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Lake macroinvertebrate assemblages and relationship with natural environment and tourism stress in Jiuzhaigou Natural Reserve, China

Yong Cao[a,*], Beixin Wang[b], Jie Zhang[b], Lizhu Wang[c], Yangdong Pan[d], Quanxi Wang[e], Daijun Jian[f], Guiping Deng[f,g]

[a] Illinois Natural History Survey, University of Illinois, USA
[b] Nanjing Agricultural University, China
[c] International Joint Commission, Great Lakes Regional Office, MI, USA
[d] Department of Environmental Science and Management, Portland State University, OR, USA
[e] Shanghai Normal University, China
[f] Jiuzhaigou Reserve Administrative Bureau, Sichuan, China
[g] School of Natural Resource & Environment, University of Michigan, USA

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ABSTRACT

With increasing human population and urbanization, tourism in natural reserves and other protected lands is growing. It is critical to monitor and assess the impacts of tourism on ecosystem health. However, there is a general lack of information on biological communities in natural reserves of developing countries and of tools for assessing human impacts. In the present study, we investigated macroinvertebrate assemblages in nine lakes in Jiuzhaigou Natural Reserve of China. Both benthic (20 dips of D-net) and light-trap samples (2 h) were collected at each lake and all benthic specimens and adults of Ephemeroptera, Plecoptera, and Trichoptera (EPT) were identified and counted. Water temperature and water quality variables were measured on site or in the Lab. Seventy taxa were recorded and dominated by dipterans and caddisflies. Light traps contributed 47% of taxa richness and 66% of EPT richness at the lakes. Detrended Correspondence Analysis showed that water temperature and tourism index were strongly associated with the changes of assemblage composition. Taxa richness and EPT richness calculated for the composite samples (benthic + light trap) were well fit with Poisson generalized linear model (adjusted R^2 = 0.83 and 0.85, respectively), generally decreasing with increasing elevation, tourism index, and total-N. Tourism index was ranked as the top predictor for EPT richness based on multiple model weights, and elevation for taxa richness. In comparison, when based on benthic samples, neither of the metrics could be fitted with the seven environmental variables selected. These findings highlight the benefit of combined use of the sampling methods for lake monitoring and offered an analytical guide to developing biological indicators of lake ecosystem health in protected areas.

1. Introduction

Recreation and tourism in national parks and other protected areas have increased rapidly across the world in the past decade (Balmford et al., 2009). This trend of increase is particularly pronounced in rapidly-industrializing countries, such as China. When the importance of tourism for the local economy is well appreciated, the impacts related to tourism have caught considerable attention from both research communities and resource managers (Lilihold and Romeney, 2000; Hall and Härkönen, 2006; Monz et al., 2013). A large number of studies have examined the effects of tourism on the physical environment, vegetation, and wildlife in terrestrial systems (Hall and Härkönen, 2006). Much less attention has been paid to freshwater ecosystems, e.g. lakes, rivers/streams (Hadwen, 2007), although they are among the most attractive locations (Kaplan and Kaplan, 1989) .

Among the limited number of studies on aquatic ecosystems, most examined the impacts of tourism and recreation (e.g. boating and swimming) on water quality, macrophytes, and algae (phytoplankton and periphyton). The effects observed include increases of nutrient levels and chlorophyll (Butler et al., 1996; Hammitt and Cole, 1998; Hadwen et al., 2010; Monz et al., 2013), degraded physical habitats, and shifts in food web structure (Mosisch and Arthington, 2004). Several studies also highlight the need for

* Corresponding author.
E-mail address: yongcao@illinois.edu (Y. Cao).

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biological monitoring as nutrients may stay unchanged under tourism stress while algal biomass or chlorophyll increased substantially (Hadwen and Bunn, 2004). Only a few studies have examined the effects of tourism on other components of aquatic ecosystems, such as macroinvertebrate and fish assemblages. Kasangaki et al. (2006) found a significant decrease in the species richness of sensitive aquatic insects and water quality in tropical streams affected by tourism and other human disturbances. Escarpinati et al. (2011) reported higher variability among macroinvertebrate samples collected from tourism-impacted river sites than undisturbed sites. Escarpinati et al. (2014) also observed immediate loss of taxa richness and abundances of macroinvertebrates in streams trampled by tourists.

Assessing aquatic assemblages in parks and conservation areas is critical for sustaining both ecosystem health and tourism. Furthermore, lakes and streams in protected areas are often the least-disturbed in their respective regions, and thus can serve as the regional benchmarks for assessing the biological conditions of other water bodies and act as regional refuges of many rare and endangered species for biodiversity conservation. Most scenic water bodies are oligotrophic and highly sensitive to human disturbances, particularly nutrient inputs, to which booming tourism can contribute significantly (Hadwen and Bunn, 2004). However, there is general lack of information on aquatic ecosystems, such as species composition and their spatial–temporal variations in relation to environmental factors, in protected areas in most developing countries, where tourism is growing fast (Balmford et al., 2009). The general low level of disturbances in protected areas also likely presents a challenge to routine monitoring methods (e.g. 300–500 fixed counts from benthic samples only, see Barbour et al., 1999) and national or regional indicators, which are intended for rapid evaluation of biological impairment caused by broad-scale or/and general disturbances, e.g. pollution and land-use change (USEPA, 2006; Cao and Hawkins, 2011).

