

# **Undulation Speed Affects Burial Performance in Flatfish**

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## **Abstract**

Burial is an understudied behavior among flatfish species. This study aims to understand the role of undulations in flatfish burial. Five species of flatfish were filmed using high speed video cameras to assess the speed of the undulations and determine the amount of sand covering the animal after completing burial. A physical model was also built to test the effect of undulation speed on burial. The results of the physical model suggest that increased speed increases the surface area of sand on the burying object; however this benefit has diminishing returns at high speeds. The live animals suggest that undulations are not the only factor involved in flatfish burial. The posterior portion of the dorsal and anal fins may contribute to burial efficiency in these species.

## **Introduction**

Many fish bury to avoid predation or to capture prey, including *Ammodytes sp.*, *Trichodon trichodon*, and *Leptocottus armatus* (Gidmark et. al. 2010; Arora 1948; Morioka 2005; Eschmeyer, Herald, and Hammann 1983). Flatfish are no exception. They bury themselves in response to light to avoid predation (Ellis, Howell, & Hughes, 1997; Kruuk, 1963). Kruuk (1963) describes burial in the common sole (*Solea vulgaris* Quensel) as consisting of “3-8 hard beats with the head on the sand” which kick sand up into the water column while the fins flick the sand onto the back of the animal. Kruuk (1963) suggests that the presence of sand on the animal may inhibit further burial behavior. This qualitative description gives a general idea of what flatfish are doing when they bury. However, a more detailed look is warranted to determine the exact role of the body undulations and the fin flicks.

Watching a flatfish bury, it is immediately obvious that they bury incredibly quickly. The reason for this rapidity is not described in the literature. The present study aims to describe why the undulations of the flatfish body during burial are so rapid.

## **Methods**

### Animal Collection and Care

Five species of flatfish (six *Isopsetta isolepsis*, six *Lepidopsetta bilineata*, three *Lyopsetta exilis*, four *Parophrys vetulus*, and three *Psettichthys melanostictus*) were caught at Friday Harbor Laboratories (FHL) from June 17-July 2 via trawls and beach seines. They were kept in flow through tanks without sand with similarly caught fish of other species. All flatfish were filmed within five weeks of capture.

### High Speed Video

Each individual was filmed burying using a Troubleshooter LE, model LE500MS, high speed camera positioned over a tank with a few millimeters of sand on the bottom. The individual being filmed was transferred to this tank alone and an acrylic divider was put about halfway down the tank to restrict the movement of the fish to within the frame of the camera. The flatfish was filmed burying in the sand at 250 frames per second, with a shutter speed of 10x, a resolution of 640x480, and a gamma of 1.5. Before and after burial, pictures were taken on a separate camera to assess the percentage of the individual's body that was buried during each trial. Each individual was filmed once.

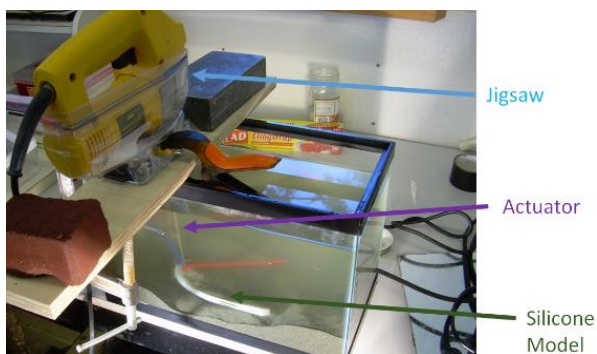
### Video Analysis

Time to burial was defined as the amount of time between the first undulation and the end of all motion. Speed of undulation during burial (cycles per second) was determined by counting the number of undulations visible (before the animal was obscured by sand) and

dividing that by the time taken to perform the same undulations. ImageJ was used to determine the percent of surface area that was buried during each trial using the pictures taken before and after the burial.

