Going in Circles: Nesting Kinematics of Bluegill Sunfish (*Lepomis macrochirus*)

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P1-97: In early summer, nesting Bluegill Sunfish (*Lepomis macrochirus*) expend large amounts of energy building nests, spawning, protecting their offspring, and chasing away predators. The energetic demands of nesting are likely significant and may heavily influence their life history and reproductive success. However, the exact metabolic cost of nesting is difficult to quantify without precise information about the three dimensional position of the center of mass of nesting fish. Field observations of Bluegill Sunfish nesting in Lake Waban (Wellesley, MA) were obtained throughout June until early July by using underwater cameras, fitted with a temperature and light sensor, calibrated to allow three dimensional tracking. The positional data of nesting Bluegill Sunfish were analyzed to derive velocity and acceleration in order to calculate their metabolic rate. We chose to analyze repetitive nesting behaviors, such as rim circling and defensive chasing, due to their frequency of occurrence and consequentially high metabolic demand. Using metabolic rates calculated from Bluegill swimming in a flume, we found that rim circling is nearly 22.2 times more metabolically expensive than the average metabolic cost of swimming in a straight path for the same velocity and duration. Since rim circling is so metabolically expensive and since we estimate that rim circling occurs nearly 25,500 times during an 8 day nesting period, our results strongly suggest that the nesting cycle is one of the most critical periods in the life history of Bluegill Sunfish. The high energetic demands of nesting and the temporary bout of starvation while the fish occupies its nest results in a small margin of error for reproductive success. These conclusions deepen our understanding of male Bluegills' true paternal investment and can serve to illuminate our understanding of their life history from a quantifiable perspective.

