Tales of Scales: The Relationship Between Hydrodynamics and Antifouling of Pleuronectidae

Ellen Pak, Isabella Claeson, Megan L. Vandenberg, Bart Boom, Karly E. Cohen, Cassandra M. Donatelli TBIOMD499

References & Acknowledgments

Background

- Fish scales are inherently multifunctional: supporting camouflage, defense, hydrodynamic performance, and antifouling (prevention of bioaccumulation). Thus, offering powerful inspiration for bioinspired design.
- Most engineered systems are optimized for either antifouling or drag reduction.
- In maritime applications, this single-function approach has led to antifouling technologies that are environmentally toxic.

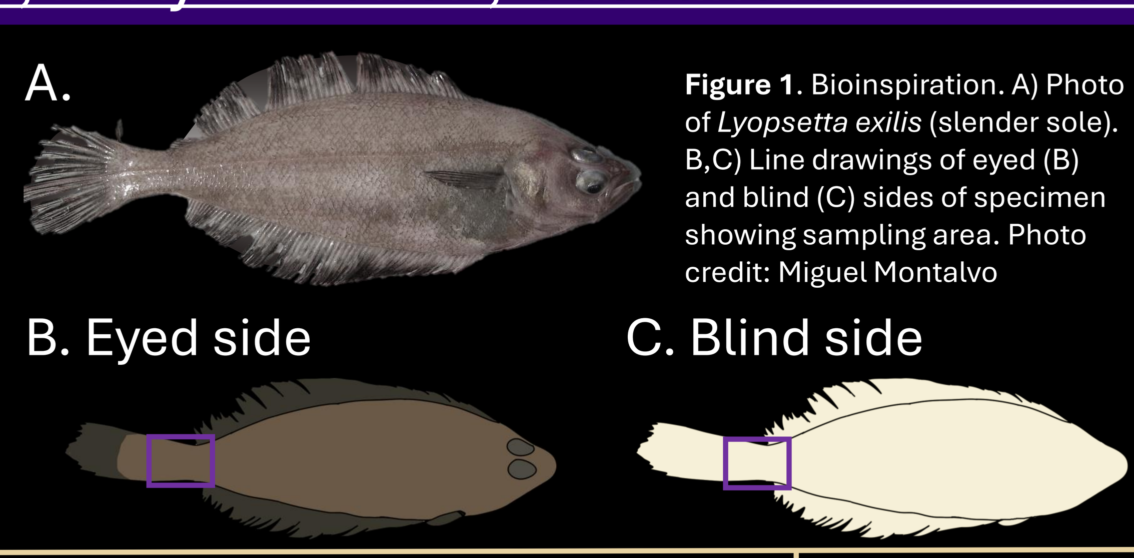

Figure 1. Bioinspiration. A) Photo of *Lyopsetta exilis* (slender sole). B,C) Line drawings of eyed (B) and blind (C) sides of specimen showing sampling area. Photo credit: Miguel Montalvo

Hypothesis

- Hypothesis 1: Staggered models will have increased friction drag reduction properties and thus, increased antifouling capability. Staggered models reflect eyed side scales, and reduced fouling would be beneficial as they have more interaction with the water column.
- Hypothesis 2: Uniform models will have lower friction drag and decreased antifouling capability. Uniform models reflect blind side scales and have more interaction with the substrate.

