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Assessing Zooplankton Behavioral Changes to Fine-scale Gradients of Vertical Flow

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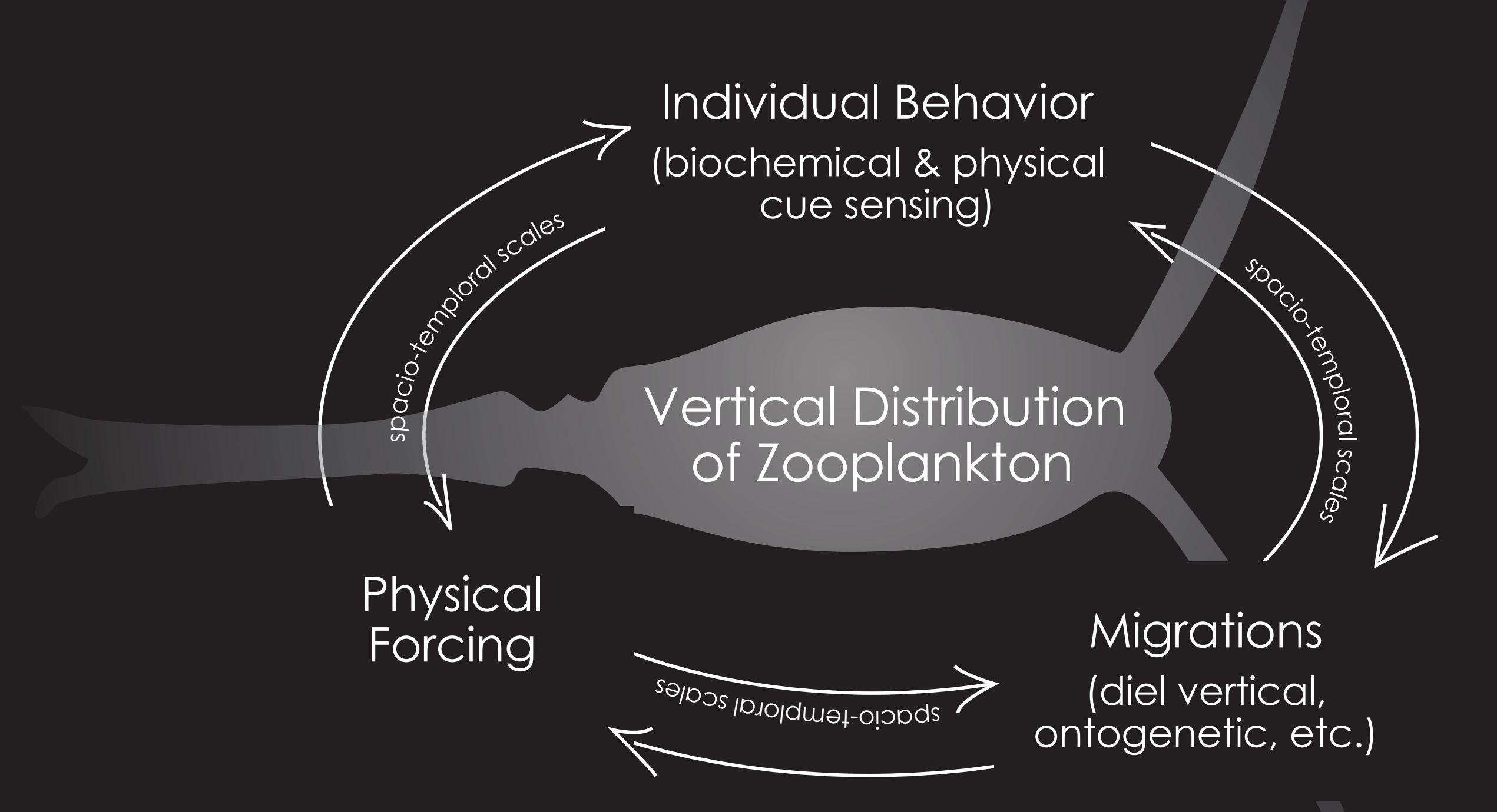
Background



Woodson et al. (2005, 2007) showed that copepods aggregate near oceanographic structure associated with biochemical and physical gradients in the water column, thin layers.

Field observations show that zooplankton swim against up/downwelling currents in order to maintain depth position (Genin et al. 2005).

