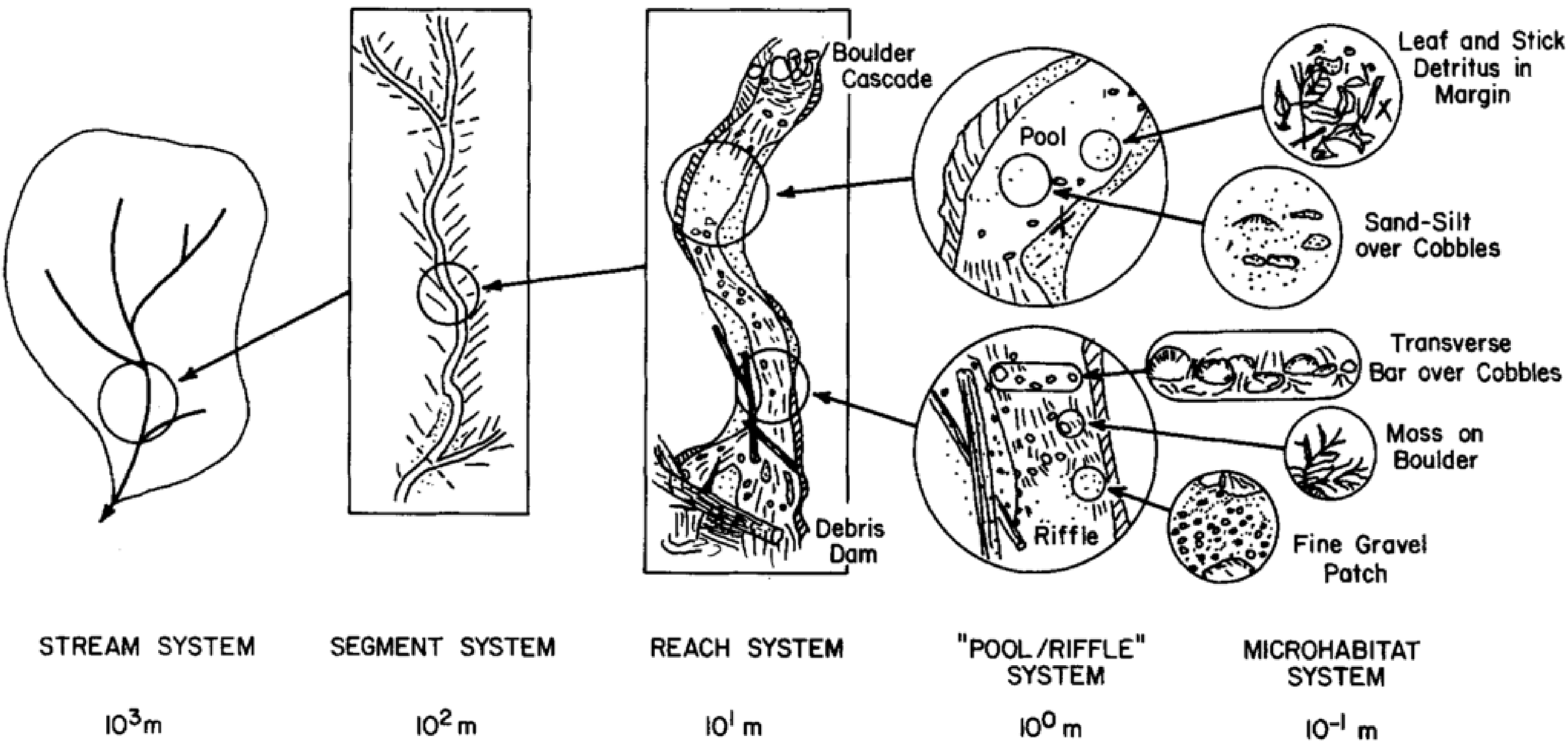
Trophic subsidy from the mainstem to tributaries by migratory mayflies is strengthen by the mainstem thermal variations.

Hiromi Uno, Mary E. Power
University of California Berkeley

Natural Streams are heterogeneous and connected

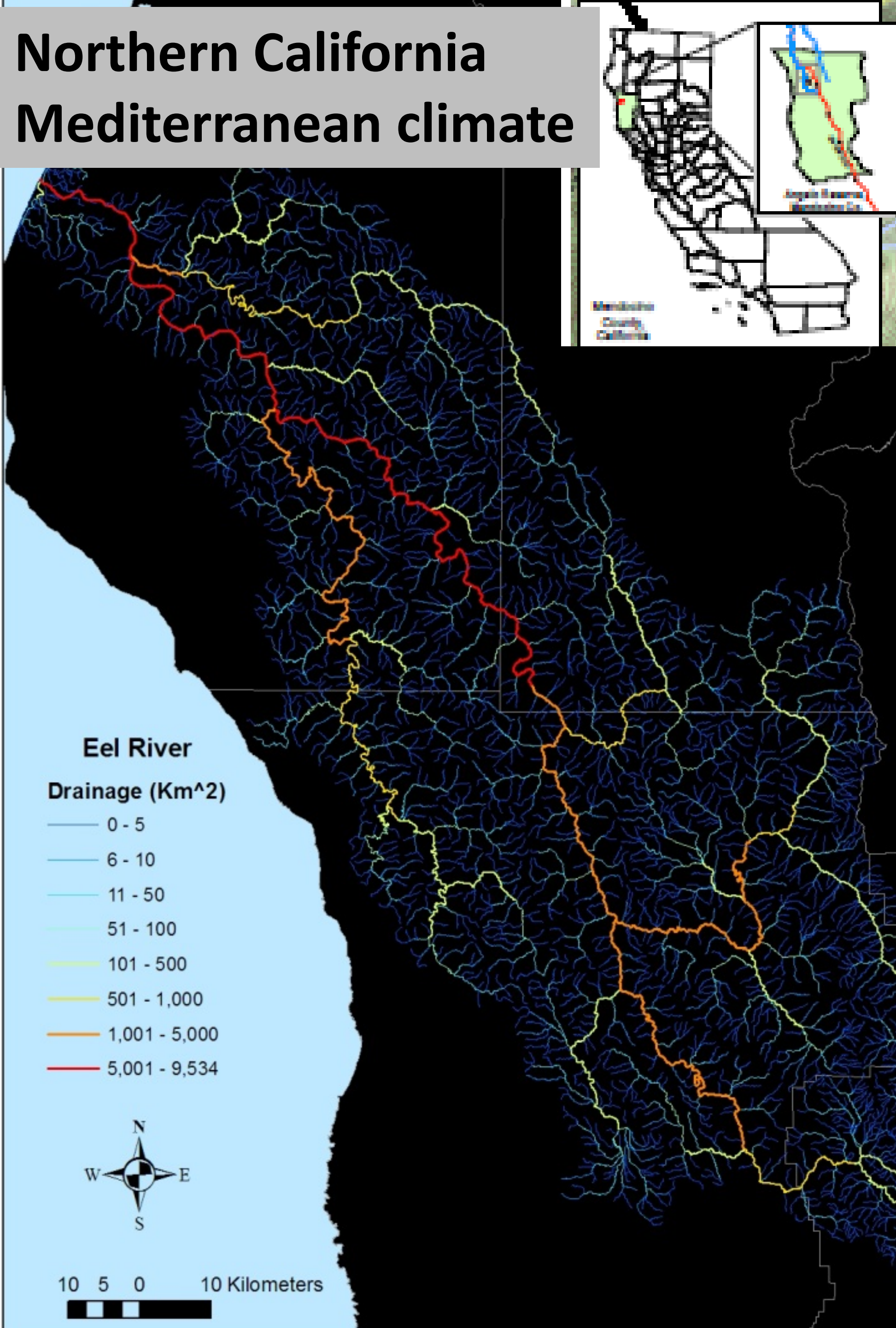
However….

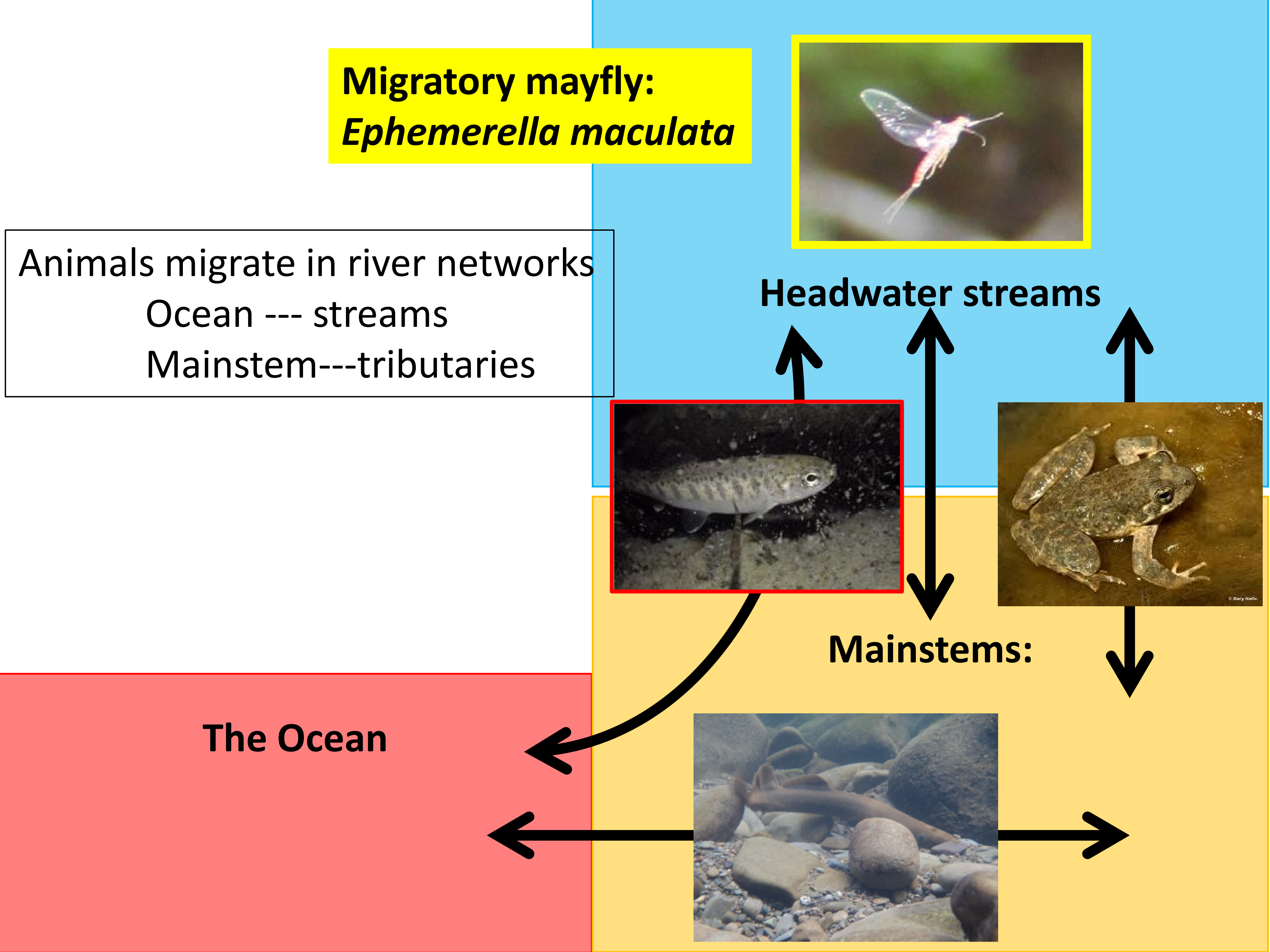
Stream is heterogeneous at multiple spatial scale



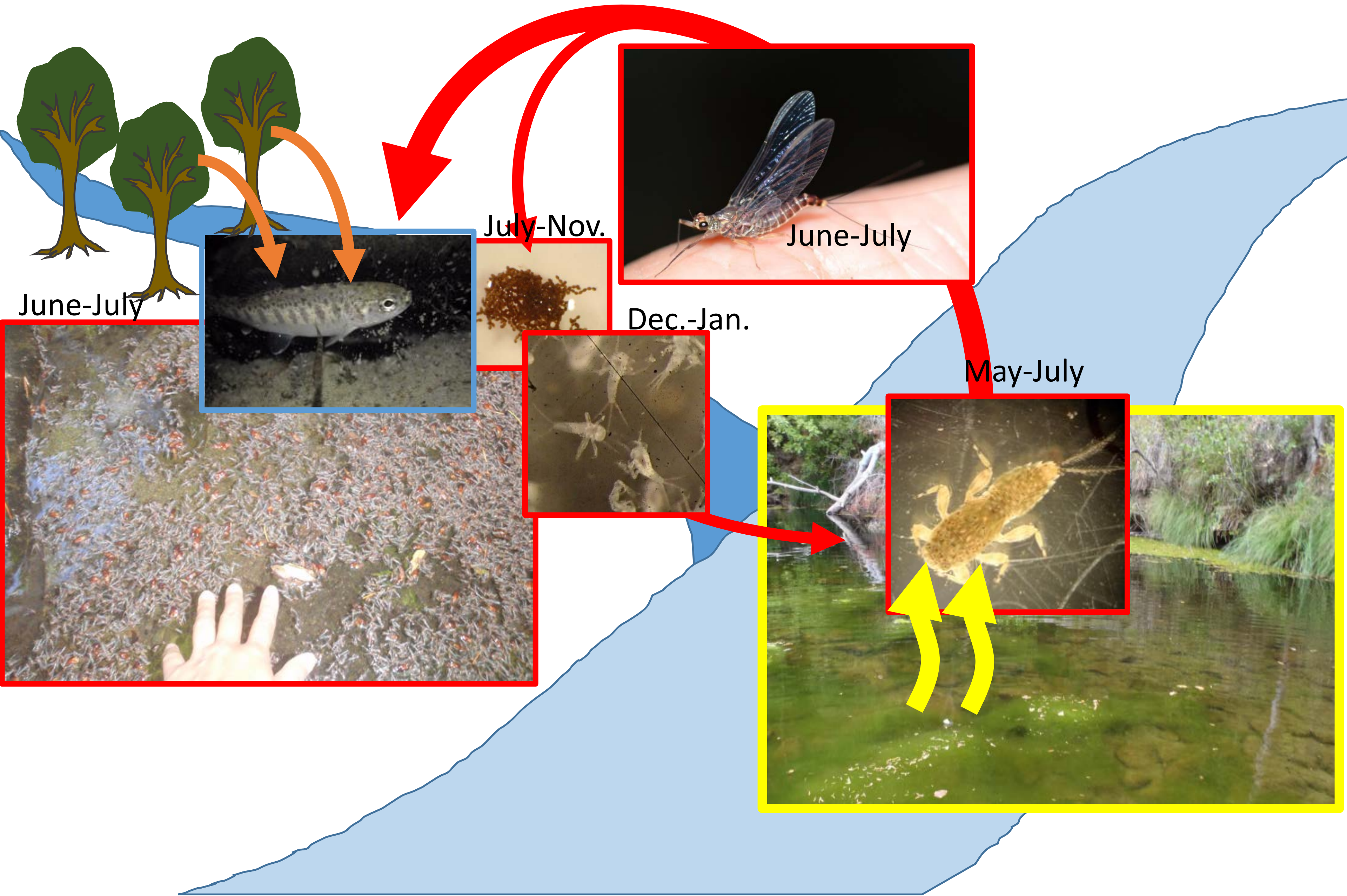
Frissell et al.(1986)

Northern California
Mediterranean climate




Migratory mayfly:
Ephemerella maculata
Animals migrate in river networks
Ocean --- streams
Mainstem---tributaries
Headwater streams
Mainstems:
The Ocean

Life cycle of *Ephemerella maculate* (Ephemerellidae)



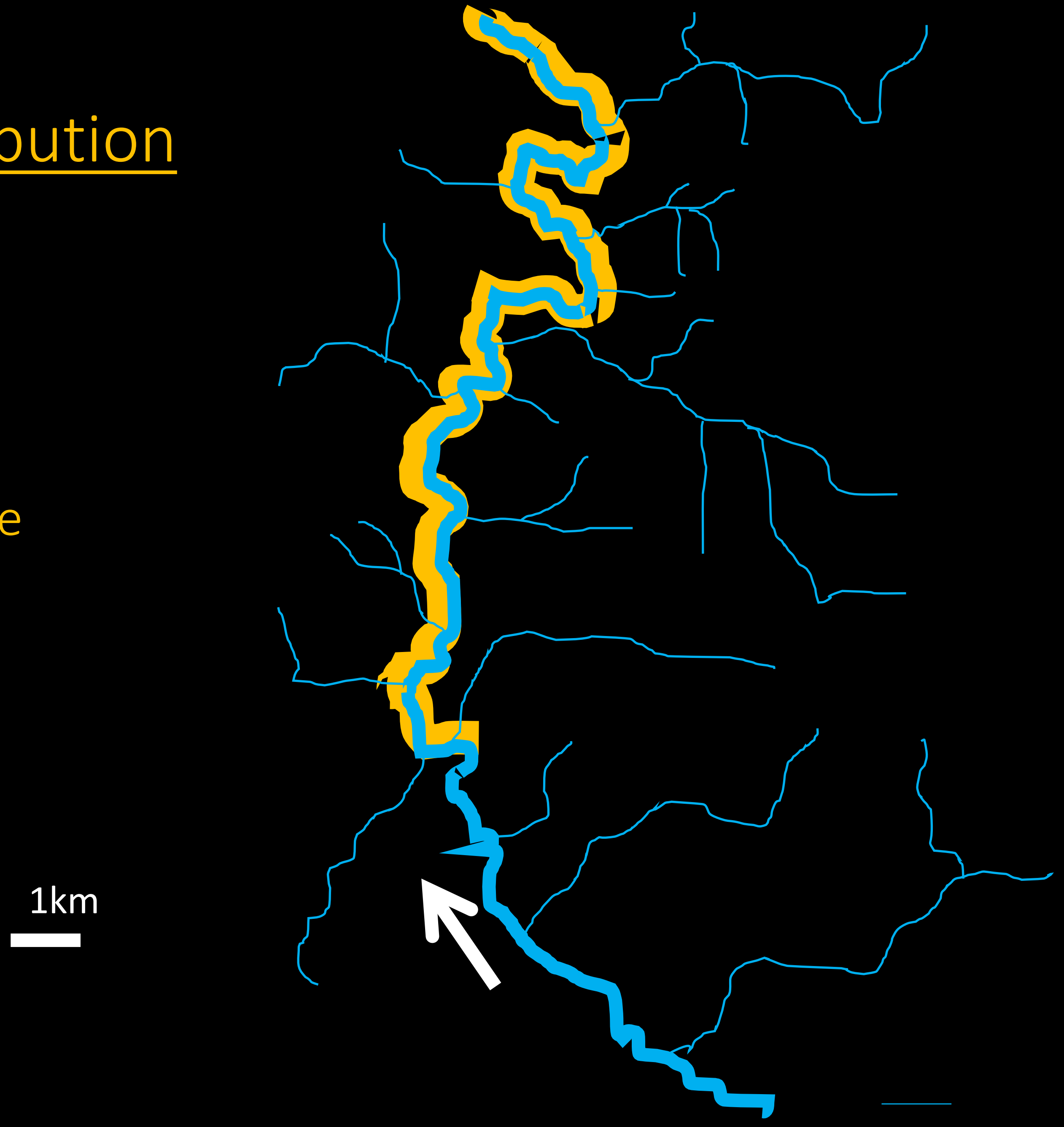
- *Female reproductive swarm*
- *everyday in dusk*
- *Females with eggs jump into riffles*

- *Ephemerella maculata* (Ephemerellidae)
Identified by Dr. Luke M. Jacobus
- All female

