I study HOW organisms interact with their physical environment.

Today:
Locomoting in a turbulent world

Basic question we've been asking:
How does interaction with fluid environment affect how animals move?

System:
Tiny animals swimming in turbulent water flow...
(trying to go somewhere specific...)

How do swimming larvae of bottom-dwelling marine animals recruit into suitable habitats?

It has been suggested that Odors...
(Dissolved chemical cues)
...from organisms on the substratum...
(...conspecifics, prey)
...can induce larval settlement into right habitat

Can odors help larvae land in the right habitat in nature...
... in turbulent flowing water:
*dilute odors?
*overwhelm larval swimming?

Phestilla sibogae:
sea slug that eats only one species of coral...
...so larvae must land on reefs where that species is abundant
Can dissolved chemical cues affect:

Larval transport to suitable habitat?

Steps to recruit onto a coral reef:

- Larval transport to suitable habitat
- Settlement (attachment)
- Metamorphosis

Can larvae use **SMELLS** (dissolved cues) to help them land in the right place in NATURE?

1. Water flow in the field?
2. Dispersal of dissolved cue?
3. Larval behavioral responses to dissolved cue?

Do responses to cue affect where larvae land in ambient water flow?

- Patch reefs
- Measured water velocity profiles above & within coral reefs

**Fast, wave-driven turbulent flow above reef**

**Slow NET transport shoreward →**

**VERY slow flow through the reef**
Slow net flow up out of reef (flat & convex reef surfaces)

Slow net flow down into reef (depressions in reef surface)

Water right above the reef contains cue

Cue distribution on scale of the larva? (200 µm)

Take a closer look in wave-flume in the lab

(mimic field flow conditions)

“Reef” of P. compressa skeletons in wave-flume

Match velocities and spectrum of flow over reefs

Fluorescent dye dissolves from coating on coral

“PLIF”

Sheet of laser light

Microscopic larva encounters filaments of cue

“cue” (dye) dissolving off coral

1 cm

coral
coral

1. Water flow in the field

2. Dispersal of dissolved cues

3. Behavioral responses of competent larvae to dissolved cue?

Behavior of competent larva in:
- cue-free water → SWIMS (0.17 cm/s)
- cue > threshold conc. → SINKS (0.13 cm/s)

Flow on scale of mm’s carries larvae

Do responses to cue affect where larvae land when carried in ambient water flow?

Flow on scale of mm’s carries larvae

Water flows back and forth in wave tank

neutrally-buoyant marker particles illuminated by sheet of laser light

Benthic organisms on floor of wave tank
瞬时速度矢量 (PIV) (红色 - 快, 蓝色 - 慢) & 瞬时“提示”浓度 (PLIF) (较浅的像素 - 较高的浓度) 变化与时间 (0.1 - 1秒)。

速度与“提示”浓度在精细空间尺度 (0.1mm - cm) 上变化。

1厘米

无味的水       提示高于阈值浓度

幼虫游泳或下沉

幼虫遇到的“提示”浓度的开/关模式

计算幼虫的轨迹

幼虫的游泳速度 = 幼虫游泳或下沉的速度 (取决于其位置处瞬时的“提示”浓度) + 当地瞬时环境水的速度 (携带幼虫)
Gradient in frequency of encounter with cue filaments

(NOT simple, diffuse concentration gradient)

**INDIVIDUAL-BASED MODEL:**
Calculate trajectories of 1000's of larvae (randomly-chosen starting positions in water)
Calculate rate of transport of larvae into the reef

**MODEL PREDICTS:**
More larvae land on seaward part of reef

**FIELD TEST:**
Is *Phestilla* recruitment greater on seaward parts of reefs?

Can dissolved chemical cues affect:
Larval transport to suitable habitat?

*model & experimental results...

**YES!**

**Anova**

<table>
<thead>
<tr>
<th>Position on Reef</th>
<th>Recruits / location (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaward</td>
<td>80</td>
</tr>
<tr>
<td>Shoreward</td>
<td>20</td>
</tr>
</tbody>
</table>

ANOVA

*p* = 0.001

*n* = 36 months

**Water flow in the field?**
*waves, turbulence*
*slow flow through & up from reef*

**Dispersal of dissolved cues?**
*filaments above reef*
*larvae encounter on-off cue*

**Responses of competent larvae to dissolved cue**
*sink:*
enhances transport into reef
*stick to surfaces*
Contour lines far apart: Larva encounters low shear. Contour lines close together: Larva encounters high shear. Shear varies on spatial scales of mm's - cm's.

Spatial distribution of shear changes with time (seconds)!

Example: What does shear do to a larva? Neutrally buoyant sinker swimmer.

Start neutral, swimming, and sinking "larvae" at same positions in water. Calculate trajectories in PIV video.

Another example: Simultaneous field measurements - PIV - Animal swimming. Paravargula trifex.
FIELD measurements of how faster flow affects behavior:
- turn less often
- fewer encounters with benthos (food)
- fewer encounters with each other (mates)

(Sutherland, Dabiri, Koehl 2011)

Take home messages:
How does interaction with fluid environment affect how animals move?

*Trajectories of small organisms depend on fluctuating fine-scale ambient flow.

* Behavior of microscopic organism can bias how environmental flow transports them

* Turbulent diffusion is NOT a good model of chemical cues encountered by microscopic organisms

Challenge: Quantify critical aspects of environment on spatial & temporal scales relevant to the organisms

Challenge: Quantify critical aspects of environment on spatial (µm's-mm's) & temporal (ms's-hr's) scales relevant to larvae