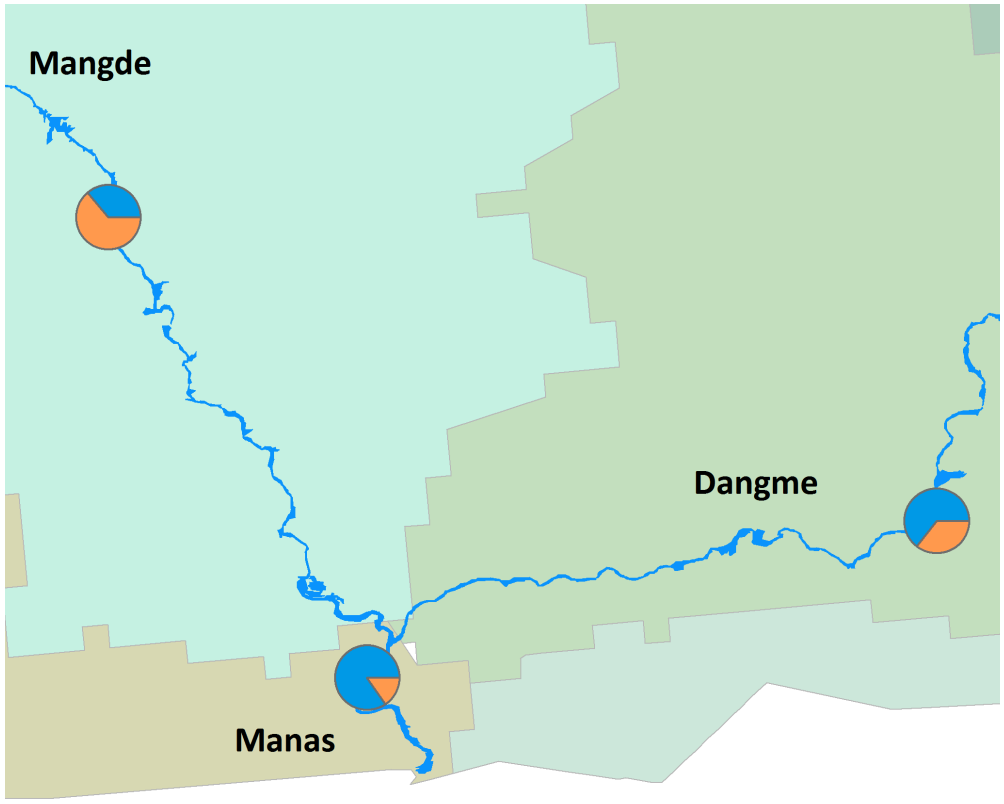


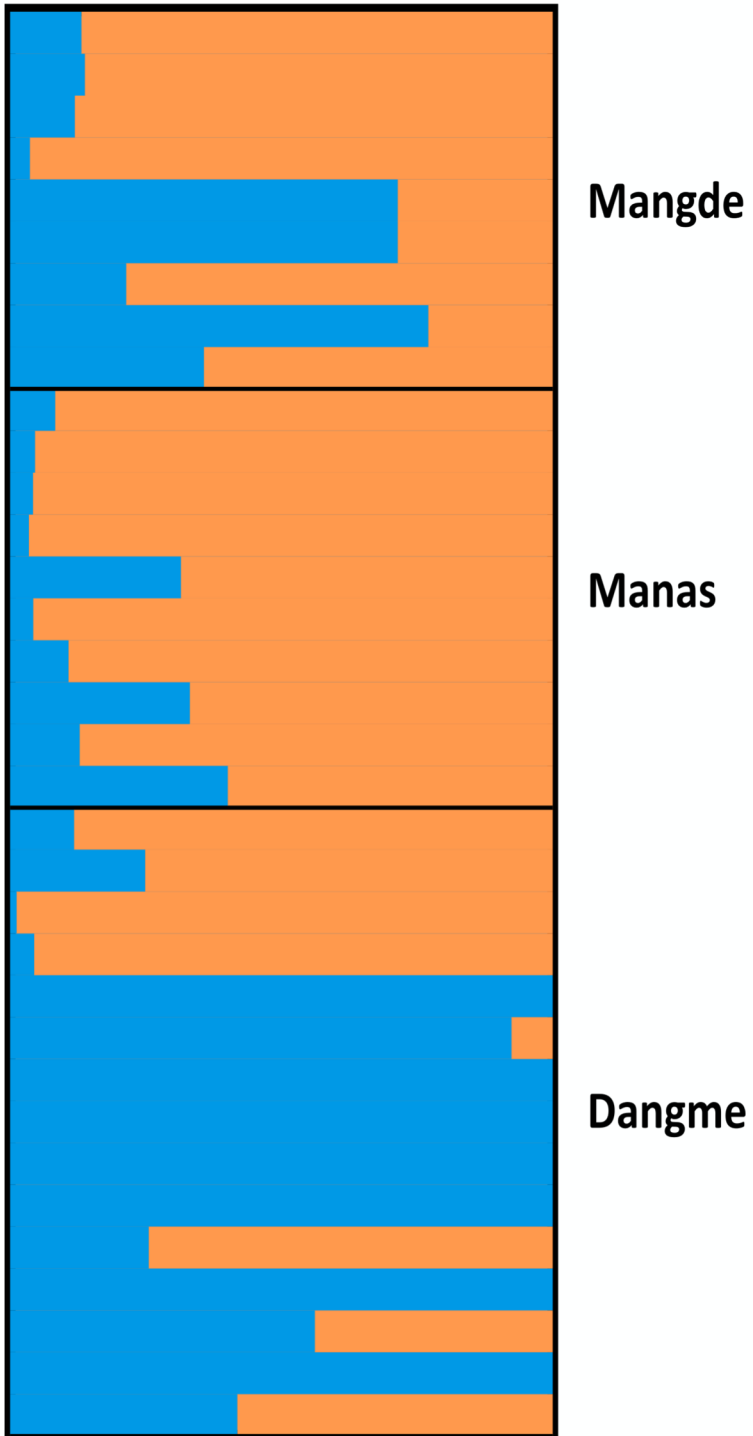


Golden Mahseer

= 2 populations

