The Sea Star Oscillatory Gait: Flow and Inclines

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Until recently, the only description of sea star's method of locomotion was as crawling (Rumrill, 1989; Montgomery and Palmer, 2012; Montgomery, 2014), which sea stars do by using podia, or tube feet. When crawling the height of the sea star above the substratum varies little. In 2013 the Johnson lab discovered that sea stars have another gait in which the height of the sea star oscillates as it locomotes (Ellers et al., 2014). This oscillatory, or bouncing, gait is to sea stars what running is to humans: it allows them to move faster to get to food quickly or to escape from stressful situations. During the bouncing gait, the center of mass of the sea stars moves up and down as it moves forward, and its kinetic and potential energy are in phase; in other words, when its center of mass is highest, it's moving the fastest (Ellers et al., 2014; Johnson et al., 2017, Ellers et al., 2018). The Johnson lab has described and analyzed this gait on flat surfaces without flow. This summer we focused on developing experiments and techniques to help us understand how this gait works in more variable flows and slopes that they encounter in the field.

The summer of 2019 was a transitional period for the lab. This summer we had four main goals: extract data from previous *Protoreaster nodosus* films to establish a description of the crawl to bounce transition, film *Luidia clathrata* on flat and inclined surfaces without flow, film *Asterias forbesi* in flow, and film *A. forbesi* on ramps. Last summer, the Johnson lab discovered and characterized the bouncing gait in *L. clathrata,* a sea star from Florida for a relatively few individuals. We intended on completing the baseline dataset for *L. clathrata* this summer, but were unable to obtain healthy *L. clathrata*. Because *A. forbesi* is a local species, we were able to collect about 50 individuals over a range of sizes and, using these individuals, to develop and test new protocols for testing them on inclines and in different flows.

To design our flow experiment with *A. forbesi*, we ran preliminary trials in the flow tank at the Schiller Coastal Studies Center marine lab using a size range of sea stars locomoting at various flow speeds to determine what speed might produce the most interesting results. Based on these preliminary trials, we decided to film 25 *A. forbesi* of a range of sizes (from 3.779 g to 252.468 g) at a set speed. With flow going left to right, right to left, and in no flow. We randomly determined the order in which each sea star would experience the flow treatments. The data from these films is still being extracted and processed. From these data we expect to answer a number of questions such as: does flow impact the direction a sea star chooses to travel? Does locomotion look different when sea stars are moving upstream versus moving downstream? Do sea stars distribute their arms differently moving upstream versus moving downstream? Are sea stars more susceptible to being blown away when they are bouncing than when they are crawling in flow? From some initial observations, we also believe that sea stars may be using flow to get more distance out of each bounce when they bounce downstream. Beginning to answer questions like these will help us understand what the *A. forbesi* oscillatory gait might look like in the field.

We also considered how inclines might impact the sea star bouncing gait. To do this, we set up and filmed *Asterias forbesi* on a plexiglass ramp. This protocol was more difficult to establish, as it was challenging to extract velocity and position data from films as the sea stars travelled up an incline. Side view films of sea stars on inclines function much the same as they do in flat conditions, but bottom view films are impacted both by the added layers of plexiglass as well as parallax, wherein the sea stars appear smaller as they move away from the camera, throwing off the scale of the film. We are still working on how to obtain publication quality velocity data from these videos. However, we were able to obtain interesting categorical data. We noticed that the sea stars frequently put one arm on the wall of the tank before travelling up the ramp, perhaps for added stability. We also noticed that a few sea stars exhibited a switchback behavior, where they would travel up the ramp in diagonal paths back and forth across the ramp, like a human would hike up a hill. Experimental procedures and initial data from our work this summer will support future research in the Johnson lab on understanding the sea star bouncing gait under a variety of conditions.

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