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The effect of link rewiring on a coevolutionary common pool resource game

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HIGHLIGHTS

- Link rewiring can stabilize cooperation in common pool resource game.
- When social network is sparse, link rewiring is more efficient.
- Re-switching is harmful when resource inflow is high, but rewiring probability is low.

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ABSTRACT

For exploitation of social–ecological systems, cooperation has been considered to be a prerequisite to avoid the tragedy of the commons. As was theorized, coupling strategic and ecological dynamics could cause social regime shifts when the resource supply is sufficiently abundant. Regime shifts indicate the collapse of social cooperation and the loss of natural resources. The phenomenon has been demonstrated in an integrated society with static complex social networks; however, exploiting agents could dynamically switch their partners (i.e., link rewiring in social networks) in the real world. In this study, we investigate the evolution of cooperation in a coupled social–ecological model in which the ecosystem evolves according to the intrinsic rules and human extracting strategy, and agents are allowed to either change their strategies or switch their partners. Our results show that link rewiring has positive and negative effects on the evolution of cooperation in the common pool resource game according to both social and ecological attributes. Importantly, the partner switching can stabilize the cooperation when the resource has high inflow or reproductivity. These results broaden our understanding of the coevolution of structural, strategic, and ecological dynamics in a common pool resource game; the results also illustrate the importance of reputation mechanisms in the sustainable development of social–ecological systems.

1. Introduction

The common pool resource (CPR) game has become the major tool to explore the sustainable exploitation of social–ecological systems (SESs), which consists of an ecological unit and its associated social actors and institutions [1,2]. CPR provides the necessary ecological features, such as resource renewable rate and environmental capacity, and CPR models the competitive exploitation of multiple agents over the limited resources [1]. At present, the main reason for damage and loss of resources embedded in SESs can be attributed to the collapse of social cooperation when all agents take actions to

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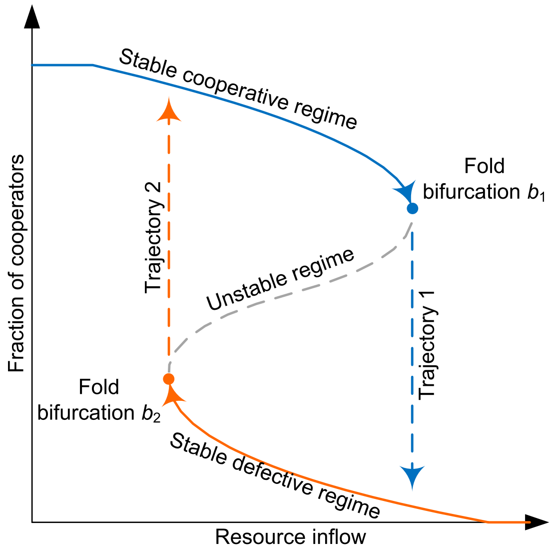

Fig. 1. Social regime shifts in common pool resource exploitation. The social–ecological system describes a group of players (either cooperator or defector) exploiting a living resource with given input rates. The system on the stable cooperative regime will, when the resource supply passes b1, undergo a sudden and large shift to the stable defective regime (trajectory 1). This change is persistent because the fraction of cooperation must be returned to a value below b2 for the system to return to its cooperative state, in another regime shift (trajectory 2). Two trajectories form a hysteresis cycle of the fraction of cooperation.

maximize their private payoffs even as their combined action could deplete or spoil the resource [3]. Therefore, exploring the cooperation mechanism in CPR is of great importance to sustainable development.

For CPR, a key discovery is the social regime shifts of the cooperative level (Fig. 1) [4–6]. For an SES with a group of well-connected agents, the increment of resource supply (i.e., inflow) would gradually reduce the cooperative level of the society until a critical point is reached. When the inflow is near the first critical point (b_1), the further increment triggers a transition from the cooperative regime to the defective regime. Once the transition occurs, the SES cannot be recovered by reversing the same path. During the inflow decrement, the cooperativeness of transited SESs cannot increase sharply back to its previous values at b_1. Instead, the cooperativeness increases gradually to a second critical point (b_2). After this point, the further inflow decrement triggers another phase transition to the cooperative regime again. The hysteresis cycle reveals the following two important facts: (1) high resource supply results the collapse of social cooperation, and (2) the recovery of social cooperation lags the resource change.

Recently, a series of literature has considered the effects of social network structure on the hysteresis cycle [7–9]. In these network-based CPR games, the social agents, who are connected with a static social network, decide to adopt a sustainable extracting effort (be cooperator) or an aggressive extracting effort (be defector) according to the gain in response to the ecosystem dynamics. These studies demonstrated the strong correlation between structural features (e.g., degree distribution and community structure) and the strategic choice in CPR games. However, the static social network does not provide explicit mechanisms to improve cooperation in CPR games. Contrarily, the adaptive network (i.e., network links can be dynamically rewired with strategic changes) has been demonstrated to widely existence and is a useful mechanism to stabilize cooperation in some games, such as public goods games and the prisoner's game [10–16]. However, unlike these games [17–21], the personal benefits in the CPR game depend not only on the strategies of all agents but also on the resource abundance in an SES. In other words, a CPR game has a dynamic payoff matrix. As a result, the effects of dynamical partner switch or link rewiring need to be clarified in CPR games.

In this paper, in addition to the coupled ecological and strategic dynamics in previous studies of CPR games, we consider the coevolution with adaptive social networks. In our model, the ecological dynamic process is based on the widely used TSL (Tavoni–Schulter–Levin) model, which takes the form of nonlinear equations that couple the dynamics of social cooperation to the dynamics of a renewable common pool resource [4]. Based on the TSL model, a link rewiring mechanism, reflecting the reciprocity in the society, is introduced for modeling the coupling of structural and strategic dynamics, in which cooperators are allowed to either adjust their strategies or switch their defective partners [22,23]. We will explore how the whether link rewiring can stabilize cooperation in CPR games.

2. Model description

In this section, we first review the ecological and strategic mechanisms described by the TLS model and later introduce our extension by importing structural dynamics of social networks.