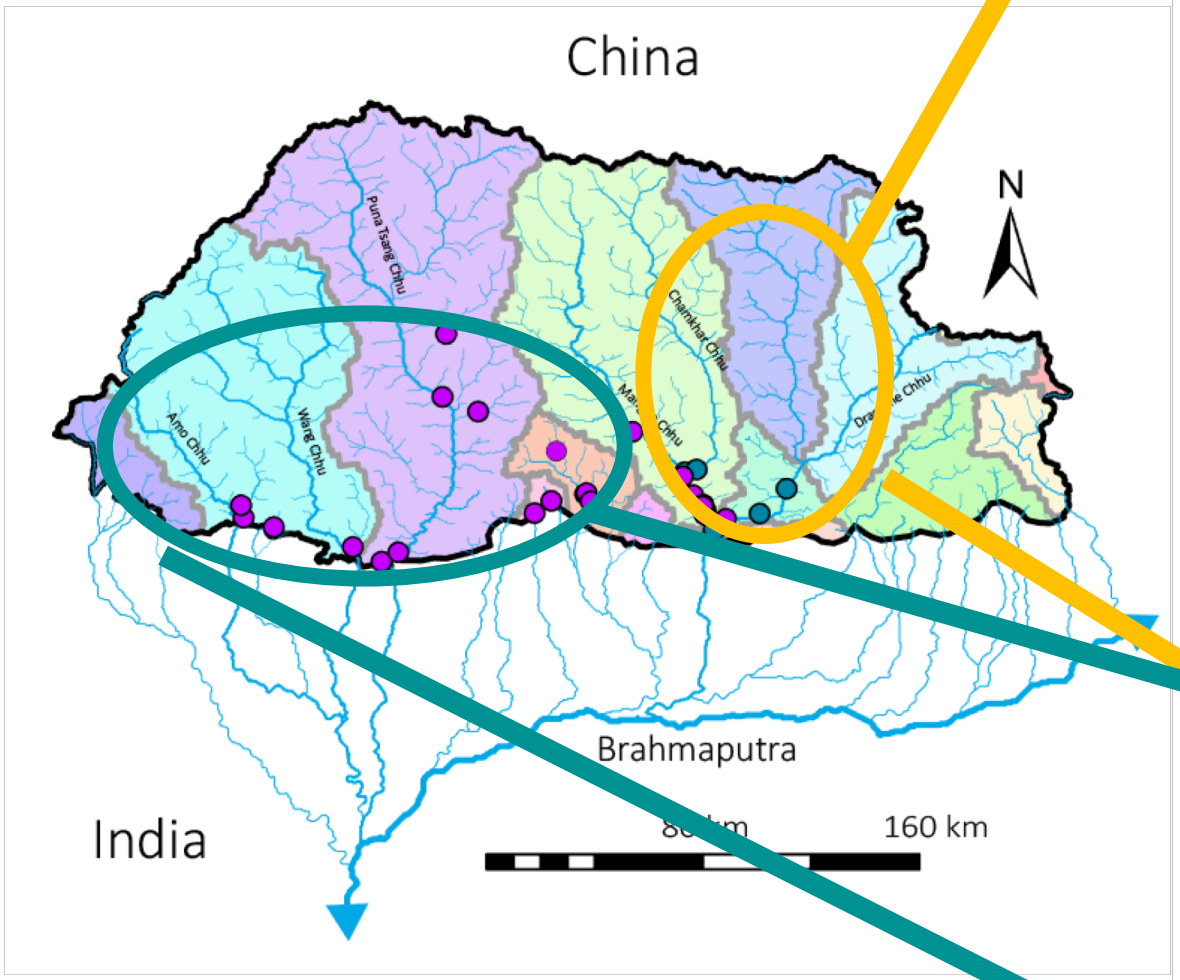
- related individuals
- ~1st cousin to half-sibling relationship