Acartia negligens

Clausocalanus furcatus

Neomysis americana

Panopeus herbstii

Methods

A laminar planar jet in a recirculating flume was used to create fine-scale up/downwelling shear flow with targeted strain rate characteristics for behavioral assays.

Behavioral Assays

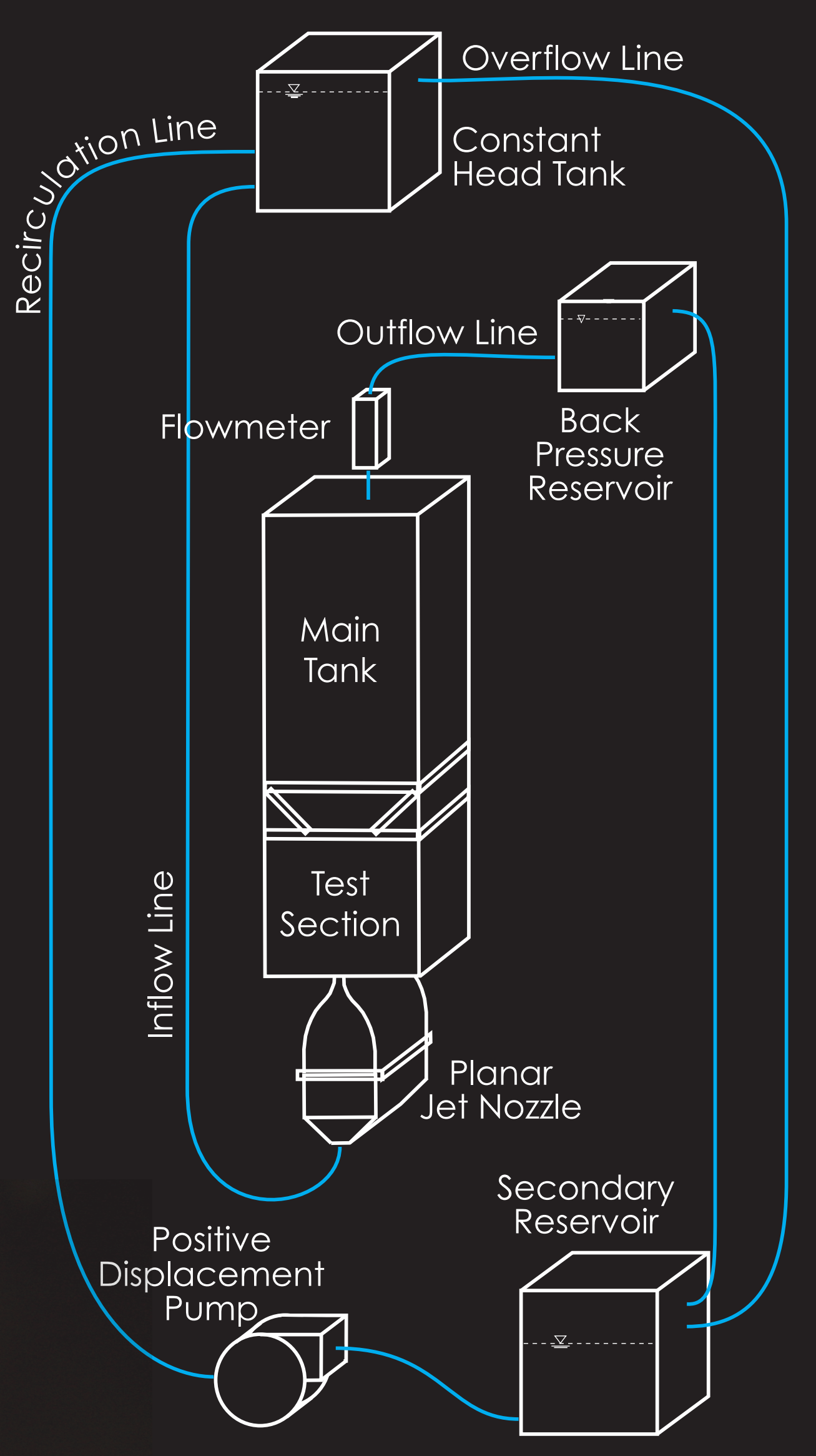
Mixed-sex, species-specific assays of 50-70 animals (collected locally, sorted, and acclimated) are conducted for two hours in a dark room at ambient water temperature/salinity.