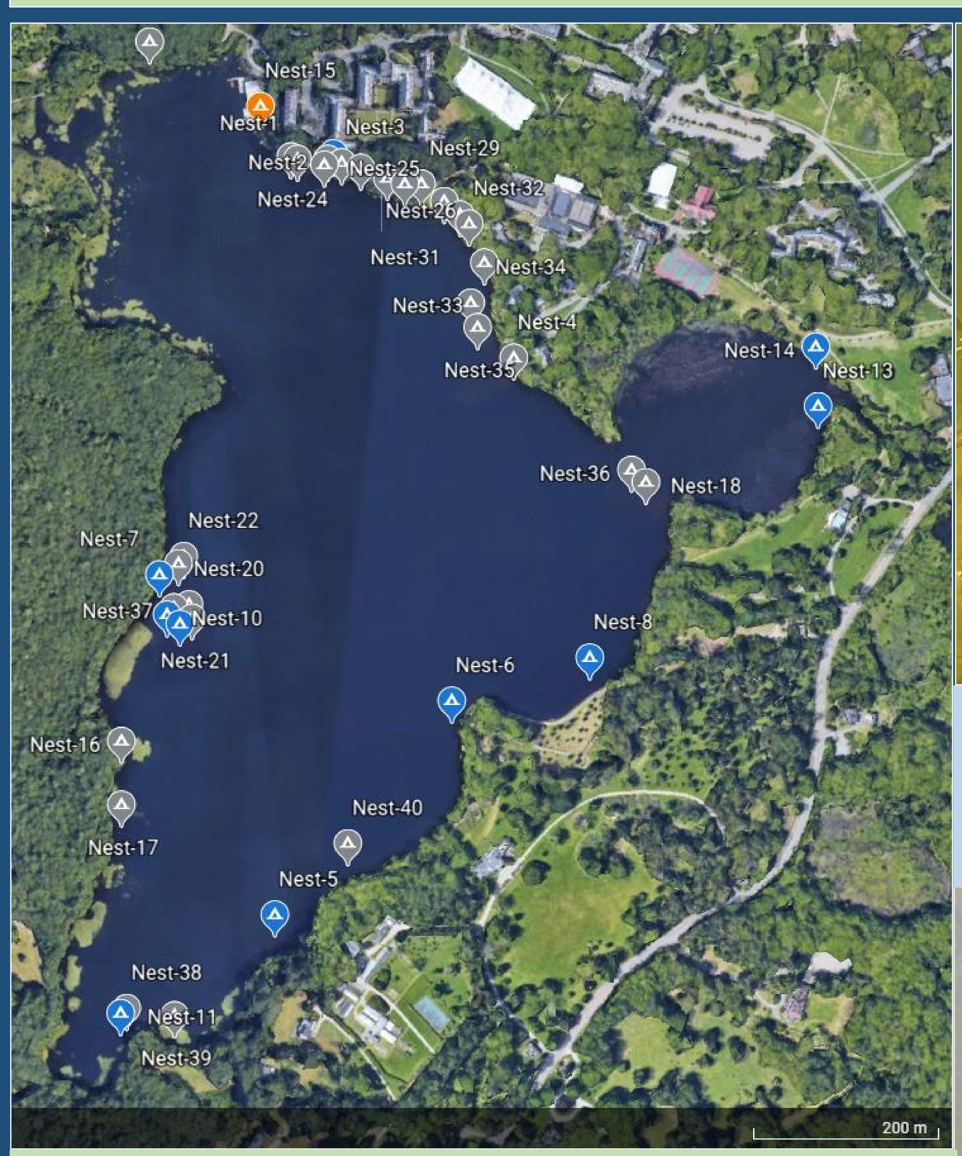


Figure 1: Bluegill Sunfish Lake Waban Nesting Sites: Active nesting was observed in shallow water near the shore around nearly the entirely lake.

Figure 2: Bluegill Sunfish Nest Morphology. Nest is formed by central depression surrounded by a rim. Nest defense involves swimming rapidly around the rim in a behavior called rim circling.