Sticky egg mass stuck at the bottom

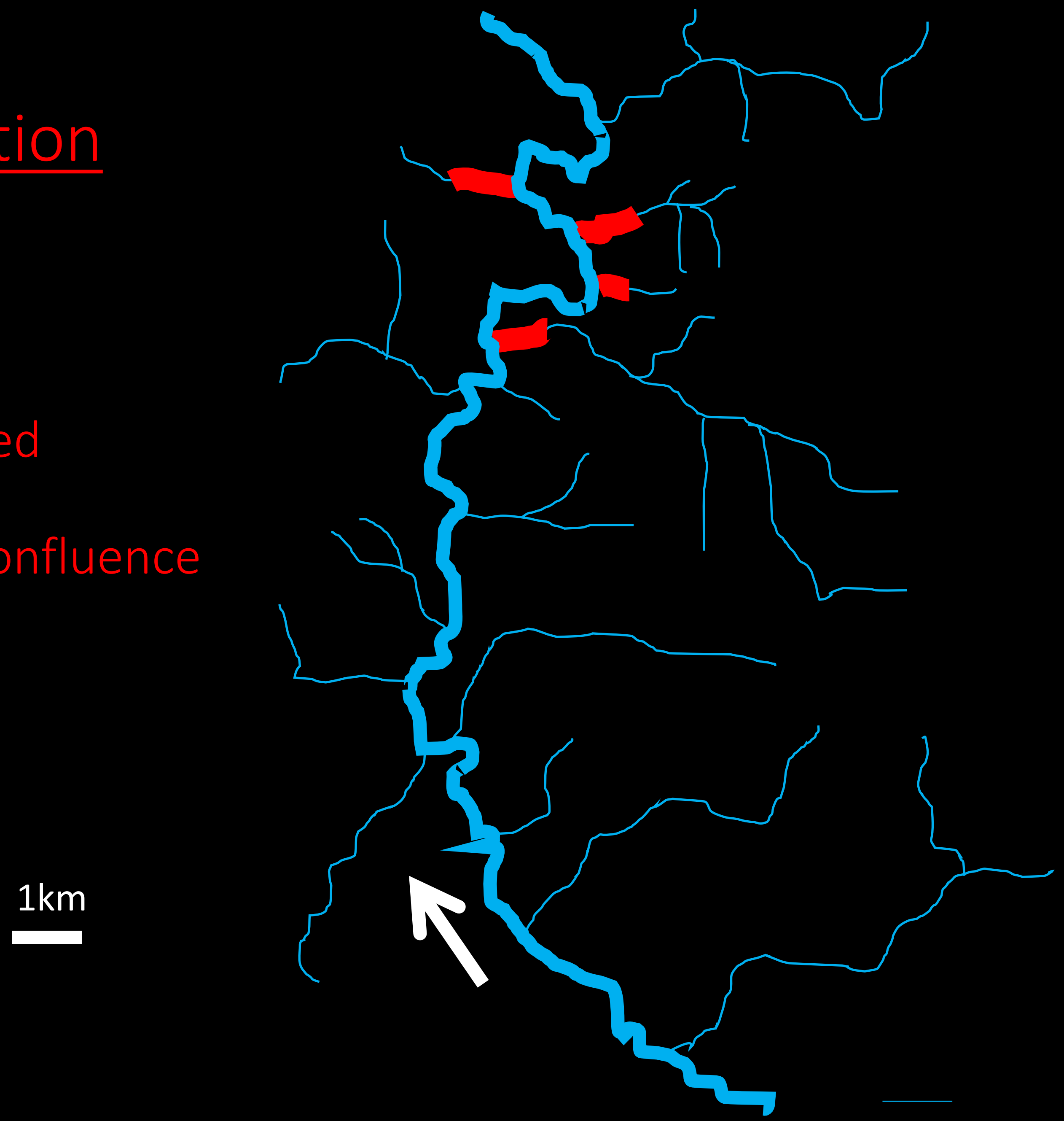
Nymph distribution

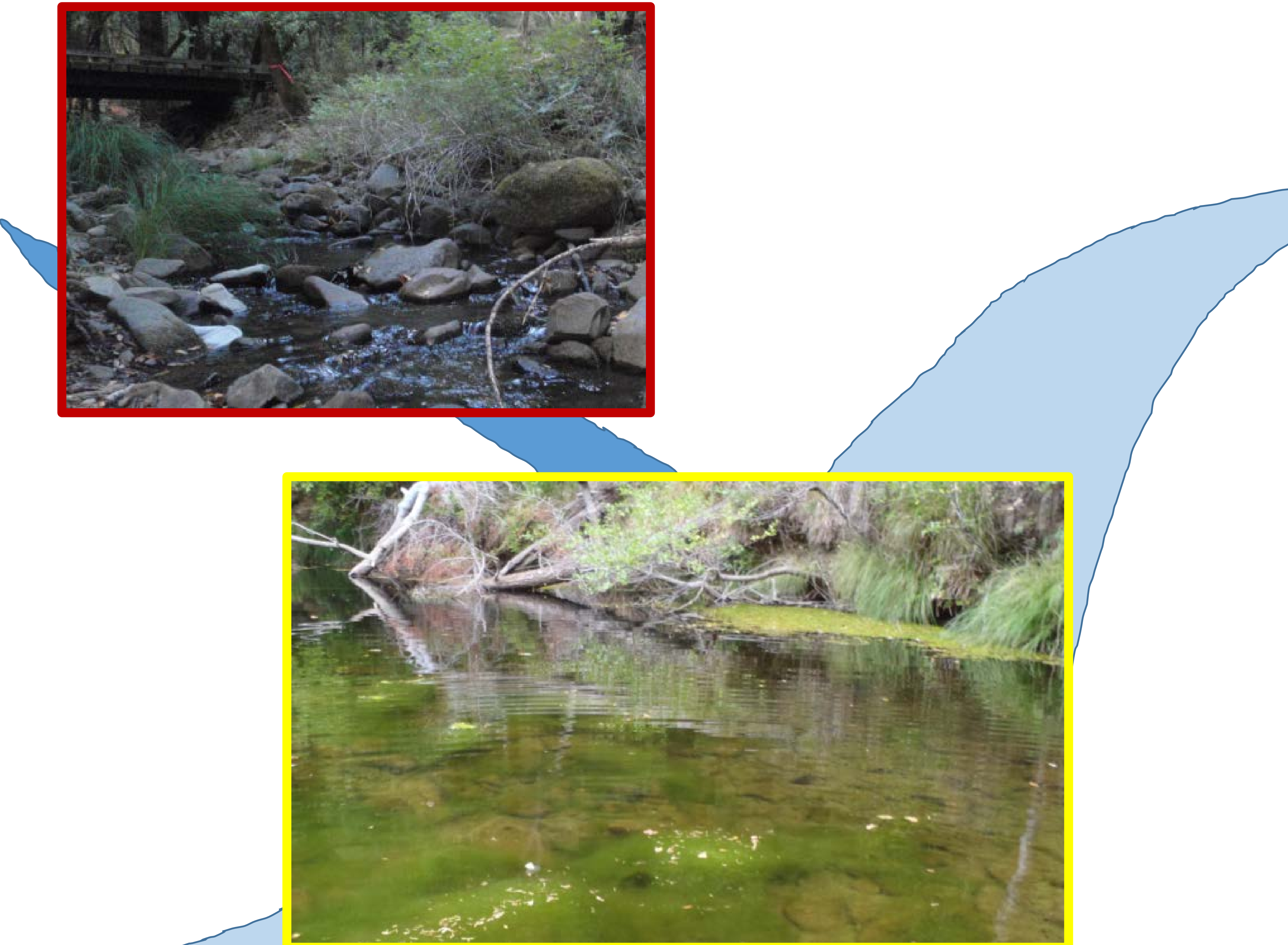
Sunny reach of the mainstem

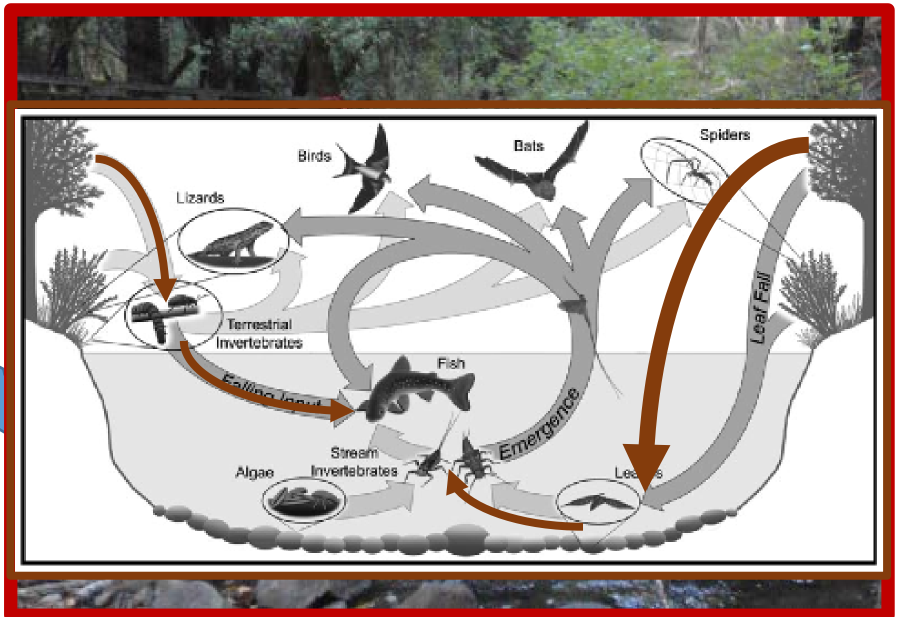


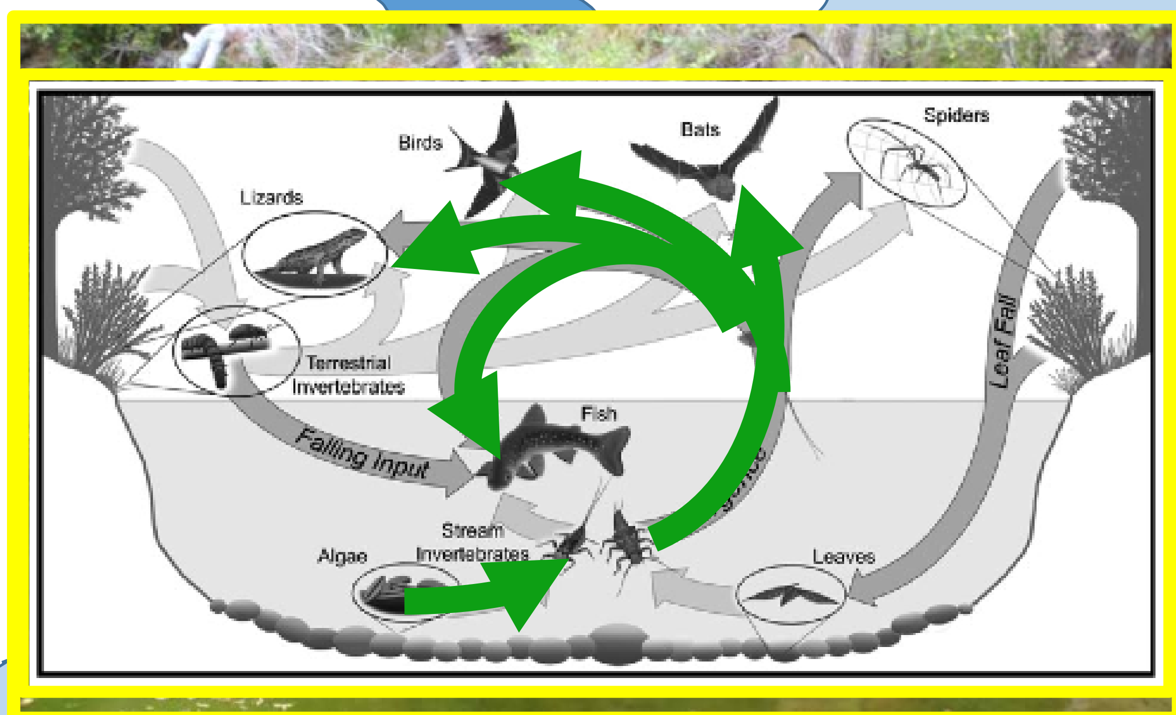
Adult distribution

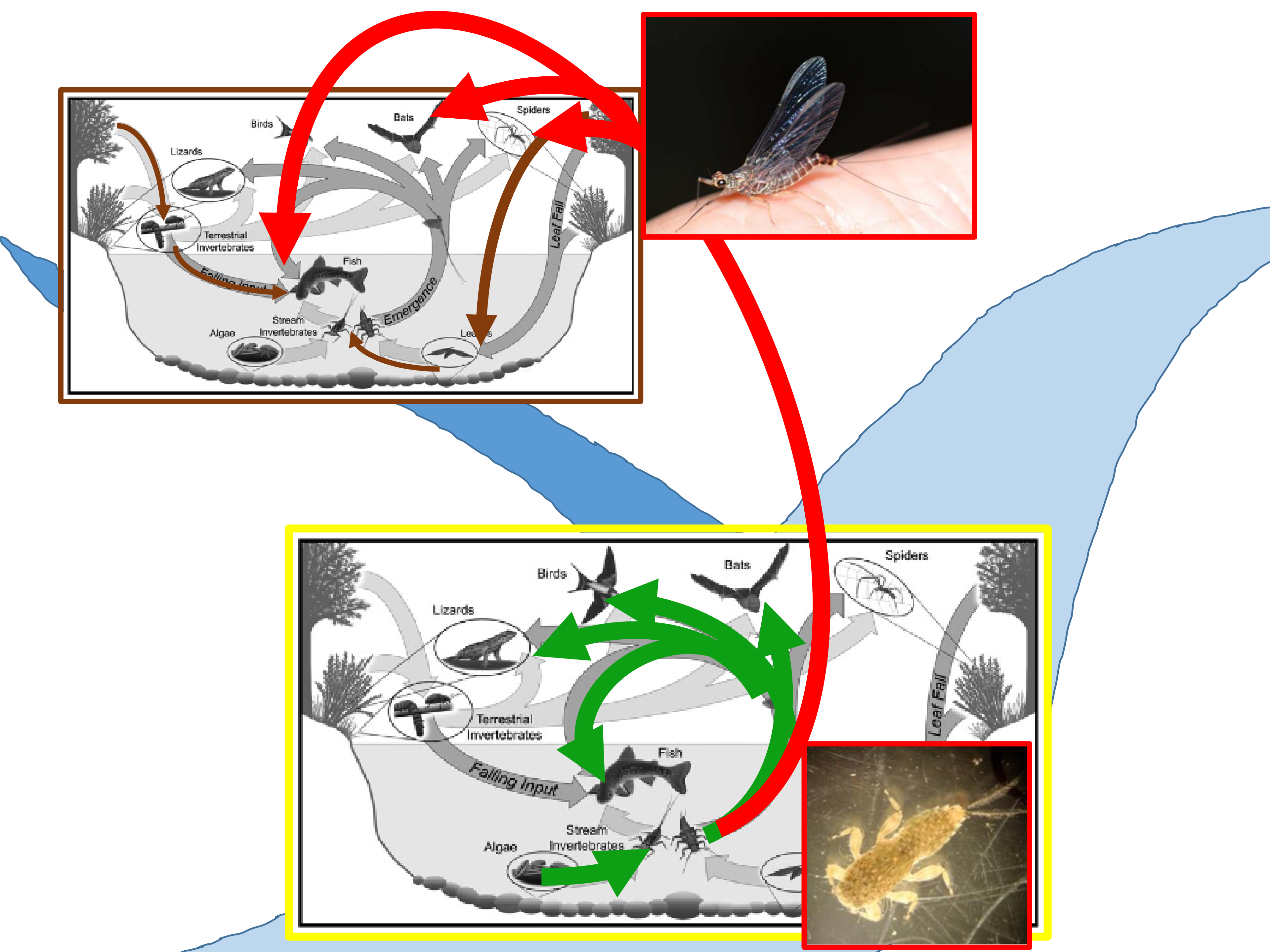
4 out of 10 surveyed tributaries
~1km from each confluence



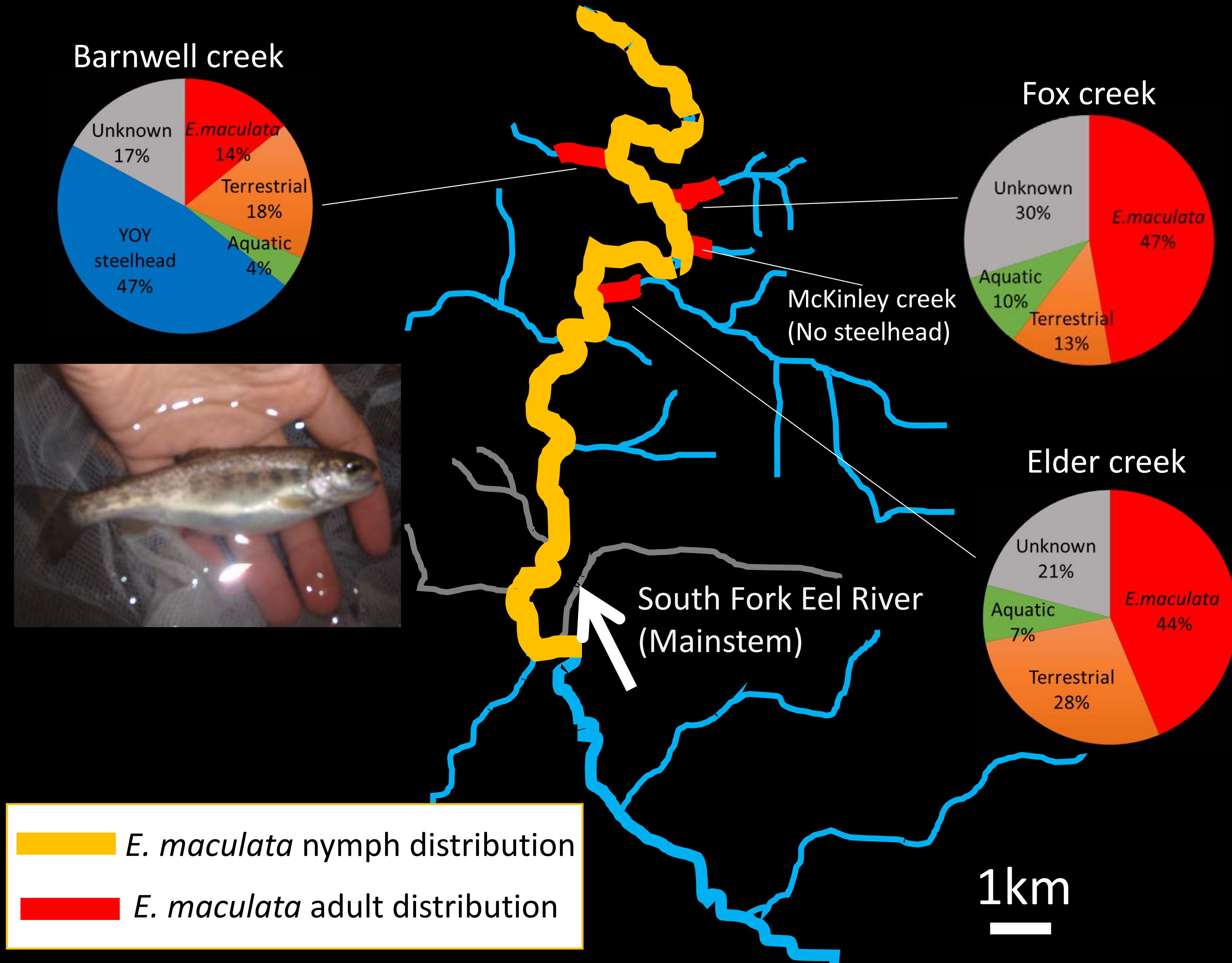


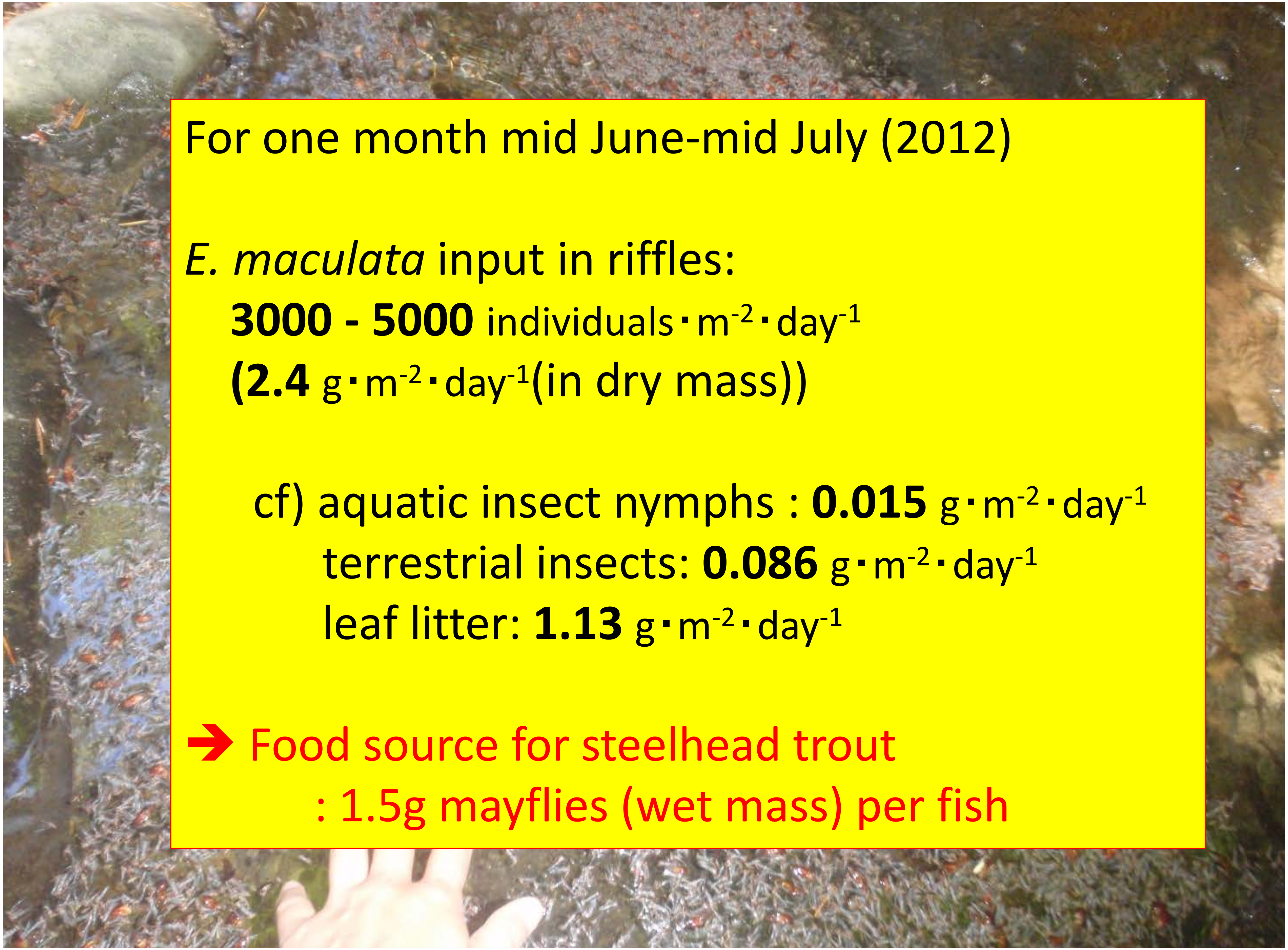

Birds
Bats
Spiders
Lizards
Terrestrial
Invertebrates
Leaf Fall
Fish
Emergence
Stream
Invertebrates
Algae


Birds
Bats
Spiders
Lizards
Terrestrial
Invertebrates
Leaf Fall
Fish
Falling Input
Stream
Invertebrates
Algae
Leaves


Birds
Bats
Spiders
Lizards
Terrestrial Invertebrates
Leaf Fall
Fish
Emergence
Stream Invertebrates
Algae
Birds
Bats
Spiders
Lizards
Terrestrial Invertebrates
Leaf Fall
Fish
Falling Input
Stream Invertebrates
Algae

Happy Predators!
@tributaries


Barnwell creek
Unknown 17%
E.maculata 14%
Terrestrial 18%
Aquatic 4%
YOY steelhead 47%
Fox creek
Unknown 30%
E.maculata 47%
Aquatic 10%
Terrestrial 13%
McKinley creek (No steelhead)
Elder creek
Unknown 21%
E.maculata 44%
Aquatic 7%
Terrestrial 28%
South Fork Eel River (Mainstem)
E. maculata nymph distribution
E. maculata adult distribution
1km



For one month mid June-mid July (2012)

E. maculata input in riffles:

3000 - 5000 individuals·m^{-2}·day^{-1}

(**2.4** g·m^{-2}·day^{-1}(in dry mass))

cf) aquatic insect nymphs : **0.015** g·m^{-2}·day^{-1}

terrestrial insects: **0.086** g·m^{-2}·day^{-1}

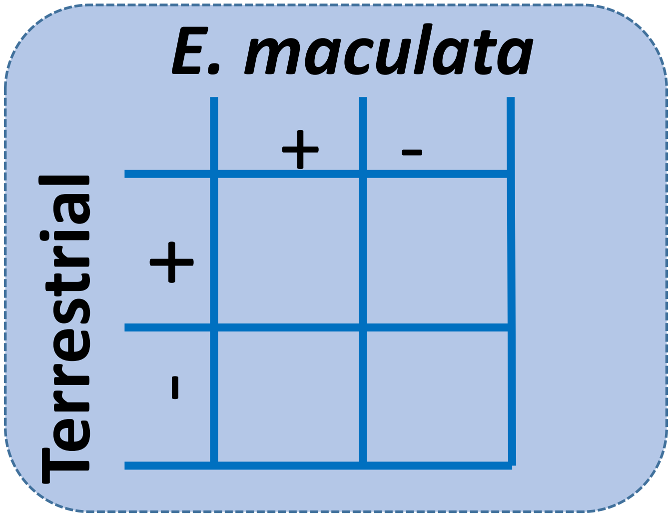
leaf litter: **1.13** g·m^{-2}·day^{-1}

➔ Food source for steelhead trout

: 1.5g mayflies (wet mass) per fish

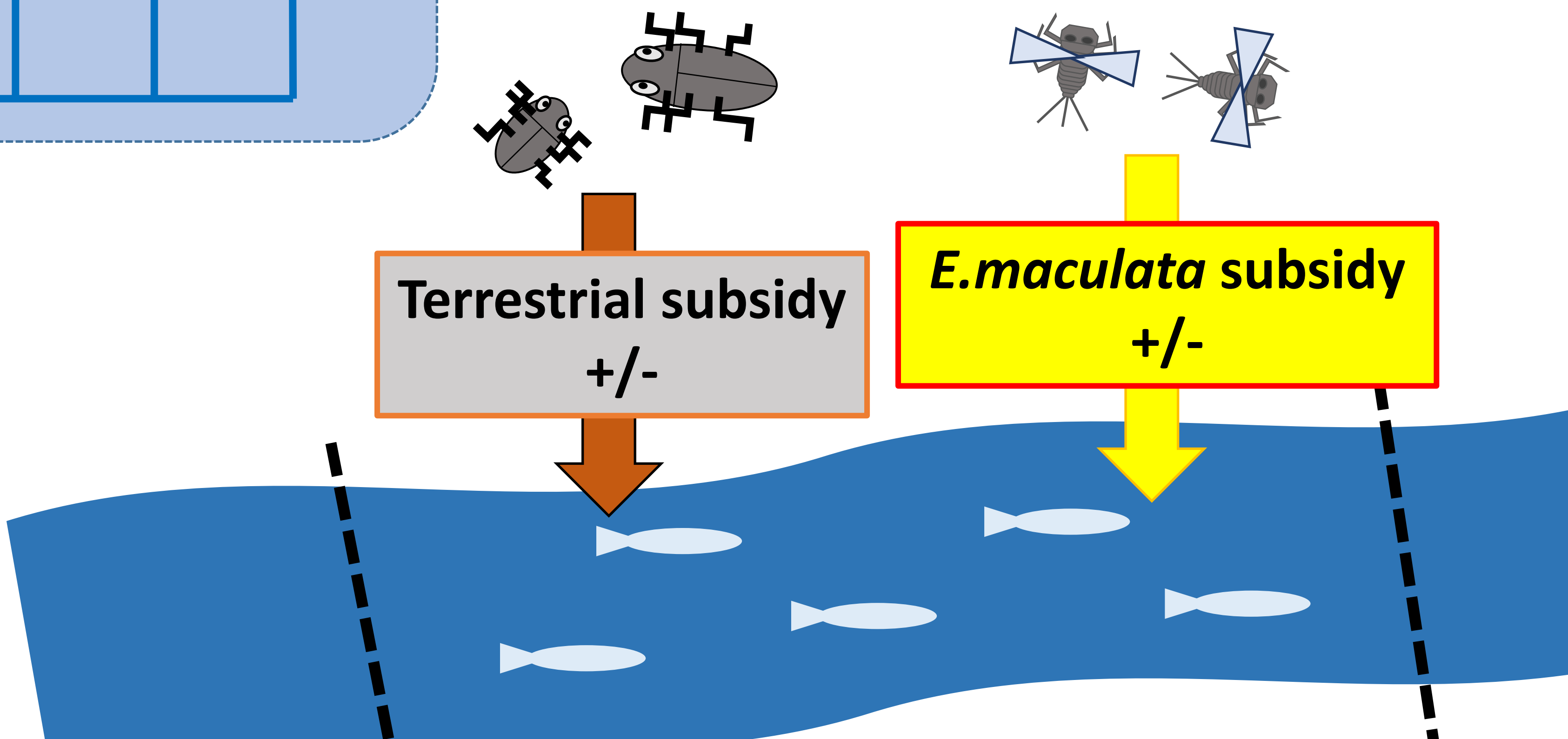
Field manipulative experiment:

Effect of subsidies on fish growth



Standardized density and subsidy

Steelhead trout YOY : 0.6 individuals /m^2 in pool
Ephemerella maculata 1.5g (wet)/fish



Up/downstream side fences
4 treatments x 4 replicates

Fish density control
0.6 individuals YOY /m^2 in pool


Terrestrial subsidy
+/-
(Without and with roof)

E.maculata subsidy

+/-

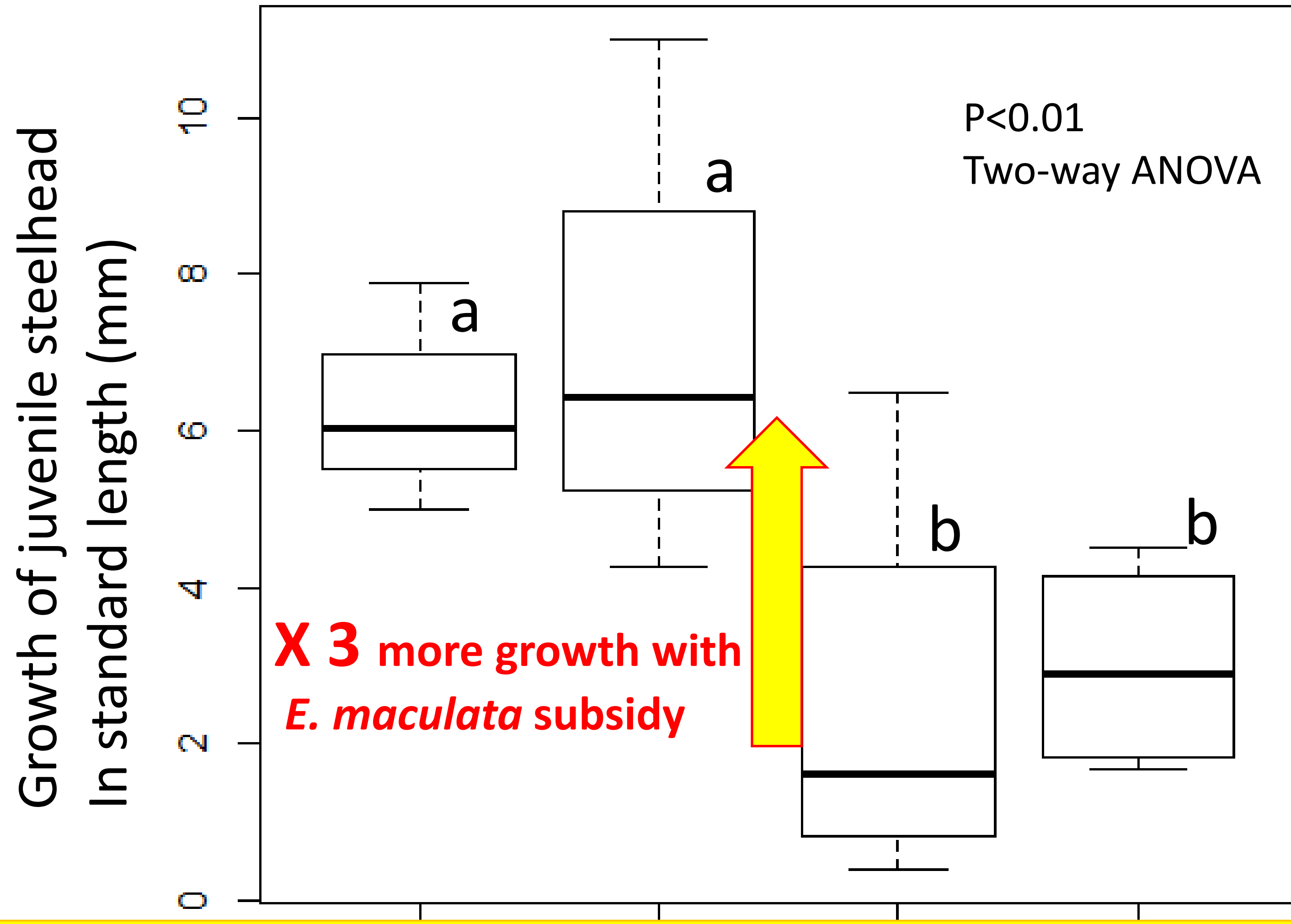
(with and without daily feeding of 1.5g frozen mayflies per fish)

