Executive Summary: Team 10

Background and Objectives: We model the escape behaviors of zebrafish. It was previously believed that zebrafish escaped simply when a predator got too close [1]. However, recent studies have shown their decisions involve other factors such as speed of the predator [1]. Zebrafish have two types of escape: (1) quick, predictable escape, and (2) delayed, unpredictable escape. The size and speed of a predator relates to the apparent size of the predator, and affects the likelihood of an escape path. Fast predators are more likely to activate M-cells, which trigger escape type 1 (called M-active), while slow predators are equally likely to trigger escape type 1 (M-active) or escape type 2 (called M-silent). We developed a system of first order ordinary differential equations to model this escape behavior based on different values of L/V.

Model & Parameters: The assumptions used in creation of the model are: (1) the predator is of equal height and width, (2) the direction of zebrafish escape is neglected, (3) the starting distance of the predator is constant, and (4) the predator is approaching zebrafish head on. The system of differential equations are as follows:

\[
\frac{d\theta}{dt} = k_1 \theta (L/V)^{-1}
\]
\[
\frac{dflee}{dt} = (k_2 \theta e^{-k_3flee})/(1 + e^{-k_3flee})^2
\]
\[
\frac{dMactive}{dt} = k_4flee^{-1}(L/V)^{-1}
\]

Where \( \theta \) is the apparent size of the predator (°), L/V is the ratio of predator length to predator velocity and varies from 0.8-1.2 (s) [1], flee is the amount of fish that escape (fish), and Mactive is the amount of fish whose M-cells have fired (fish). k1, k2, k3, and k4 are the parameters and are valued at 0.001 (-), 70 (fish/°), 0.8 (fish^{-1}), and 0.1 (fish^2), respectively.

Results and Analysis: Figure 1 shows the type of escape made by fish as a predator approaches at an L/V of 0.8. The amount of fish that employ M-active escape equals the number of fish that employ M-silent escape are equal when \( \theta \) is roughly 70°. The initial conditions for solving this system are: \( \theta(0) = 15 \), \( flee(0) = 1 \), \( Mactive(0) = 0 \).

Figure 2 shows \( \theta \) as a function of time for different values of L/V. As L/V increases, \( \theta \) grows at a slower rate. This qualitatively corresponds to empirical data found in literature [1].
An effort to determine the stability of the system was conducted, but there are no fixed points or steady states of the system of differential equations based on the Jacobian. Stability analysis showed that $k_4$ is a sensitive parameter but $k_3$ is not.

**Supplemental Issue:** We were tasked with finding the best strategy for a predator to successfully catch a prey animal using our model. It is assumed that fish are easier to catch with active M-cells since they exhibit more predictable movement. The best strategy for the predator will be attaining the $L/V$ that produces the most M-active fish.

Figure 3 shows the time at which the population of M-active fish becomes greater than the population of M-silent fish, with varying $L/V$. Figure 3 shows the smaller $L/V$ values (faster predator) would more likely catch the fish sooner.

Figure 4 shows the percent of fish that are M-cell active once the predator reaches $35^\circ$ (time at which all fish will flee). The predator should have the $L/V$ that results in the greatest percentage of M-active fish. This $L/V$ should be 0.9.

**Future Work and Improvement:** The model should be refined to allow determination of steady states, and thus stability. Optimization of parameters and additional sensitivity also need to be conducted. The model can also implement varying approaches from the predator, the tail angle velocity of the zebrafish escape, and the probability of freezing when M-cells are activated [1].