Behavioral assays with two tropical copepods, a temperate mysid, and an estuarine crab larvae were run in both upwelling and downwelling flow configurations (separately).

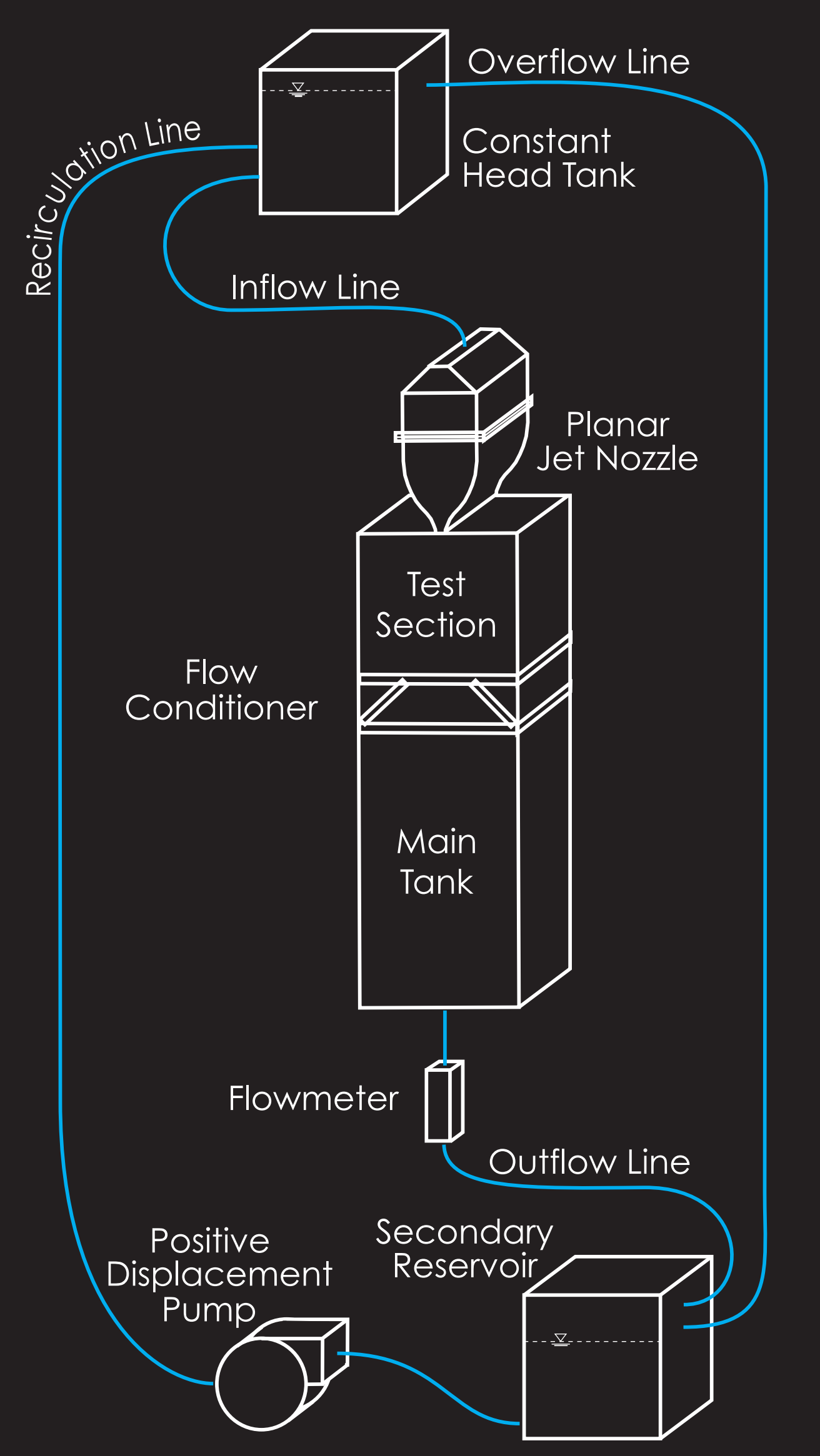
Zooplankters are allowed to interact freely with an upwelling or downwelling jet and trajectories are recorded under infrared illumination.