<u>Measure body size of steehead</u>

start: **July 10th (46mm average)**

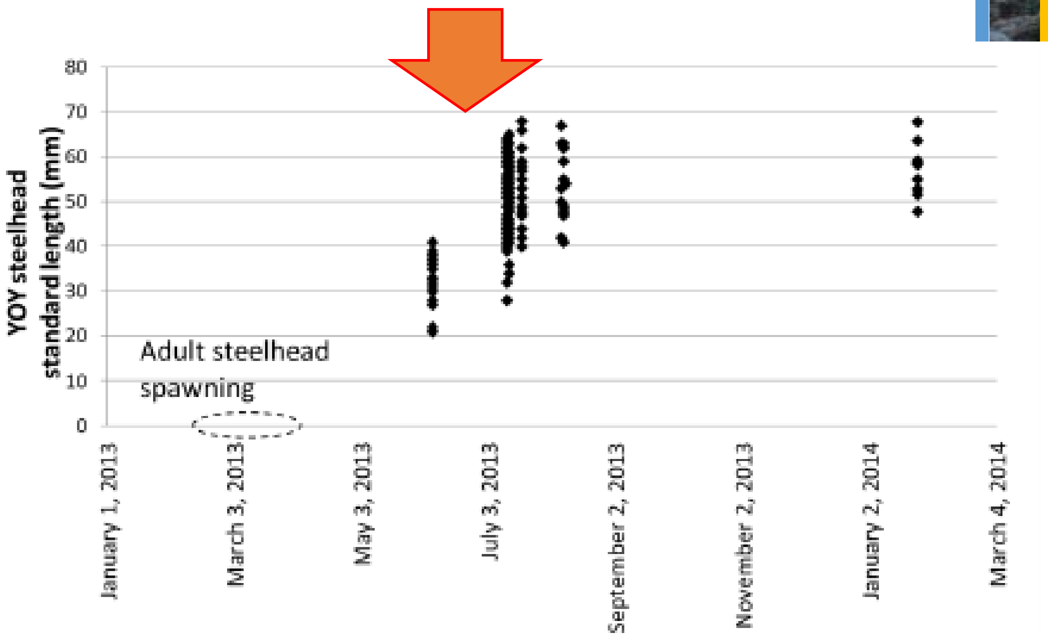
end: **August 10th**

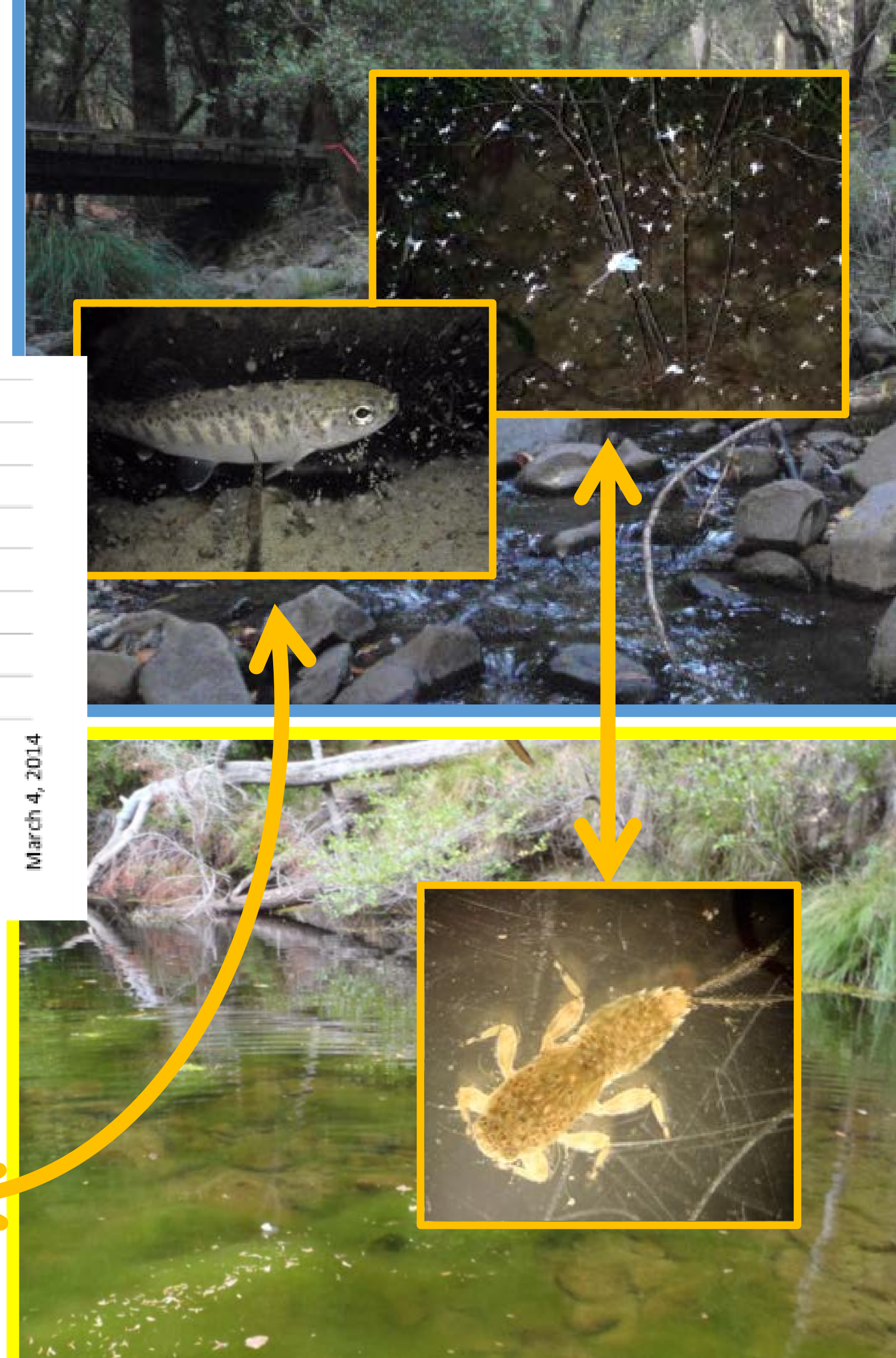
Results

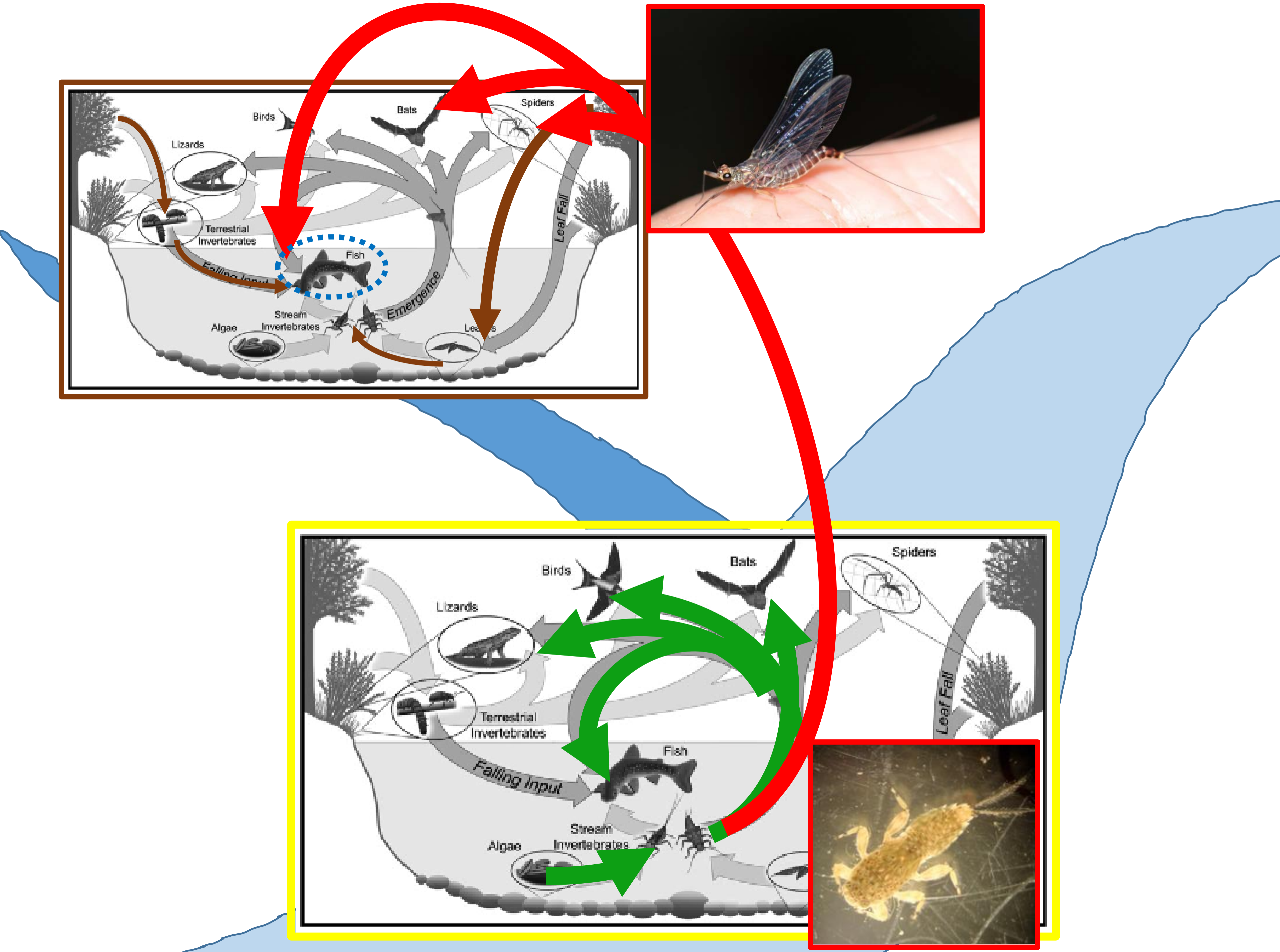


E.maculata subsidy	+	+	--	--
Terrestrial subsidy	+	--	+	--

matching of migrations Mayfly subsidy during the critical growth period for fish







Birds
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Spiders
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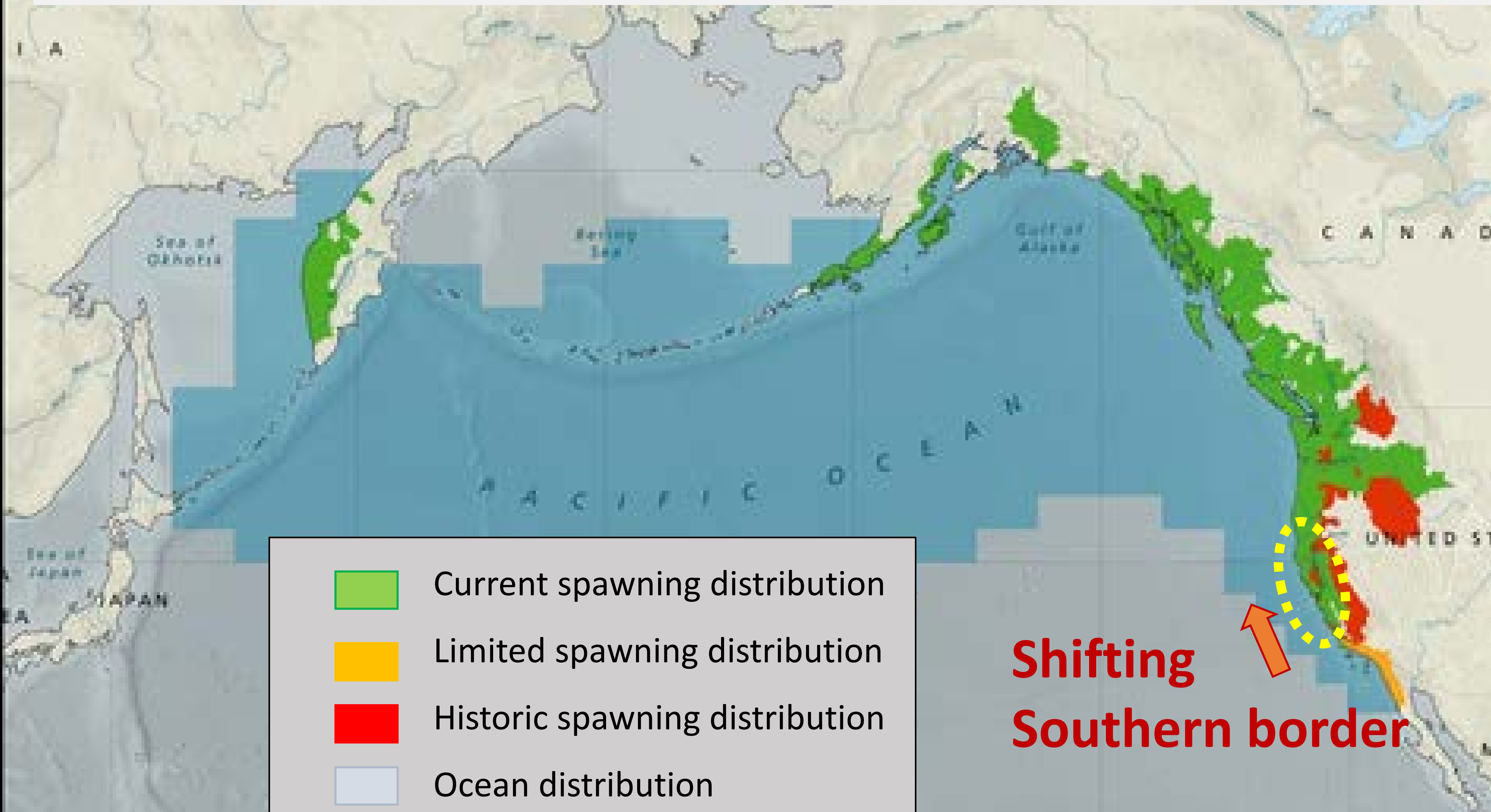
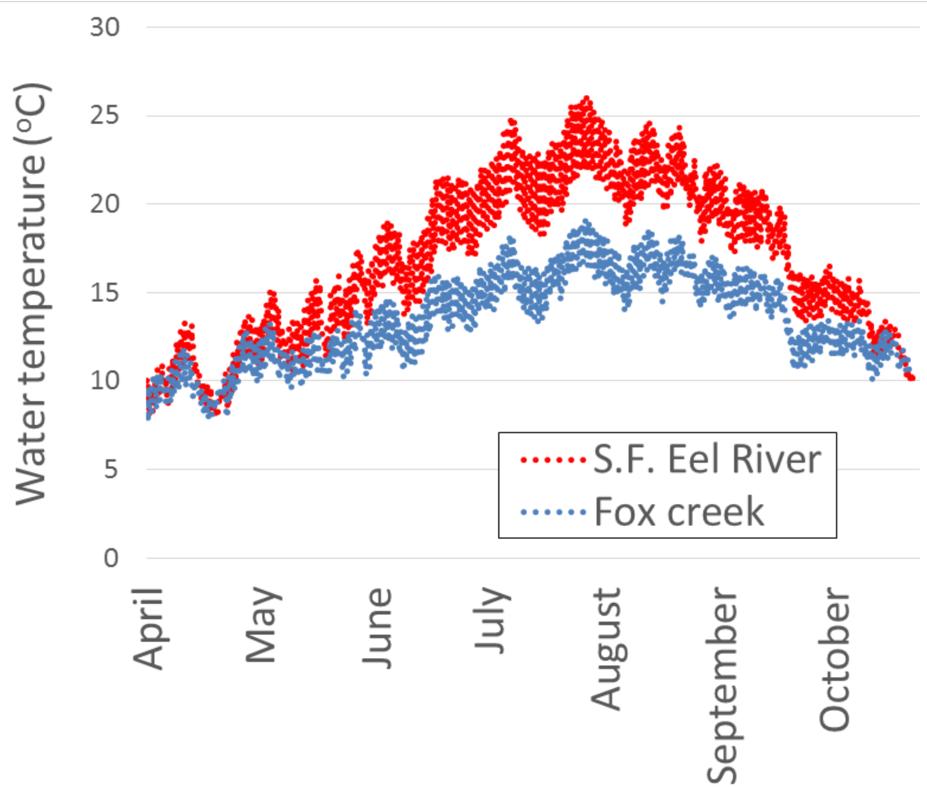
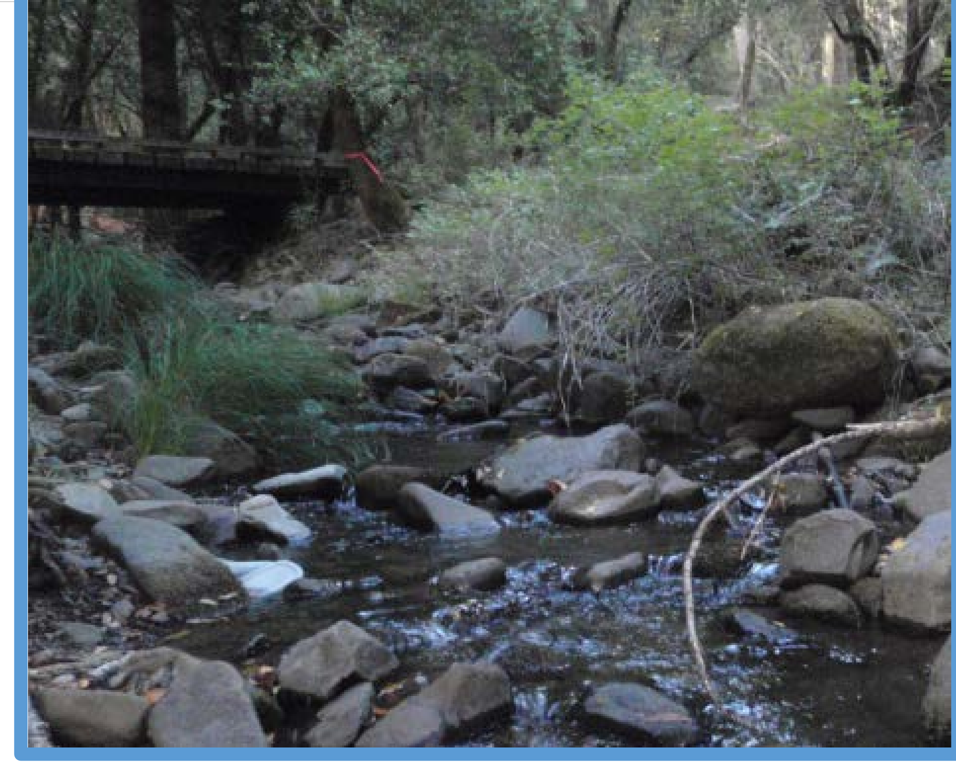
Terrestrial Invertebrates
Fish
Falling Input
Emergence
Leaf Fall
Stream Invertebrates
Algae
Birds
Bats
Spiders
Lizards
Terrestrial Invertebrates
Fish
Falling Input
Stream Invertebrates
Algae
Leaf Fall

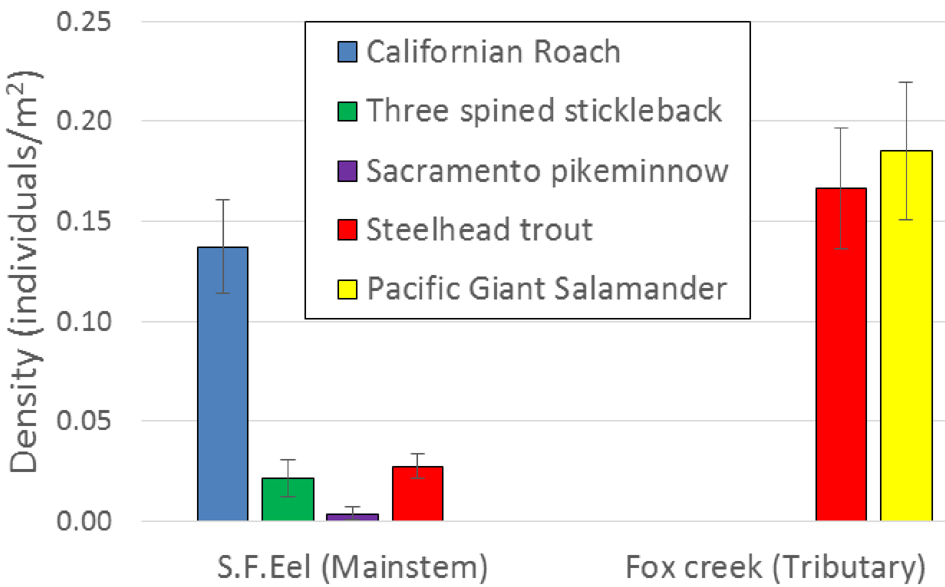
Distribution of steelhead trout (*Oncorhynchus mykiss*)

Mayfly migrations provide resilience to steelhead population against river warming

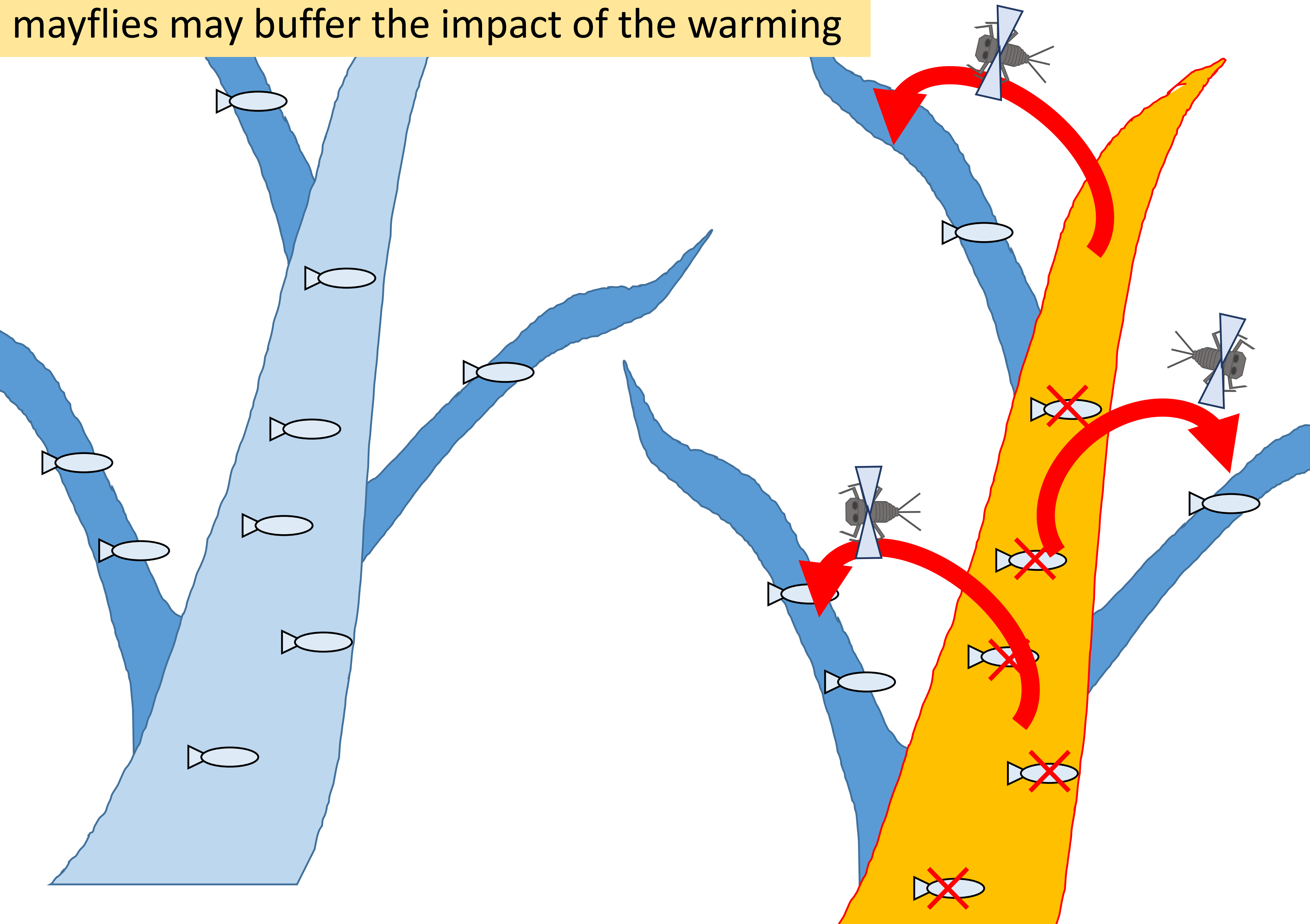



Water temperature (°C)
30
25
20
15
10
5
0
April
May
June
July
August
September
October
S.F. Eel River
Fox creek