Micro-Morphology

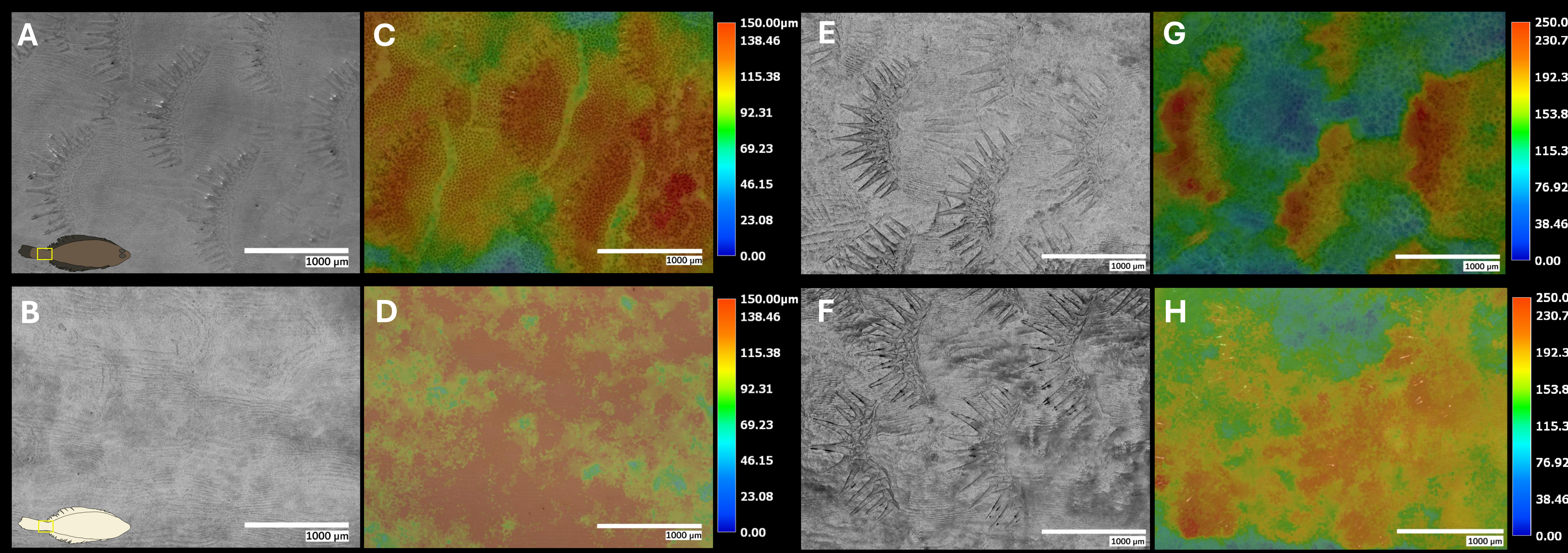

Figure 2. Micromorphology of Pleuronectidae scales from the Burke Museum. Images of *E. jordani* scales (A-D) taken from the Keyence microscope of eyed side (A) and blind side (B) scales at 100x. C,D) height-color maps generated from Keyence measyrements of (C) and blind side (D) scales. Images of *I. isolepis* specimens (E-H). Keyence microscopy of eyed (E) and blind side (F) scales taken at 100x. G,H) height-color maps generated from Keyence measurements of eyed (G) and blind (H) scales.