### Modeling

A 100x170x8mm oval flatfish model was created using EcoFlex 0050 silicone rubber. This was actuated by a DeWalt DW 318 vs orbital jigsaw modified with a metal pole in the place of a blade. The saw rested on a wooden plank over a tank of water (see Figure 1). The model was undulated by the jigsaw at different frequencies (3.7-31.9 Hz) over sand in the water to simulate flatfish burial. The setup was filmed using the same high speed camera and settings as above, except with a shutter speed of 5x instead of 10x. This video was analyzed to determine the speed of the undulations. Before and after burial, pictures were taken of the model to determine the surface area of the model that was buried during each trial. Two dead *L. bilineata* (small: standard length: 12.5cm, depth: 3mm; large: standard length: 19.4cm, depth: 14mm) were then attached to the jigsaw in place of the silicone model and undulated over the sand to bury.



*Figure 1: Model Setup. A DW318 vs orbital jigsaw was attached to a metal pole, where the blade would normally have gone, which acted as an actuator, moving a silicone fish model at a specified frequency.*

## Results

### High Speed Video

All except for two individuals buried more than 80% of the surface area of their bodies when viewed from the top. Many individuals buried 90-100% of the surface area of their bodies (see Figure 2). There was no statistical difference in the surface area buried among the five different species (ANOVA,  $p > 0.05$ ). The time taken for the burial behavior was very brief, taking from 1-2.8 seconds (see Figure 3). There was no difference in the time taken between different species (ANOVA  $p > 0.05$ ). The speed of the undulations produced by the body of the animal during burial varied significantly between the species (ANOVA  $p < 0.05$  for all shown in Figure 4, except between *L. bilineata* and *P. melanostictus* which had  $p < 0.01$ ) and was between 5.2-10Hz (see Figure 4). There was no relationship between the size of an individual and its undulation speed (see Figure 5). No relationship was found between the speed of the undulations and the burial performance, measured as the surface area buried, (see Figure 6). Nor was there a relationship between the speed of the undulations and the time of the burial behavior (see Figure 7).

### Modeling

The silicone model showed a positive, nonlinear correlation with the percent surface area buried (see Figure 8). Undulation speeds from 3.7~10Hz show a rapid increase in percent surface area as the undulation speed increases. At high undulation speeds, the correlated increase in percent surface area becomes slower and becomes negligible after ~22Hz. The model data from the dead fish follow the same trend as the silicone model.

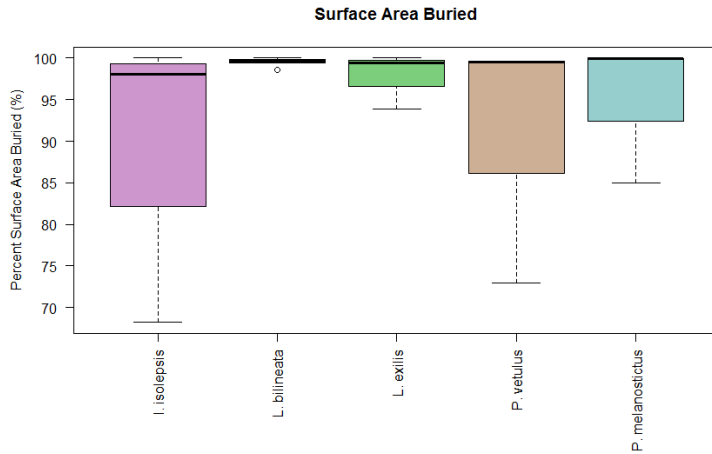


Figure 2: Surface Area Buried. All individuals buried more than 60% of their bodies' surface area. There was no significant difference in surface area buried among species.

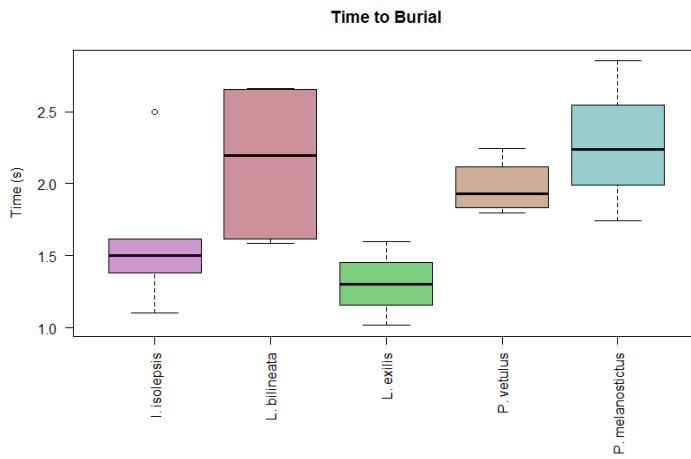


Figure 3: Time to Burial. The time taken to bury varied between 1-2.8 seconds, but was not significantly different between species.

