

## **Tipping Phenomena in Ecological Systems Under Forcing**

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Tipping represents a phenomenon that makes a large transition from one stable state to another due to a small perturbation. It has been reported in nature, climate, ocean systems and ecology and even engineering systems. Examples of tipping elements that show up such transitions are many, EL-Nino, Atlantic meridian overturning circulation (AMOC), Indian monsoon and Greenland ice cap melting due to global warming, rainforest to mention a few. As an after effect, many undesirable large changes, closing of AMOC, outbreak or extinction of species, in the future have been expected. Studies on tipping started through rigorous mathematical approaches mainly in the last two decades using simple models. The studies involve simple non-autonomous (time dependent) dynamical models under external perturbations that differs from the time-independent autonomous dynamical framework. The mathematics itself is a challenging issue. Besides developing the mathematical framework of non-autonomous systems for appropriating the model studies, many numerical studies on such non-autonomous forced systems have revealed interesting tipping behaviours such as the bifurcation tipping, rate-induced tipping and noise induced tipping. Each of them shows specific characteristic features of tipping and their ultimate effect on the tipping element in several model systems. I will discuss, in brief, with examples, what is the meaning of tipping and how it appears in some natural systems. Finally, I will share our experience in ecological models how they respond to environmental variability leading to tipping.

### **References**

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