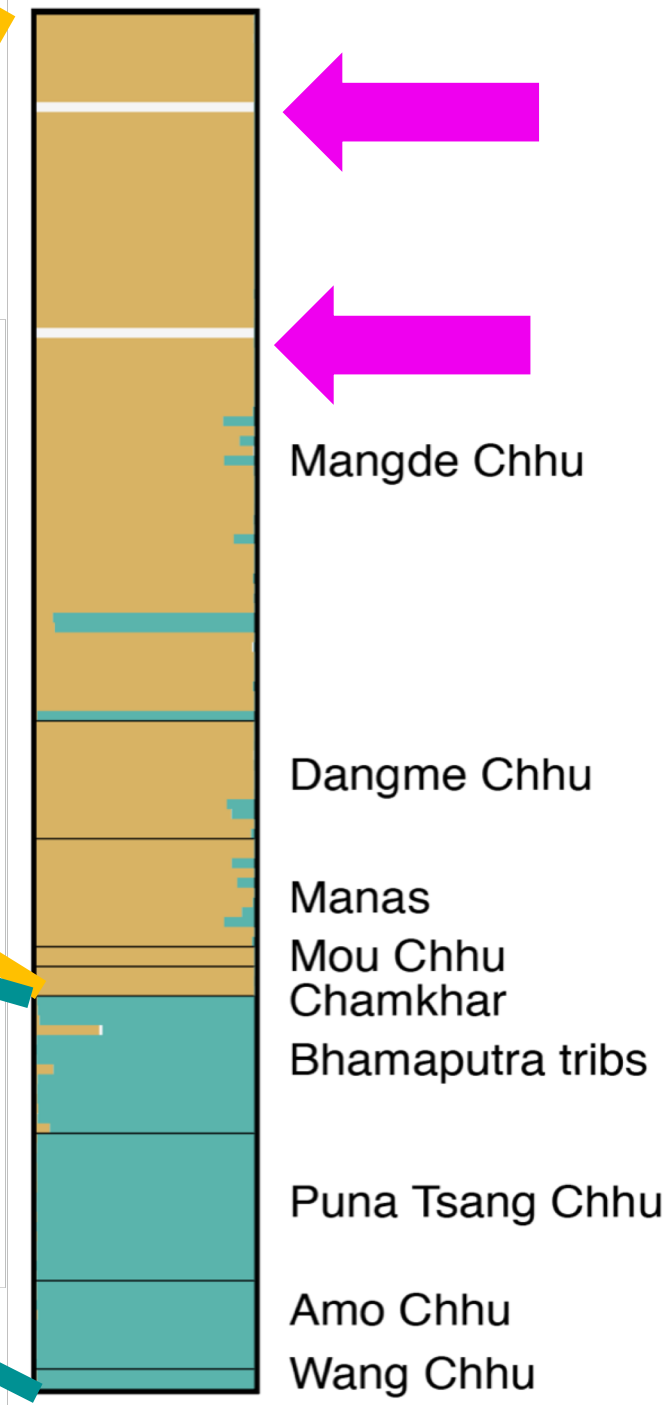




Chocolate Mahseer

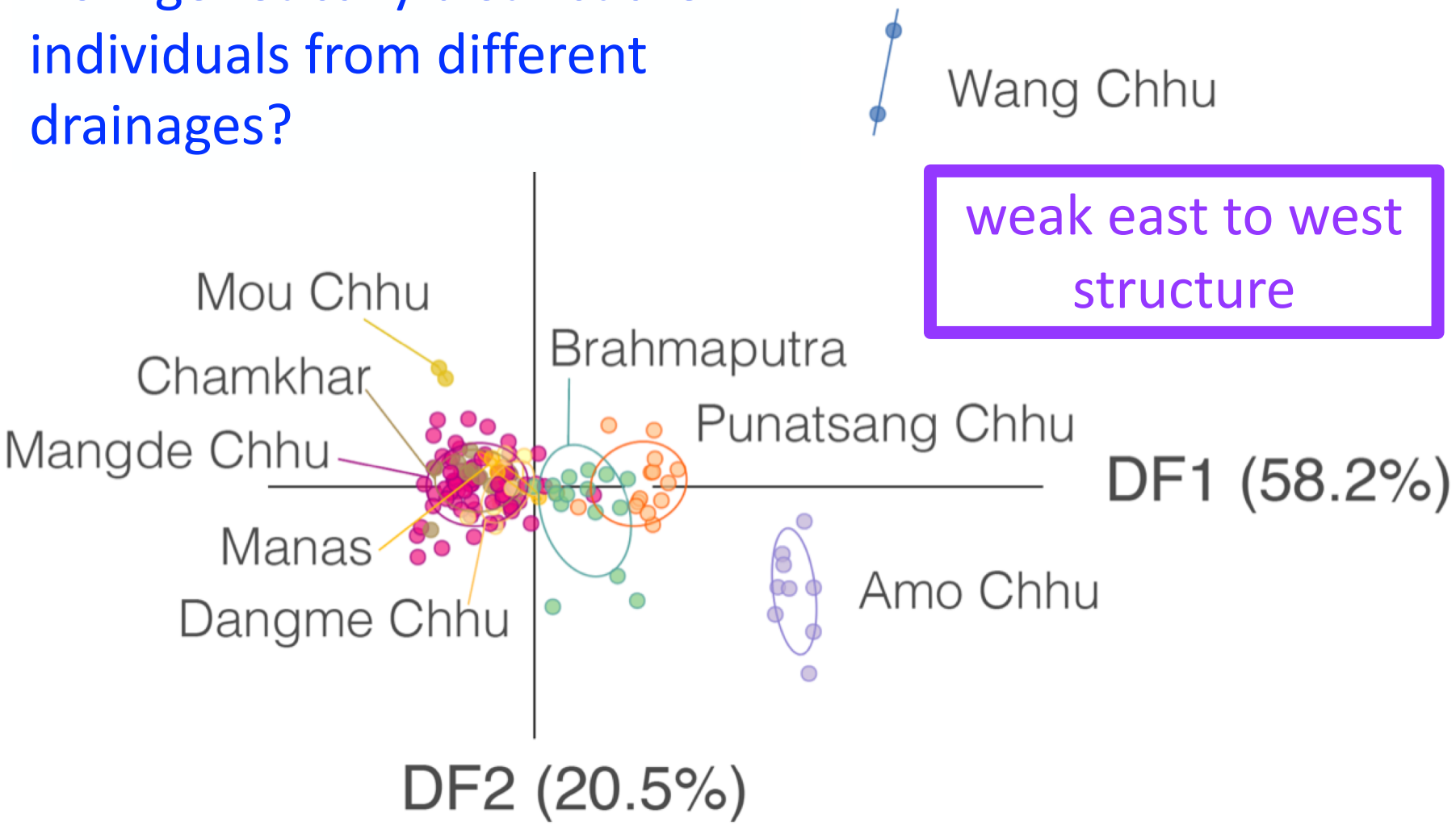
= 3 populations





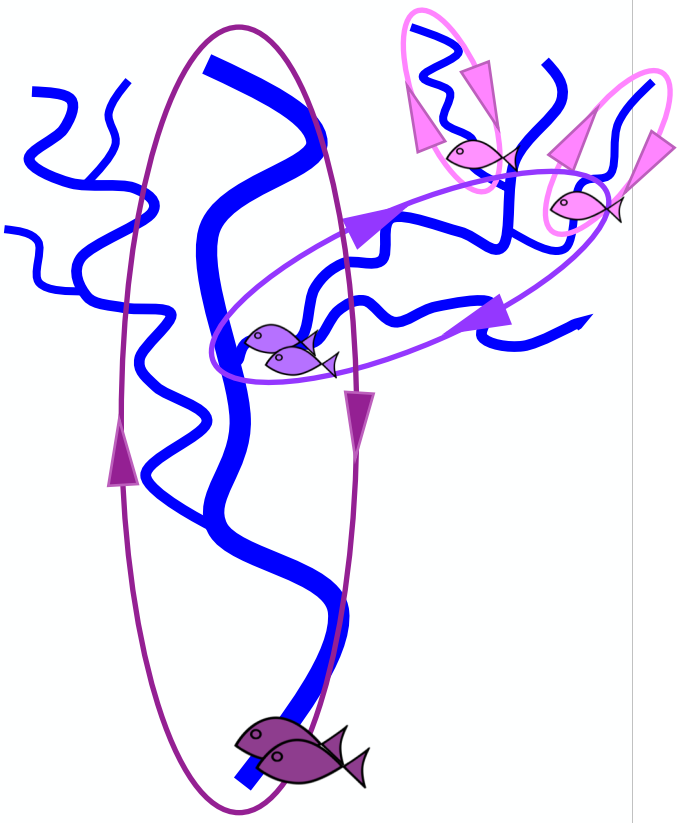