Videos are digitized (LabTrack, BioRAS) to obtain path trajectories and various behavioral parameters are computed for portions of the path inside and outside the jet, as well as pre- and post-contact with the jet (swim speed, turning frequency, residence time, etc.).

Upwelling Flow Configuration



Downwelling Flow Configuration



Governing Equations for Laminar Planar Free Shear Flows

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\frac{\partial^2 u}{\partial y^2} \qquad (2)$$

$$\frac{\partial P}{\partial y} = 0 \qquad (3)$$

Analytical Self-Similar Solution by Bickley (1937)

$$\frac{u}{U_0} = \operatorname{sech}^2\left(\frac{ay}{\delta}\right) \qquad a = 0.81136$$

where the jet half-width grows as

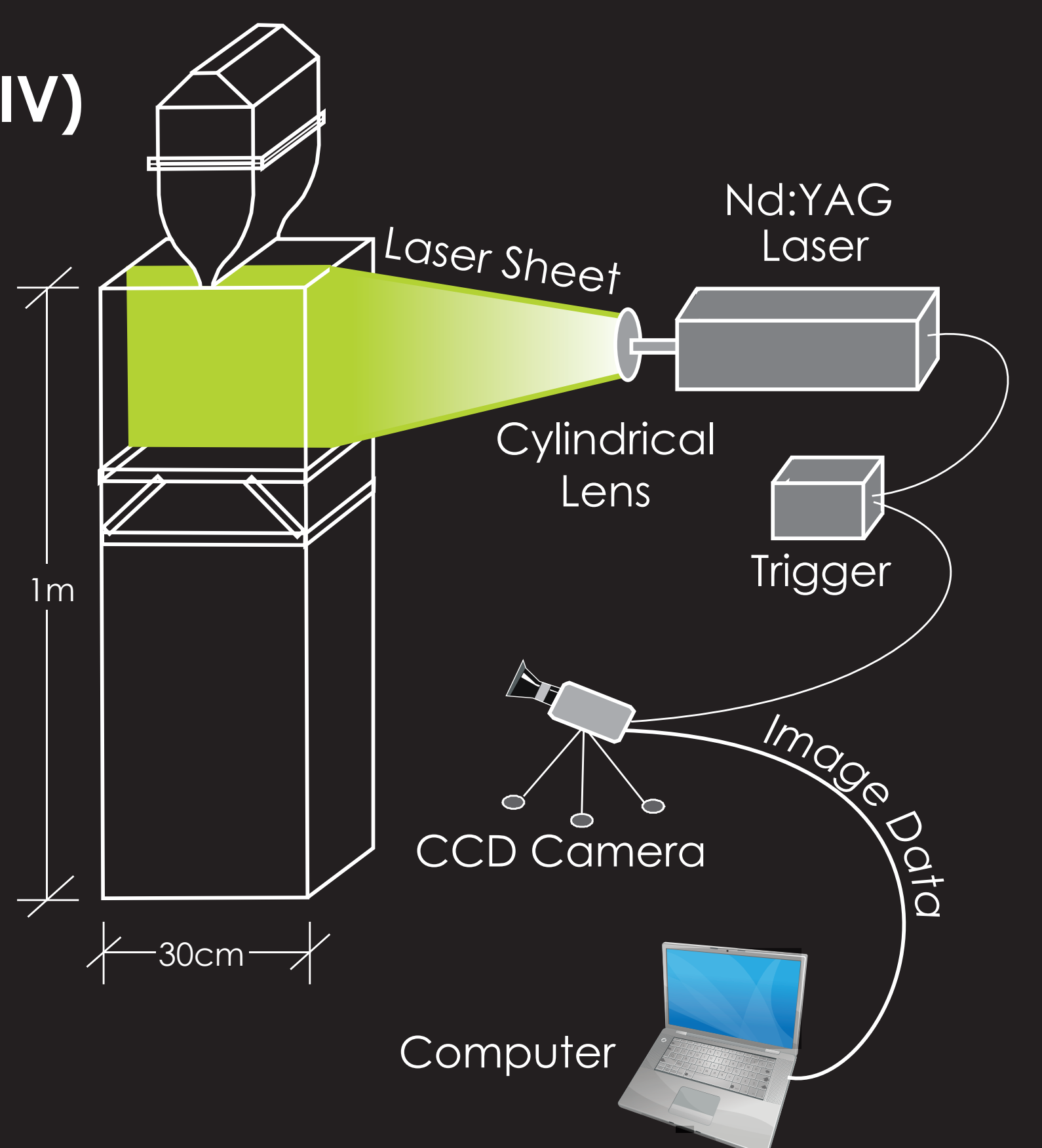
$$\delta = a\left(\frac{48\nu^2 x^2}{M}\right)^{1/3}$$

