Understanding larval movement in turbulent estuarine systems

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Introduction

As constructed wetlands emerge as a promising nature-based solution to wastewater treatment, the impact of this remediation technique on these ecosystems must be monitored. The behavior of fish and insect larvae can be studied to assess impacts of a treatment system on resident biota. This project aims to better understand larval movement in order to identify abnormalities when they arise. We adopt the assumption that larval motility can be modeled as a diffusive process and is therefore described via a random walk analogy (Kiørboe, 2008). In addition to their motility, larvae passively diffuse due to stochastic motions in ambient water flow, namely turbulence and Brownian motion. Thus, the movement of larvae in turbulent water can be described as a series of layered diffusive processes: motility (modeled as diffusion) and physical particle diffusion (due to turbulence and Brownian motion). Video footage taken in Burns Bog Delta Nature Reserve near Vancouver, Canada was used to study larval movement.

Methods

The first method used herein is a synthetic stochastic process or "Monte Carlo" model, with which the relationship between larval track data and calculations of diffusivity can be explored. Random walk simulations of 100 particles taking 500 steps (n) were modeled using Python in one, two, and three dimensions (Nilesh, 2008). The standard deviation (σ) of the particles in the 1D simulation was measured every 25 steps in order to correlate σ with n, as seen in Figure 1.

Ordinary linear regression (ORL) was performed on a log-log plot of n vs. σ to obtain an equation relating the two variables. The best fit line, $\log(\sigma) = \alpha + \beta\log(n)$, represents this curve of best fit plotted on logarithmic axes. Raising both sides of the equation to the exponential power gives the curve of best fit, $\sigma(n) = An^{\beta}$, where A is e^{α} (Kawwa, 2020). Thus, the intercept term in the linear equation can be used to obtain the scaling factor for the curve of best fit, while the slope term represents the exponent's value. After constants α and β for the curve of best fit were estimated, 95% confidence intervals were found for each constant. Rough proofs were outlined for finding best fit using ORL and calculating associated uncertainties. It is important to note that advection was not included in the model, despite its impact on particle dispersion in real water flow.

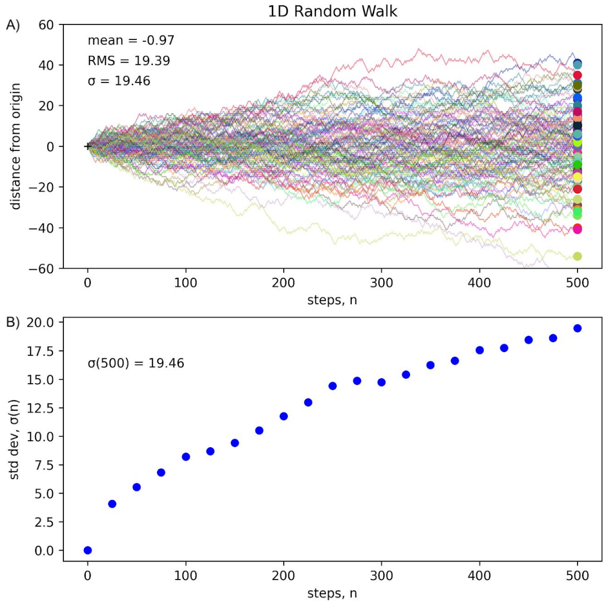

Figure 1. A) One dimensional random walk with 100 particles taking 500 steps, (n). B) Standard deviation (σ) of the random walks, every 25 steps.

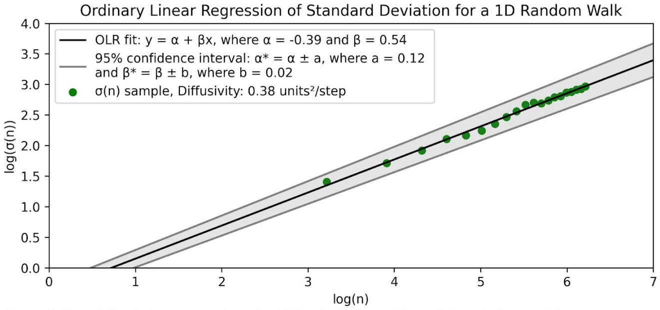

Figure 2. Correlation between σ and n using ORL with 95% confidence intervals for α and β.

The second method used herein is an exploration of image processing methods that allow for analysis of larval movement recorded in the field. Blurriness, low contrast, and low light occur often in field footage. These issues may arise due to a variety of factors, including fast movement of larvae, water turbidity, and limits to the footage resolution. Underwater video footage (29.97 fps) taken on June 22, 2018 in Burns Bog Delta Nature Reserve, BC, Canada was examined and swimmers (i.e., motile organisms such as larvae) were identified. Selected frames with sufficient image clarity and identifiable swimmers were identified. Adjacent frames were subtracted from one another to obtain velocities (in pixels/frame and mm/s) for the motile larvae and passive particles. Larval diffusivity (mm^2/s) was obtained from this result.

Results & Discussion

The Monte Carlo simulation elucidated key relations that describe diffusive processes. Standard deviation (σ) was found to vary proportionally to $\sqrt{n}$, validating the canonical correlation. In the experiment shown in Figure 2, $e^{\alpha} = A = 0.83$ and $\beta = 0.47$, leading the curve of best fit to be $\sigma(n) = 0.83 * n^{0.47}$. Again, this result agrees with the expected square root (or $n^{1/2} = n^{0.5}$) relation between $\sigma(n)$ and n.

Image processing revealed the dispersion velocity of the larvae to be 42 ± 14 pixels/frame, or 13 ± 4.3 mm/s, while the passive particles moved at 12 ± 0.90 pixels/frame or 3.9 ± 0.28 mm/s. Previous dispersion velocity estimates in the literature range from 1-10 mm/s and 3-30 mm/s, validating this project's results (James et al., 2019; Largier, 2003). The dispersion velocity translated to a diffusivity value of about 130 mm^2/s for the larvae. Challenges with larvae swimming out of focus in the footage prompt further work on experimental setup.

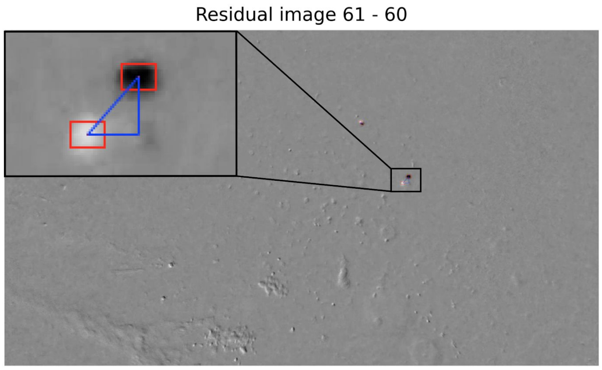
Residual image 61 - 60

Figure 3. Residual image from field footage showing how larval movement between frames was measured.

Conclusion

Studying larval movement *in-situ* confronts many difficulties due to image quality issues and complex underlying fluid dynamics. This project aimed to arrive at a preliminary understanding of the fundamental components used to analyze larval movement in turbulent estuarine systems. Future studies that use more advanced techniques such as machine learning and automatic image cross-correlation to identify and track particles are recommended.

References

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