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Detecting early signs of environmental degradation in protected areas: An example of Jiuzhaigou Nature Reserve, China

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ABSTRACT

Identifying early signs of anthropogenic disturbances in protected areas is critical for determining overuse, safeguarding natural beauty, protecting biodiversity, and sustaining resource use and economy. Assessing disturbances to aquatic systems of such areas is challenging due to the low-dose, diffused, and cumulative nature of disturbances; high risk at iconic sites; and difficulty of linking human activities with degradation. Using Jiuzhaigou Nature Reserve as an example study to overcome such challenges, we developed an approach that integrated human activities known to impact aquatic systems to calculate a holistic disturbance index for assessing the extent of human uses at scales of entire reserve and individual sub-watersheds. We linked human disturbance index with benthic algae and macroinvertebrate indicators of individual waterbodies to identify early signs of degradation. We conducted *in situ* nutrient experiments and intensive sampling of biota at iconic sites with early signs of degradation to provide direct linkage between tourist activities and eutrophication, and to pinpoint mechanisms of how human disturbances have resulted in such degradations. We found that the human disturbance index significantly correlated with benthic algae and macroinvertebrate indicators, and Jiuzhaigou is largely in healthy condition. For the two identified iconic sites with early signs of degradation, intensive tourist activities at observation and rest areas of Five-Color Lake seemed to link to extra amount of nitrogen input into the lake and resulted in overgrowth of phytoplankton and filamentous algae during summer peak tourist months. Extra amount of phosphorus input from tourism activities at Pearl Shoal seemed the cause of changes in substrate colors and of shifts in attached moss and algal communities. Our example study demonstrates that early signs of degradation can be visually observed and should be further assessed by measuring water quality and sensitive biological indicators at high risk areas of a waterbody during summer and peak tourist seasons. Sensitive biological indicators (e.g., intolerant diatom and macroinvertebrates) are better indicators than nutrient concentrations because of rapid assimilation of nutrients by algae and macrophytes. Our assessment approach and findings of studying Jiuzhaigou have broad applications to other protected areas for determining overuse, and hence for making science-based policy and taking adequate management actions to prevent overuses.

1. Introduction

World protected areas are established to preserve the areas of exceptional natural beauty for future generations and universal value natural habitats for *in situ* conservation of biological diversity (Schmutz and Elliott, 2016). These designated natural areas are also used to contribute to ecosystem services and human wellbeing through tourism, water resource use, income, employment, and playing a part in the mitigation and adaptation of climate change and thus global sustainability (Watson et al., 2014). The activities of meeting ecosystem service demands inevitably degrade natural resources intended for protection and create conflict of interests between natural resource use provision and iconic landscape and biodiversity protection goals (Zhang et al., 2015). Hence, identifying early signs of degradation by those

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human uses for determining overuse and maintaining sustainability becomes a focal point for research and science-based management policy making.

As tourism pressure increases in protected areas, many iconic locations are showing signs of overuse and more protected-area managers reported tourism and recreation as threats to the sustainability of protected areas (Hadwen et al., 2007). In order to manage the impacts of visitors at the level that can ensure the "presentation and transmission to future generations" of the iconic sites, it is critically important to monitor and assess not only visitors' activities, but also the environmental conditions they impact so that early sign of overuse can be detected and visitor impact mitigation can be implemented.

Detecting early sign of overuse by visitors is particularly important for karst protected areas because the process created the natural scenery that attracts visitors also makes them more vulnerable to human disturbances (Pan et al., 2017). Waters originated from karst geology region are rich in calcium carbonate, which precipitates and covers the bottoms of lakes and rivers to form crystallized substrates (travertine). This process also locks up nutrients (e.g., phosphorus) in the bottom of waters and makes them extraordinarily clear. The crystallized bottom with rich microbes and clear water column provide amazingly beautiful colors, which makes them extremely popular tourist destinations. For the same process, thin limestone soils and rapid surface-aquifer transmission of water in karst watersheds provide minimal filtration in preventing pollutants from entering surface waters (Kresic, 2013; Pan et al., 2017). Additionally, disturbances associated with tourists are often low-dose, diffused, and cumulative and such effects can go unnoticed until a threshold or tipping point is exceeded, which can reverse the nutrient deposition process and cause catastrophic regime shifts of aquatic ecosystems (Scheffer et al., 2001; Scheffer and Carpenter, 2003). Hence, detecting early signs of overuse by visitors is especially important for karst protected areas.