and the initial jet momentum flux is given by

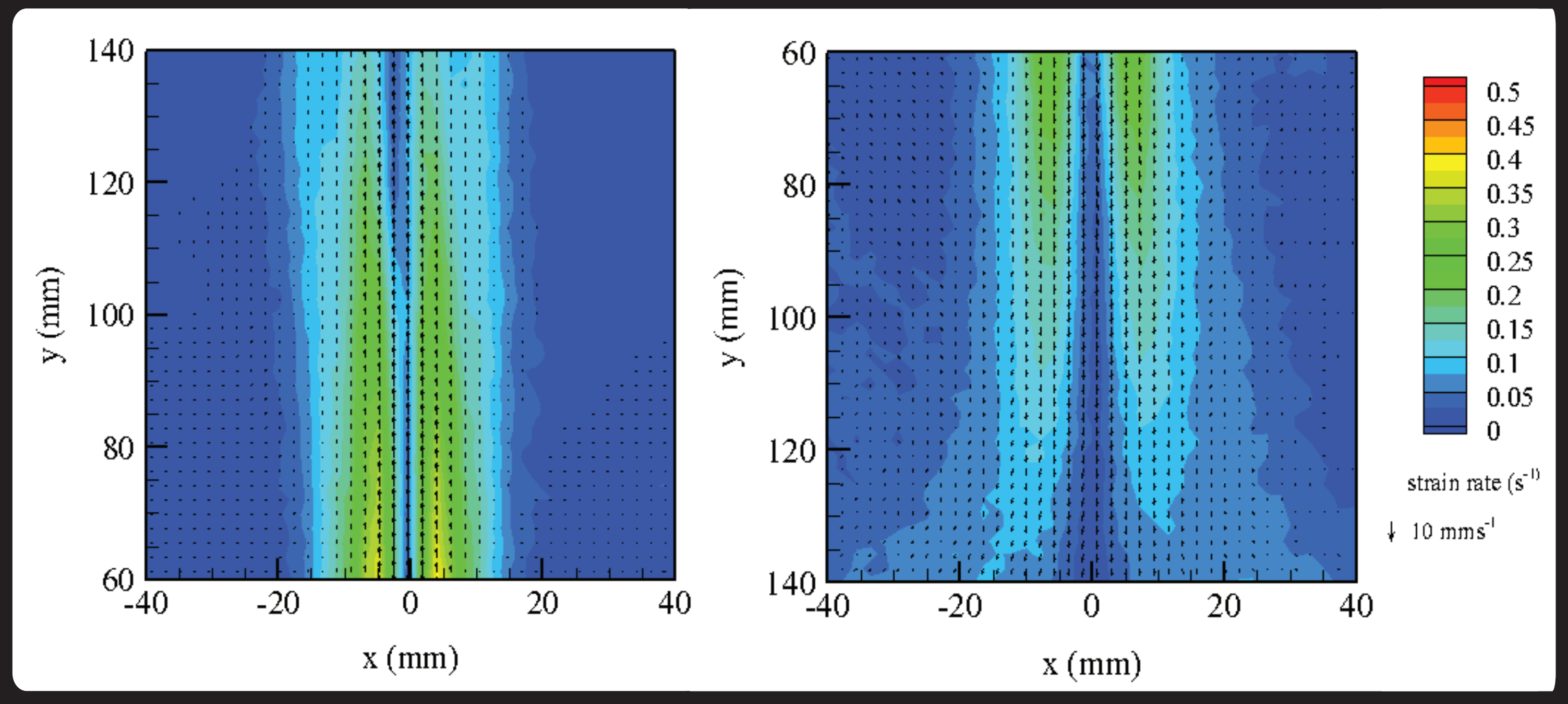
$$M = \int_{-\infty}^{\infty} U^2 \, dy$$

Particle Image Velocimetry (PIV)

- Nonintrusive technique for quantifying flow fields
- Flow seeded with neutrally-buoyant particles
- Flow illuminated with an Nd:YAG laser (532 nm)
- CCD camera captures 500 images at 15 Hz
- Particle displacement divided by laser pulse frequency
- Produce velocity vector field, shear field, etc.

