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TIPPING POINT PLANNER
Supporting Sustainable Communities in Great Lakes States

Sea Grant ILLINOIS-INDIANA

Tipping Points: What Are They and Why Are They Important?

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The Great Lakes social-ecological system

The eight states in the Great Lakes region of the United States contain both natural and human systems. The Social Systems and Ecological Systems are intricately woven together to create one complex socio-ecological system (Figure 1). Changes in the structure or function of specific system components (or processes) within the natural system can have profound impacts on other natural system components (or processes), as well as on the structure and function of the region's social system, and vice versa. Changes in one part of a socio-ecological system are often felt within other parts of the system. As such it is important to consider the links between system components (i.e., natural and social) when making land use planning and natural resource management decisions. One of the underlying goals when making land use planning and natural resource management decisions should be to maintain, or restore, if necessary, the integrity of the ecosystem. The term ecological integrity refers to a socio-ecological system that balances natural system processes with those of the social system without compromising the structure, function, or self-organizing way the two systems interact (Francis and Reiger, 1995).

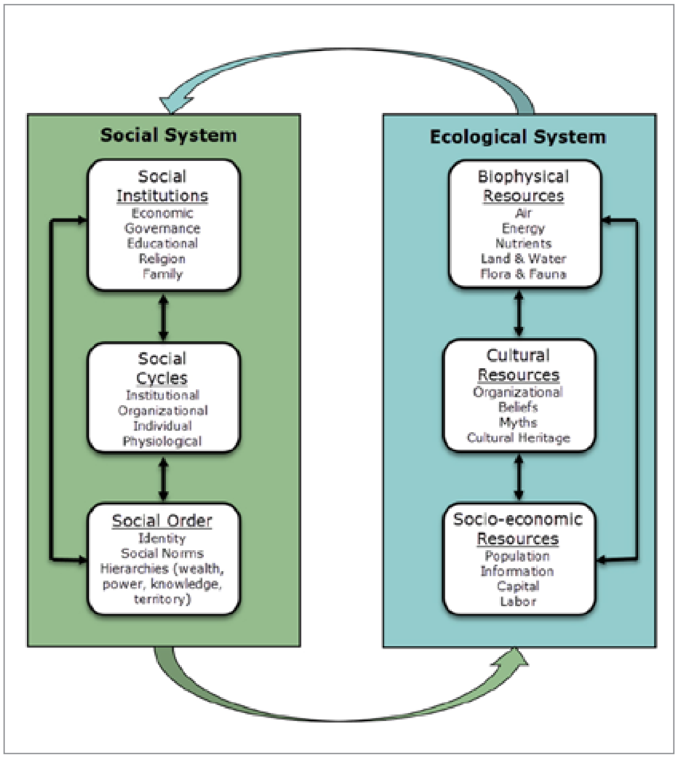

Figure 1. Socio-ecological system framework modified from Grove, Hison, and Northrop (2003).

Within the Great Lakes states (Figure 2), measures of ecological integrity can be used to assess to what extent the socio-ecological system within the region has the ability to:

- Self-regulate itself and adjust to disturbances without compromising its structure or function
- Support healthy biotic and abiotic communities (both terrestrial and aquatic)
- Support the integral role humans (or their impacts) play within the system

One way to measure the ecological integrity of a region is through the assessment of system tipping points or thresholds.

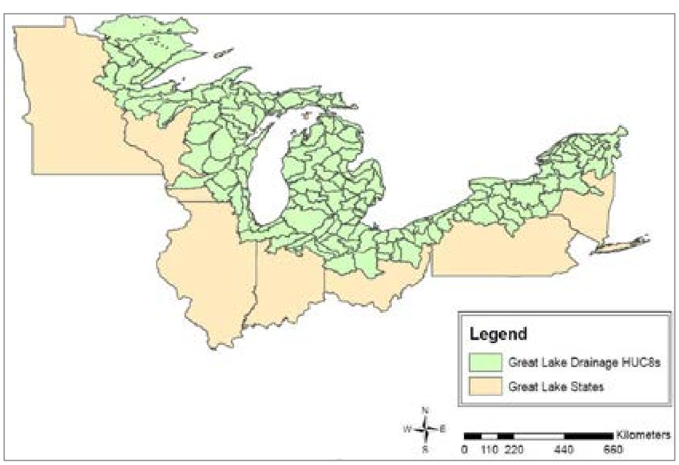

Figure 2. The states that make up the Great Lakes region.