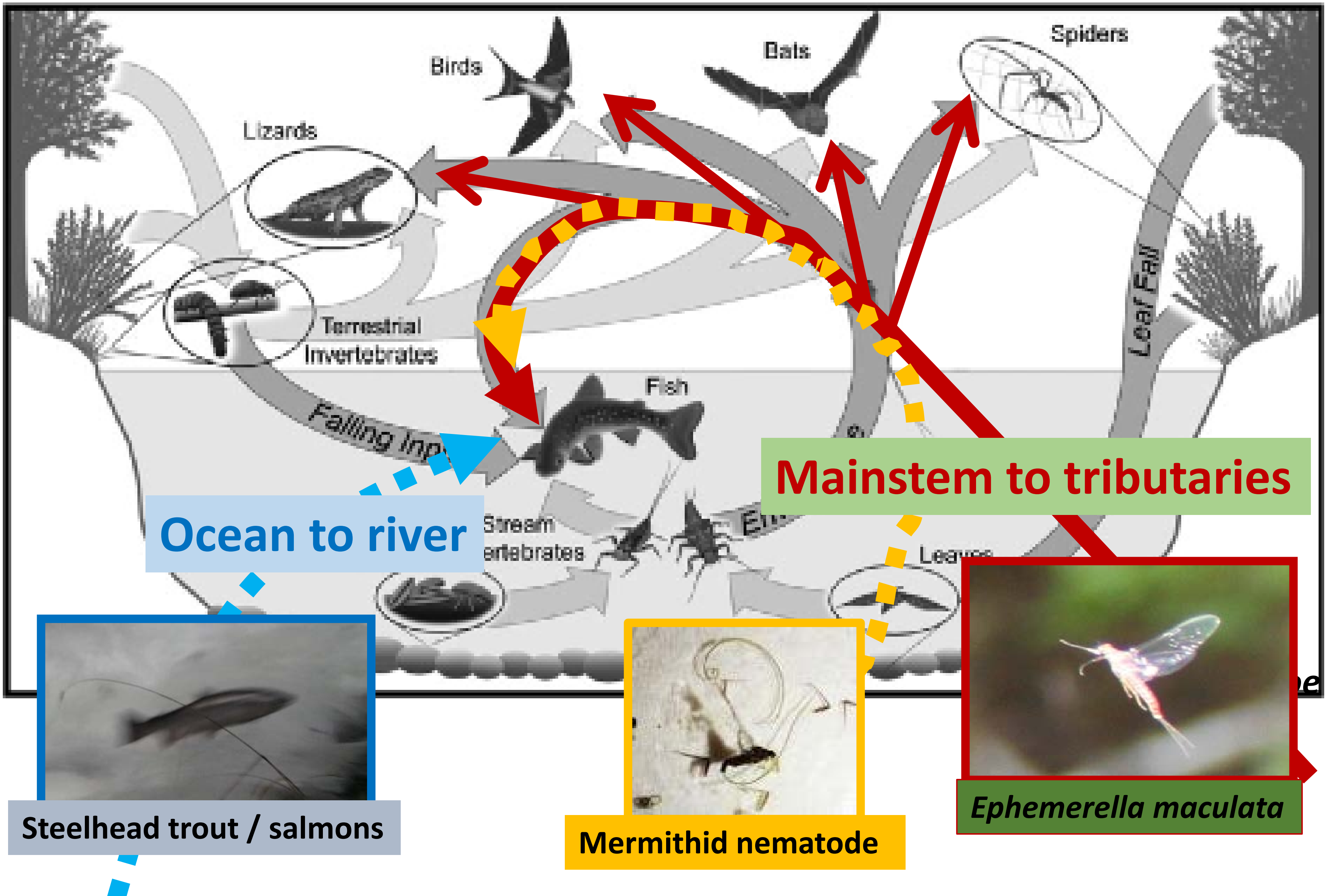



Density (individuals/m²)
0.25
0.20
0.15
0.10
0.05
0.00
Californian Roach
Three spined stickleback
Sacramento pikeminnow
Steelhead trout
Pacific Giant Salamander
S.F.Eel (Mainstem)
Fox creek (Tributary)

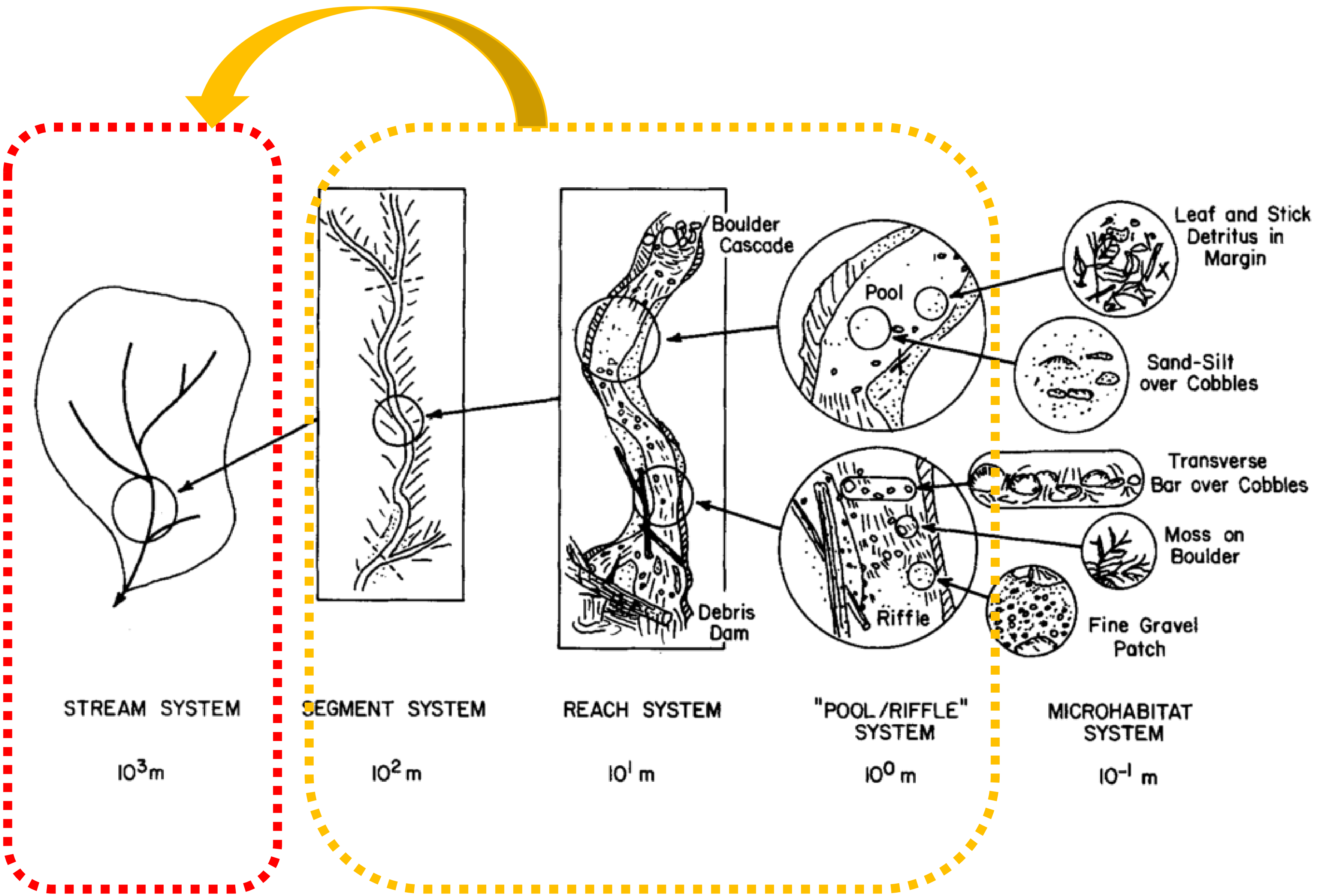
Resource transportation to thermal-refuge by mayflies may buffer the impact of the warming



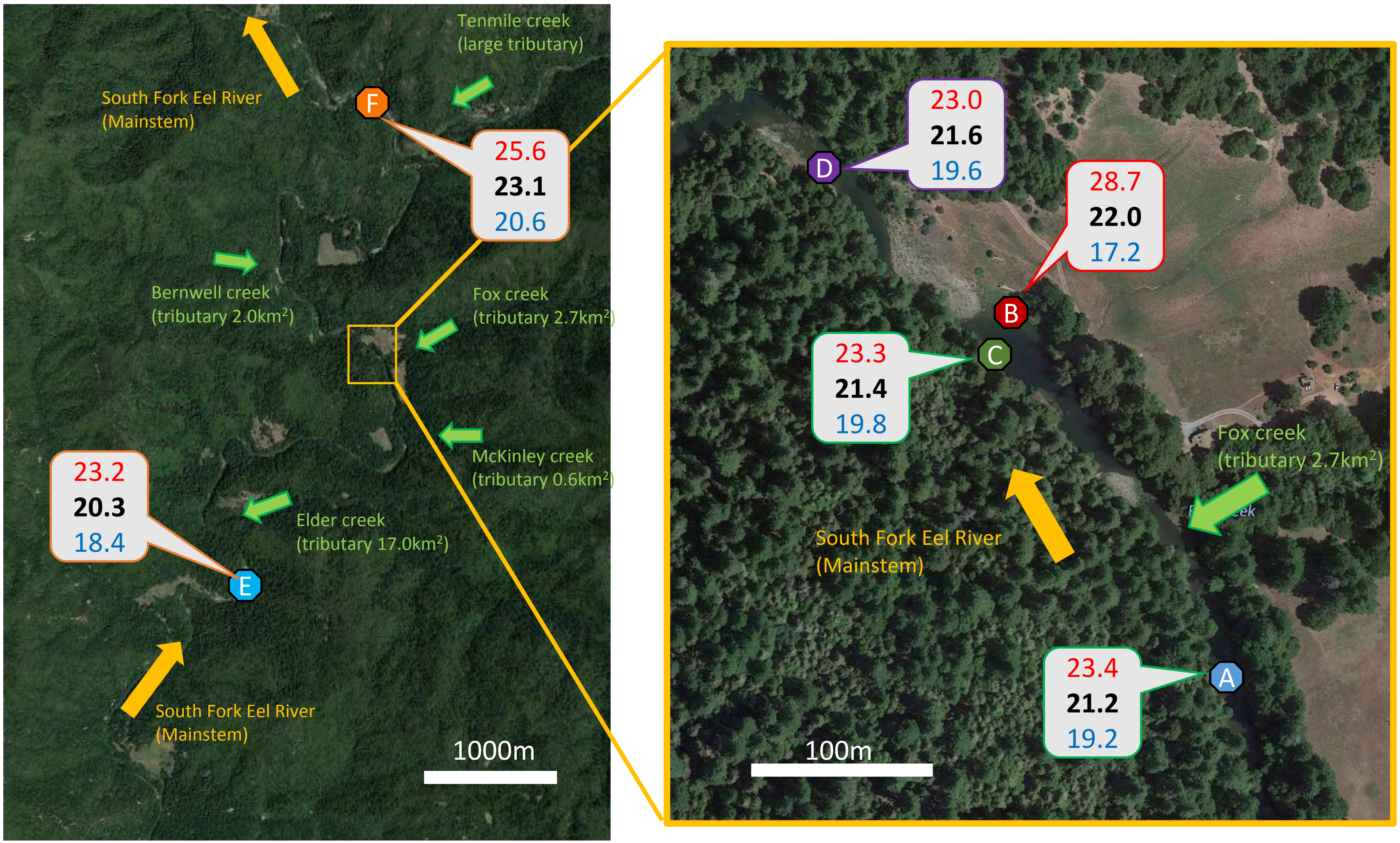
Dynamic food webs in river networks



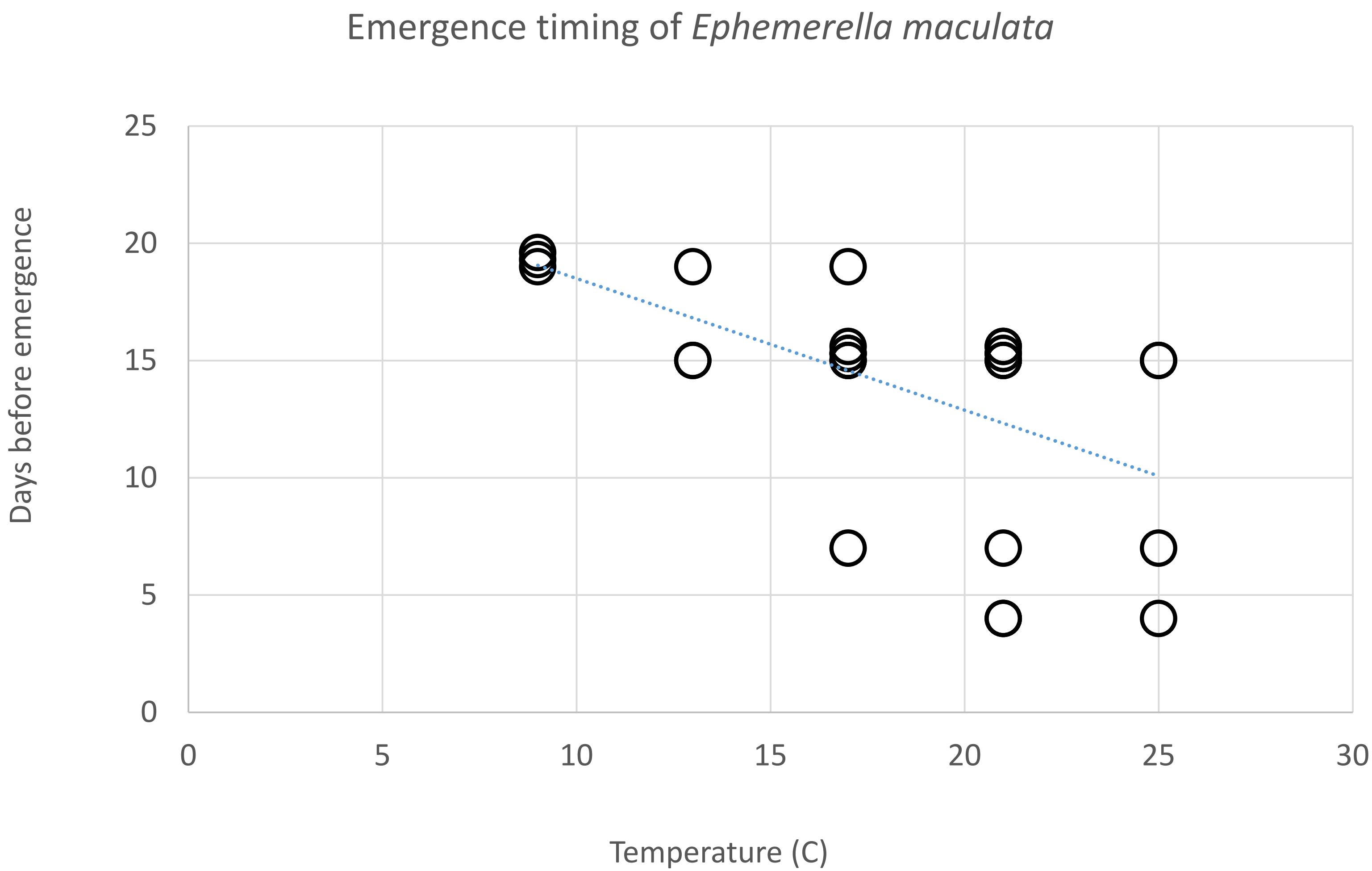
How does the spatial heterogeneity of the mainstem affect on the trophic relationship?



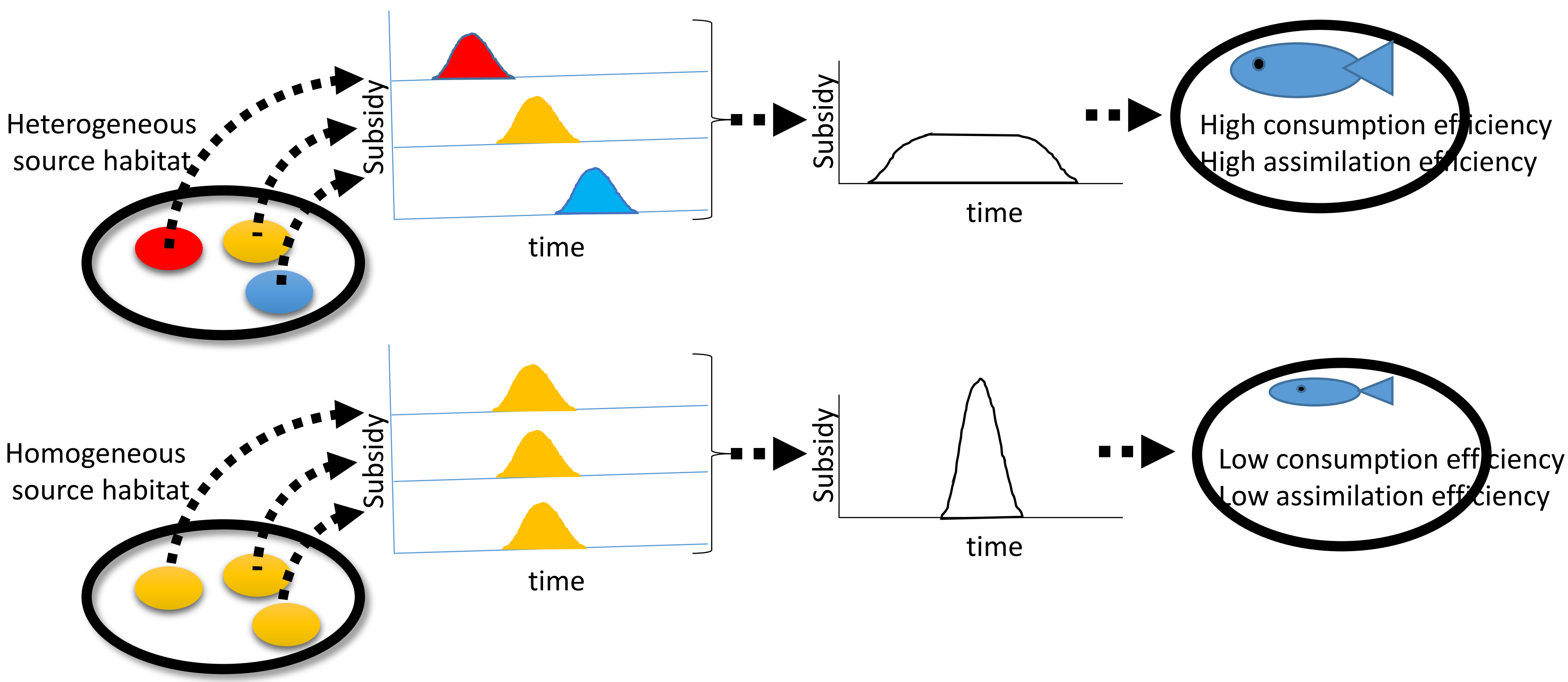
Spatial variation of the water temperature in river!!!



Lab raring experiment
mayfly emerge earlier at warmer temperature



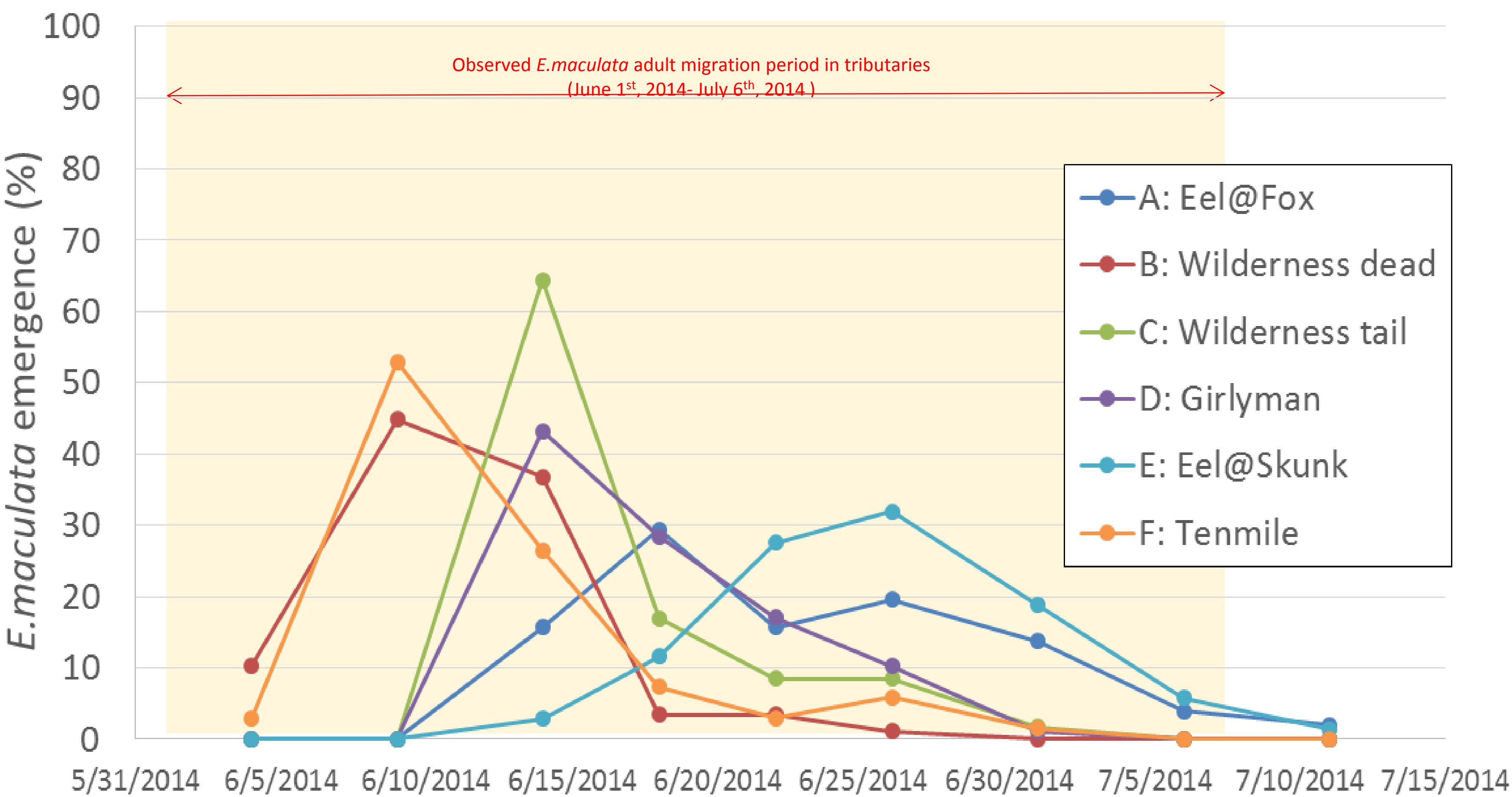
Do thermal heterogeneity in river mainstems prolong a subsidy to tributary salmonids by migratory mayflies?



