# Deciphering the hidden interactions within biological networks of varying sizes

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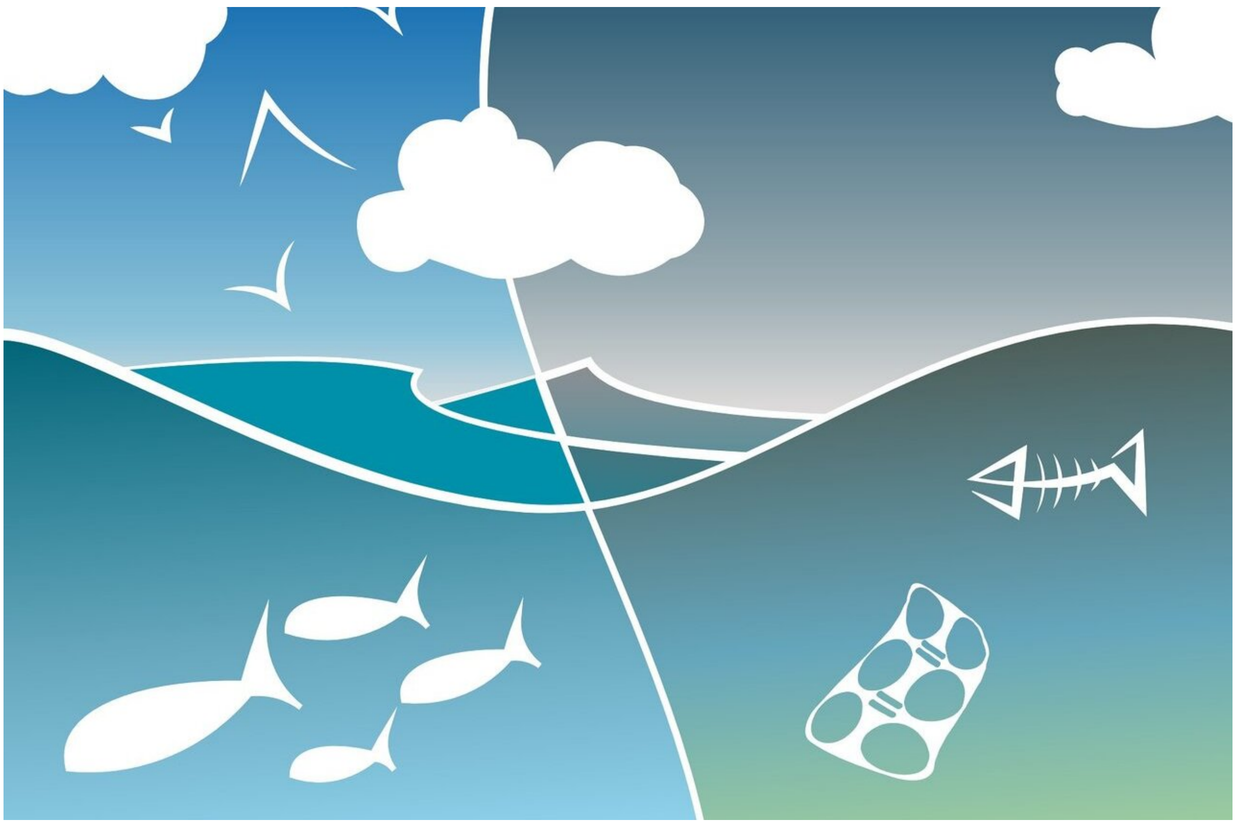

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Collective behaviors are the result of dynamic local interactions between individual members of the collective. While the actions of a collective are readily observable, the interactions remain hidden and have traditionally been difficult to analyze. Now, researchers from the University of Tsukuba applied integrated information theory to understand how varying sizes of a collective of fish affect the interactions between its individual members.

Originally developed to measure the degree of consciousness from brain activity, integrated information theory is an elaborate computational tool that enables the study of groups of elements within a system—like a biological network—whereby each element has the ability to affect another through the cause-effect principle. In this context, "integrated" means that the information that the biological network yields is more substantial and informative than the information derived from the individual elements of the network. By measuring integrated information, overarching systems such as consciousness can be quantified from empirical data, including electroencephalographic (EEG) or functional magnetic resonance imaging (fMRI) recordings. In the behavioral sciences, this overarching system could be seen as a collective of animals, whereby actions of individual members could yield data to help understand the collective.

"Collective behaviors like swarming, fish schooling and bird flocking function so smoothly and seemingly effortlessly," says lead author of the study Professor Takayuki Niizato. "The quintessential question is how these collectives function as efficiently and coherently as they do. The goal of our study was to further our understanding of the dynamics of collective behavior by applying integrated information theory to schools of two to five fish to understand the intrinsic differences between these groups."

To achieve their goal, the researchers studied groups of Plecoglossus altivelis, also known as sweetfish. They chose juvenile fish, as these display typical schooling behavior, whereas adult fish tend to show territorial behavior. The researchers randomly picked fish and moved them together without any prior training to ensure the formation of a school of a given size.

By analyzing the trajectories of the fish using integrated information theory and including the visual field, distance and turning rate of each member of the collective in their analysis, the researchers found a discontinuity between three- and four-fish schools. Interestingly, this means that there was a substantial change in group behavior when the number of fish was increased from three to four, an observation that had not been made before.

"Our findings underscore the dynamics of collective behavior with varying collective sizes," says Professor Niizato. "Specifically, as collective size increases, a leadership emerges that determines group integrity. Our study highlights the intricacies of group dynamics and could help improve our understanding of more complex patterns of collective behavior."

**More information:** Takayuki Niizato et al. Finding continuity and discontinuity in fish schools via integrated information theory, *PLOS ONE* (2020). DOI: 10.1371/journal.pone.0229573

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