Goal: Link population dynamics to flow conditions

Task 1: Detect emergent population patterns

Task 2: Explore the mechanisms of velocity effects on tadpoles

Task 3: Demographic study
Emergent patterns from egg mass time series

- S. Fork Eel, unregulated
  - compare rainy vs dry springs
- N. Fork Feather, regulated
  - Poe, spring spill, no summer pulses
  - vs
  - Cresta, spring spill + summer pulses
- Alameda Creek
  - unregulated vs. spring spills
Rainfall / pulse effects on survival to hatching
SF Eel  Spring 2005

- 19% scoured by pulsed flows
- 1% survived pulsed flow intact
- 9% partial eggmass remaining after pulse
- 10% laid after pulse, intact


Followed fate of previous 270, found 119 new
Fate of previous 119, found 39 new

270 clutches followed fate of previous 270, found 119 new
Fate of previous 119, found 39 new

1% scoured by pulsed flows
19% survived pulsed flow intact
9% partial eggmass remaining after pulse
71% laid after pulse, intact
Annual rate of change in breeding population, \( \lambda \)

Dark bars = 3 yrs after “no pulse” springs
Light bars = 3 yrs after “pulse” springs
Three year lag between detrimental breeding season conditions and declines in the population growth rate.

$N = 482 \pm 47$ egg masses / yr

Mann Whitney $U = 45$, Bonferroni corrected value for three comparisons

$p = 0.05$
N. Fk. Feather
Support for 3-yr lag recruitment limitation hypothesis

N. Fk. Feather
Support for 3-yr lag recruitment limitation hypothesis

Poe

Cresta

Egg masses

10,000

1,000

50

10,000

1,000

50

Egg masses

10,000

1,000

50

10,000

1,000

50
Time to reproductive maturity supports recruitment limitation / lag time hypothesis

female growth predicted from Von Bertalanffy Growth Equation

Data from NFFR Collected by Garcia and Associates for PG&E and CEC
Data from Coyote Creek by Earl Gonsolin
Above diversion, near Camp Ohlone

clutches / km      discharge (m³sec⁻¹)

(a)

near confluence with Calaveras Ck.

clutches / km

(b)
What is the shape of the function relating poor recruitment conditions to population trajectories?
Task 2: Velocity Manipulations

Survival after two weeks in flow through enclosures

\[ r^2 = 0.61 \]
Mixed stage older tadpoles -- artificial stream
Mean Velocities

<table>
<thead>
<tr>
<th>$V_1$</th>
<th>0.95 ± 0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_2$</td>
<td>6.20 ± 0.5</td>
</tr>
<tr>
<td>$V_3$</td>
<td>17.00 ± 0</td>
</tr>
<tr>
<td>$V_4$</td>
<td>40++</td>
</tr>
</tbody>
</table>

$n=5$ paired hour-long trials, 20min at $V_1-V_3$.

One side with rocks embedded in foam

Other side rocks sitting on foam
Artificial Stream Channel as velocity increased

Tadpoles became less active ... and stayed in refugia

activity

emigration

Repeated-measures ANOVAs:
• no effect of embeddedness
• significant velocity effects

...or got completely flushed downstream when we turned the big pump on
Field manipulations similar to “V₂” in Artificial Stream

<table>
<thead>
<tr>
<th>Final fate</th>
<th>Drift fence</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># tadpoles</td>
<td># tadpoles</td>
</tr>
<tr>
<td></td>
<td>(n=50)</td>
<td>(n=10)</td>
</tr>
<tr>
<td>Returns to shore</td>
<td>18%</td>
<td>0%</td>
</tr>
<tr>
<td>Swept away</td>
<td>52%</td>
<td>80%</td>
</tr>
<tr>
<td>Finds refuge</td>
<td>30%</td>
<td>20%</td>
</tr>
</tbody>
</table>
Box Flume