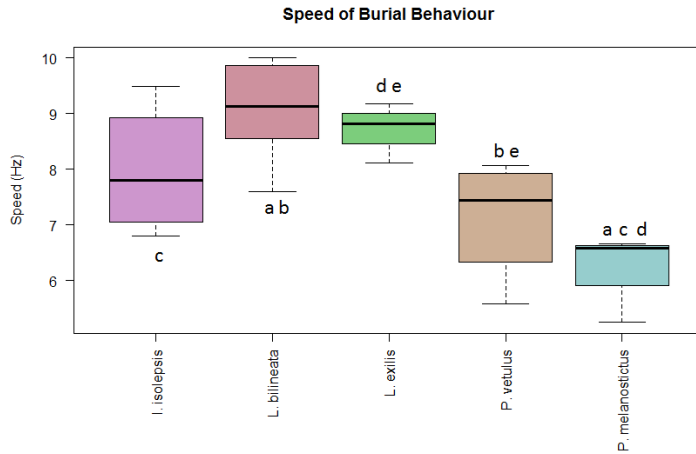


Figure 4: Speed of Undulations During Burial Behavior. Speed differed significantly between species. Matching letters on the graph above indicate that those two treatments were significantly different from each other. For example, *L. bilineata* and *P. melanostictus* differed significantly in the speed of their undulations as indicated by both boxplots sharing the letter “a”. All significance had a  $p < 0.05$  except for “a” which had a  $p < 0.01$ .

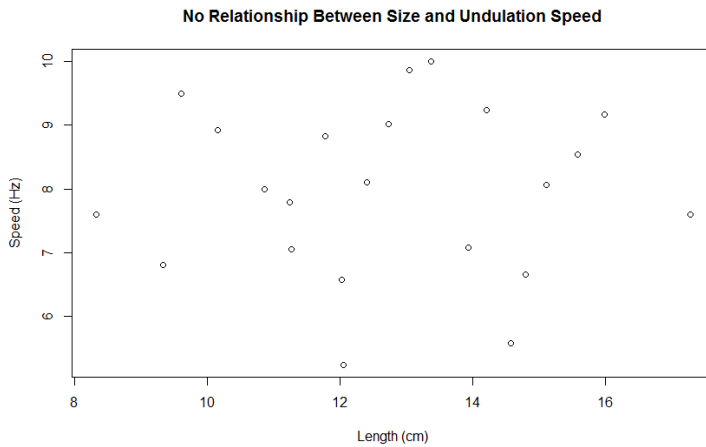
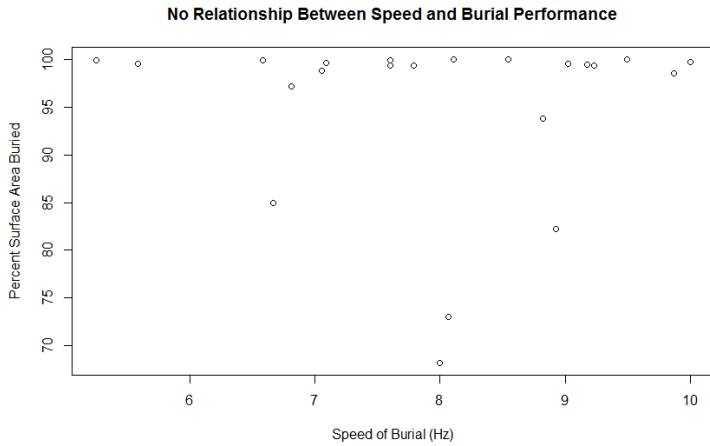
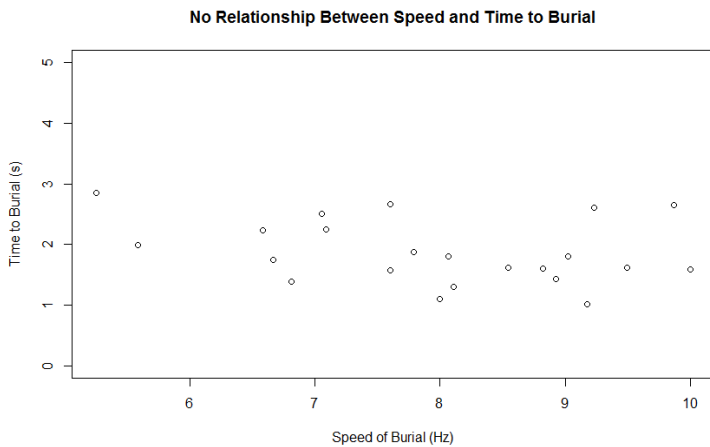