We here report a study on macroinvertebrate assemblages in karst lakes of Jiuzhaigou Natural Reserve, a great tourism attraction in southwestern China. We addressed three questions: (1) what macroinvertebrate taxa occurred in those lakes and how the assemblage composition was related to the environment; (2), how combined use of benthic sampling and light trapping benefited our estimates of certain biotic metrics (e.g. taxa richness and percent of sensitive taxa), and (3) how taxa richness and other biotic metrics changed in relation to lake characteristics, water quality, and tourism stress. We then discussed the implications of our findings for assessing the biological conditions of lakes in the park and beyond.

2. Study area

Jiuzhaigou Nature Reserve is a mountainous watershed of 643 km^2 on the edge of Tibetan Plateau in the upper Yangtze River, China (32° 54′-33° 19′N, 103° 46′-104°4′E) (Fig. 1). The elevation of the park varies from 1996 to 4764 m. Stream density is high, 0.8 km/km^2. There are more than 110 lakes/ponds, 17 waterfalls, and 47 springs in the valley. Most lakes are located along streams, and are often fed by groundwater because of the karst geology in the region (Florsheim et al., 2013). Most of those lakes were formed when landslides jammed streams or when travertine built up into a dam (Deng, 2012), with high water clarity, low temperature, low nutrients, and almost always saturated oxygen. The climate is subtropical with annual precipitation of 700–800 mm, depending on elevation (Li et al., 2014). Vegetation changes from cool mixed forest at low elevation to cool conifer forest, and taiga at mid elevation, and to tundra at high level (Schwartz et al., 2013). The land cover consists of forests (32.1%), bare rock/snow cap (32.2%), grass (23.0%), brush (12.5%), water (0.5%), and road/building (0.1%) (Deng, 2012). It is one of the key reserves for panda and other endangered species in China, but famous mostly for its scenic and pristine waters. The park routinely monitors water-quality and discharge at a small number of sites in the lakes and streams. The eastern branch (right in Fig. 1) of the stream is seasonal and contributed little to the overall the downstream flow. Average dissolved oxygen based on monthly sampling over 2006–2012 at multiple lakes was 8.7 mg/L (6.5–11.9 mg/L), and Secchi-Depth was often greater than 15 m (Deng, unpublished data). Dead logs, roots, and rocks on lake bottoms are covered by thick travertine and form unique underwater landscapes.

The study area was historically subject to farming, logging, and other human disturbances (Li et al., 2014). It was established as a nature reserve in 1978 and registered as a World Heritage site in 1992. Since early 1980s, farming, logging, hunting, and major disturbances have stopped and, vegetation has well recovered. Tourism has rapidly grown in the past decades, from <0.03 million visitors in 1984 to >4.5 million in 2014 (Pan et al., unpublished data). To serve tourism, the Park Administration Bureau has built paved road of >60 km and boardwalk of >39 km. Other developments include rest shelters, wash rooms, and one restaurant complex. Most lakes and streams appear largely pristine or minimally disturbed. The main human disturbance includes increase in fine sediments from road construction, previous deforestation, and rise of nutrients in some lakes (Li et al., 2014), presumably from tourists (Wang et al., 2006).

3. Methods

3.1. Field sampling and lab processing

We conducted lake macroinvertebrate surveys in nine lakes in summer 2013. The lakes were chosen to represent an elevation gradient and potentially different levels of human disturbances. We used a D-net (30.5 × 25.4 cm, 500-micron) to sample macroinvertebrate assemblages in the lakes. Twenty dips were applied to various habitats along the nearshore of a lake (e.g. macrophytes, tree-root overhangs, solid substrates, and snags). All materials were preserved with 70% ethanol in the field. Because most lakes had steep shoreline and rocky substrates covered by travertine, our benthic samples might not adequately characterize the local benthic assemblages. The low level of disturbances in the park may also requires higher sampling intensity to detect. We therefore added ultraviolet-light trapping (12 V DC, 15 W) to our sampling plan, targeting three major groups of aquatic insects, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) or EPT. The 2 h trapping was conducted between 8 and 10 pm on the shore of each sampled lake and, all specimens collected were preserved with 70% ethanol and labeled for lab analysis. Benthic macroinvertebrate specimens and adult caddisflies were identified to the lowest possible taxonomic level, often genus based on a key by Morse et al. (1994) at Aquatic-Entomology lab of Nanjing Agricultural University. Stonefly and mayfly adult specimens were identified at Illinois Natural History Survey (Ed DeWalt's lab). All individuals of aquatic taxa except non-EPT adults were identified and counted. Because the specimens of the same family or genus were often at varying development stages and thus identified to different levels, operational taxon units (OTU) were established as Cao and Hawkins (2011) described. Oligochaetes and flatworms were treated as two OTUs. Those individuals not belonging to any OTU were eliminated in estimating taxa richness, but were kept in estimating percent EPT individuals. Two OTU lists were established, for benthic samples and composite samples (benthic + light trap), respectively.