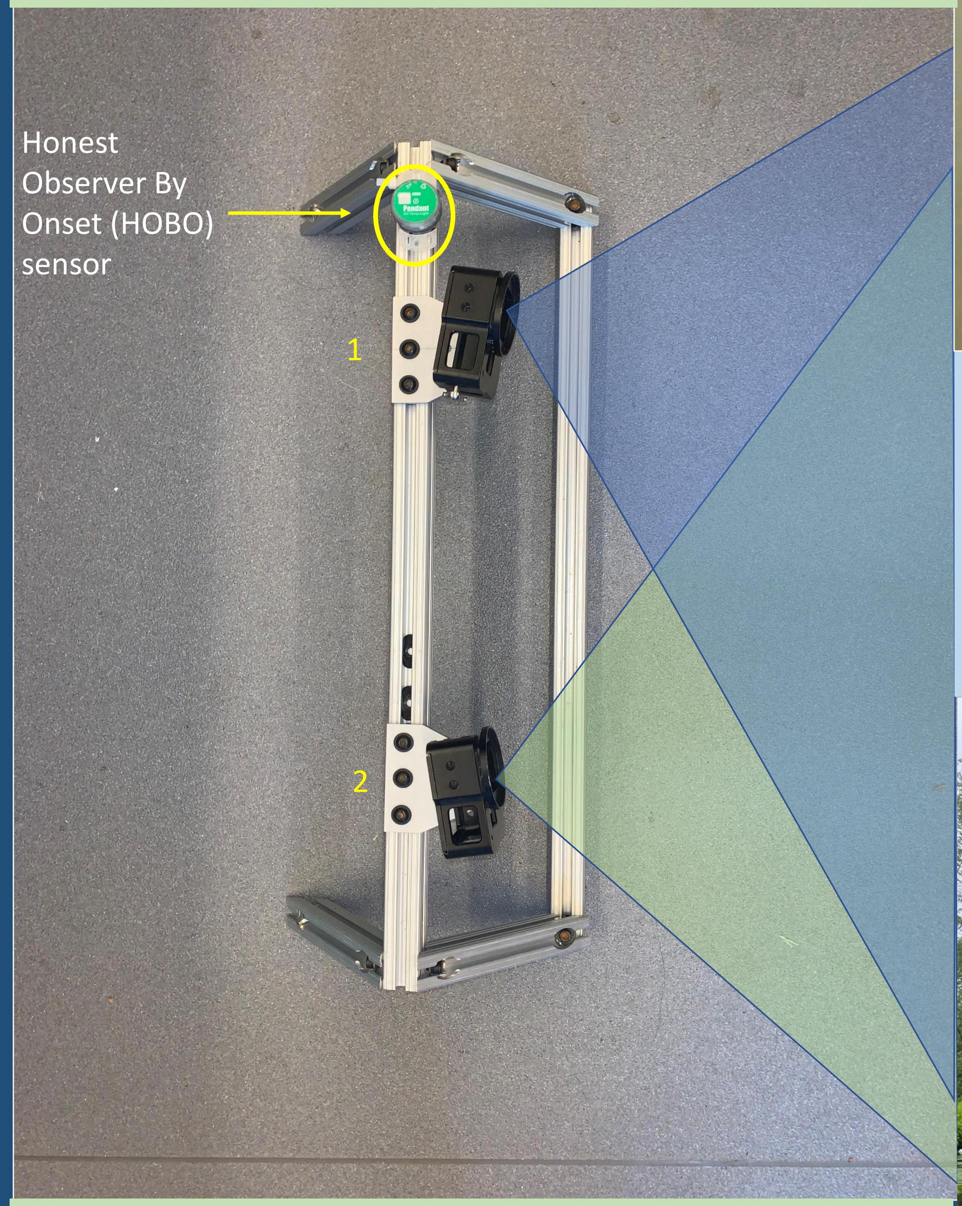


Figure 3: Underwater Camera Rig. Two cameras mounted with overlapping fields of view (green and blue shading) allow tracking of 3D position. Rig is fitted with HOBO temperature and light sensor.

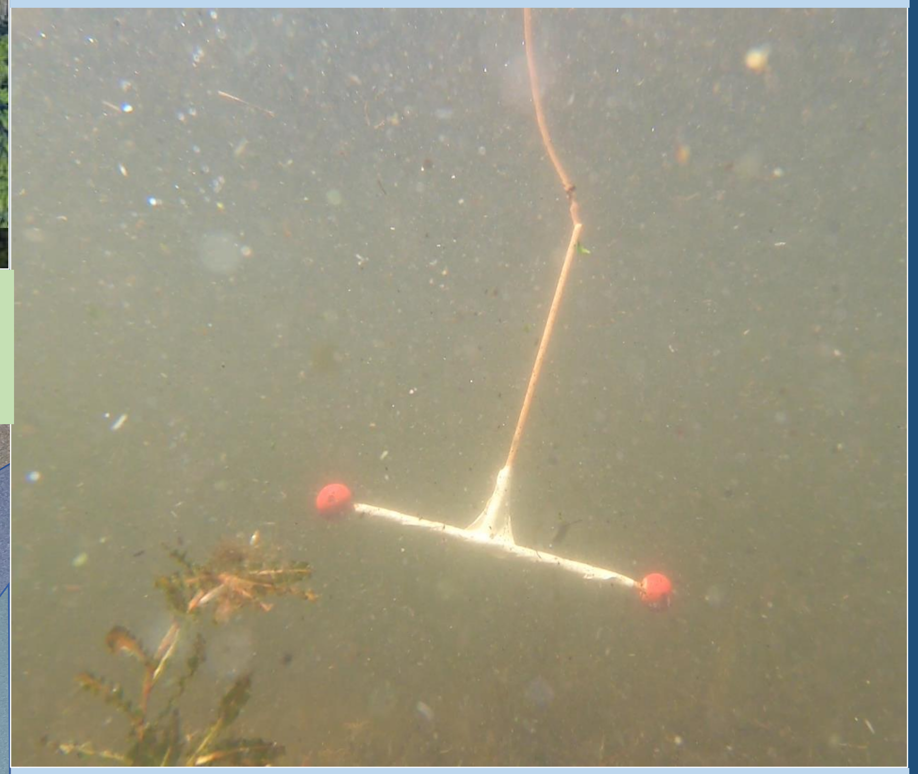


Figure 4: Wand Calibration Tool. Cameras are calibrated with an object of known length, called the wand, by tracking the same points as seen in each camera field of view and digitally converting the corresponding pixels into an xyz-Cartesian coordinate based on direct linear transformations performed in MatLab app EasyWand5.

Figure 5: Field Work. The camera rig was often deployed via boat.