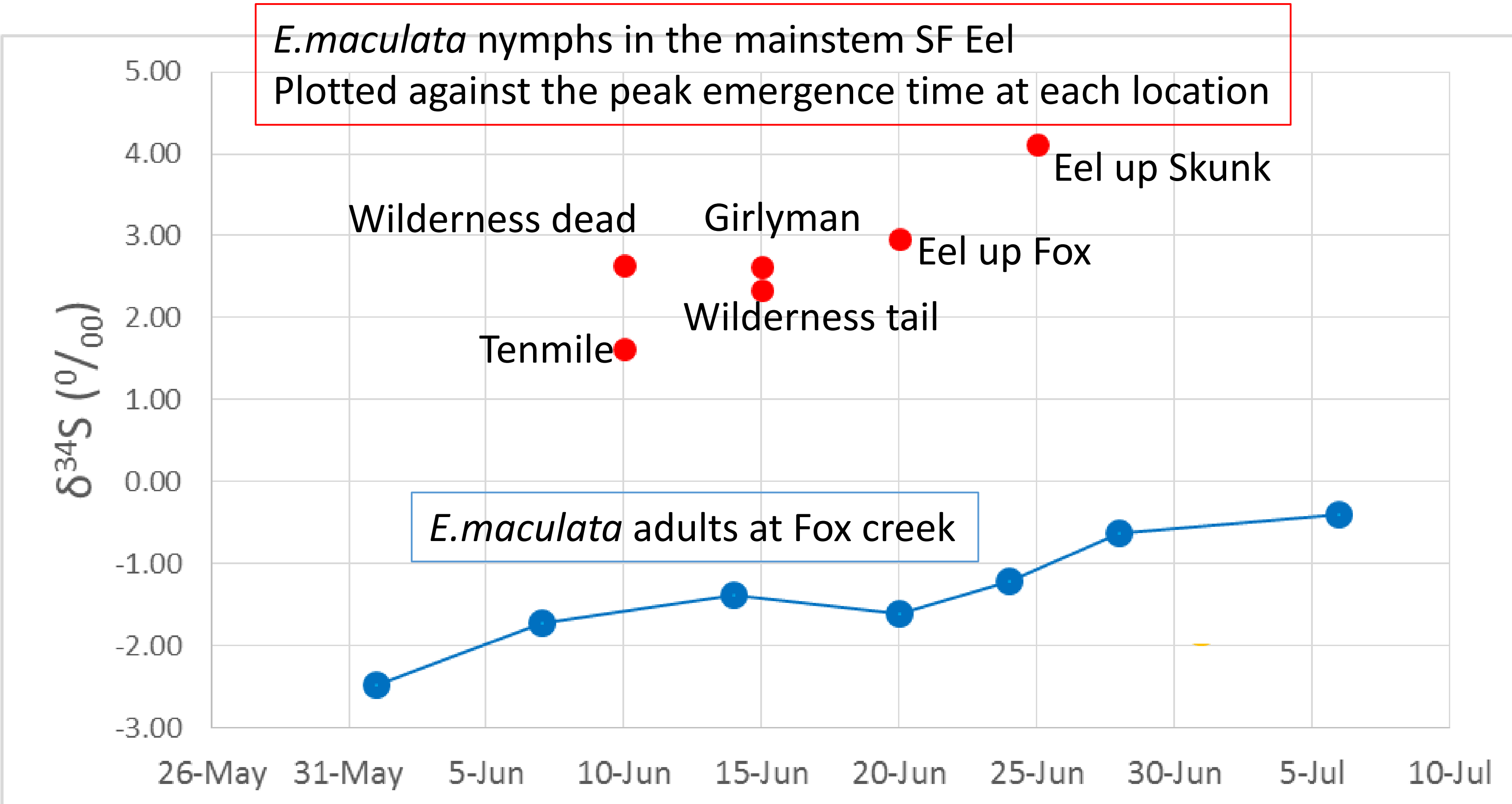
Field raring experiment:
monitor when insects emerge

E.maculata emerged earlier in warmer part, then later from colder part

- 2weeks emergence period at each location,
- 4 weeks emergence as a whole

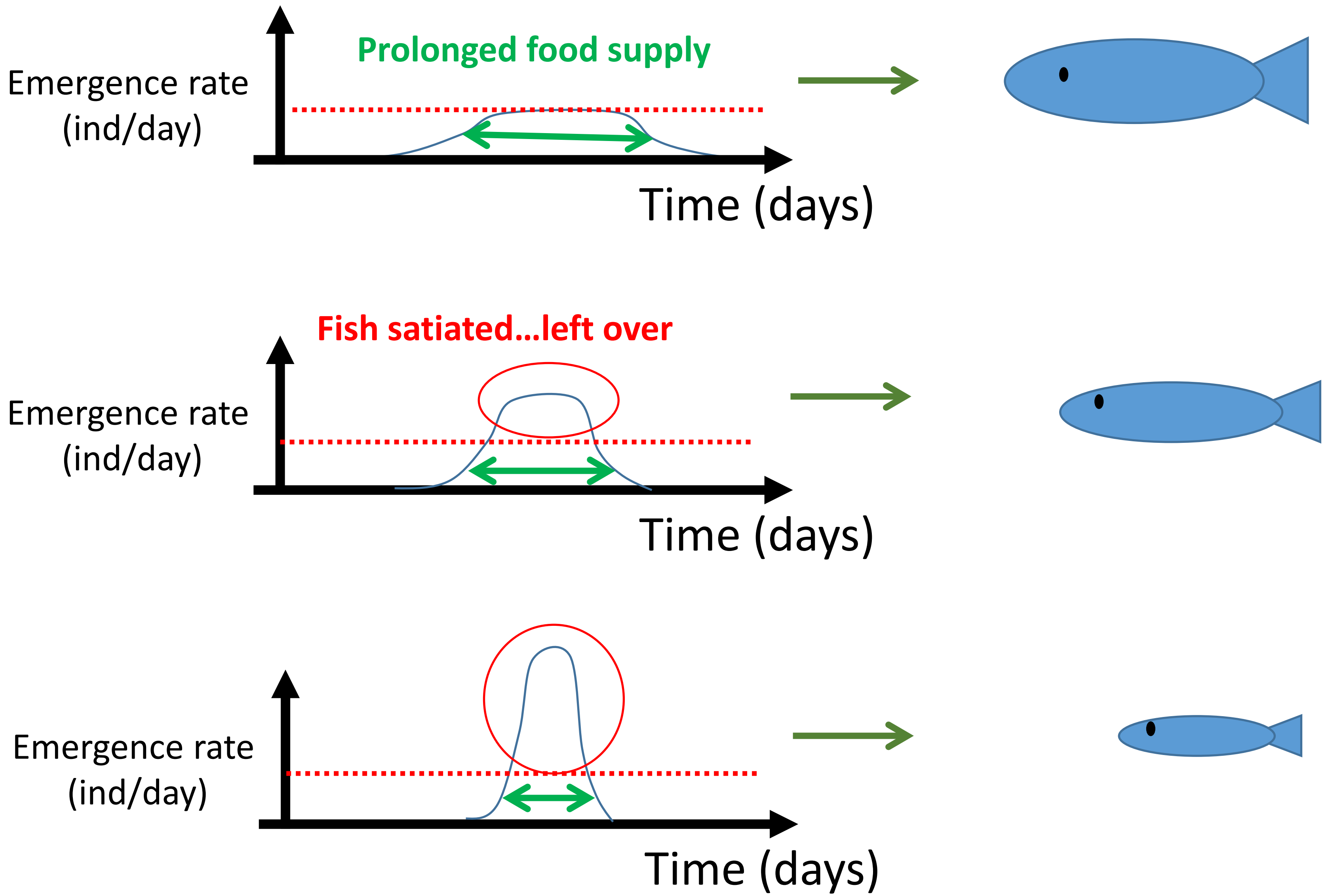


Are the adults flying in the creeks early coming from warmer area? Isotope analysis

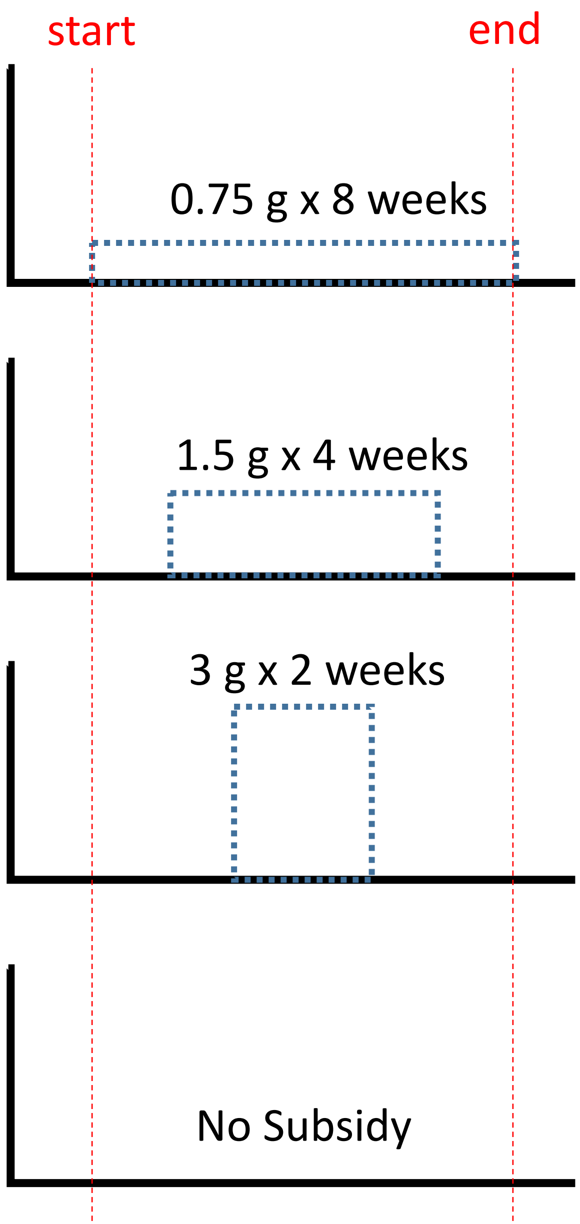


Do extended subsidy promote the growth of fish?

Consumption efficiency & Assimilation efficiency



2015 field experiment (Plan)



Compare the fish growth in summer 8 weeks.

Also monitor individual fish growth and over winter mortality/out migration after experiment.

Thank you!

<u>Professional advices</u>

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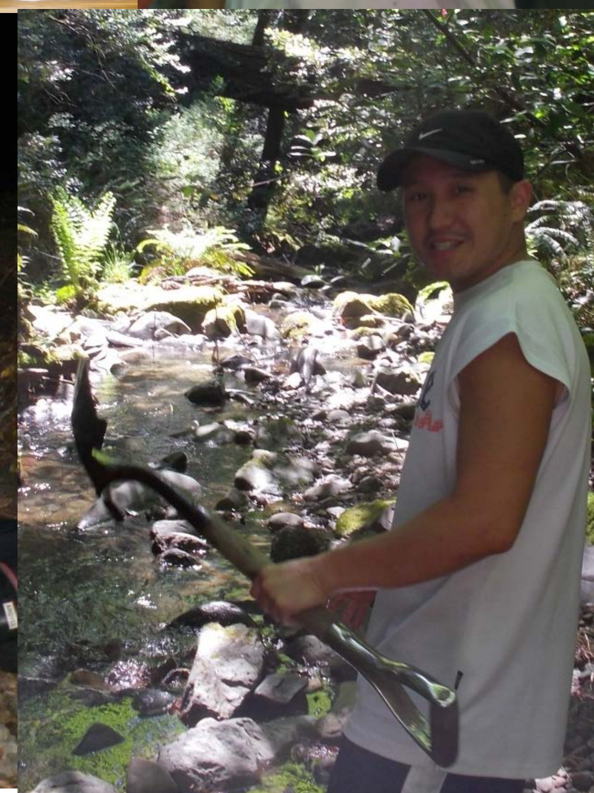
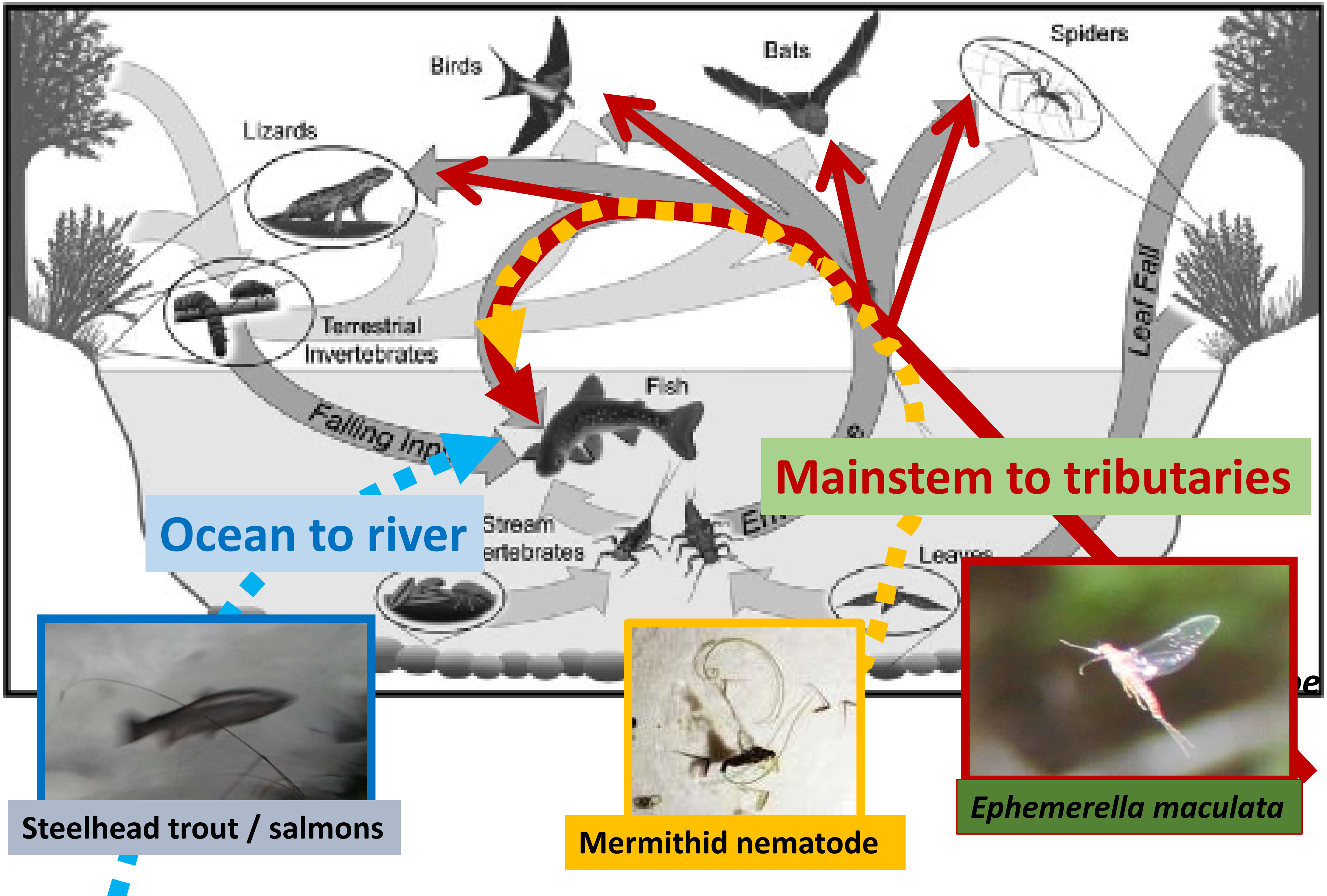
<u>Angelo Coast Range Reserve</u>

Peter Steel

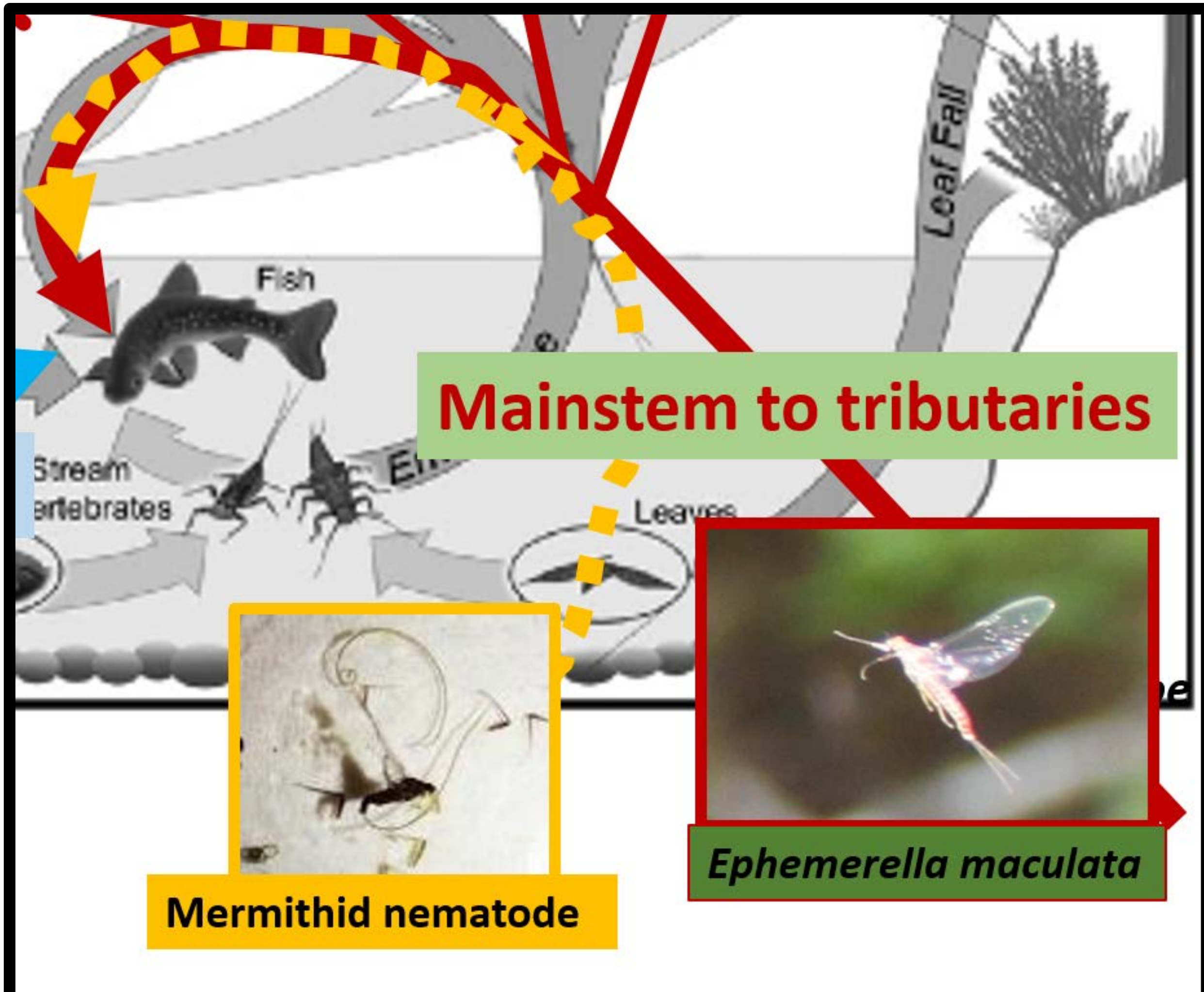


On-going projects: Dynamic food webs in river networks

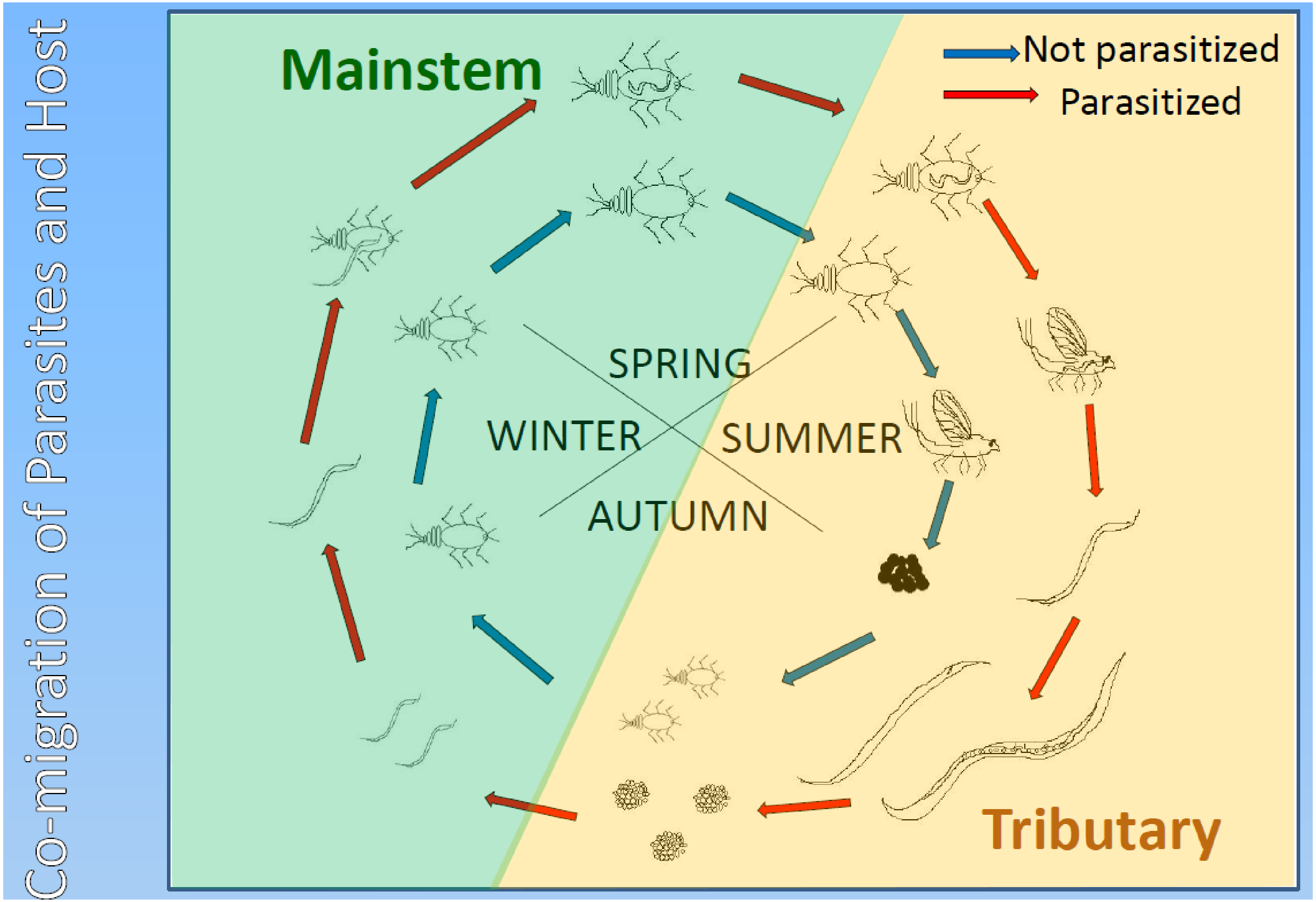


Mermithidae nematodes

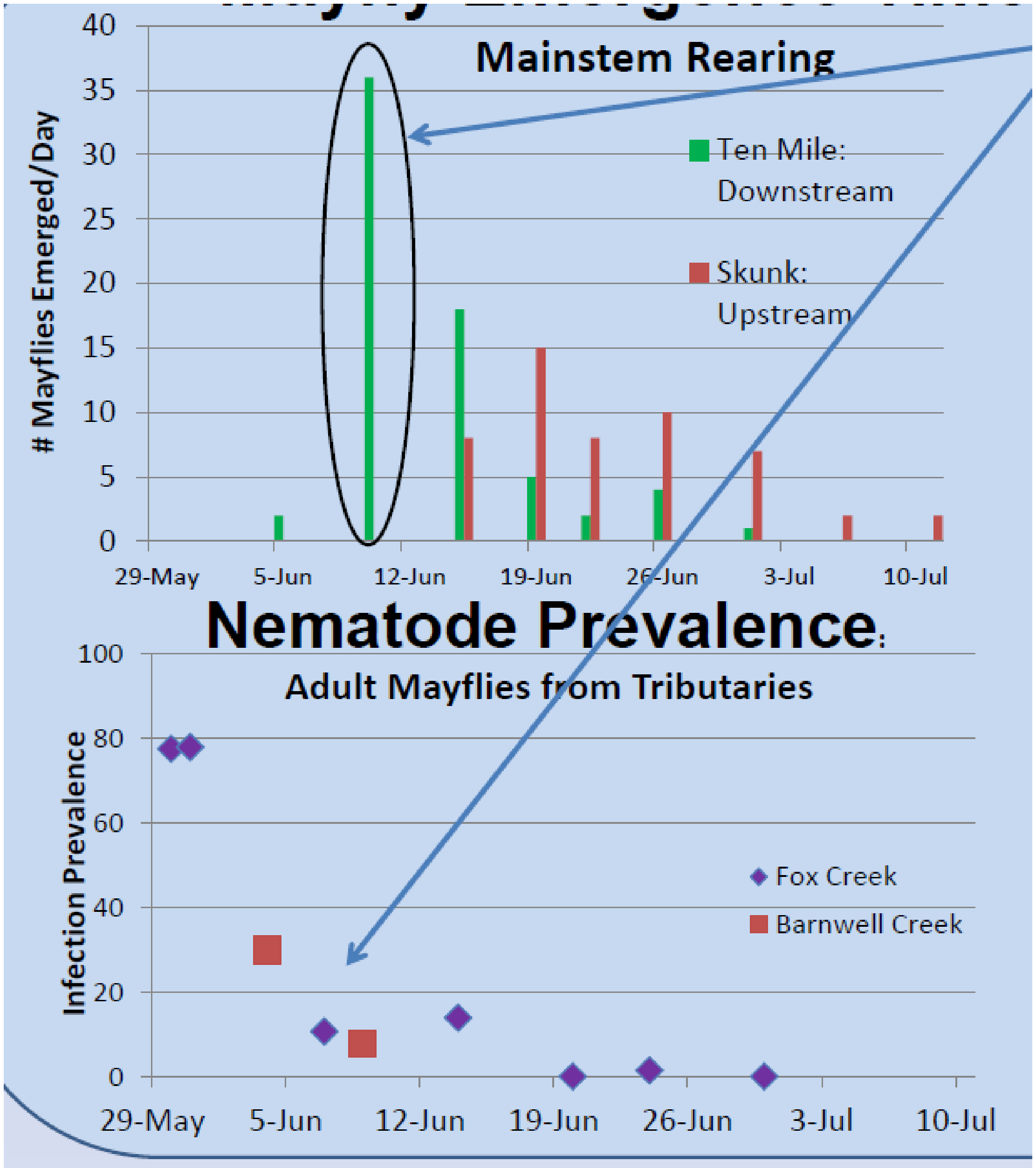
Larissa Walder




September 1, 2014
@ Fox creek, Angelo
Photo: Shelley Pneh

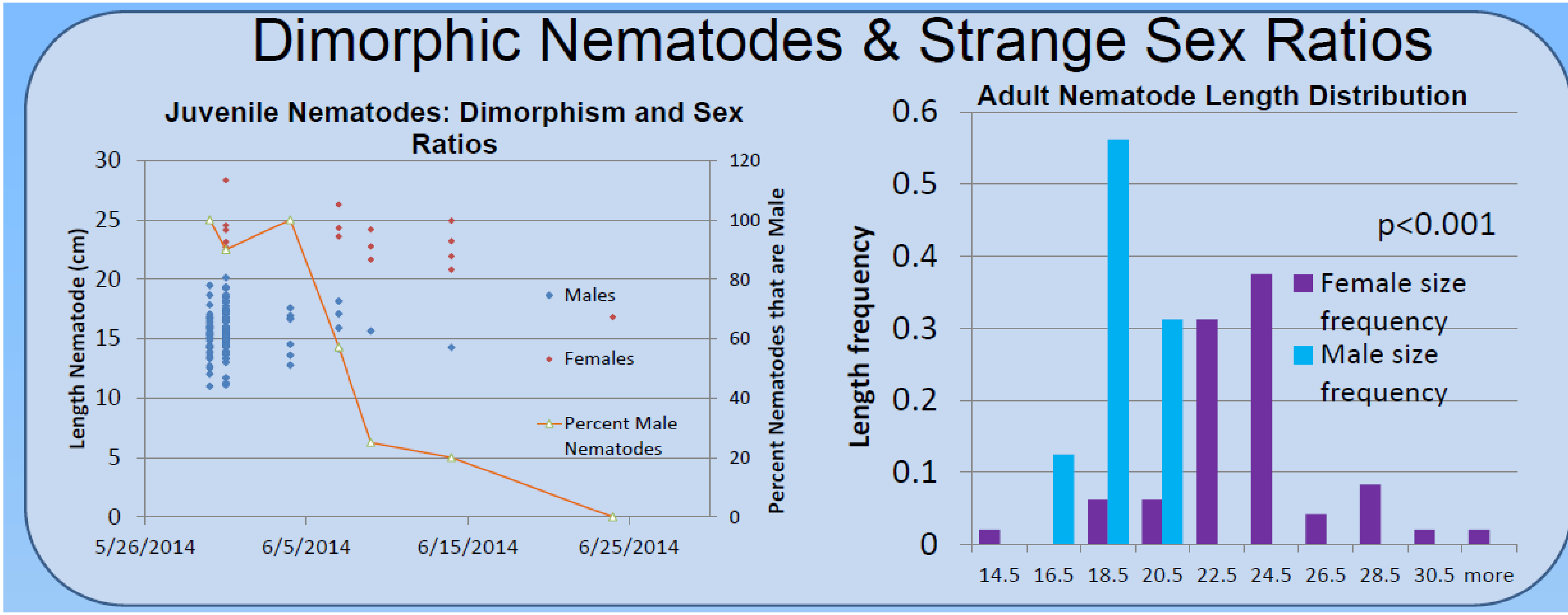


Larissa Walder, Hiromi Uno, Mary Power, 2014, *ESA poster*



High prevalence in early season

#Host mayflies from warmer habitat had higher prevalence?