Figure 5: No Relationship Between Size of Individual and Undulation Speed.



*Figure 6: No Relationship Between Speed and Burial Performance. Most individuals buried almost all of their body. There was no correlation with speed.*



*Figure 7: No Relationship Between Speed and Time to Burial. The duration of a burial behavior varied between 1-2.8 seconds and did not correlate with the speed of the undulations during the behavior.*

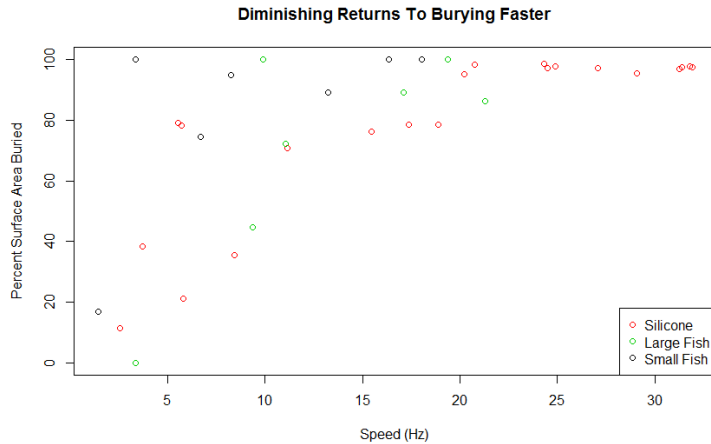


Figure 8: Diminishing Returns to Burying Faster. Faster undulations led to a higher percent surface area buried in the silicone model as well as the dead fish.

### Discussion

The flatfish in my trials all buried themselves very efficiently. Their time to burial and the percent surface area that was buried are nothing short of impressive. The times to burial in these flatfish is similar to the summer flounder, *Paralichthys dentatus* which buries in 1.5-3 seconds (Olla, Samet, and Studholme, 1972). The differences between the undulation speeds among the species may be an artifact of low sample size. But the speed that the fish can undulate their bodies, even the slowest of them, is still incredible.

The observation that size does not correlate with undulation speed is probably due to the low distribution of sizes in this sample. These sizes were chosen to fit constraints related to ease of convincing the fish to bury (larger fish are less likely to bury) and with being able to see the fish on camera (very small flatfish are transparent).

The lack of a relationship between the speed of the undulations and the time of the burial activity suggests that undulations are quick for some other reason. The model data suggests that this other reason is that there is a minimum speed at which the fish need to undulate in order to bury themselves completely. However, when the model ran at the

same frequencies as the live flatfish, it did not perform as well as the dead flatfish run at the same speeds. This suggests that there is a shape component to burial efficiency.

Additionally, the dead flatfish did not bury as well as the live flatfish at the same frequency, which suggests that there may be a behavioral component aside from undulation. In the high speed video, the flatfish were moving their dorsal and anal fins in a flicking motion. While this was not analyzed in depth in this study, it seems that this flicking motion may be what is causing the discrepancy between the model burial efficiency and the live fish data.

One important point is that these trials were all run on the same size sediment. Flatfish have preferences for different sized sediment that change as they get larger (Stoner and Ottmar, 2003; Moles and Norcross, 1995; Phelan et. al. 2000). There is the possibility that different behaviors, including undulation speed and time to burial, would have been seen on different substrate sizes. Future work could look at the effect of substrate type and size on these behaviors.

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