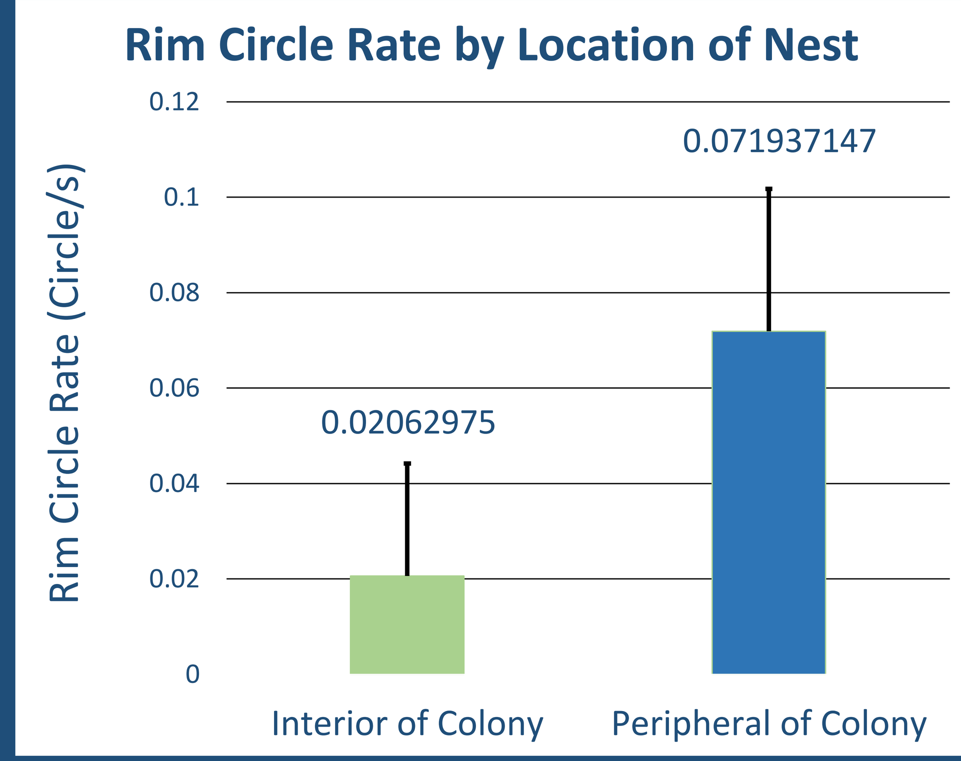


Figure 6: Rim Circle Rate of Peripheral and Interior Bluegill Colony Nests. Rate of rim circling was calculated using sample video of over 1000 seconds in length. Interior to the colony was designated when the nests were fully surrounded by other nests. The mean rate of rim circling for nests on the peripheral edge of the colony is almost 3.5 times higher than that of a bluegill in a nest on the interior of the colony (t-test, tstat = 0.0719, df = 13, p = 0.013, α = 0.05).

Figure 7: Flume Swimming for Metabolic Mathematical Modeling. The metabolic rate of aerobic straight-line swimming Bluegill Sunfish was calculated from respirometry experiments of Bluegill swimming in a closed water tunnel flume (A-B). Flume metabolic rate can be calculated as:

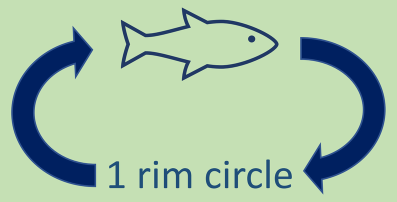
$$M_{flume} = 0.46 + 0.23u^{2.75} \quad \text{(Cathcart et al. 2017)}$$

The metabolic rate of curved path swimming during rim circling can be calculated as:

$$\frac{M_{curve}}{M_{flume}} = \sqrt{1 + 2\frac{V^{1/3}}{RC_D}\left(\frac{pf}{pw} + \lambda\right)^2} \quad \text{(Weihs 1981)}$$

The metabolic cost of anaerobic swimming during a defensive chase was estimated from total anaerobic total capacity (Binder 2016) in relation to the length of the chase.

Rim Circle Metabolic Cost



A singular rim circle with an average velocity of 1.34 BL/s and an average radius of 0.180 m has a metabolic cost of **3.33 calories** (n=20).

During full nesting period, consisting of minimum 8 days with 15 hours of sunlight in late June, we estimate to have minimum 32,724 rim circles due to an average of 3.53 circles/min (n=15). Total metabolic cost of circling during nesting is **84.75 kcal**.

Calories Supplied by Meal Worms

Meal worm (*Tenebrio molitor*)
119 cal/worm

One rim circle requires **2.80%** of a meal worm.

Meal worm (*Tenebrio molitor*)
119 cal/worm

One full nesting period of rim circling requires **713** meal worms.

Figure 9: Metabolic Results. The schematic outlines the metabolic costs for a single rim circle, a single chase, and the amount they would have to eat from a common food source meal worms. The lower row estimates the total minimum metabolic cost of an entire nesting period for the fish measured in figure 7, as well as the amount of meal worms required to supply the calories used.

Methods: Video was collected with 2 GoPro Hero 7 cameras. Temperature and luminosity was measured using a Honest Observer by Onset sensor. Video was calibrated using the Easywand5 app in Matlab version R2019b. The center of mass of the respective Bluegill Sunfish were tracked using Matlab app DLTdv8a. From positional data, velocity and acceleration were further derived using Igor-pro (64-bit). Metabolic rates were calculated by hand.

