Bio-mixing due to profundal quagga mussels' filtration – Preliminary results

February 2018

Through field experiments, we would like to test the following two hypotheses:

- Mussels' filtration generates siphonal currents, which can maximize food capture by keeping phytoplankton particles in suspension in a thin layer immediately above mussels.
- Siphonal currents can enhance turbulent transport and exchange of nutrient between benthos and the water column.

An underwater PIV system had been developed (Liao et al., 2009, 2014; Wang et al., 2013) and it was upgraded for this project to measure 2D velocity field immediately above the bottom of Lake Michigan at a mid-depth (latitude = 43.09503 and longitude = -87.77119, water depth = 55 meters) location, which is full covered by quagga mussels. The autonomous PIV (cf. Fig 1) is self-contained, including a laser unit that generated a light sheet by scanning the laser beam, a digital camera unit that captures images of particles illuminated by the laser "sheet". Laser and camera are synchronized by a signal generator and images are captured by a single board computer that runs a Linux Arm OS. The system was programed to turn on 17 times per day and captures 6,000 image pairs in 10 minutes for each duty cycle. The battery capacity (15 AH 12V) allows 7 days of operation with this duty cycle configuration. The system was deployed untethered between Aug 2 and Aug 9 2017 for seven days. Image acquired covered an area of 8 $\times$ 9 cm2 (width $\times$ height). PIV interrogation resolved a 2D velocity field on a 41 $\times$ 35 mesh with a spatial resolution of 1.7 mm.

(a) (b)

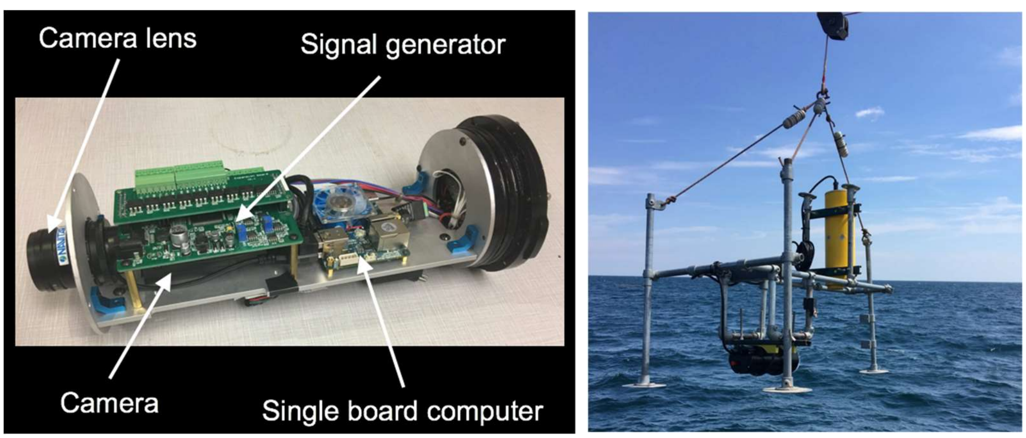

Fig 1. (a) Image acquisition unit of the underwater PIV system (b) deployment of PIV in Lake Michigan

From images captured (cf Fig. 2), we can identify if quagga mussels were actively feeding (siphons extended) or not (siphons retracted). Excurrent and incurrent flows through mussel siphons were also clearly resolved by the PIV measurement.

(a) (b)

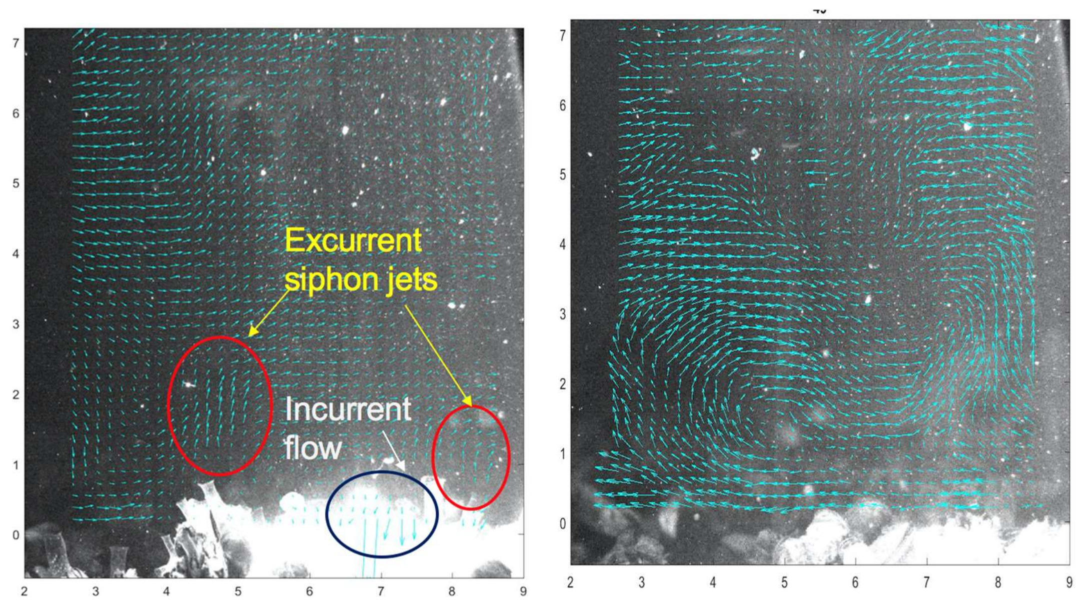

Fig 2. (a) Sample PIV results with mussels active feeding (siphons extended) (b) mussels inactive (shell closed, siphons retracted)

