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Walther, Jens H.; Asadzadeh, Seyed Saeed; Kiørboe, Thomas

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Trade-offs in flagella propulsion, feeding and stealth*

Presenter:
JENS H WALTHER
(Technical University of Denmark)

Authors:
JENS H WALTHER
(Technical University of Denmark)

SEYED S ASADZADEH
(Technical University of Denmark)

THOMAS KIØRBOE
(Technical University of Denmark)

Flagellates are key components of aquatic microbial food webs. Their flagella propel the cell through the water and generate a feeding current from which bacterial prey is harvested. However, the activity of the flagella also disturbs the ambient water, thereby attracting the flagellate's flow-sensing predators. Here we use computational fluid dynamics to explore the optimality and fluid dynamics of the diverse arrangements, beat patterns, and external morphologies of flagella found among free-living flagellates in light of the fundamental propulsion-foraging-predation-risk trade-off. We examine 5-μm-sized representative model organisms with different resource acquisition modes: autotrophs relying on photosynthesis and uptake of nutrient molecules, phagotrophs that feed on bacteria, and mixotrophs that employ both strategies. For all types, the transport of inorganic molecules is diffusion dominated, and the flagellum in autotrophic species therefore mainly serves propulsion purposes. Flagellates with a single, naked flagellum found among non-foraging swarmer stages have a waveform (less than one wave) that is optimized for swimming and stealth but inefficient for feeding. Flagellates with a hairy flagellum typically have many waves, which optimizes swimming and stealth but is suboptimal for foraging, leading to a design trade-off. However, when compared with naked flagella, the presence of hairs allows an efficient feeding current, making these primarily phagotrophic flagellates the most efficient and dominant bacterivores in the ocean. Autotrophic biflagellates have wave patterns optimized for both propulsion and foraging but conflicting weakly with stealth. Finally, the mixotrophic haptophytes are optimized for foraging, conflicting with both stealth and propulsion. This is largely due to the long haptonema that improves prey collection but at the cost of stealth and propulsion.

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