Chocolate Mahseer: DAPC

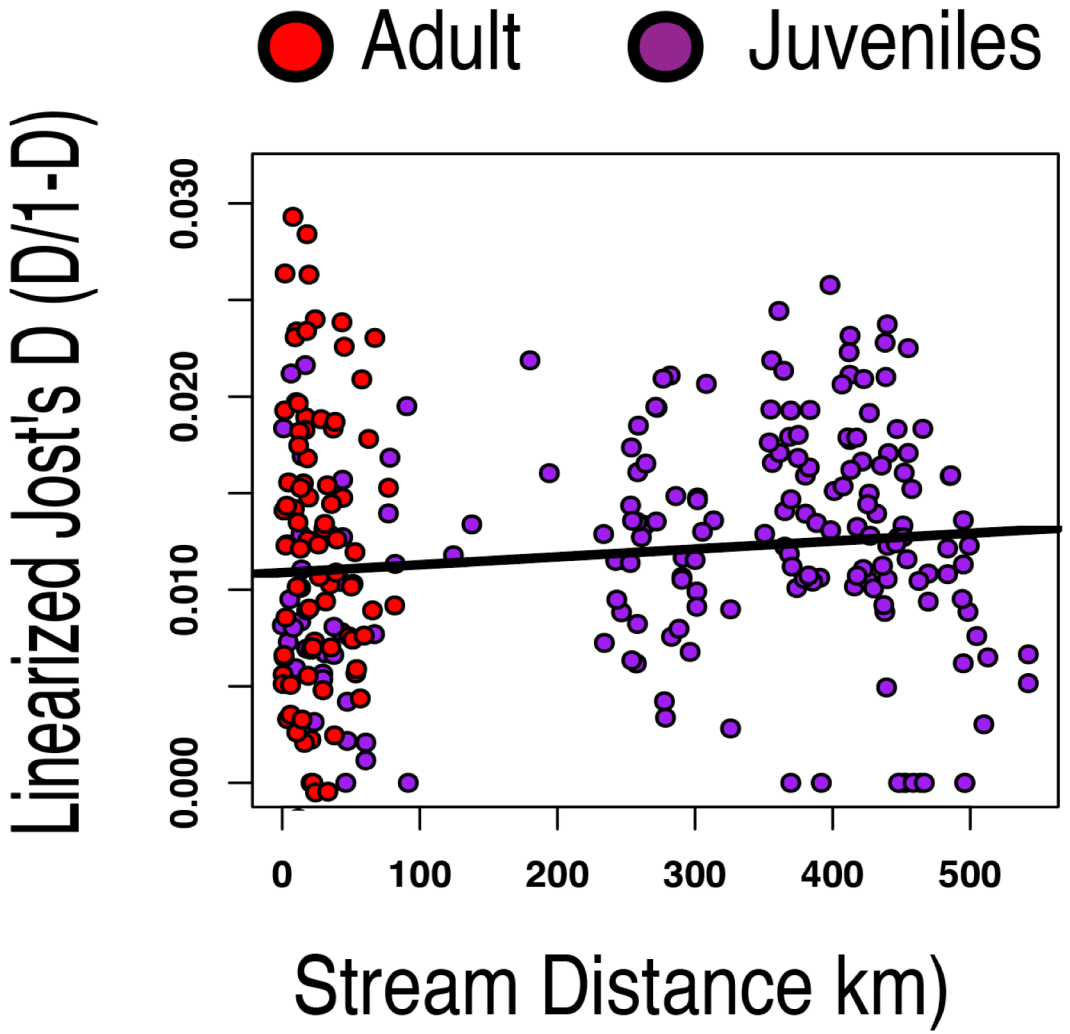
How genetically distinct are individuals from different drainages?



Chocolate Mahseer: Isolation by Distance

