Plankton Fluid Dynamics

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Introduction

Planktonic organisms play key roles in the biological processes in the ocean and range from micron-sized bacteria over unicellular flagellates and ciliates to crustaceans and centimetre-sized gelatinous organisms. Many plankton graze on other organisms, flagellates and ciliates, e.g., graze on phytoplankton and bacteria, and they thereby transfer the primary production to higher trophic levels. The key process of resource acquisition, i.e., how plankton capture their prey, remains unexplored for most life forms. In the low Reynolds number fluid dynamical world of micro-swimmers, viscosity impedes predator-prey contact, and the physical mechanisms by which micro-swimmers nevertheless clear huge volumes of water for prey are not well understood. Here I present a series of studies that combine fluid dynamics and marine ecology to explore and model swimming and feeding plankton using direct observations of flagellates, ciliates, and crustaceans, flow-visualisation techniques, computational fluid dynamics, and theoretical modelling.

Swimming, Feeding, and Stealth of Flagellates

Flagellates use long, slender appendages (flagella) to swim and create flows that support their prey capture (Fig. 1). However, the created flows also expose the flagellates to flow-sensing predators, and stealthy swimming is therefore advantageous to avoid predation. I will present theoretical models to explore the dependence of swimming kinematics, feeding rates, and flow disturbances on flagellar arrangement and beat pattern, and I will compare model predictions with experimental results on freely swimming flagellates [1-3].

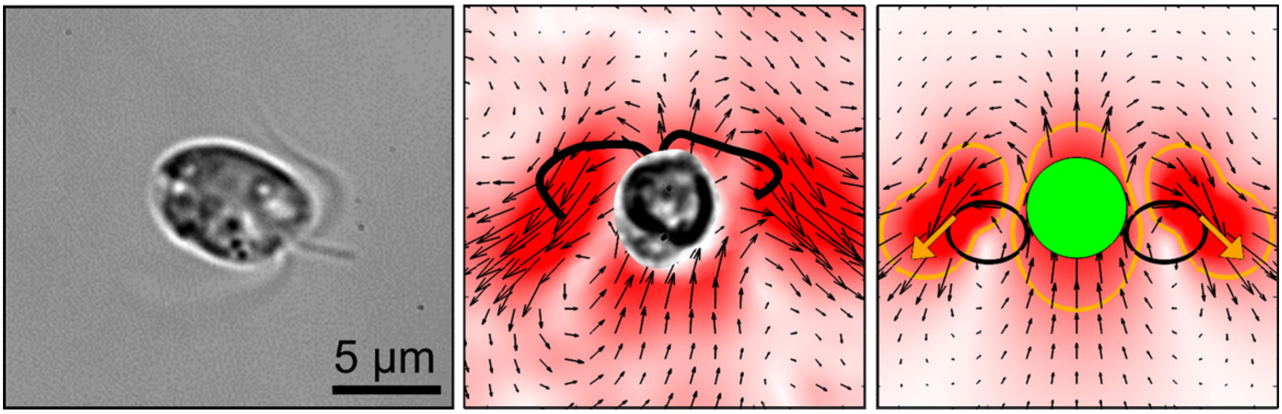

Figure 1: Individual of the flagellate *Prymnesium parvum* (left), measured snapshot of the velocity field around *P. parvum* (middle), and snapshot of the velocity field in the theoretical model of *P. parvum* (right). The two point forces represented by the orange vectors (right) model the two beating flagella (middle). Adapted from reference [3].

Filter Feeders: Dense Dwarfs and Gelatinous Giants

Many plankton from microbes to large gelatinous organisms are filter feeders that create a feeding flow through fibrous structures where bacteria-sized prey are retained (Fig. 2). I will describe the fluid dynamics of the filter feeding choanoflagellate *Diaphanoeca grandis* that is equipped with a single flagellum, and I will discuss how the flagellate is able to overcome the high resistance of the fine mesh and create its strong feeding flow with a flow-rate of one million times its own cell volume per day [4, 5]. Further, I will present a theoretical model of planktonic filter feeders that allows comparison of small unicellular filter feeders like choanoflagellates (dense dwarfs) and large gelatinous filter feeders such as salps (gelatinous giants), and explains why large filter feeders need to be gelatinous to survive in the marine environment [6].