<table>
<thead>
<tr>
<th></th>
<th>Trial 1 (n = 20 larvae / trial, 18 hours)</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (cm/sec)</td>
<td>16.5±0.5</td>
<td>20.1±2.8</td>
</tr>
<tr>
<td>Final fate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swept away</td>
<td>40%</td>
<td>70%</td>
</tr>
<tr>
<td>Finds refuge</td>
<td>60%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Arrows indicate direction of flow

![Flume diagram](image)
Critical velocity in Brett Chamber

Significant effect of mass (ANCOVA p<.001)
no effect of source, or mass X source
Critical velocity as a function of Developmental Stage and Size

Gosner stage range (mean tadpole mass)

- 27-30 (0.26 ± 0.04 g) with n=7
- 31-34 (0.62 ± 0.14 g) with n=19
- 35-38 (1.06 ± 0.05 g) with n=17
- 39-42 (1.94 ± 0.06 g) with n=10

Lungs & gills, legs & tail, Mouth change
Energetic consequences of being less active and staying in refugia

2005 Results
Experiment duration approx 6 weeks

- Low velocity
  - Temperature °C: 18.5 ± 0.2
  - Total length (mm): 35.3 ± 1.5 **
  - Gosner stage: 34.5 ± 0.3 **
  - Weight (g): 0.62 ± 0.05**

- Elevated V
  - Temperature °C: 18.5 ± 0.3
  - Total length (mm): 29.5 ± 1.9
  - Gosner stage: 32.4 ± 0.24
  - Weight (g): 0.33 ± 0.04
Tadpoles risk predation when in flow refugia under rocks.

- **Velocity**
  - Low
  - Low $\uparrow v$
  - $\uparrow v$

- **Predator**
  - -
  - +

- **Treatment**
  - n = 6 enclosures / trtmt

- **2-way ANOVA:** Significant effects of predator, velocity $p=0.1$

- **Graph:**
  - # of tadpoles per enclosure over time (5/25/06 to 6/22/06)
  - Velocity (cm/sec): 0, 2, 4, 6, 8, 10, 12
  - Cleaned screens 24 hrs later
  - low vel, - pred
  - hi vel, - pred
  - low vel, + pred
  - hi vel, + pred

- **Bar Graph:**
  - Velocity x predator
  - 5/25/06 6/1/06 6/8/06 6/15/06 6/22/06
Tadpole Response to Velocity Manipulation: Summary

- **Brett Chamber**
  - Critical velocity varies with stage, size, population, and activity
  - 66% exhausted @ 30 cm/sec

- **Artificial Stream**
  - Tadpoles shelter in crevices
  - 39% displaced at 16-22 cm/s
  - 100% at 40 cm/s

- **Flow-through enclosures**
  - Elevated velocities
  - Reduced growth / development
  - Lethal to hatchlings
  - Vulnerability to predators ↑ 1.9x

- **Flume Box**
  - 40% swept downstream

- **Drift Fence**
  - 70% displaced / not located

- **Open Relocation**
  - 80% swept away

Realism of Venue?
- Brett Chamber: least
- Artificial Stream: more
- Flow-through enclosures: more
- Flume Box: more
- Drift Fence: more
- Open Relocation: most
To discuss this afternoon:

- To what extent are these elements influenced by flow regime?
- What are the other important drivers of these demographic rates in your study systems?

- fecundity
- survival to hatching
- survival of tadpoles to metamorphosis
- first over-winter survival
- time to maturity
- adult survival
Thanks to Many People at Many Institutions

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Joe Drennan et al. GANDA

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Dennis Cocherell, Joe Cech UC Davis, CABA

Collin Bode, Mary Power, Bill Dietrich UC Berkeley.
**Fecundity**

**Embryos per egg mass**

![Bar chart showing fecundity in different locations: Alameda Ck., SF Eel, NF Feather.](image)

**Survival to hatching**

![Bar chart showing survival rates in different locations: Alameda Ck., SF Eel, NF Feather.](image)