Bioinspired Models

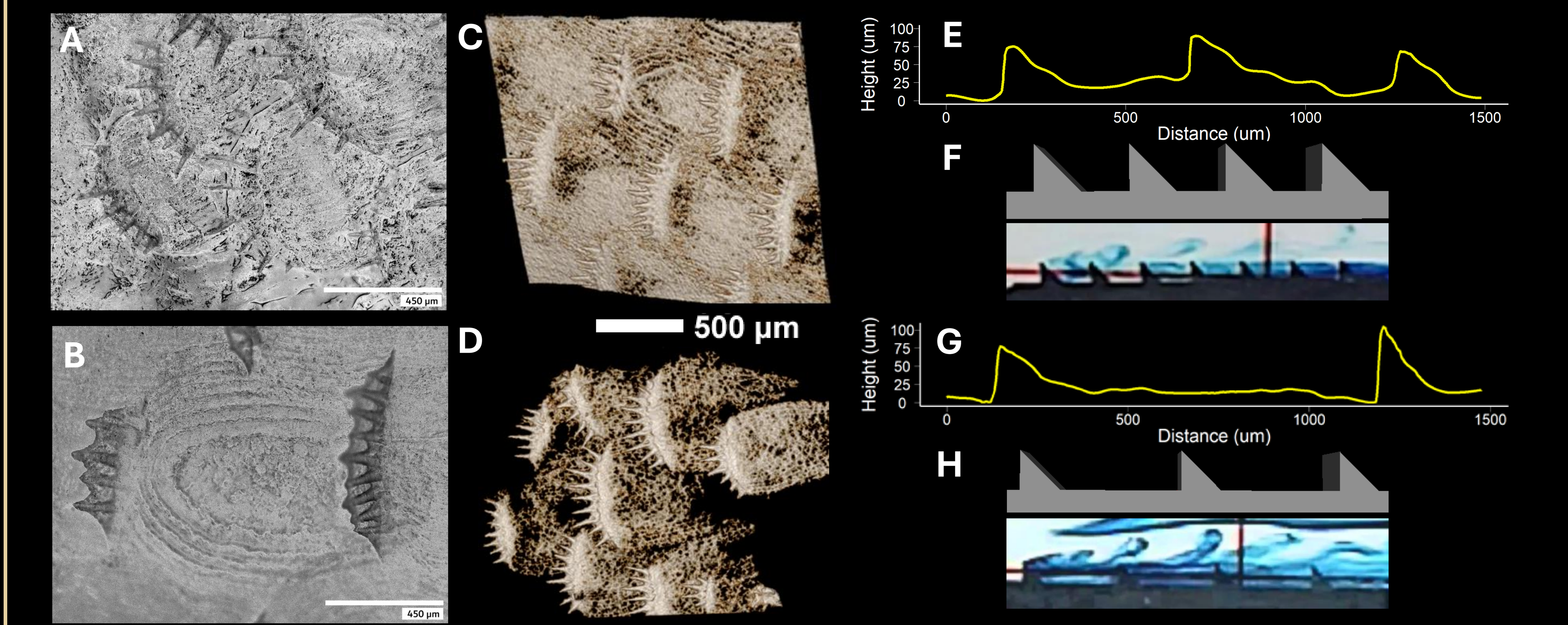

Figure 3. **Preliminary bioinspiration model process.** A&B) SEM filter images of *L. exilis* eyed (A) and blind (B) side scales with Keyence microscopy. C&D) µCT scans of eyed (C) and blind (D) side scales scanned at 6.8 µm. E&G) Topographic height profiles taken using Keyence software across the highest point along the scales in across the distance (um) for eyed (E) and blind (G) sided scales. F&H) CAD models of eyed (F) and blind (H) sided scale models based on Keyence height maps. Dye visualization tests utilizing these models are represented below. These flow measurements were what allowed for the continuation of Pleuronectidae scale models.