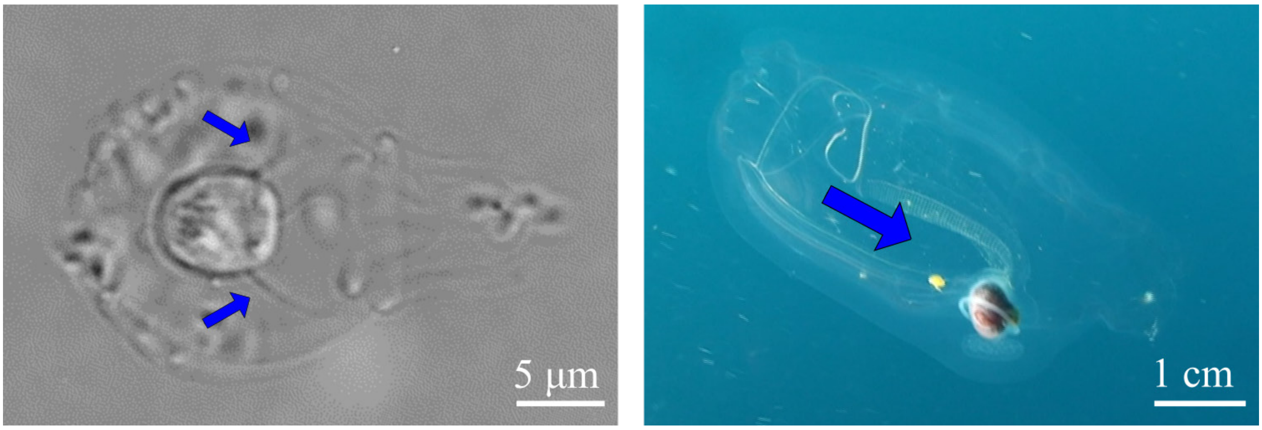

Figure 2: Plankton that capture prey on a mesh by filtering water through it are common and include unicellular choanoflagellates (left) and large gelatinous salps (right). The blue arrows indicate the directions of the feeding flow. The images are shown by courtesy of Lasse Tor Nielsen and Kelly R. Sutherland. Adapted from reference [6].

Copepod Swimming, Attacks, and Escapes

Copepods are crustaceans which constitute the dominating group of millimetre-sized marine zooplankton, and copepods are therefore of great importance. Many copepods swim in jumps with alternating power and return strokes of their swimming appendages, and some copepods carry out surprisingly fast jumps to either attack prey or escape from predators [7-9]. I will discuss the fluid dynamics of such jumps, and explain how copepods can carry out ambush attacks without pushing away their prey (Fig. 3).

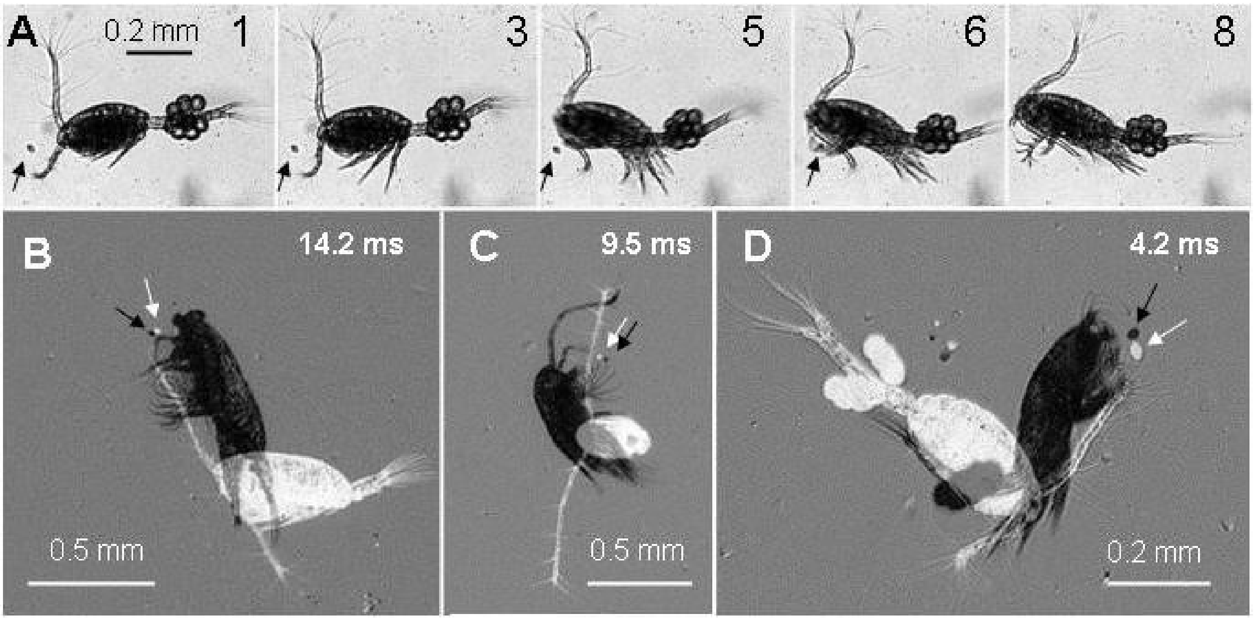

Figure 3: Prey capture in two different species of ambush-feeding copepods. (A) Frame numbers are shown with consecutive frames 0.5 ms apart. (B), (C), and (D) The positions of the copepod and the prey indicated by the arrows are shown before (white) and after (black) the attack jump. Adapted from reference [8].

References

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