What are tipping points and why are they important?

The vast majority of watersheds within the Great Lakes states are dominated by human activities and are often categorized as complex adaptive systems. Complex adaptive systems are able to change over space and time. They have the potential to exist as numerous different stable states (also called regimes) in which linkages and feedbacks from both social and natural processes remain fairly stable and predictable. Rapid changes in these systems caused by natural events or human disturbances, however, can alter both the structure and function of the systems. Changes to a system's structure and functions often lead to the complex adaptive system shifting from one stable state regime to another.

The point at which a system can move away from one stable state and into another is called a tipping point (or threshold). As stated by Cairns in 2004, the term tipping point refers to the point in which "the forces that create stability are overcome by the forces that create instability… [and the] system tips over into disequilibrium." Eventually, over time, a socio-ecological system will reach a new equilibrium (i.e., stable state) in terms of both structure and function, but the ecological integrity is often severely degraded and may not be able to adequately support the natural and/or social systems relying on it. The crossing of socio-ecological tipping points may come about as a result of a series of small changes to the socio-ecological system or as a large abrupt change to system properties, phenomena, drivers of change, or feedback loops (Groffman et al., 2006). To help illustrate the tipping point concept, Lewontin (1969), and later Walker and Salt (2006), portrayed tipping points and stable states (i.e., regimes) using a ball-in-basin model (Figure 3).

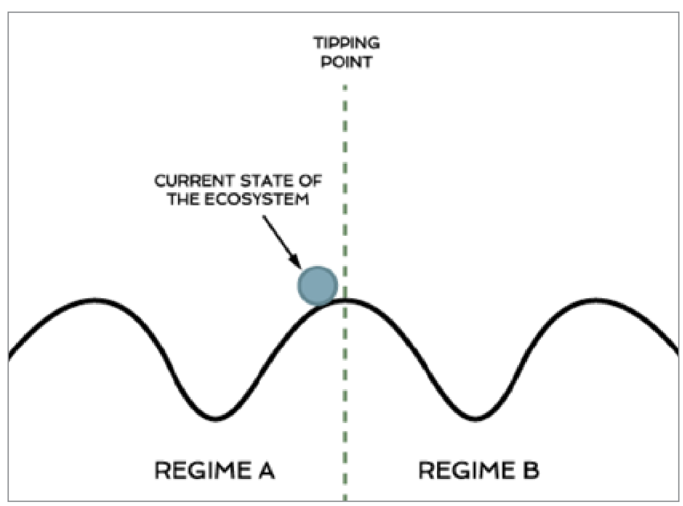

Figure 3. Tipping point concept as represented by the ball-basin model adapted from Walker and Salt (2006) and Lewontin (1969).

In this model, the basins represent ecosystem regimes, while the ball corresponds to the current state of the ecosystem. As the ball moves up the edges of one basin and toward the second basin, the ecosystem approaches an ecological tipping point. When the ball reaches the tipping point between the two basins, it has an equal propensity to move into either basin. Likewise, as an ecosystem reaches a tipping point, it can either remain in its current regime or shift to a different regime, changing both the ecosystem's structure and function. However, once a tipping point has been crossed, the system will automatically begin to rearrange itself into the new regime. If tipping points are crossed and result in unfavorable changes, transitioning from the new equilibrium state back to the old equilibrium state may be difficult—if not impossible. Forcing a complex adaptive system to revert back to an old equilibrium state, if even possible, often requires a considerable amount of energy and potentially significant monetary resources if humans engage in system restoration efforts.

Early detection of ecological tipping points is challenging but is possible with advanced modeling techniques.