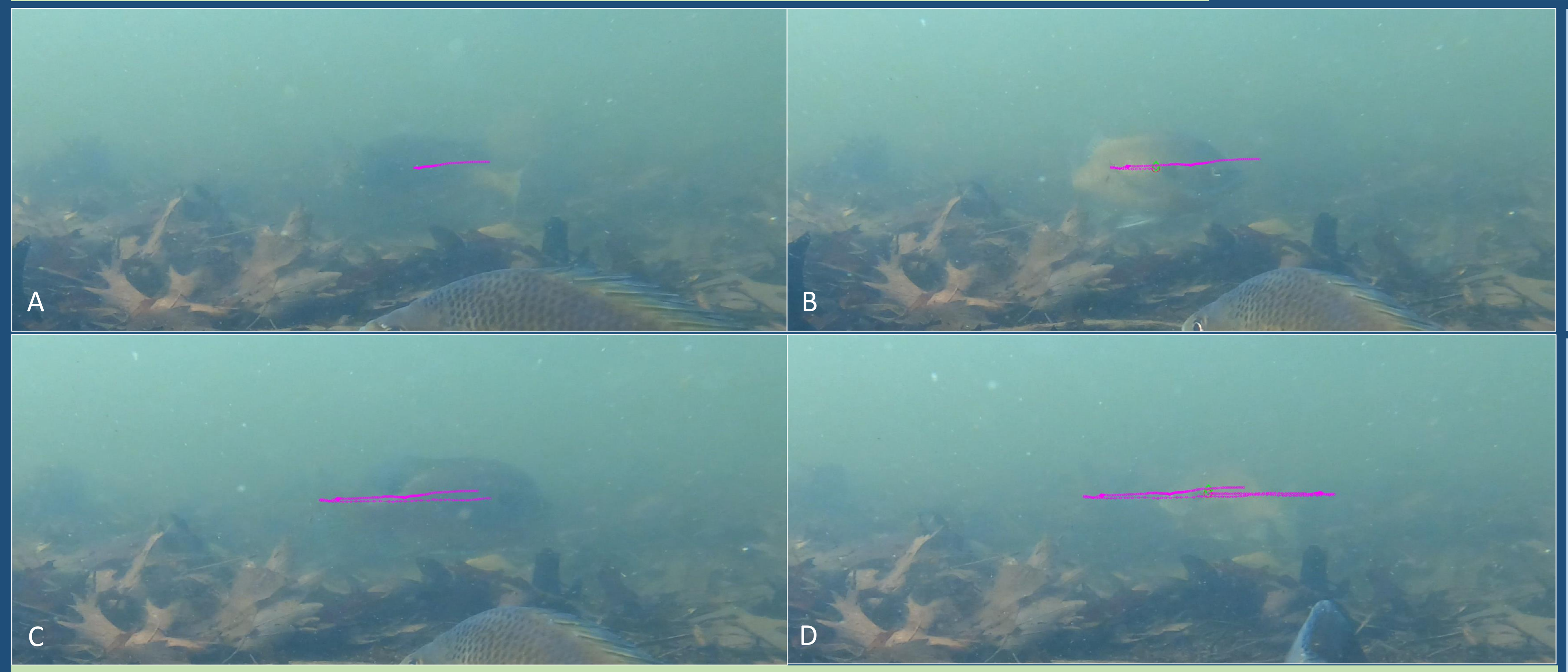


Figure 8: Tracking a Rim Circle. Bluegill Sunfish were tracked with Matlab app DLTdv8a during rim circling behavior in Lake Waban to determine their instantaneous 3D position. (A-D) Tracking a single instance of rim circling behavior by a male Bluegill Sunfish (TL = 0.1867 m). For this instance, the average radius of the swimming circle was 0.164 m, water temperature was 27.86 °C, and luminosity was 11845.9 lux.

Acknowledgments:
This research was performed on the ancestral and present unceded lands of the Massachusett tribe. We recognize that we are on stolen land, and affirm with gratitude the sovereignty of the Indigenous people who have rich histories here and continue to care for this land, including the Massachusett, Wampanoag, and Nipmuc nations. We would also like to thank the involuntary participatory Bluegill from Lake Waban, with special thanks to Appa, LeFou, Clark, Roderick, and Tiny. Funding was provided by NSF Grant 1754650 (Wellesley College) / 2135851 (UMW) to Bradley Wood.

Works Cited:

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