Does geographic distance influence connectivity?





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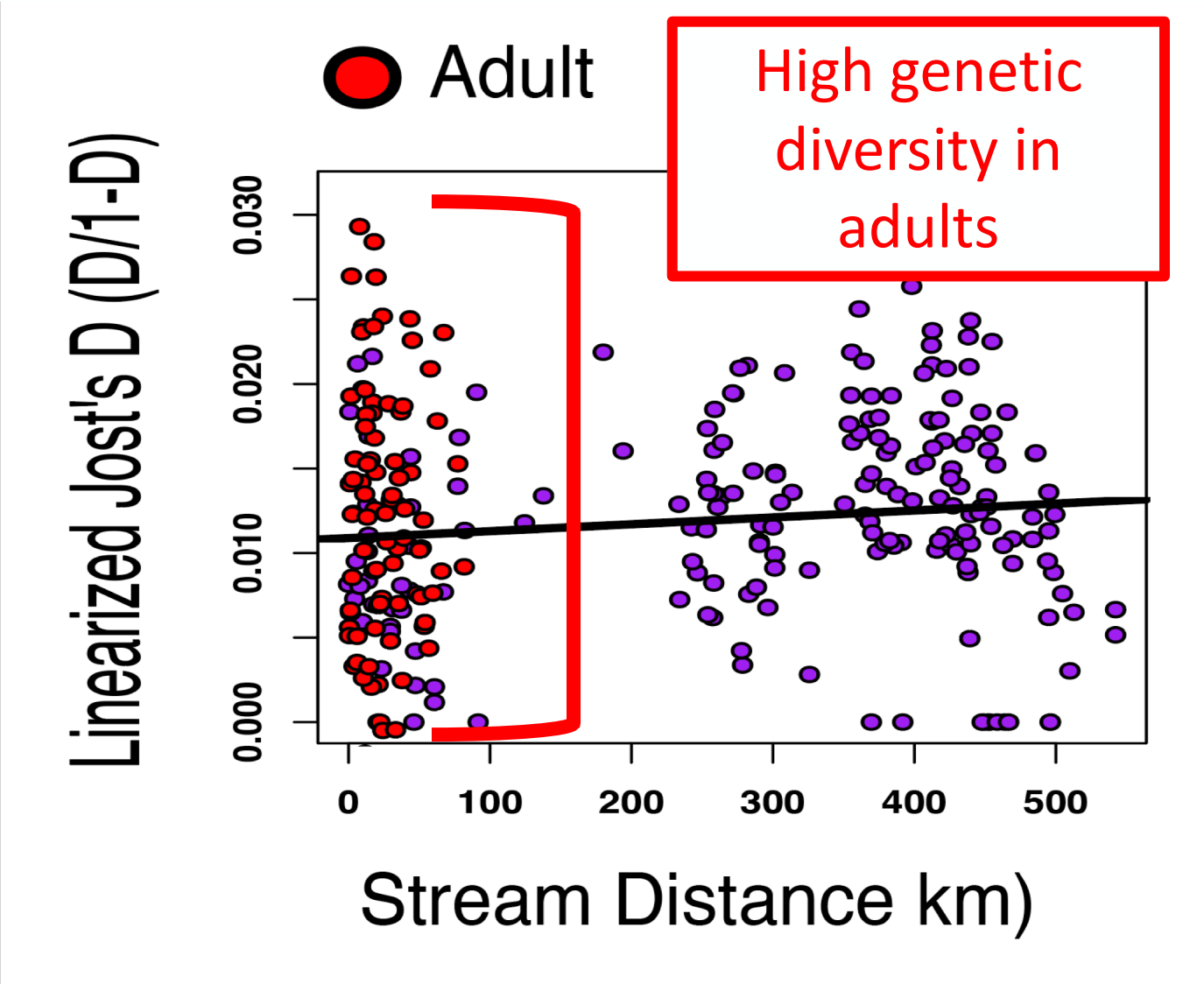