Past research

Since the 1960s, concerted efforts to counteract or alleviate human-induced stresses in the Great Lakes region have been a priority for many government organizations and scientific researchers (Kim, 2012). Research shows that even very low levels of urbanization within a watershed introduces water quality degradation and negative impacts to aquatic communities (Booth and Jackson, 1997; Yang et al., 2010). These studies show that when watershed land area is converted to impermeable surface area (i.e., parking lots or paved roads) of greater than 8-15%, most often associated with urban land use, the watershed crosses a possible ecological tipping point. When a watershed exceeds this percentage of impervious surface area, macroinvertebrate populations measured by quantities of Ephemeroptera, Piecoptera, and Trichoptera (EPT) significantly decline (Booth and Jackson, 1997; Yang et al., 2010).

Macroinvertebrate populations have been shown to serve as an indicator of water quality and health of stream systems because they are important in aquatic food webs, have low mobility, and are sensitive to nutrient and toxic pollution (Bode et al., 2002, Growns et al., 1997, Smith et al., 2007).

The National Non-point Education of Municipal Officials (NEMO) network has promoted Booth and Jackson's potential tipping point for many years. More than 30 states, hundreds of watershed planning groups, and many local governments have adopted Booth and Jackson's potential tipping point. These groups now require consideration of an averaged 10% impervious surface area threshold when writing master plans (Kim, 2012). However, as pointed out by Kim (2012), the 10% impervious surface area "rule" does not hold true for all locations, as considerations need to be made based on the percentage of other land use/covers present within a watershed, the configuration of those land uses/covers in the watershed, and the variation in local geomorphological effects on stream ecosystem health.

Current research

Researchers from throughout the Great Lakes region are working to identify potential water quality tipping points based on regional watershed similarities and differences. These researchers have been tasked with developing land use/cover indicators for the Great Lakes region and studying the relationship of measured indicator changes to current ecosystem structure and function. Great Lakes Environmental Indicator (GLEI) project scientists have also developed a list of 14 ecological indicators linked to responses of amphibians, diatom algae, fish, birds, micro-invertebrates, and wetland vegetation to human-induced stressors. By studying the relationship between land use/cover indicators and changes within the ecosystem, potential tipping points within the Great Lakes region's socio-ecological system have been identified.
Results from a study conducted by researchers at the University of Michigan and Purdue University have identified potential tipping points associated with impacts of riparian zone agriculture and urban lands on water quality. They studied changes in the variety of species and abundance of EPT taxa (i.e., macroinvertebrates, such as stoneflies, mayflies, and caddisflies) in response to varying percentages of urban and agricultural lands within the Great Lakes region catchment buffer zones, or a 150-meter area of land that drains into rivers and streams) (Kim, 2012). Results from the Kim (2012) study show significant differences in EPT taxa populations within catchments when 15-20% of the buffer zone land along rivers and streams are composed of urban and agricultural lands. When 30% of the entire catchment is composed of urban and agricultural lands, EPT taxa in the states of Illinois, Michigan, and Wisconsin seem to reach a tipping point.

Additional tipping points research, conducted by Wiley et al., (in prep) from the University of Michigan in partnership with Purdue University, predicts that when the percentage of land within a watershed is composed of urban uses, that particular watershed is heading down a "slippery slope" toward an ecological tipping point. By the time the watershed reaches 22-23% urban, the quality of water in its rivers and streams will become impaired. Slightly higher percentages in the amount of agricultural lands are needed to reach impairment than urbanized land. According to Wiley et al., (in prep) river and stream impairment is reached when approximately 33% of the watershed is composed of agricultural lands. Although these identified potential tipping points results are only preliminary, the urban and agricultural land use cut-off percentages values proposed by Kim (2012) and Wiley et al. (in prep) closely mimic those identified by the U.S. EPA and other researchers working throughout the Great Lakes region.

Using the potential tipping points identified by both Kim (2012) and Wiley et al., (in prep), Robinson (2013) identified several watersheds in the United States Great Lakes drainage basin that are predicted to become impaired by the year 2060. New research at Purdue University shows that land use indicators can be identified, or be nominal tipping points, in catchment and riparian buffers, using EPT taxa biotic scores (Wiley et al., in prep), and U.S. EPA. Future land use/cover predictions for each of the watersheds were developed by Tayebbi et al., (2012) using the Land Transformation Model (LTM), originally developed by Purdue University (Pijanowski et al., 1997; Pijanowski et al., 2002) with continued improvements (Pijanowski et al., 2014). If these predictions hold true, the vast majority of watersheds in the Great Lakes region may lose their ability to maintain the current ecosystem structure and functions needed to preserve surface and ground water quality and to support societal needs and processes of these watersheds.