Statistics of turbulence above the mussel bed were calculated from PIV measurements, including the mean horizontal current velocity U, variance of turbulent fluctuations: $\overline{u'^2}$, $\overline{w'^2}$. The turbulent kinetic energy(TKE) was estimated as $k \approx \frac{1}{2}\left(\overline{u'^2} + 2\overline{w'^2}\right)$, assuming isotropy of turbulence along directions that is perpendicular to the mean current U. The turbulent dissipation rate was estimated with a "direct" method (Wang and Liao., 2016),

$$\varepsilon \approx \nu\left[4\overline{\left(\frac{\partial u'}{\partial x}\right)^2} + 4\overline{\left(\frac{\partial w'}{\partial z}\right)^2} + 3\overline{\left(\frac{\partial u'}{\partial z}\right)^2} + 3\overline{\left(\frac{\partial w'}{\partial x}\right)^2} + 4\overline{\frac{\partial u'}{\partial x}\frac{\partial w'}{\partial z}} + 6\overline{\frac{\partial u'}{\partial z}\frac{\partial w'}{\partial x}}\right]$$

Turbulent mixing is then assessed through the estimated "eddy" viscosity/diffusivity following a $k - \epsilon$ modeling approach, i.e.,

$$\nu_T \approx 0.09\frac{k^2}{\varepsilon}$$

Six selected cases are presented here to demonstrate how profundal mussels' feeding activities along with the ambient lake current affect hydrodynamic mixing in the bottom boundary layer of Lake Michigan. Fig 3 shows the vertical profiles of mean current and "eddy" diffusivity for the six cases. Mussels were observed to be "inactive" in cases A, B, and C, and "active" in cases D, E and F. These preliminary data suggested that while lake current speed is generally very low at the 55-m depth (< 4 cm/s), the measured "eddy" diffusivity varied by nearly three orders of magnitude. The strength of mixing is significantly affected by the interaction between the means current and mussels' feeding activities. For example, mean velocity in cases A and C is greater than that in D and E, but the eddy viscosity is much lower. The current in case E is nearly zero, but the mixing coefficient is the greatest, likely due to mussels' active pumping. These observations suggested that mussels' may raise their feeding activity in order to increase mixing and food delivery when the lake current is very low.

(a) (b)

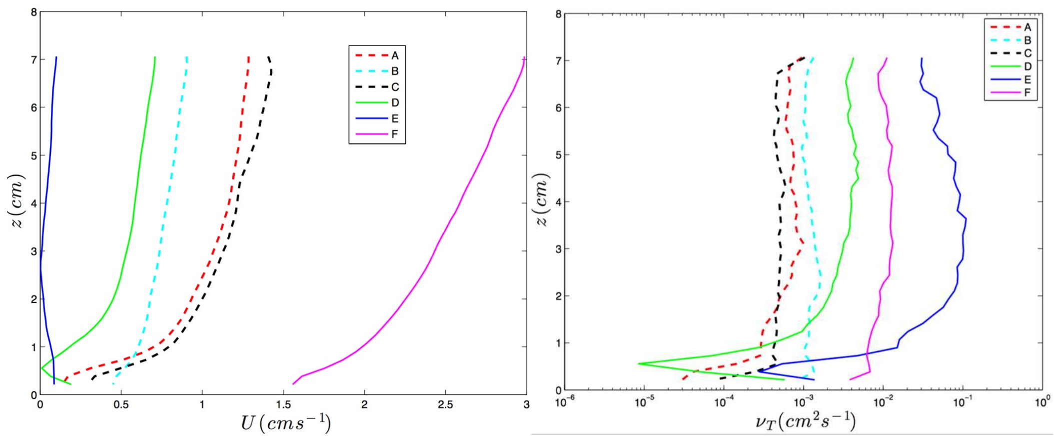

Fig 3. Vertical distribution of (a) mean current speed and (b) "eddy" diffusivity. Mussels were observed to be "inactive" in cases A, B, and C, and "active" in cases D, E and F.

Ongoing field work will measure the mean concentration profile of dissolved phosphorus concurrently with PIV. The flux of DP due to mussel excretion can be estimated as $F \approx \nu_T \frac{\partial C}{\partial z}$.

References

Liao, Q., Bootsma, H. A., Xiao, J., Klump, J. V., Hume, A., Long, M. H., and Berg, P. (2009). An *in situ* Underwater Particle Image Velocimetry (UWPIV) system. *Limnology & Oceanography:Method,* 7, 169-184

Liao, Q., Wang, B., and Wang, P.F. (2014) In Situ measurement of sediment resuspension caused by propeller wash with an underwater Particle Image Velocimetry and an Acoustic Doppler Velocimeter. *Flow Measurement and Instrumentation*. 41, 1-9.

Wang, B., Liao, Q., Bootsma, H.A. (2013) A free drifting PIV system: measurement of small scale turbulence in the wind surface layer. *Journal of Atmospheric and Oceanic Technology*. 30, 1494-1510

Wang B., and Liao, Q. (2016) Field observations of turbulent dissipation rate profiles immediately below the air-water interface. *Journal of Geophysical Research: Ocean.* 121(6), 4377-4391