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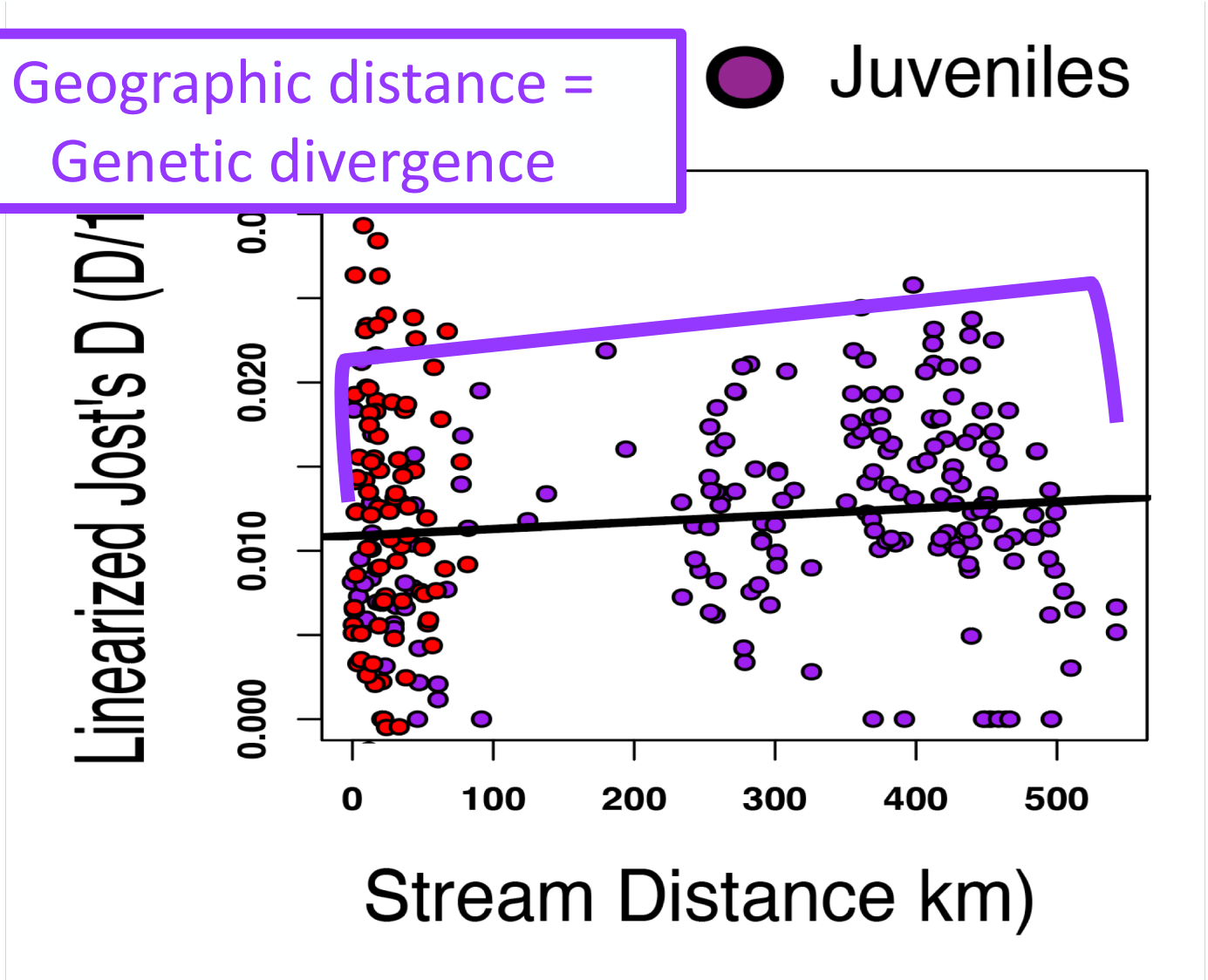
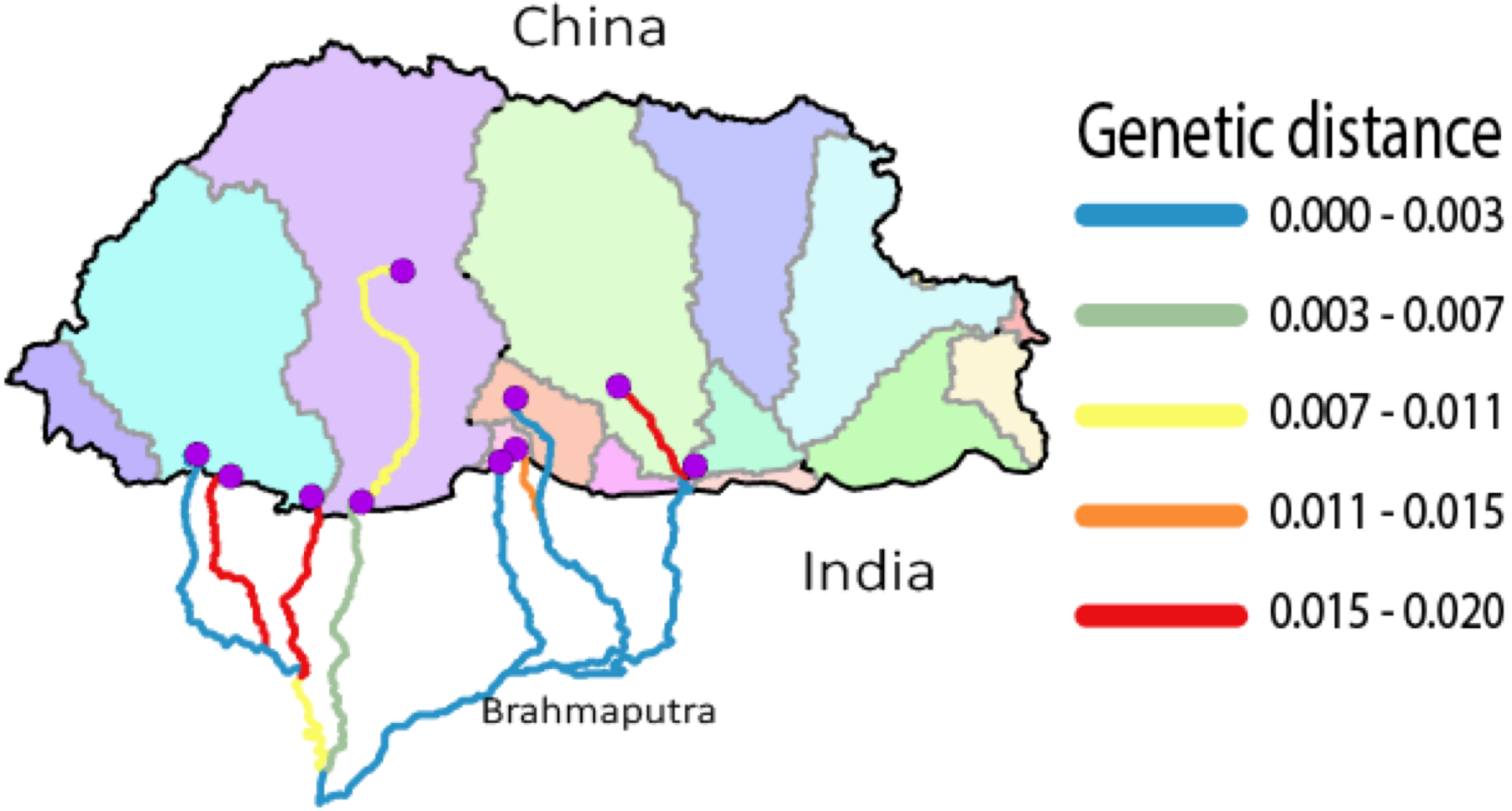


