How Bali could teach the world to manage its limited resources

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Water is a limited resource. As such, efficient ways to jointly manage and optimize water reserves are essential for our present and future. But how can a well-balanced system be established? In order to single out the relevant parameters, an international team of scientists, including Stefan Thurner from the Complexity Science Hub Vienna (CSH), applied a method from physics to a system in equilibrium: the century-old rice irrigation practices in Bali.

According to their work just published in *Physical Review Letters*, the current equilibrium self-organized over the course of the past thousand years, maybe driven by farmers'—conflicting—planting schedules.

Balancing conflicting constraints

Over the centuries, Balinese rice farmers had to deal with two constraints. On the one hand, the water to irrigate the paddies is a limited resource. "Intuitively, one would think that an unsynchronized flooding would lead to a fairer water distribution between farmers," explains CSH-President Thurner. Yet, there is also a need to control rice pests such as insects that can easily move from field to field. The farmers learned from experience that pest control needs the synchronized flooding of neighboring paddies.

These two constraints have opposing effects. "The larger the agricultural area that follows the same irrigation schedule, the more water stress appears from the synchronized irrigation cycles," the study reads.

To find patterns in synchronized and unsynchronized farming schedules, the scientists analyzed satellite images of several rice growing regions in Bali from 2002 to 2015. They classified which of the four characteristic planting patterns—growth, harvest, flood, or drain—occurred when and where. Now they developed a way to relate these patterns to the balance of stresses in Balinese farming.

A formula for an equilibrium

"We present a formula that explains how a balance between water stress and pest stress is realized and how the system eventually reaches an equilibrium," says Thurner. "If the stresses were managed differently, the rice growing regions would look very different from what we observe in reality."

According to the complexity scientist, "it is a razor-sharp balance between different states and can tip at a tipping point or a phase-transition point, as the physicists would call it."

How fast the seemingly eternal equilibrium can get out of control became apparent in the 1970's. The so-called Green Revolution made farmers use pesticides and cultivate their paddies without their traditional synchronization system.

"At first, harvests increased," says Yérali Gandica from Cergy Paris University, the first author of the paper. "But within a couple of years, farmers reported chaos in water schedules and an explosion in pests." When too many paddies in higher regions were flooded at the same time, farmers with lower terraces experienced water stress. Disharmony between neighbors grew, the carefully maintained Balinese culture of social harmony was disturbed. It was only when the traditional method was reinstated that the equilibrium (mostly) returned.

"It might seem a very theoretical approach, but it could have a practical side in other coupled human-environment ecological systems: One can relate easily observable environmental patterns to stress balance—and thus detect weak points in their management," Thurner concludes.

More information: Yérali Gandica et al, Bali's Ancient Rice Terraces: A Hamiltonian Approach, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.127.168301