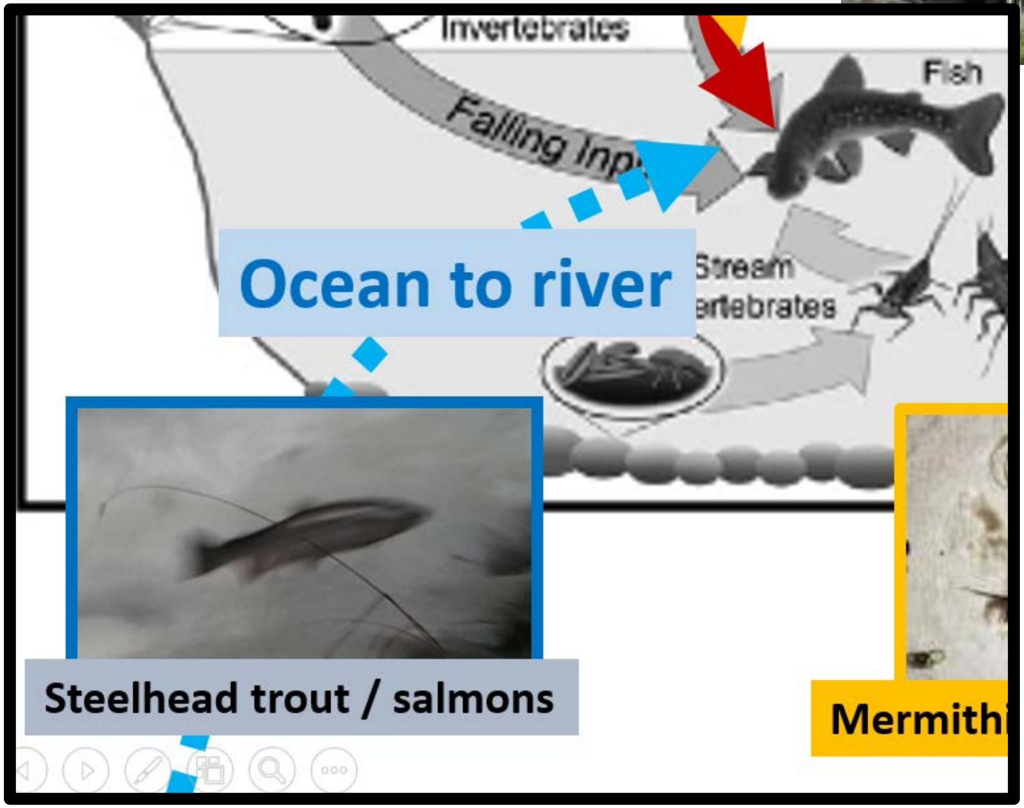


More male nematodes in early emerging mayflies

→ Male nematodes make mayflies emerge earlier to arrive the habitat earlier than females?

Steelhead trout movement in river networks

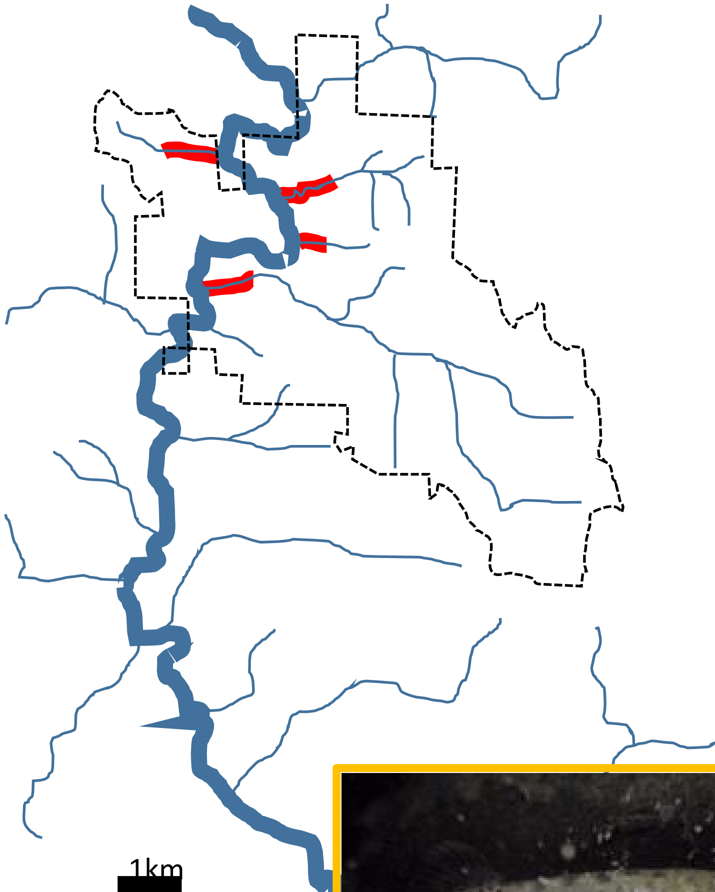
Eel River Recovery Project



OREGON
Fish & Wildlife

Oregon Department of Fish and Wildlife

Valuable fish density: time and space



Year to Year variation (@Fox creek)

in 2012 (Wet year): 0.35ind/m^2

in 2013 (Dry year): 0.07ind/m^2

in 2014 (Dry year): 0.001ind/m^2

Tributary to tributary variation (in 2013)

<Density>

0.1 - 3.7 individuals/m^2

<Body size>

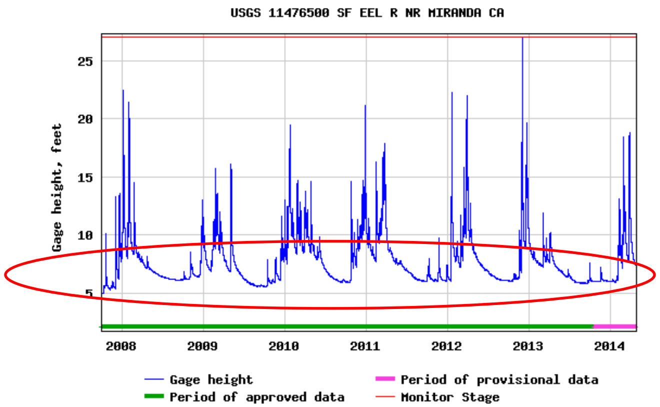
35 – 55mm

Many Small juveniles

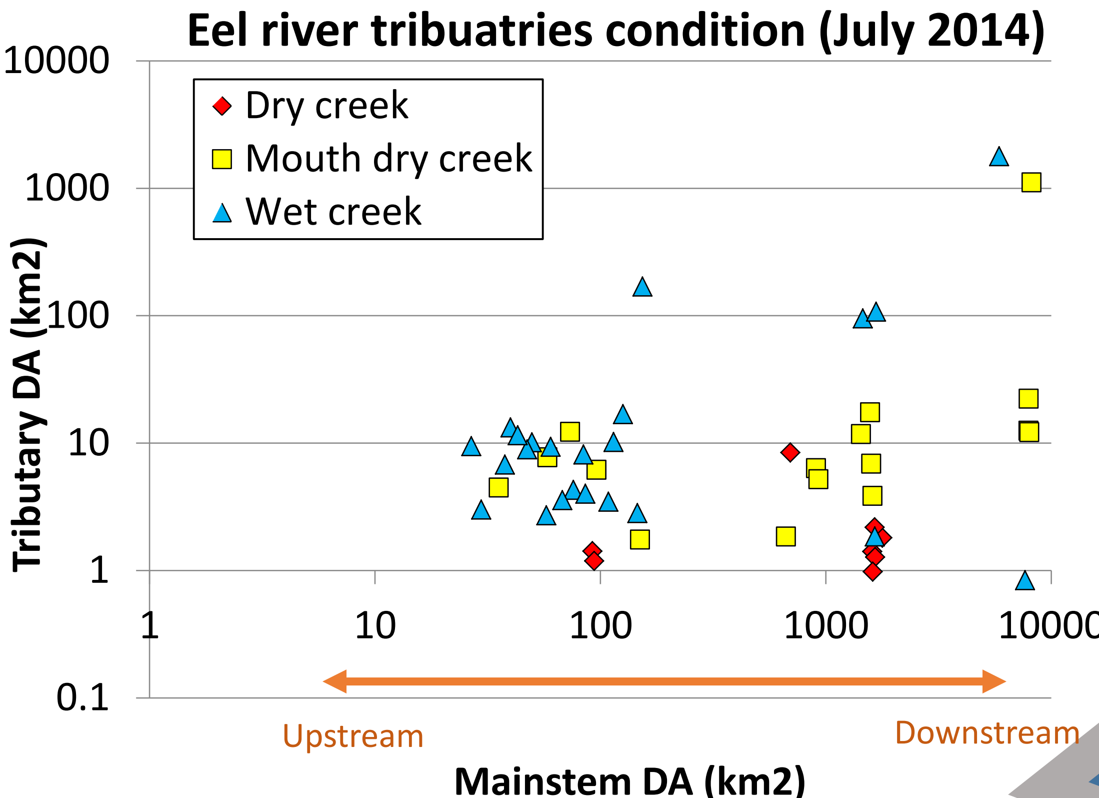
or

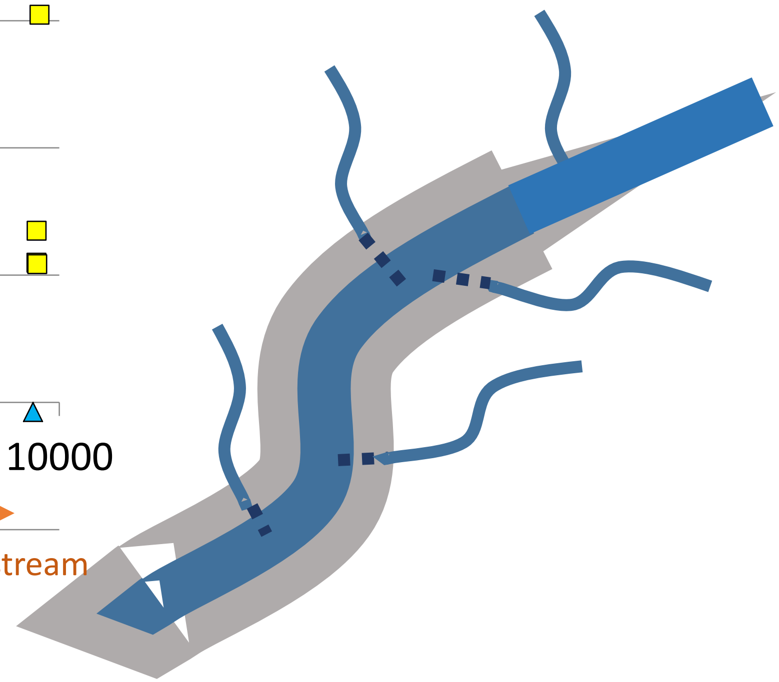
Few Large juveniles


2013.05.17

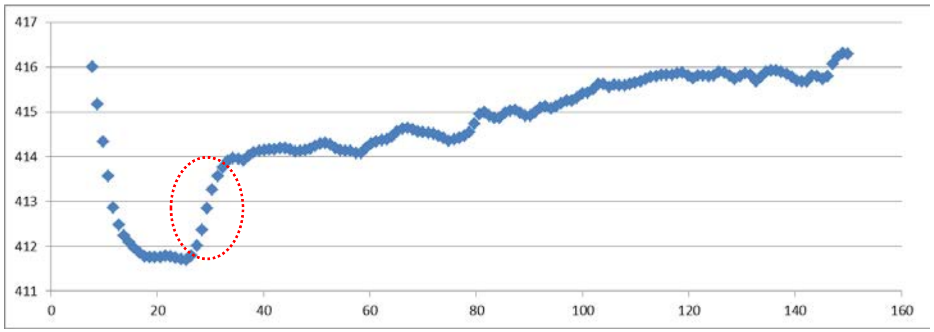


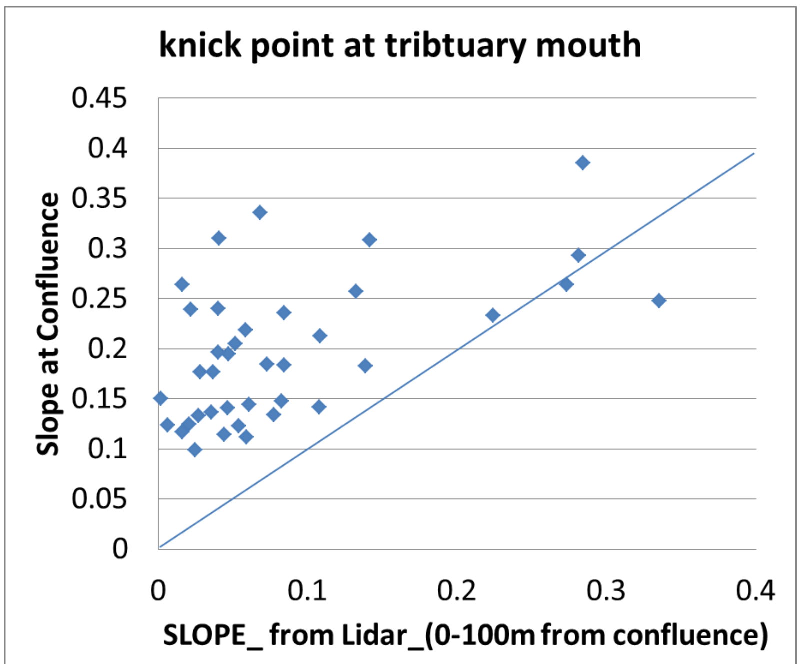
1. Many tributary mouths dry up in summer!





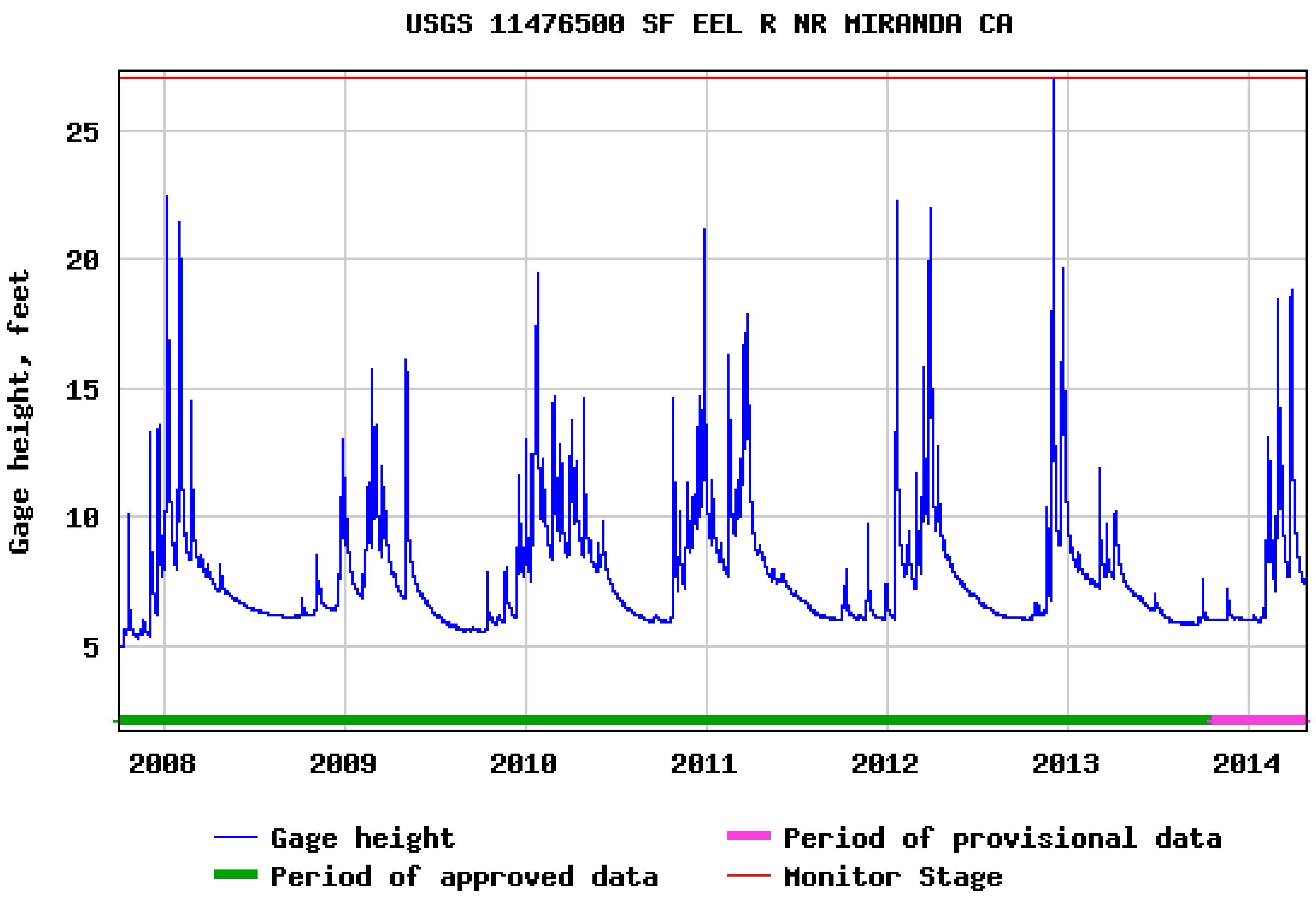
2. Gap at the mouths in low flow



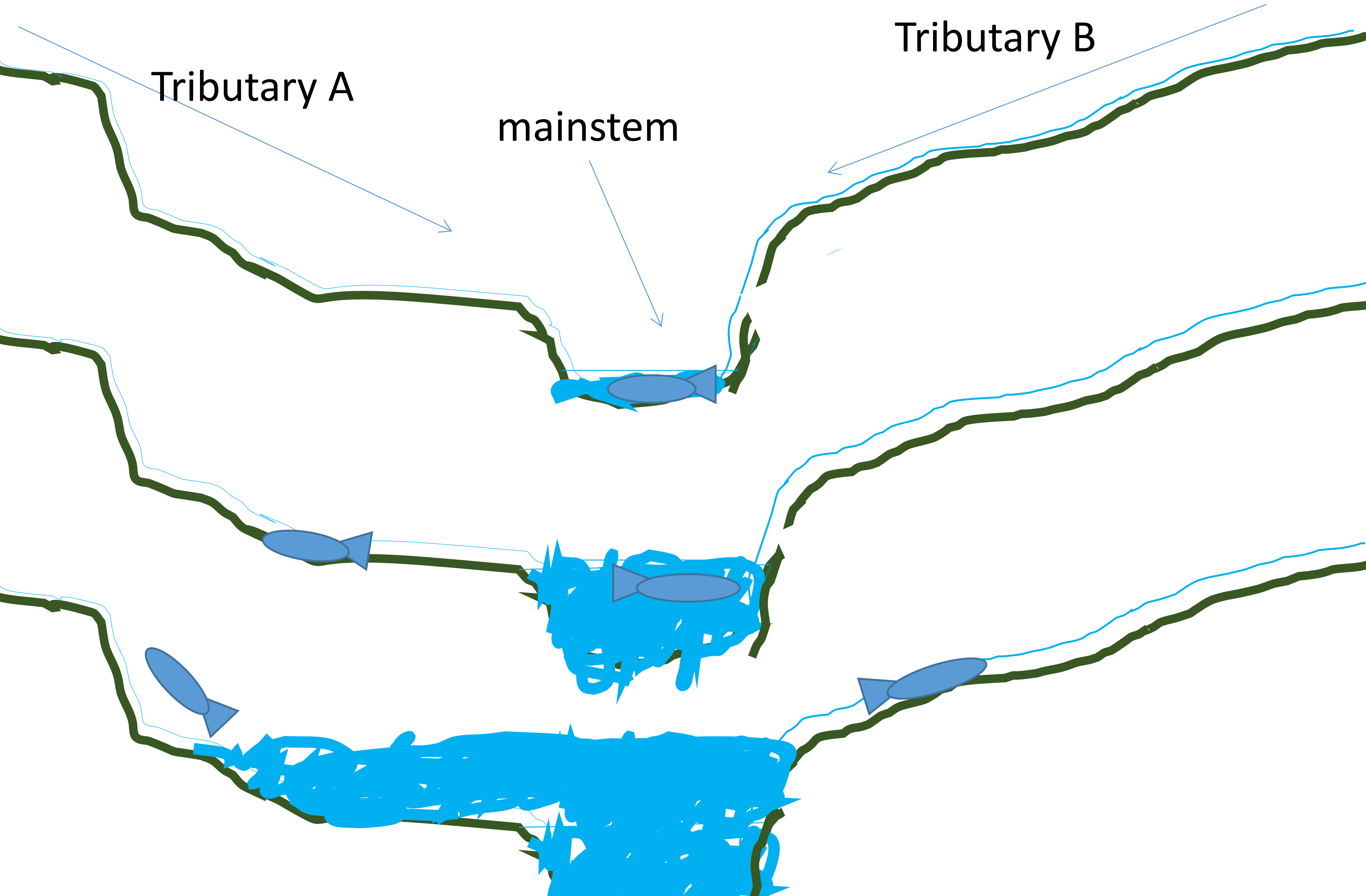


Summer low flow

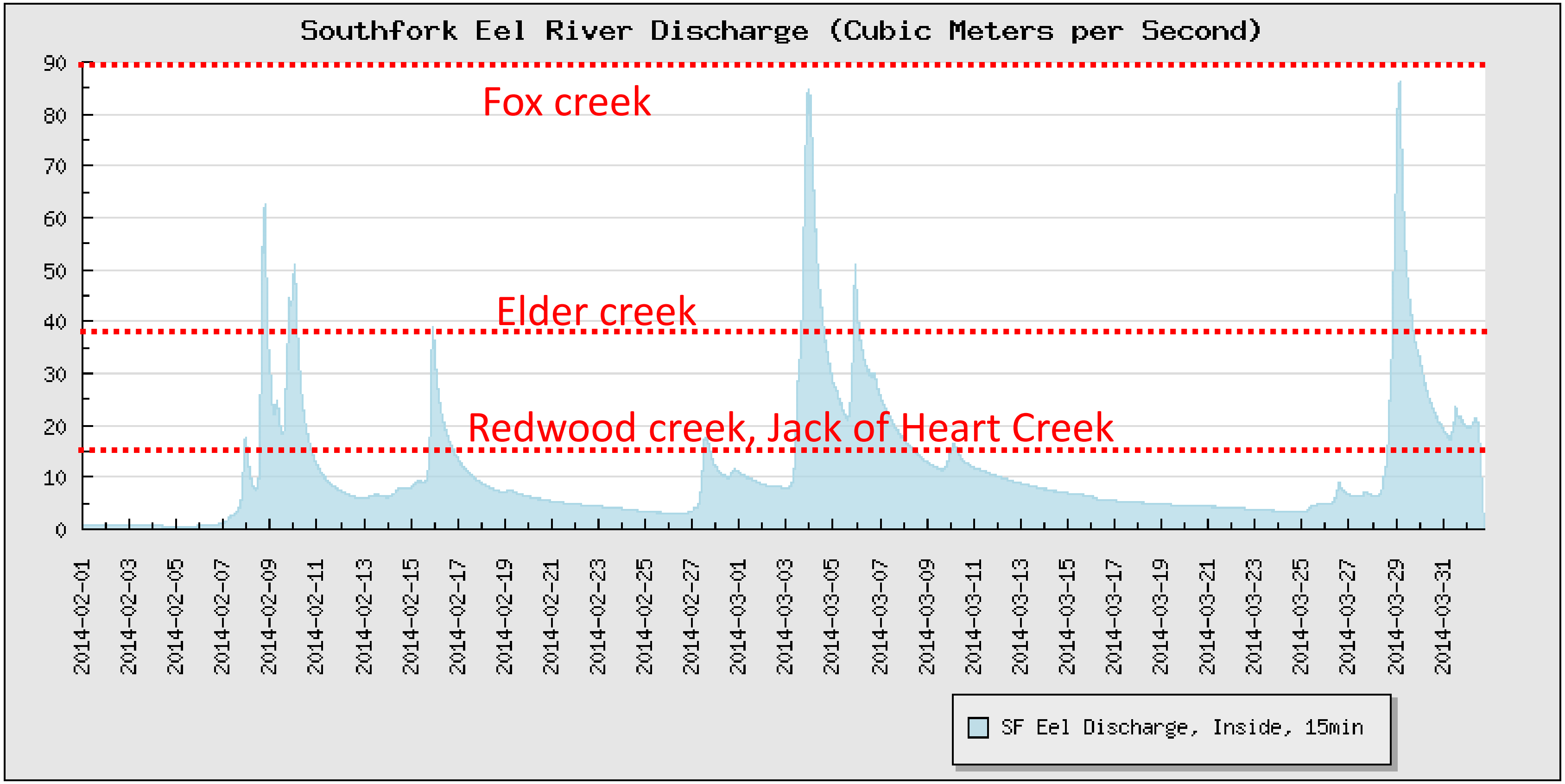
Winter flood


USGS 11476500 SF EEL R NR MIRANDA CA
Gage height, feet
25
20
15
10
5
2008
2009
2010
2011
2012
2013
2014
Gage height
Period of approved data
Period of provisional data
Monitor Stage