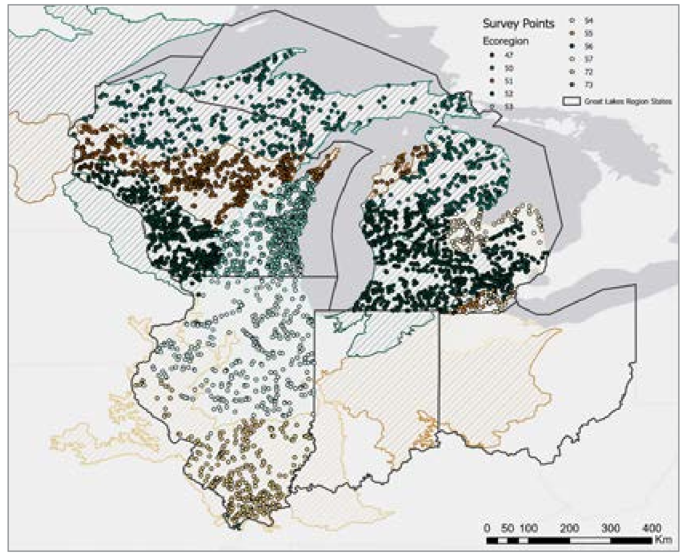

Figure 4. Sites where EPT taxa were sampled in Illinois, Wisconsin, and Michigan. These samples, along with values from the Land Transformation Model, were used to determine watershed vulnerable to tipping points in 2060. Plots are shown on top of EPA ecoregions of the Great Lakes.

Use of tipping points for land use planning and natural resource management

Historically the management of Great Lakes water resources (both surface and ground water) within the United States has been reactionary in nature (i.e., policies were put in place following the identification of existent threats to human health or aquatic communities) (Huber, 1989). More recently, however, governmental entities and local watershed restoration/conservation groups have begun to recognize the importance of preemptive management (i.e., before problems arise) when it comes to managing natural resources and ecosystems. Monitoring the current status of ecosystem components (i.e., water quality) and directing management efforts based on potential tipping points may help to maintain or restore favorable ecosystem characteristics while avoiding unfavorable changes in ecosystem status, structure, and function.

As with overall water resource management within the Great Lakes region, current uses of tipping points for ecosystem management today are often retrospective in nature (Kim, 2012). Changes to ecosystems are recognized and studied only after tipping points have been crossed. This retrospective can be associated with the current lack of knowledge about and identification of tipping points within the Great Lakes socio-ecological system. Nevertheless, some potential tipping points have been identified. Despite the lack of abundance of identified tipping points, land use planners and natural resource managers can still work to avoid unfavorable changes associated with reaching and exceeding tipping points within socio-ecological systems by engaging in adaptive management efforts. Adaptive management allows for the adjustment of planning/management decisions and implementation strategies based on observable environmental (Gunderson, 1999; Pijanowski et al., 2019) and societal impacts. Engaging in adaptive management will ensure that decisions are being made with the recognition that outcomes from these decisions may result in a number of different acceptable outcomes, each allowing for the socio-ecological system to adapt to the changes in a way in which its ecological integrity remains uncompromised.

In addition, by responding to unfavorable changes resulting from planning/management decision, land use planners and natural resource managers will have the ability to avoid ecological tipping points without having to necessarily know exactly where the tipping points are. Indeed, if tipping points are known, planning and management decisions can be made with the tipping points in mind. It should be noted that the exact value of the tipping points may vary slightly due to regional or watershed characteristics. Thus, when making decisions based on a specific tipping point, it is important to remember that there may be a tipping point range (without exact tipping point falling within a range of possible values) instead of an exact tipping point threshold value.

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