Assessment protocols and evaluation criteria are broadly available for identifying anthropogenic disturbance to aquatic ecosystems (e.g., Karr, 1999; Stoddard et al., 2006; Wang et al., 2008) using physicochemical (e.g., Rankin, 1995; Bolstad and Swank, 1997) and biological indicators (e.g., Karr, 1981; Wang et al., 2001) indirectly, or measuring intensity of human activities directly (e.g., Wang et al., 2010; Esselman et al., 2013). These assessment methods are largely designed for evaluating whether waterbodies meet their designated uses by comparing condition of target waterbodies with that of references of the same type of waters within a specific geographic region (Reynoldson et al., 1997; Stoddard et al., 2006; Wang et al., 2008). Those methods are not suitable for assessing human disturbances for protected areas because the environmental conditions of the protected areas are usually as good as or better than the reference conditions themselves. The visitor alteration to the sites tourists visit is often obvious only at iconic sites or part of an iconic site of protected areas. Hence, the random or stratified sampling design and reporting of average condition of a waterbody by the traditional monitoring program may overlook or underestimate such human disturbances. The aim of human disturbance assessment for protected areas is not to evaluate whether waters meet their designated uses but to detect changes before long-term and irreversible changes in the condition of the ecosystem have occurred. Hence, identifying the cumulative effects of low-dose, defused tourist disturbance in protected areas requires measurement of ultrasensitive indicators at appropriate temporal and spatial scales to detect early warning signs of the initial phase of disturbance and thus to inform management practices before the regime change occurs.

Due to the rapid increase in tourism pressures and extremely vulnerable nature of karst protected areas to human disturbances, a rapid increasing number of studies have evaluated a broad spectrum of tourism impacts. For example, Li et al. (2005) and Barros et al. (2013) assessed hiking trails impacts on vegetation and soil erosions; Pickering and Hill (2007) evaluated recreation and tourism on plant biodiversity and vegetation; Steven et al. (2011) reviewed impacts of recreation on wildlife; and Qiao et al. (2015) assessed air deposition effect on a protected area. Efforts have also made to link tourist activities with nutrient increase in surface runoff (Wang et al., 2006), identify sensitive aquatic indicators (Cao et al., 2016; Pan et al., 2016), and assess factors affecting tufa degradation (Liu 2017). These studies provide invaluable information in identifying early signs of human disturbances. However, such studies are highly fragmented, principally comprised site-scale case studies, and employed a diverse array of approaches. It is ineffective to assess human disturbances to ecosystem components that are connected and interactive separately at specific local and temporal scales. It would be challenging to use results of such spatial and temporal specific studies to integrally evaluate whether a protected area is overused. Hence, it is highly desirable to develop a method that allows a disturbance assessment for an entire protected area and for each of its spatial components.

The overall objective of this study was to develop a novel approach to assess ecological degradation for protected areas in general and for karst protected areas in particular using intensity of human activities at multiple spatial scales from the entire protected area to the individual spatial components comprising of a protected area. Using Jiuzhaigou Nature Reserve as an example study, we illustrated how human disturbances at different spatial scales can be synthesized and linked to the condition of ecosystem spatial components. By linking human activities with potential stressors of aquatic ecosystem, we demonstrated the utility of such an approach in detecting early signs of overuse of protected areas. The specific objectives of the study were to: (1) develop an approach for assessing human disturbances and attribute those disturbances to specific waterbodies (i.e., river segments, lakes, shoals, etc.) by calculating a disturbance index using factors that are known to impact the health of such waterbodies; (2) use relationship between human disturbance index and biological indicators to assess overall impacts of human activities on the health of Jiuzhaigou aquatic system; and (3) identify mechanisms of how human activities had resulted the observed early signs of degradation in water quality and biological communities for iconic sites.

2. Methods

2.1. Study area

Jiuzhaigou Nature Reserve is located at the transitional belt of the high elevation Qingzang Plateau and the low elevation Sichuan Basin, China (Fig. 1). Jiuzhaigou encompasses of a relatively small watershed area (643 km^2), but has a large elevation variation from 4,764 m at the ridge of the watershed to 1,996 m at its confluence with the Bai River, a tributary of the Jialing River that flows into the Yangtze River. The climate in this area is cool and dry in the winter (average 2.5 °C and 43 mm precipitation in January) and is mild and wet in the summer (average 17 °C and 104 mm precipitation in July) (Deng, 2012).

Jiuzhaigou is rich in biodiversity and endemic species. Many of the 2,007 terrestrial species of vascular plants, 222 species of birds, and 78 species of mammals inhabiting in this region (Liu et al., 2007; Deng, 2012) are under National Grade I or II protections (Liu et al., 2007). The aquatic system is especially unique in that it consists of 114 alpine lakes, 17 groups of waterfalls, 5 shoals, 47 springs, and 11 sections of rapids (Deng, 2012). This system is formed with valleys surrounded by steep-slope mountains and are largely fed by groundwater. Due to its karst geological setting, the bottoms of aquatic system are covered by crystallized calcium carbonate travertine. The extraordinarily clear water column and crystallized bottom provide amazingly beautiful color scenery. Jiuzhaigou was enlisted as a World Heritage Site in 1992, National Nature Reserve in 1994, and World Biosphere Reserve in 1997; and is under protection of UNESCO world heritage convention.

Due to its iconic scenery of original forests, unique wildlife, extremely attractive aquatic system, Jiuzhaigou has been a subject of increasing tourist pressure and intensive tourism management. Since