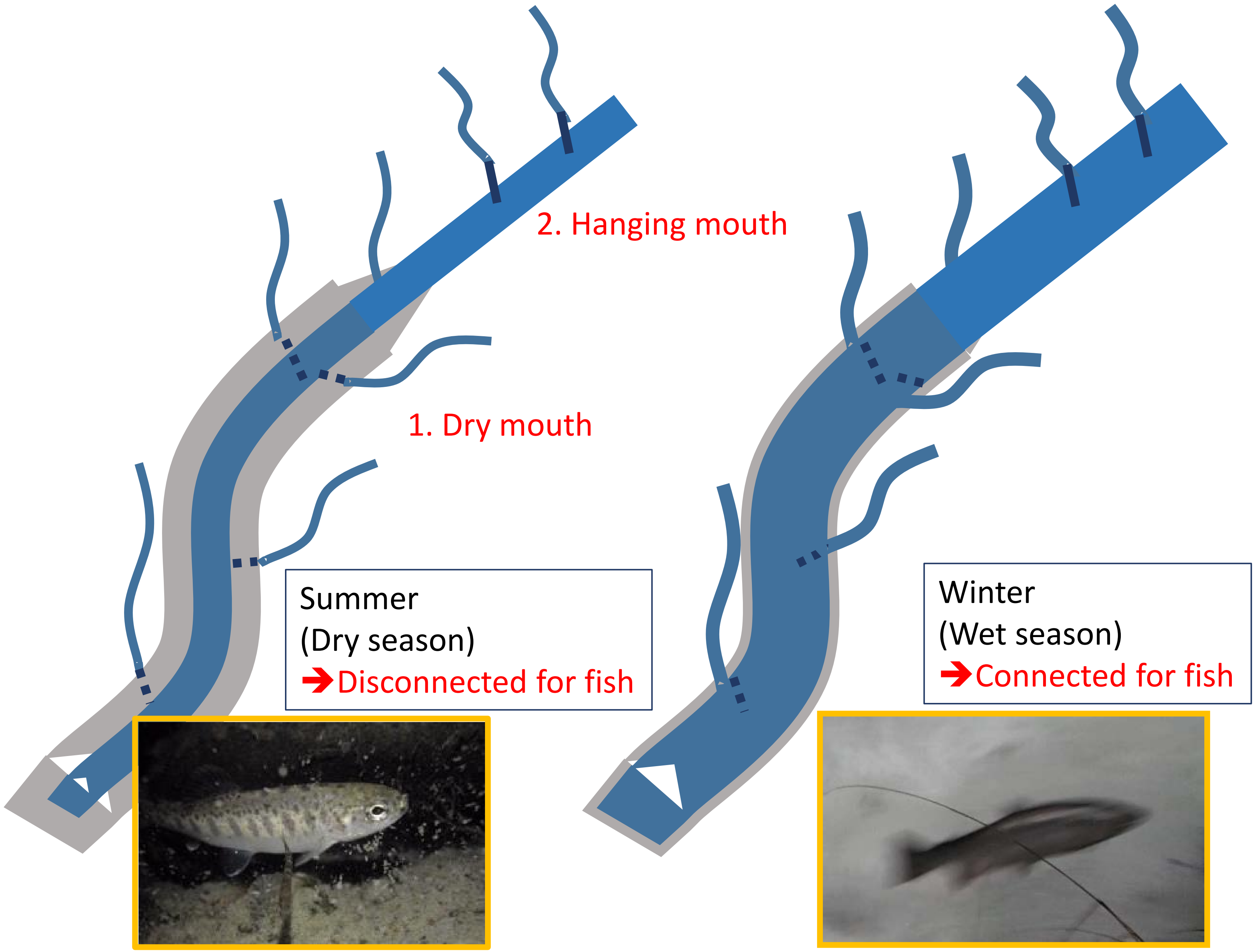
Recruitment control by Fish gate



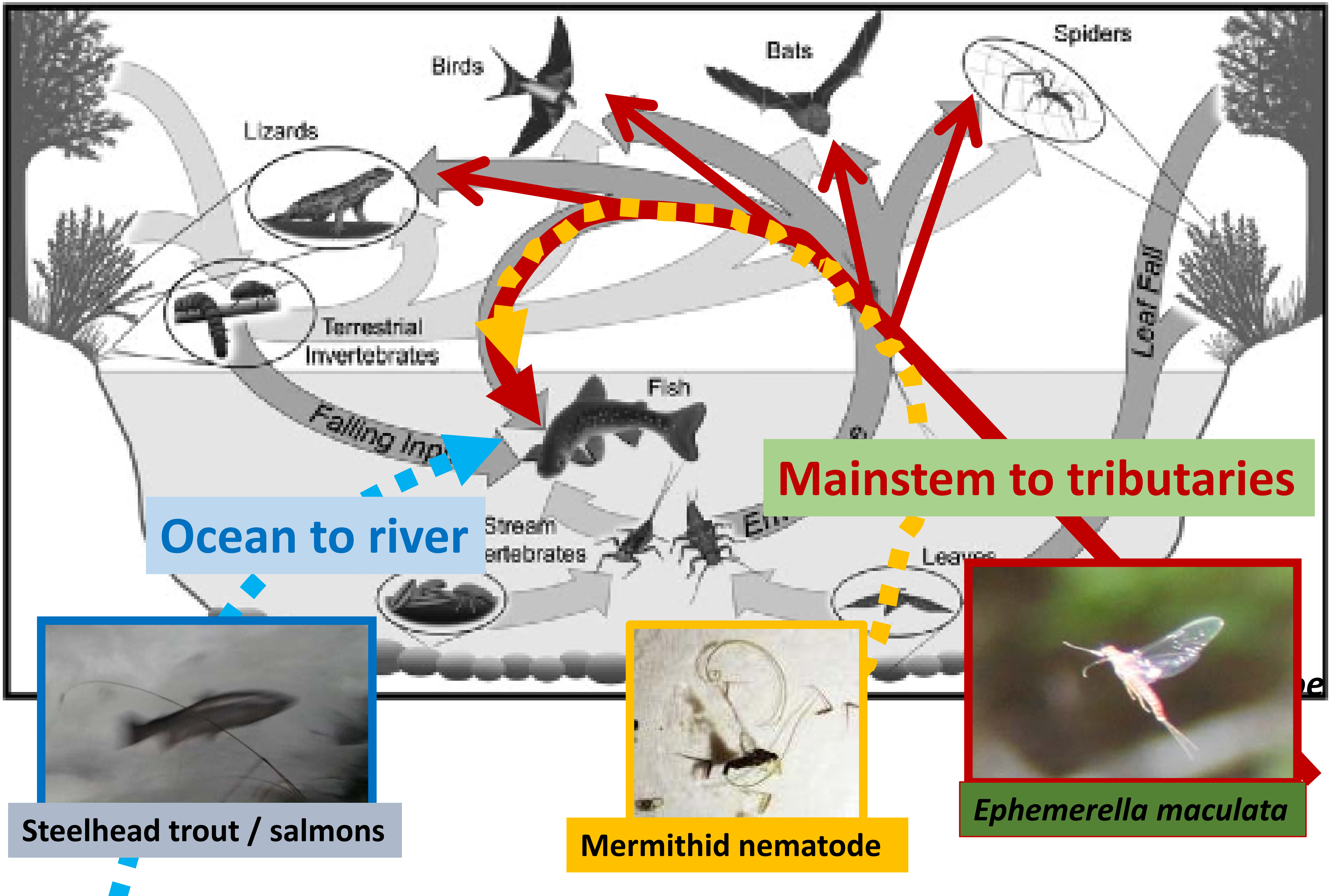
Adult salmonid accessibility monitoring ~2014 winter~



Fox creek: no adult access in 2014➔absence of juveniles in summer


2. Hanging mouth
1. Dry mouth
Summer
(Dry season)
➔Disconnected for fish
Winter
(Wet season)
➔Connected for fish

Dynamic food webs in river networks



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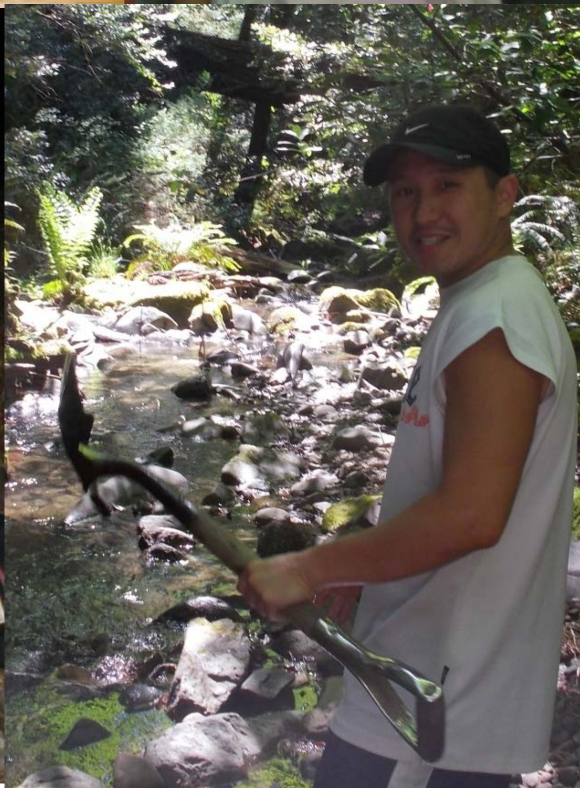
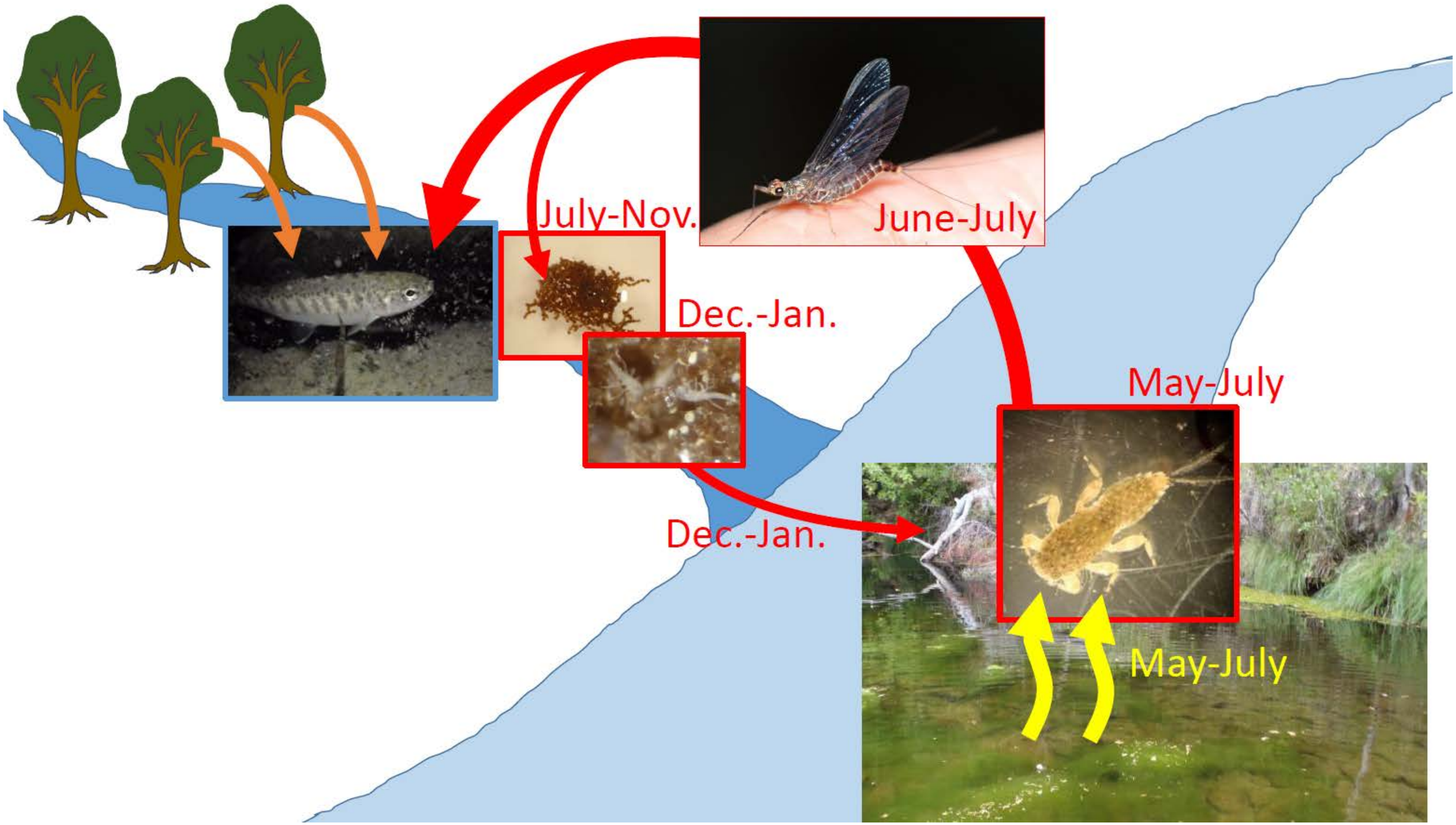


Steelhead movement in river network

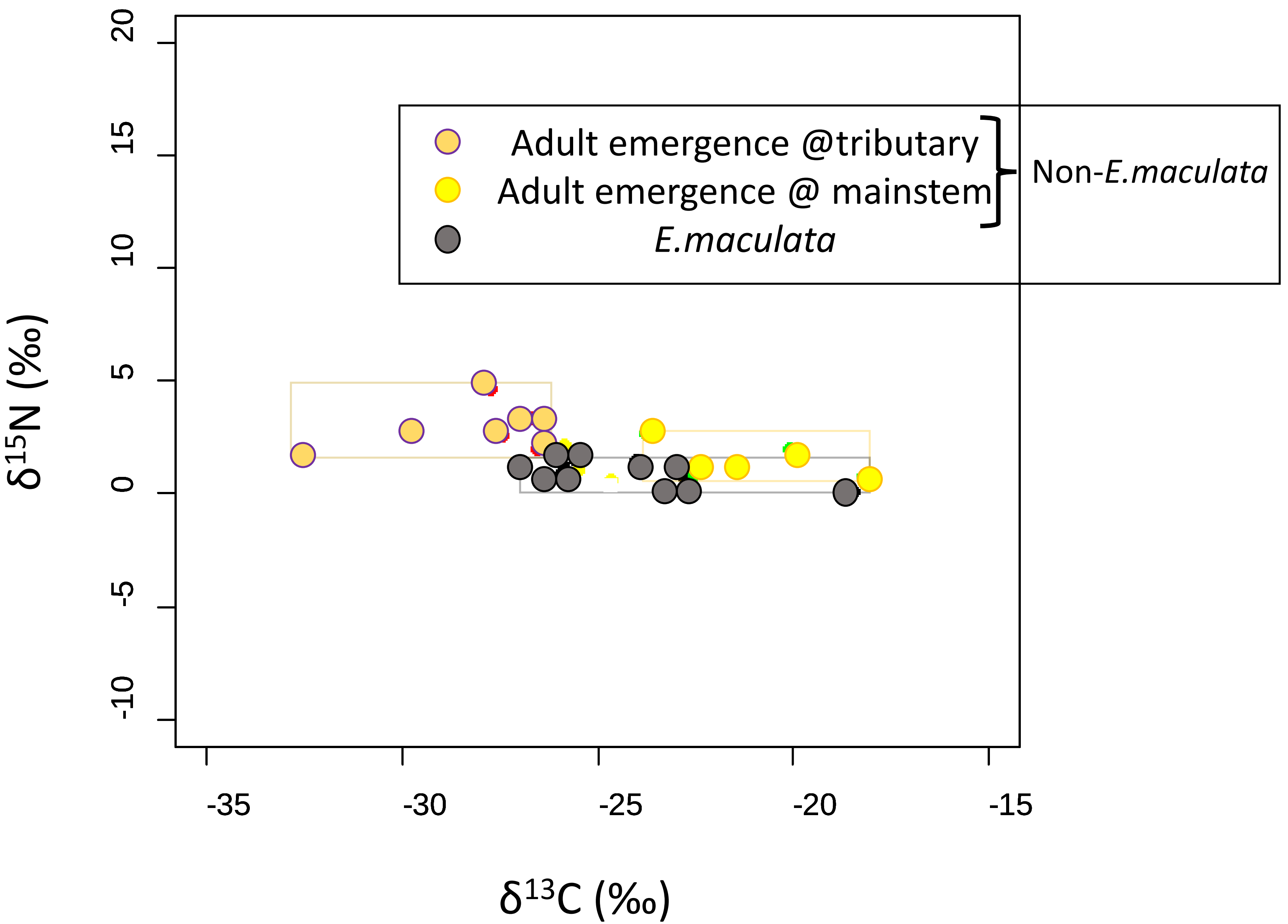


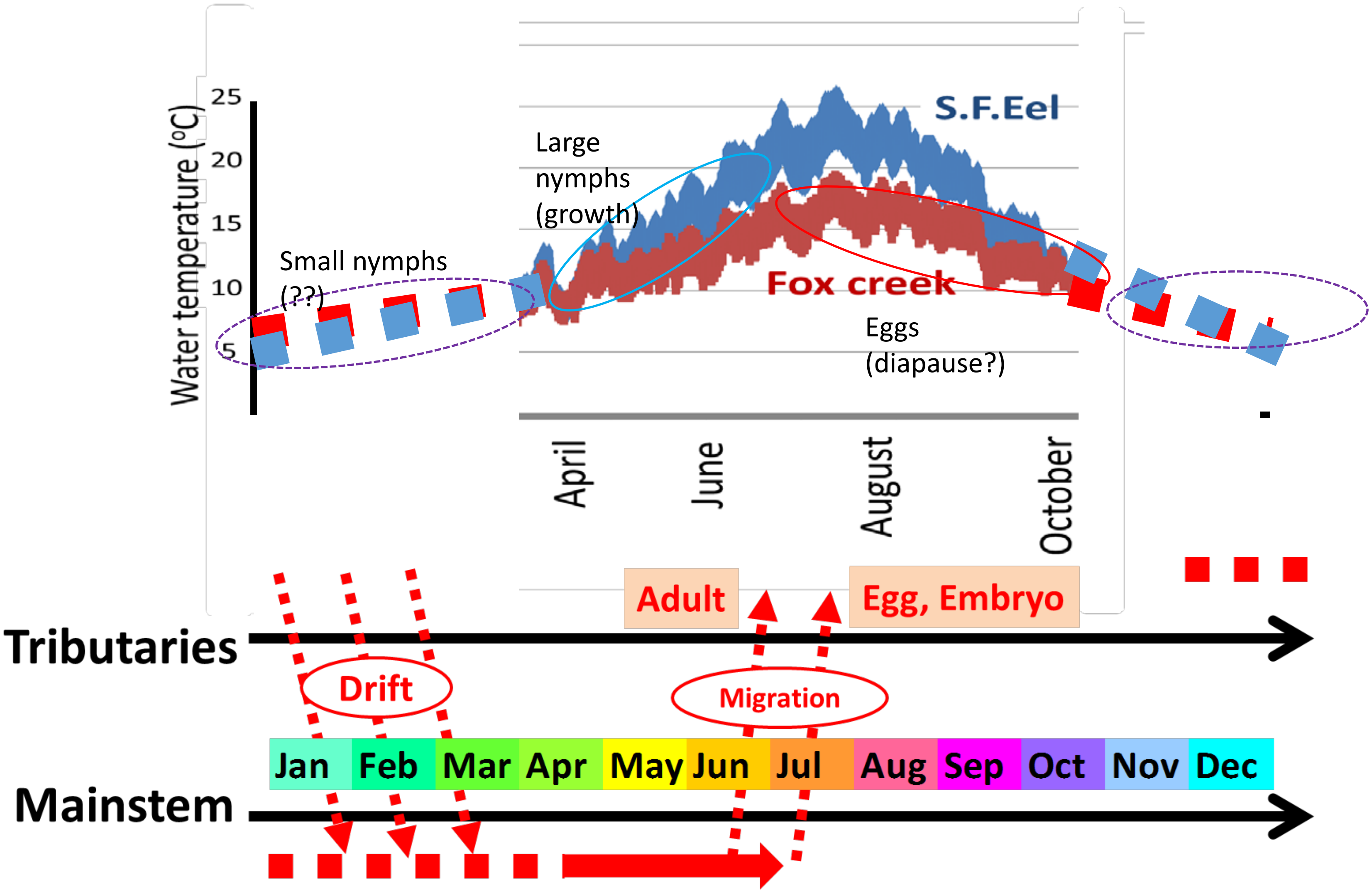
June-July
July-Nov.
Dec.-Jan.
May-July
Dec.-Jan.
May-July

Why do *E.maculata* migrate?

- Thermal adaptation?
- Food availability?

Stable isotope analysis also support the migration!!





Water temperature (°C)
25
20
15
10
5
S.F.Eel
Fox creek
Large
nymphs
(growth)
Small nymphs
(??)
Eggs
(diapause?)
April
June
August
October
Adult
Egg, Embryo
Tributaries
Drift
Migration
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Mainstem


September 1, 2014
@ Fox creek, Angelo
Photo: Shelley Pneh

Today’s talk

- Why do *E.maculata* migrate?
- Ecological consequence of the migration
- What tighten the effect of the subsidy?

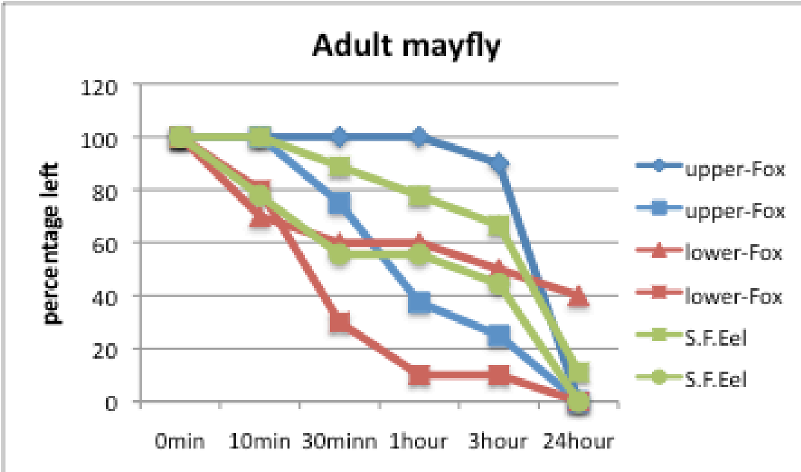
- Other migrants
  - Migration of nematodes that parasitize the migratory mayfly
  - Steelhead migration within river network

Why do *E.maculata* migrate?

- Predator avoidance?
- Thermal adaptation?
- Food availability?

Predator avoidance? Bondage experiments

Aquatic predator(fish, salamanders, water striders)

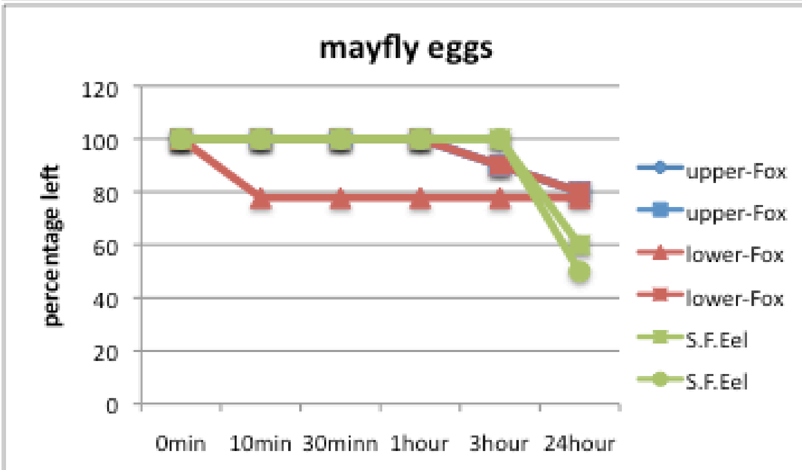


Adults eaten by predators but not eggs

Adult aquatic insect consumer by predators quickly

But

Eggs were not consumed by predators



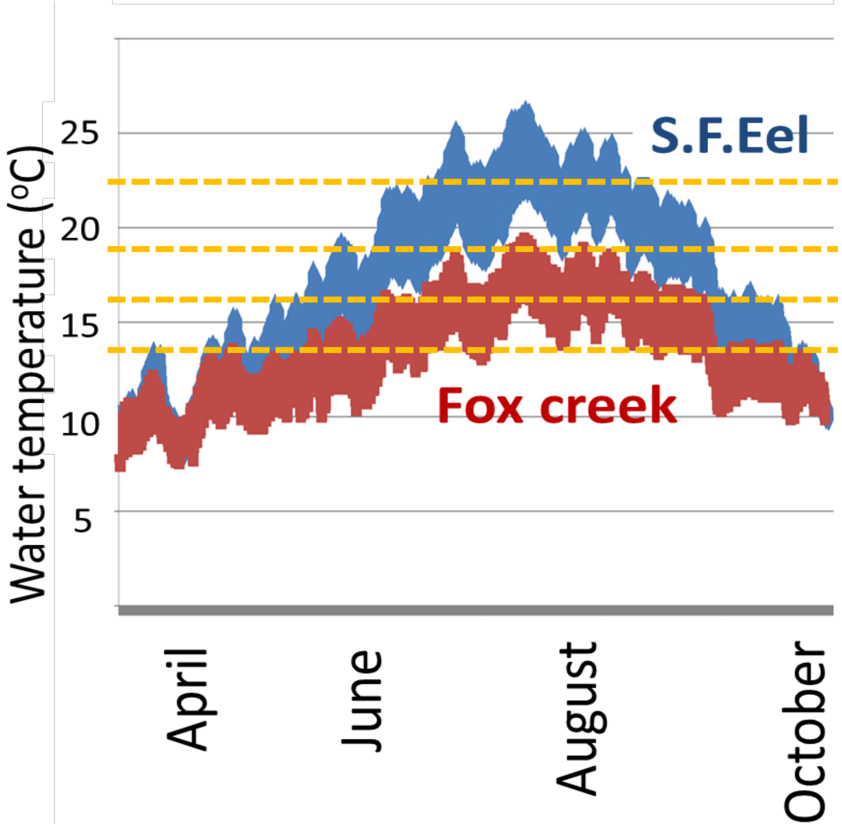
Eggs de-touch from female adults 1-3 sec after adults plunge into the water

Many *E.maculata* adults found in steelhead trout fish gut contents but no eggs

Thermal adaptation?