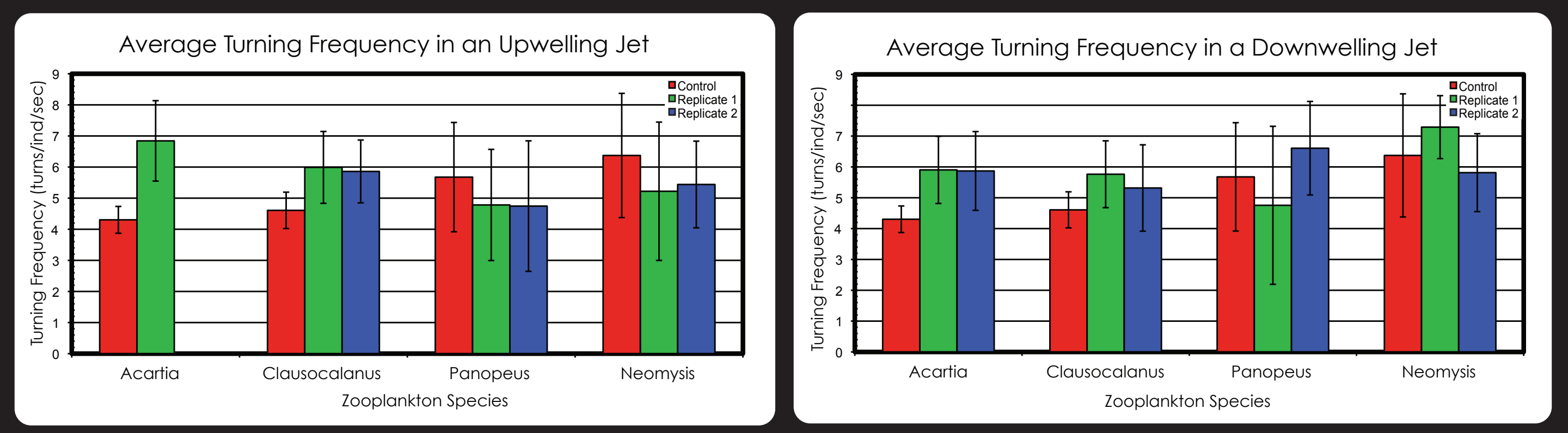


Velocity and Shear Fields from PIV

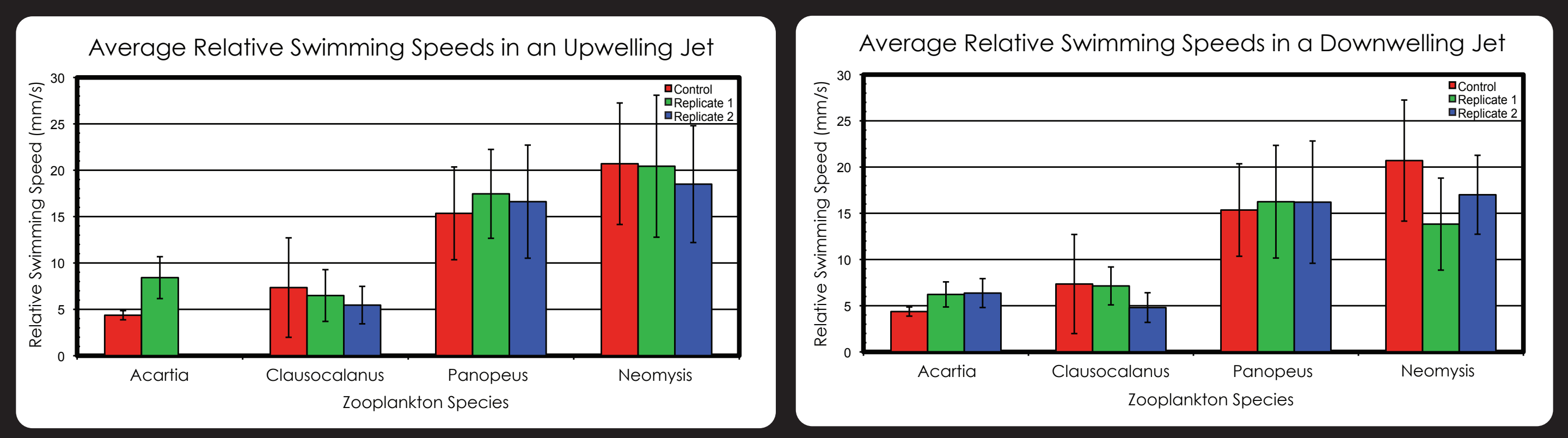


Upwelling Downwelling

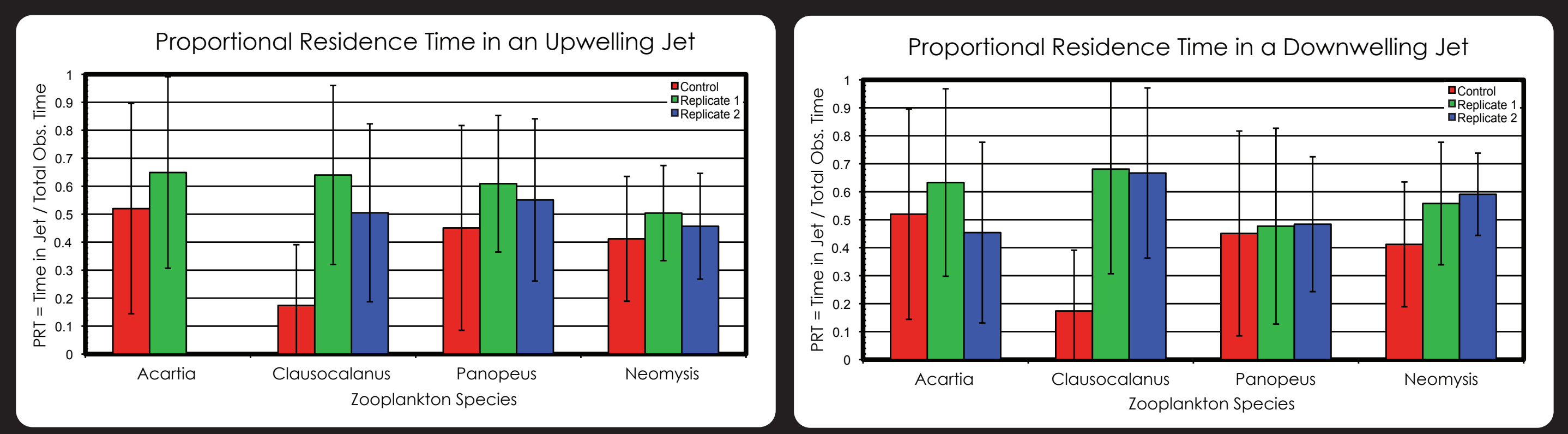
Results



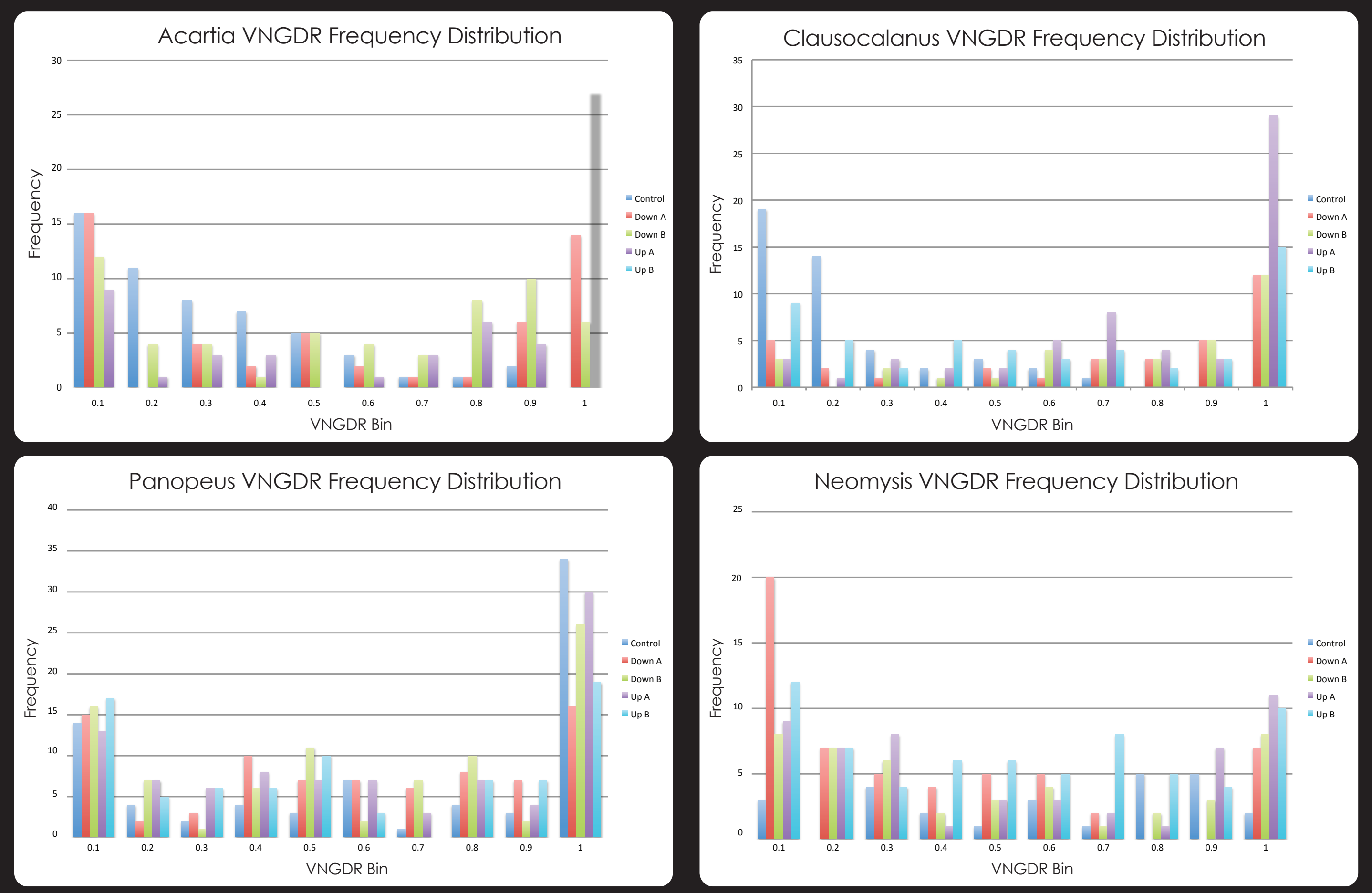
The increase in TF for the 2 copepods indicates a definite behavioral responses to the jet layer. The slight decrease or stagnation in TF for the larger zooplankton indicates either a lack of response, or perhaps a mismatch in body size as it relates to the scale of the jet layer and the animals ability to sense the shear flow.



Behavioral responses seen through changes in relative swimming speed are less pronounced than for TF, however trends within species are consistent for both upwelling and downwelling flows.



All species in both upwelling and downwelling flows show an increase in PRT, indicating an active choice to remain preferentially in the jet layer.



The peaks in the VNDGR frequency distributions at 0 and 1 for the jet treatment compared to the control (stagnant) cases for the 2 copepods shows a definite change in behavior in response to the jet. Low values of VNGDR indicate "U" or "n" shaped paths, indicating an active choice to exit the vertical flow, whereas high values indicate more linear, vertical paths, indicative of a choice to remain in the jet layer. These phenomena could very well be the same behavior seen at different scales, and for the smaller (copepod) species show most likely an aversion to the jet layer. The larger species show more linear behavior in general (high VNGDR) and again may indicate a disparity in body size and mechano-sensitivity versus the jet layer size.

Future

Further analyses will examine tracks to determine thresholds of shear strain rate that trigger maximum behavioral changes for each species.

Identifying threshold shear values will allow us to define an exact geometric region based on the fluid mechnaics of the jet, and thus compute behavioral parameters for regions inside and outside the jet layer, as well as pre- versus post-contact with jet.

ANOVA will be used to quantify statistical signinficance of behavioral changes.

Present results from a behavioral fractal analysis will be examined in the context of foraging and population-scale aggregations.

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