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Testing early-warning signals for the transition of ecological network properties in wetland complex

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Wetlands, which exist in both natural and man-made landscapes, play a critical role in providing various ecosystem services for both ecology and human-being. These services are affected not only by regional hydro-climatic and geologic conditions but also by human activities. On a landscape scale, wetlands form a complex spatial structure by their spatial distribution in a specific geological setting. Consequently, dispersal of inhabiting species between spatially distributed wetlands organizes ecological networks that are consisted of nodes (wetlands) and links (pathways of movement). In this study, we generated and analyzed the ecological networks by introducing deterministic (e.g., threshold distance) or stochastic (e.g., exponential kernel and heavy-tailed model) dispersal models. From these networks, we evaluated structural or functional characteristics including degree, efficiency, and clustering coefficient, all of which are affected by disturbances such as seasonal hydro-climatic conditions that change wetland surface area, and shocks that may remove nodes from the network (e.g., human activities for land development). Specifically, by using the characteristics of the corresponding ecological networks, we analyzed (1) their network robustness by simulating the removal of nodes selected by their degree or area; and (2) the change of variance as the early-warning signal to predict where critical point may occur in global network characteristics affected by disturbances. The results showed that there was not a clear relationship between network robustness and wetland size for node removal. However, when nodes were removed in the order of degree, the network fragmented rapidly. Also, we observed that the variance of network characteristics in the time-series increased in drier hydro-climatic conditions for all the three network models we tested. This result indicates a possibility of using increasing variance as the early-warning signal for detecting a critical transition in network characteristics as the hydro-climatic condition becomes dry. In sum, the observed characteristics of ecological networks are vulnerable to target attack on hubs (structurally important nodes) or drought. Also, the resilience of a wetlandscape can be low after hubs were destroyed or in a dry season causing the fragmentation of habitats. Implications of these results for modeling ecological networks depending on hydrologic systems and influenced by human activities will provide a new decision-making process, especially for restoring and conservation purposes.