

Stochastic dynamics of schooling fish

Elena G. de Lamo^{1,*}, Romualdo Pastor-Satorras¹ and M. Carmen Miguel^{2,3}

¹Dept. de Física, Universitat Politècnica de Catalunya, Campus Nord B4, 08034 Barcelona, Spain and ²Dept. de Física de la Matèria Condensada, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain and ³Institute of Complex Systems (UBICS), Barcelona, Spain

*elena.garcia.de.lamo@upc.edu

Key words: Fish dynamics; Group cohesion; Collective behavior

Social animals frequently form groups in which interactions among individuals serve as the primary mechanism for coordination. A fundamental aspect of this coordination in many species is the maintenance of spatial cohesion, which is crucial for navigating complex environments [1]. Consequently, the confinement arising from cohesion plays a significant role in shaping the internal dynamics of social animal groups. The movement of the school can thus be understood both at the collective level, represented by the center of mass of the entire group, and at the individual level, where internal movement within the school is analyzed through the center-of-mass framework. This framework provides a means to study cohesion and its effects systematically.

This study aims to investigate the impact of cohesion in fish schools of varying group sizes, with a particular focus on intermediate-sized groups. To achieve this, a coarse-grained approximation has been employed to describe the attraction of individuals towards the center of mass, interpreting this attraction as a consequence of social grouping. Subsequently, experimental data have been utilized to infer an effective potential that confines individual fish within the school. In other words, we model the effect of group presence on individual fish and the mechanisms that enable them to remain together. Furthermore, we propose a model based on stochastic differential equations that captures key characteristics of fish school behavior.

In developing this model, we demonstrate that fish movement can be described by a system of Langevin-type stochastic differential equations, a well-established approach in the study of animal movement [2]. Different forces are inferred from experimental data using kernel-based regression [3], which allows for a robust estimation of the drift and diffusion terms. This methodology has been successfully applied in other biological studies [4] and provides a reliable framework for analyzing fish school dynamics.

The model performs well in describing several characteristics observed in experimental data, which have been used both to construct and validate the model. Moreover, the model not only replicates the behavior of finite-sized fish schools but also offers an approximation for schools of infinite size.

Our findings suggest that the cohesion of fish schools can be modeled within the center-of-mass framework as the result of individual fish swimming freely while being subjected to a central force that acts to draw them back toward the group. It is shown that this force is essential for maintaining the structural integrity of the school and ensuring an effective exploration.

References

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