PIV Results

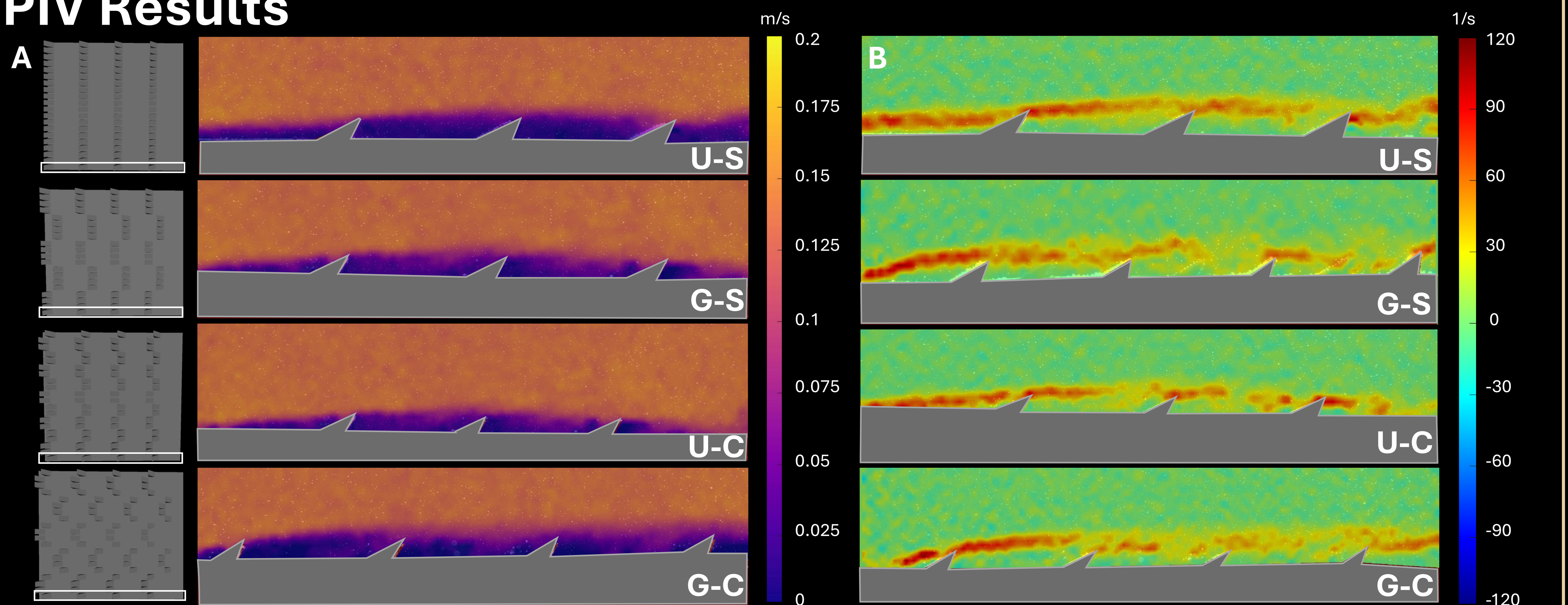

Figure 5. PIV results of differing spacing pattern (G & U) and arrangement (S & C) of Ecoflex model protrusions. White outline represents the row of protrusions observed in the eight MATLAB screenshots. Measurements were taken with PIVLab in MATLAB software. A) velocity (m/s) results of final models. B) vorticity (1/s) results of final Ecoflex models. 60 trials were done in all, with varying flow speeds and model orientation