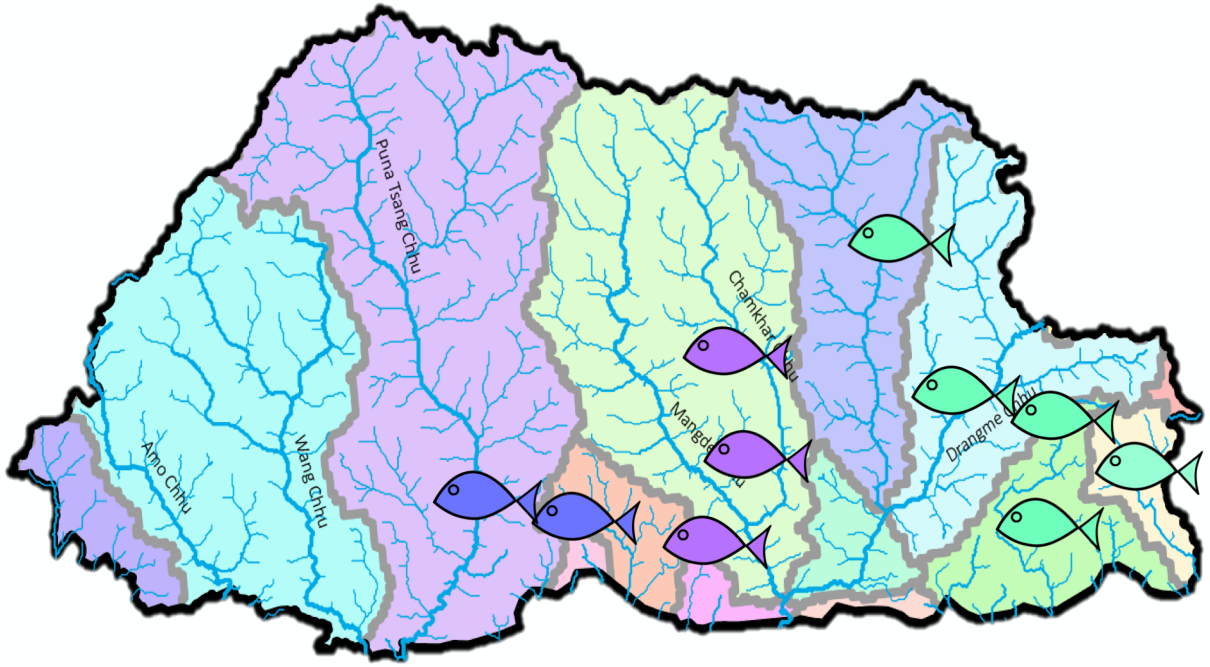
Chocolate Mahseer: StreamTree Analysis

Do landscape features influence population connectivity?



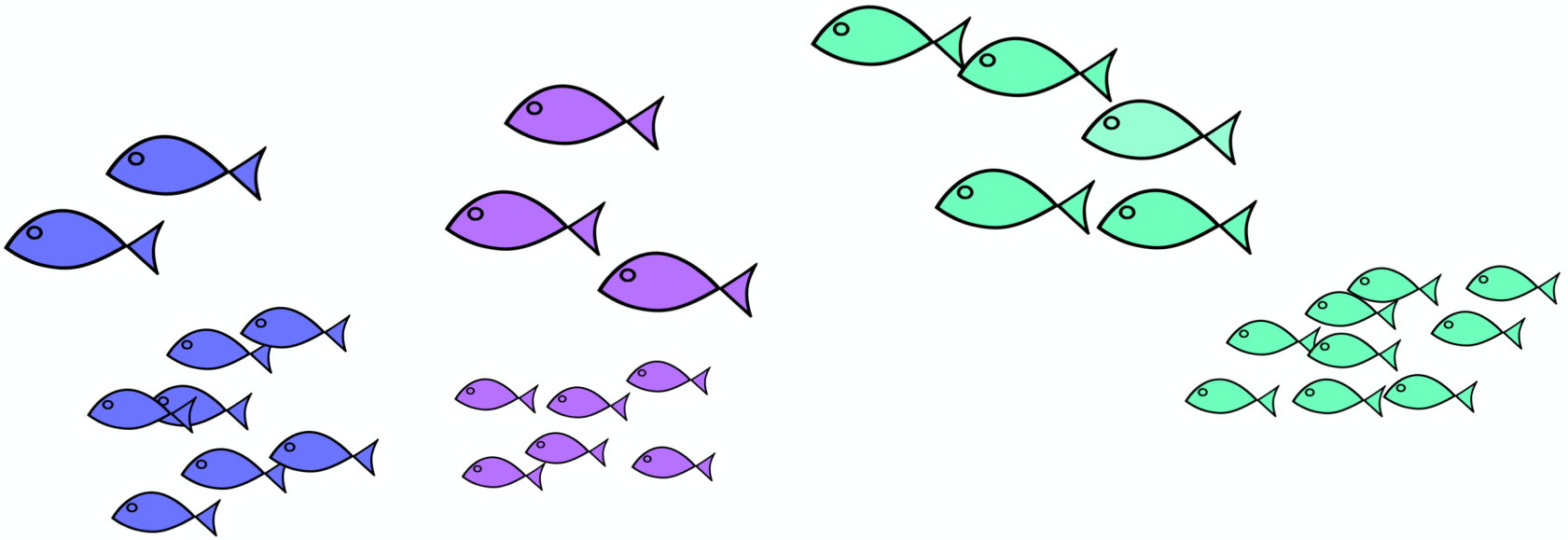
Conclusions: Preliminary

- Key Findings
  - Genetically distinct populations
  - Distinct genetic stocks in each basin
  - Riverscape determines population connectivity



Conclusions: Preliminary

- Future research
  - Expand study across all basins
  - Increase sample size → finer resolution
  - Population genetic parameters
    - Effective population size *N*e
    - Effective number of breeders *N*b




Thank you!