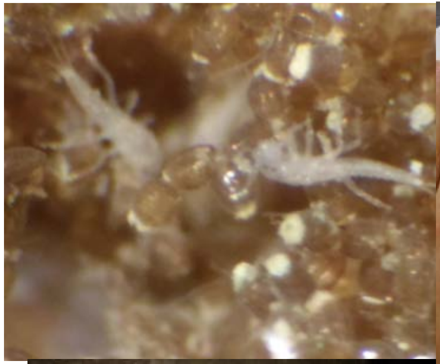
- Examine the optimal temperature for various life stages by rearing experiment in aquariums

(embryos, young nymphs and large nymphs)



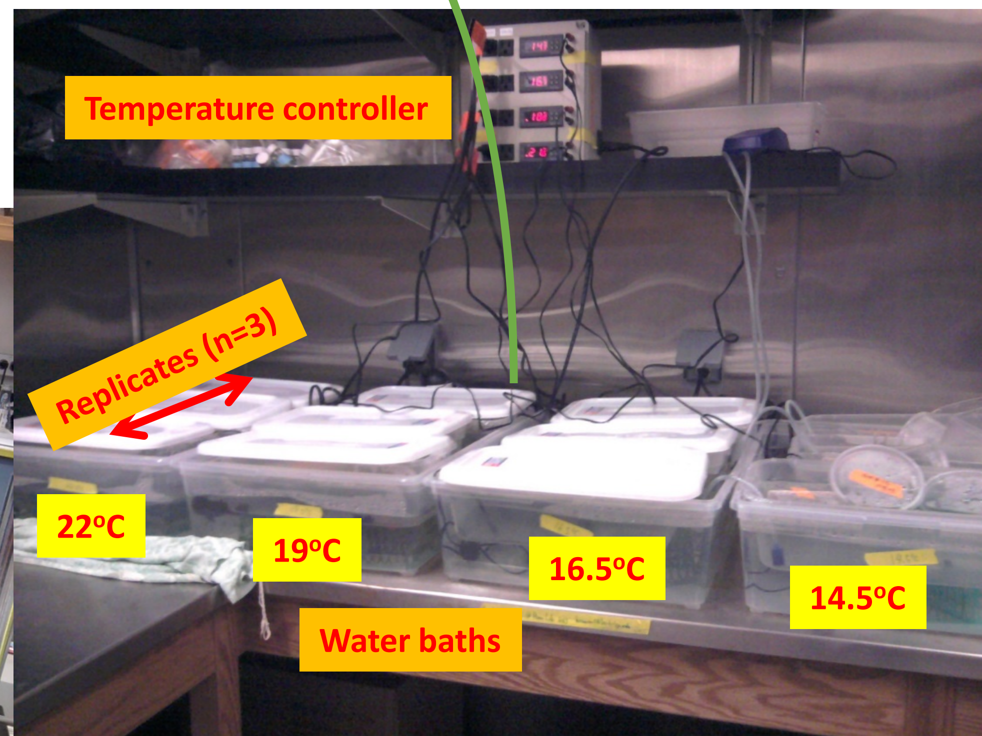
(Data by Goodrich M.L., 2004)

22C: summer mainstem
19C: summer mainstem low, Fox high
16.5C: summer Fox average
14.5C: summer Fox low



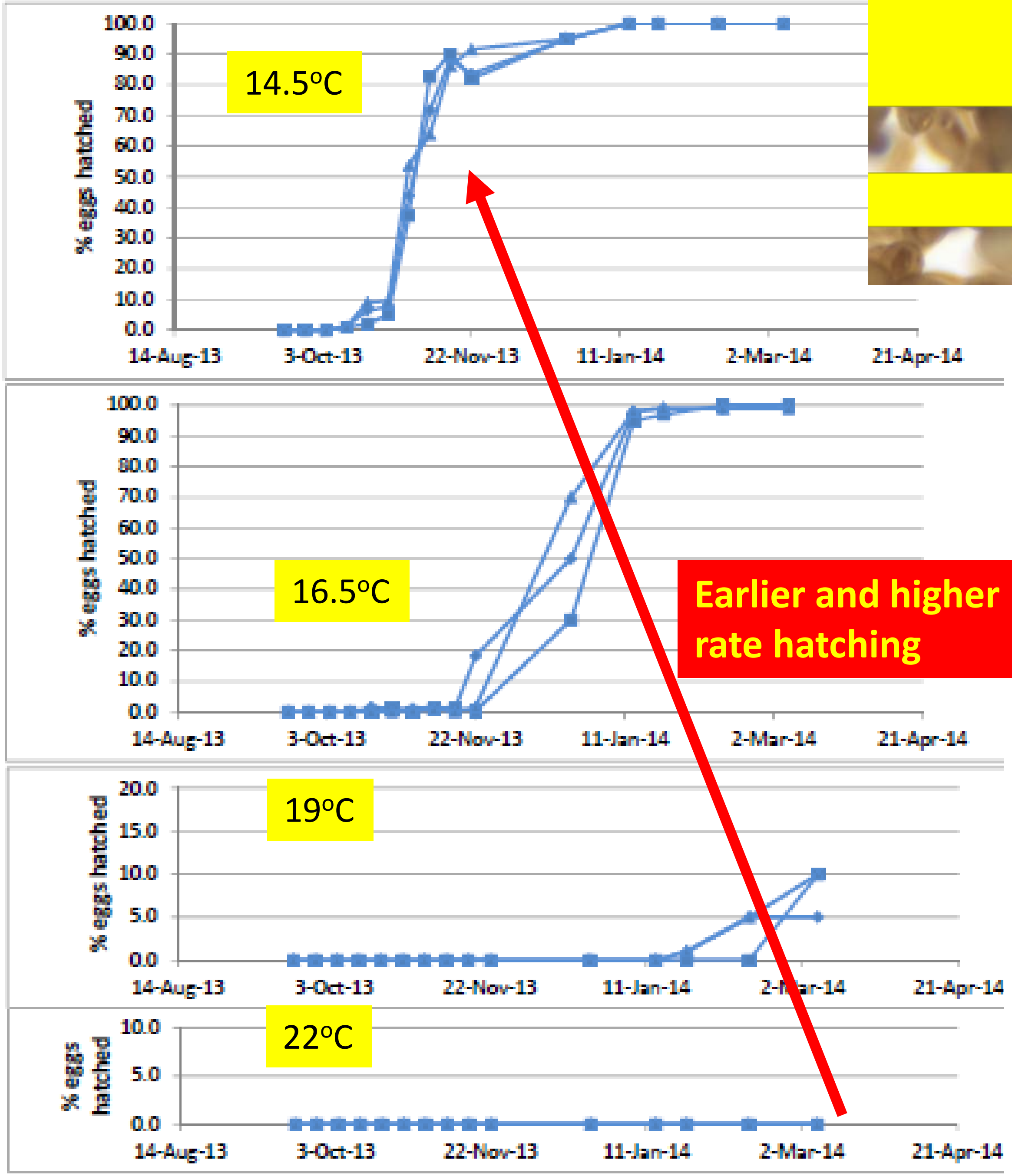
Each container contains one egg cluster (~30 egg masses)

Examine 5 visions and estimate the hatching rate



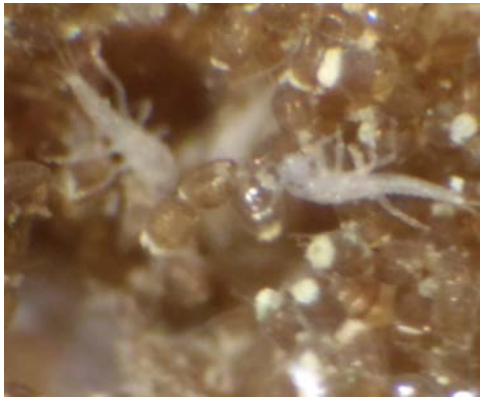
Results: Eggs

Summer tributary temperature

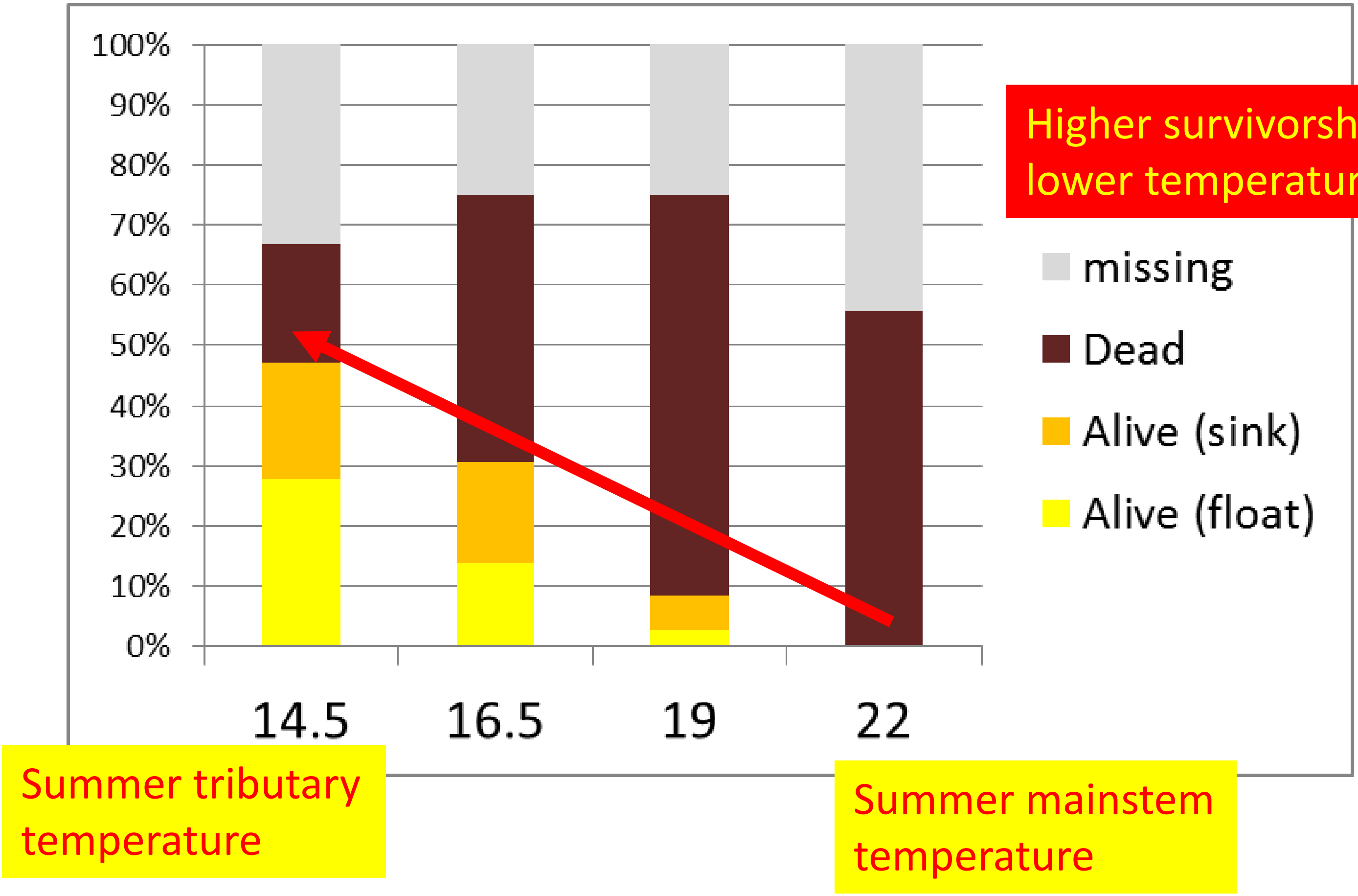


Summer mainstem temperature

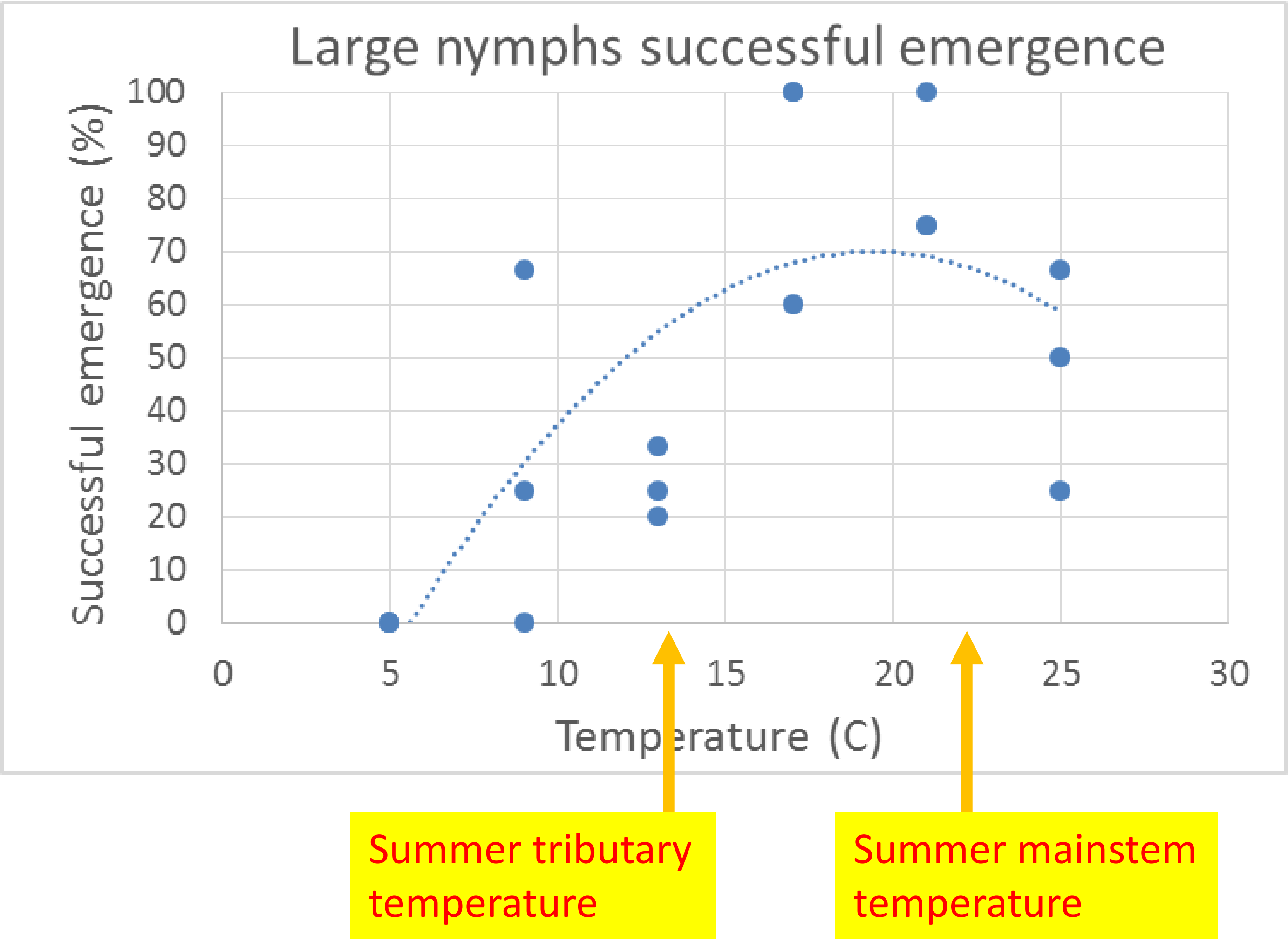
Results: Young nymphs



Survivorship after 10 days



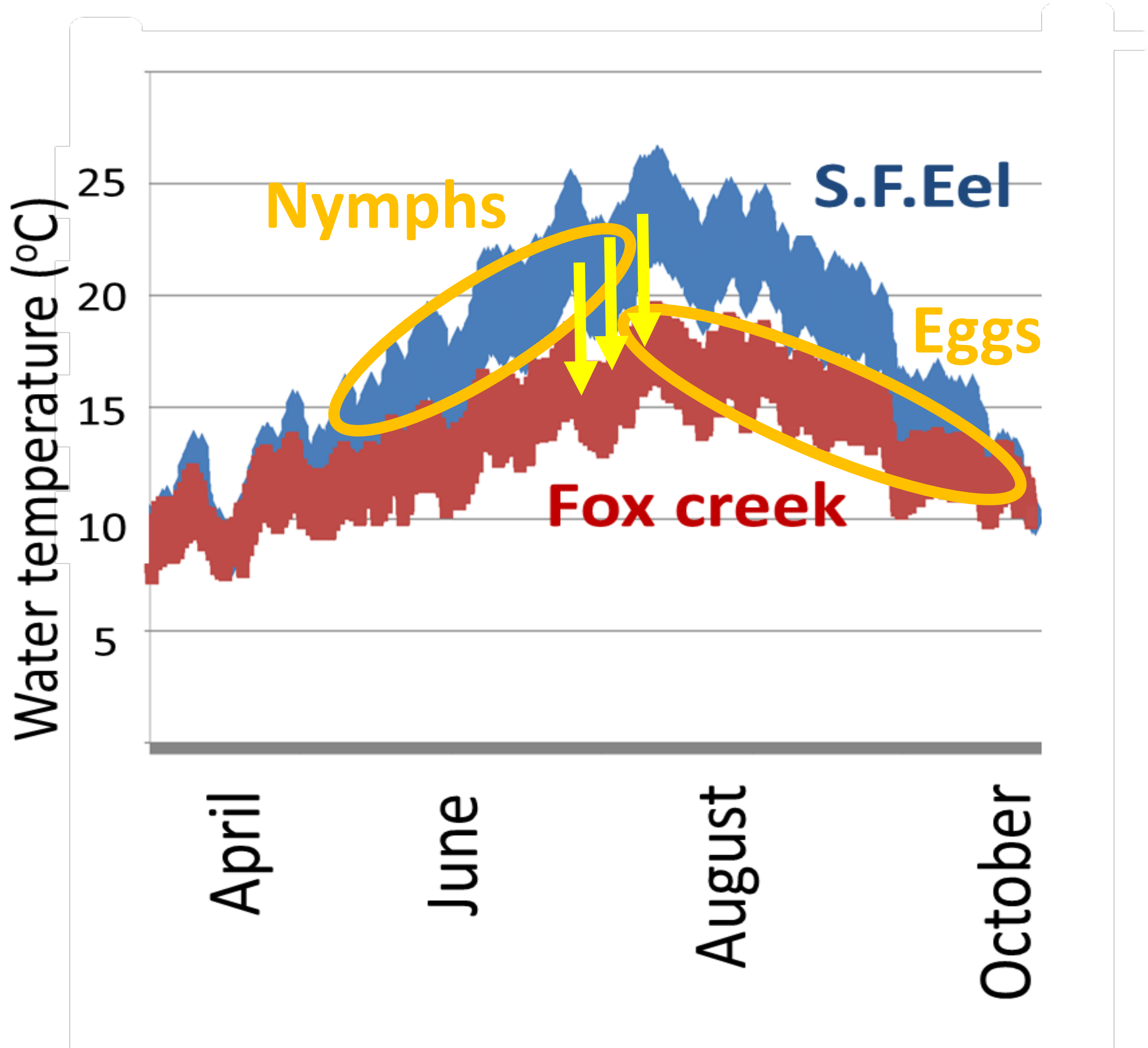
Results: large nymphs



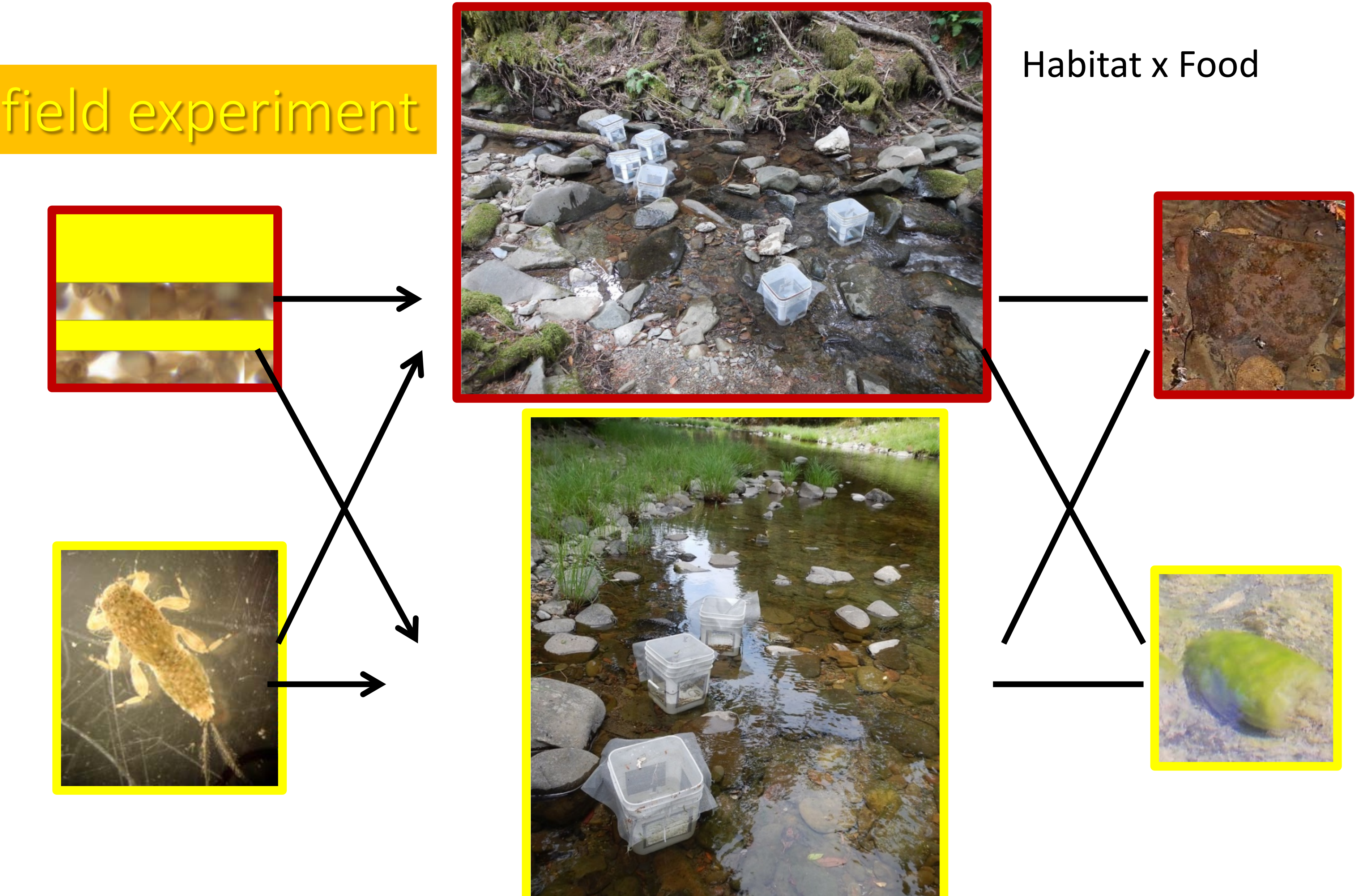
Higher survivorship at mainstem temperature

Optimal temperature differs among life stages

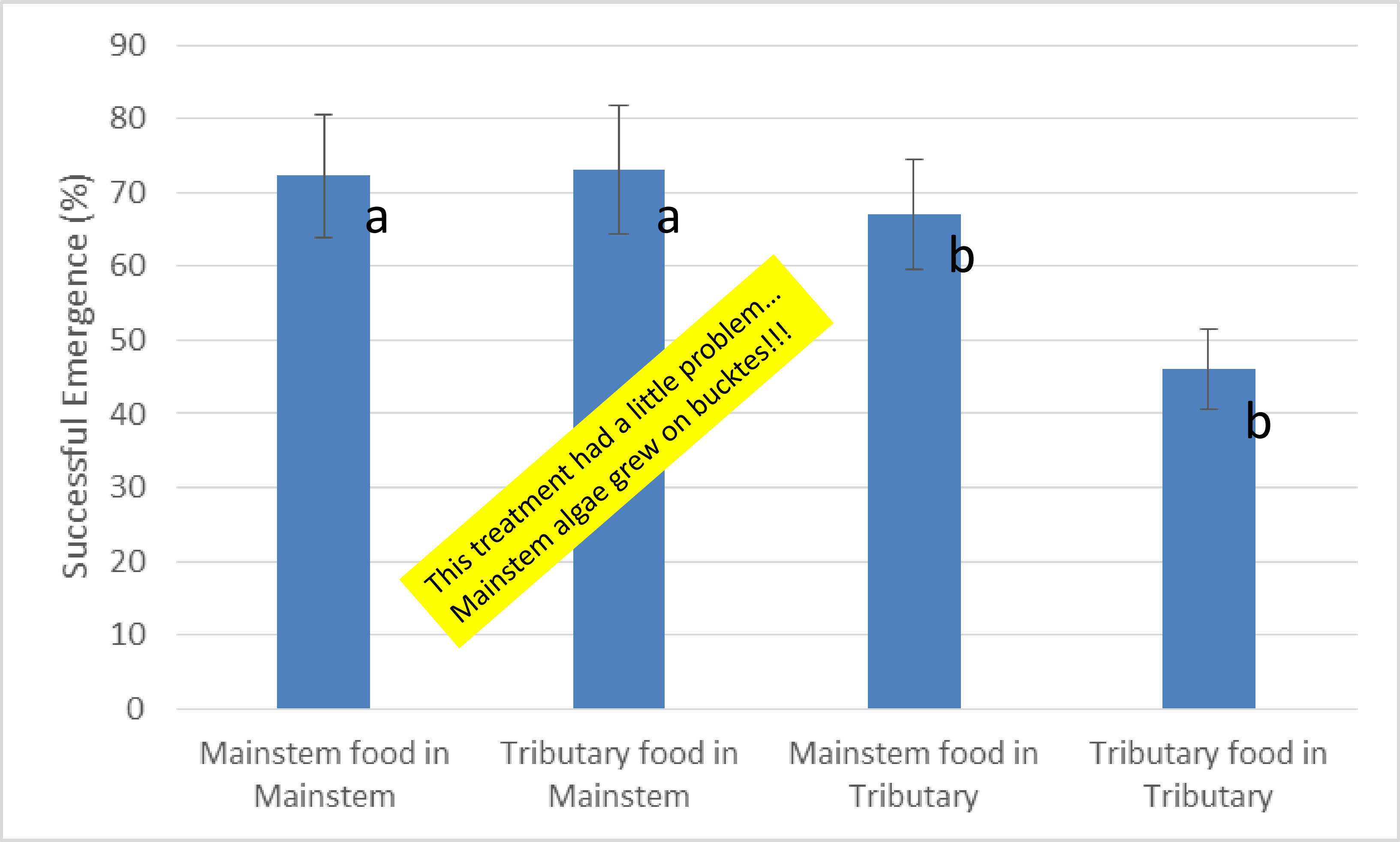
- Eggs and young nymphs: better at tributary temperature
- Large nymphs: better at mainstem temperature



Food availability? Feeding experiment



Results: transplant experiment



Food is also important factor for large nymphs in addition to temperature

Summary: why they migrate?

- Predator avoidance? **X**
- Thermal adaptation? **O**
- Food availability? **O**

Ecological Consequences of the migration