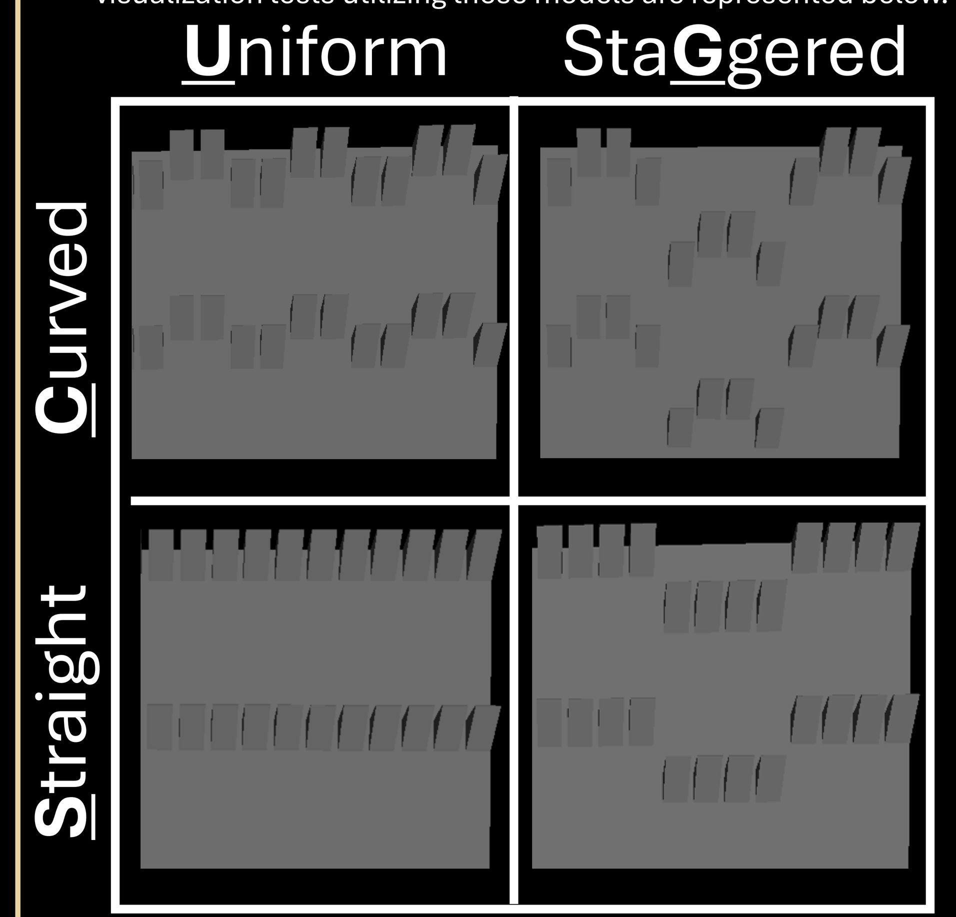

Figure 4. **CAD Models and arrangement types.** In current results, two parameters were observed, protrusion spacing pattern and arrangement. Bolded and underlined letters represent abbreviations used in Fig. 5 & 6. Models zoomed in to show 3x2 "scales", while actual models are 4x5 (seen in Fig 5.)

Antifouling Tests

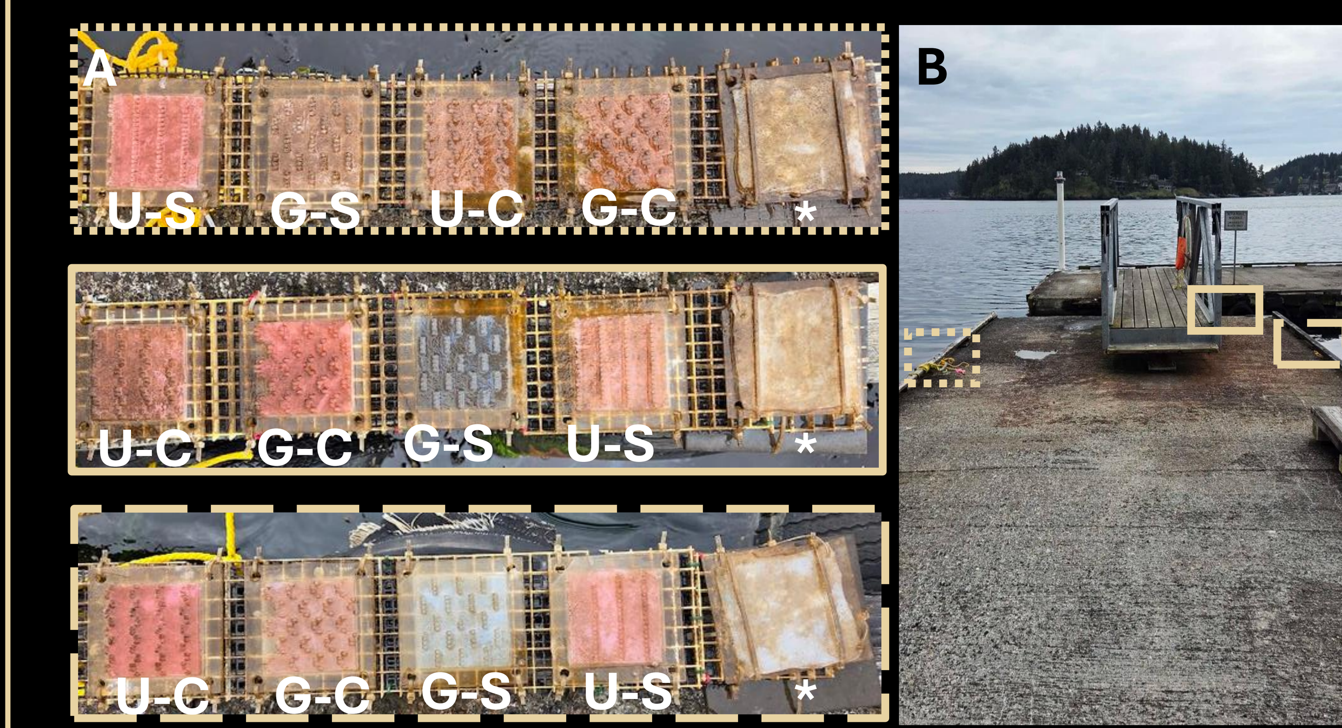

Figure 6. Preliminary antifouling test results. A) Preliminary photos taken of models left in the FHL docks for ~2 months at three different locations on the dock to observe a variety of wave movement. The same abbreviation scheme used in Fig 5. is also utilized here to differentiate each model. * labelled models are control flat Ecoflex models. B) Photo of the dock orienting the viewer to the three different test sites. Dotted, dashed and solid outlined photos in A correspond to locations on the dock from left to right.

Methods

- Keyence microscope takes multiple images from the lowest focal point of the region to its highest focal point
- From each image, height averages are taken based on focus that translate the area into a 2D plot and topographic heat map data
- Rolling Hills flume utilized for PIV testing. Water flow moves left to right. A thin laser beam shines on the desired area of measurement to visualize silver particle flow.

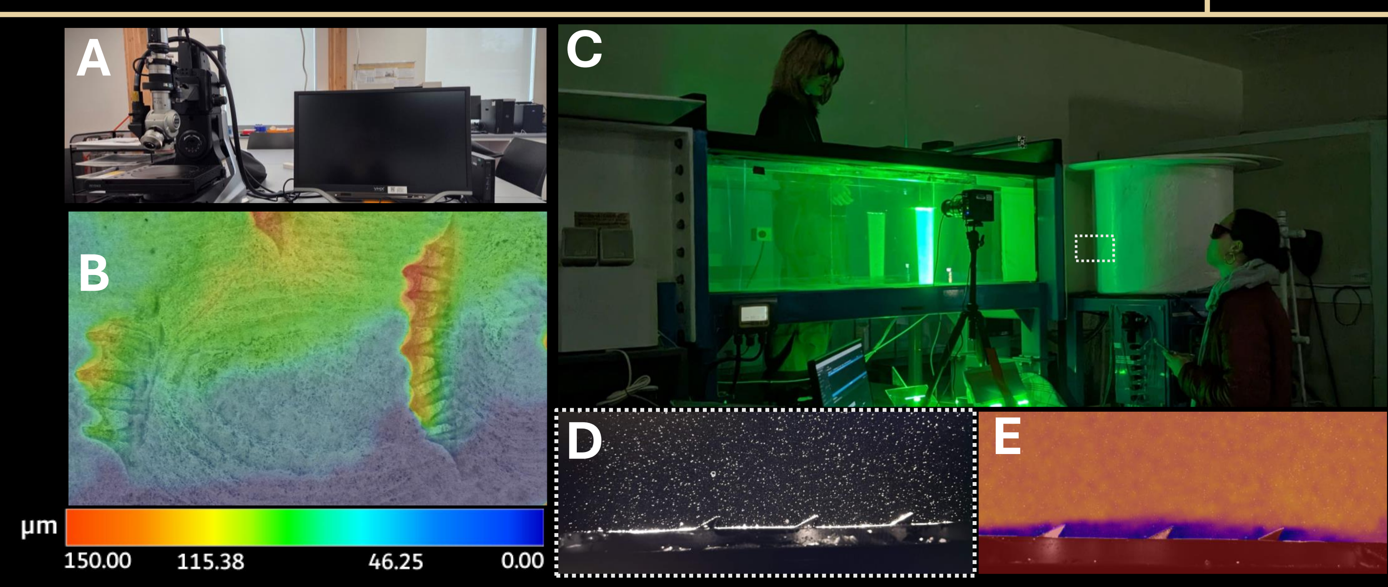

Figure 7. Methods. A) Keyence Microscope. B) Topographical height map at 200x magnification showing height of scales used for bioinspired models. C) PIV setup. D) PIV Image (raw). E) Processed PIV image showing velocity in the flow direction.

Conclusions

- Staggered and curved models increase turbulence between the spines and the base of the model.
- U-S and G-C models retain their boundary layers, increasing friction drag, but reducing wake drag.
- G-S and U-C models release the boundary layer earlier, decreasing friction drag and increasing wake drag, leading to more antifouling capability.
- Increased vorticity and smaller boundary layers would reduce fouling since the turbulent flow would make it difficult for microorganisms to attach themselves.
- While friction drag is negligible in most cases, since fish are small, it has significant impacts on their drag.