Water Research 105 (2016) 297–304

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Analysis of intensity and spatial patterns of public use in natural treatment systems using geotagged photos from social media

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ARTICLE INFO

Article history:
Received 1 June 2016
Received in revised form
6 September 2016
Accepted 6 September 2016
Available online 13 September 2016

Keywords:
Ancillary benefits
Constructed wetlands
Cultural ecosystem services
Ecological engineering
Recreation demand
Waste stabilization ponds

ABSTRACT

Patterns of public use in 273 natural treatment systems worldwide are investigated by means of geotagged data from two popular photo-sharing websites, using spatial analysis and regression techniques. Standardized Major Axis (SMA) regression is found to perform better than other univariate calibration models in terms of goodness of fit with reported visitation frequencies and predictive accuracy, and is used to predict visitation rates in 139 systems that are associated with at least one geotagged photograph. High visitation rates are found in free-water surface (FWS) constructed wetlands and mixed pond-constructed wetlands systems, as well as systems treating surface water or stormwater runoff. Geographic Information System (GIS) techniques are used to map hot and cold spots of public use in two highly visited systems. Binomial logit regression reveals that the probability to be associated with at least one geotagged photograph is a function of system size, system type, and influent water quality. The findings are discussed in terms of their implications for the evaluation of public use in multifunctional ecologically engineered systems as well as the applicability of the proposed methodology to other natural and man-made ecosystems.

1. Introduction

The provision of ancillary benefits, a term used here to indicate all benefits that are secondary to the primary function of water quality enhancement, is among the characteristics that make ecologically engineered (also known as “natural”) treatment systems unique in the panorama of water and wastewater treatment technologies (Knight, 1992, 1997). It greatly contributes to determine their potential role in promoting sustainable water management practices (Campbell and Odgen, 1999; Howe et al., 2011). Previous research has shown that ancillary benefits potentially extend to cover a wide range of provisioning (Solano et al., 2004), regulating (Mitsch et al., 2014; Moore and Hunt, 2012), habitat (Thiere et al., 2009; Hsu et al., 2011; Semeraro et al., 2015), and cultural ecosystem services.

The provision of cultural services, such as may be associated with non-consumptive public use for recreational, research and/or educational purposes, is often explicitly incorporated in the design of natural treatment systems in the form of park-like features such as trails, boardwalks, and interpretive signs (Kadlec and Wallace, 2008). Ghermandi and Fichtman (2015) provide an extensive review of the recreational and educational benefits of natural treatment systems with public use. Their database includes reported visitation rates for 60 natural treatment systems worldwide. It covers a range of system types, including waste stabilization ponds, free-water surface (FWS) and sub-surface flow (SSF) constructed wetlands, and influent water qualities. To date, however, the extent of the quantitative understanding of the public use of natural treatment systems is limited by the fact that monitoring of public use is restricted to a small fraction of the existing systems, and mainly to large and emblematic sites (Ghermandi and Fichtman, 2015).

User-generated geotagged data uploaded by users of online social media has been proposed as a proxy source of revealed information regarding patterns of public use and visiting frequency in tourism destinations of general interest (Tammet et al., 2013), and for nature-based recreation in particular (Wood et al., 2013). This approach is considered an emerging, crowd-sourced alternative to more common methods involving, for instance, visitors' monitoring through surveys (Rieser-Schüssler and Axhausen, 2014). Popular photo-sharing websites such as Flickr (http://www.flickr.com) and

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http://dx.doi.org/10.1016/j.watres.2016.09.009
0043-1354/

Panoramio (http://www.panoramio.com) have been used as sources of information regarding recreational behavior in urban areas (Sun et al., 2013; Hollenstein and Purves, 2010; Forst and Foster, 2015), marine and coastal ecosystems (Howarth, 2014), mountain landscapes (Tenerelli et al., 2016; Produit et al., 2014), and lakes (Keeler et al., 2015). Geotagged photographs have been employed to characterize visitation rates (Keeler et al., 2015; Wood et al., 2013), spatial and temporal distribution of visits (Tenerelli et al., 2016; Kisilevich et al., 2010), and other aspects related to tourism demand such as visitors' country of origin (Da Rugna et al., 2012). The Recreation module of the Natural Capital Project's Integrated Valuation of Ecosystem Services and Tradeoffs software (InVEST; http://www.naturalcapitalproject.org/invest/; Tallis and Polasky, 2009) uses the number of photographs uploaded to Flickr as a proxy of visitation rates and, through multiple linear regression analysis, to predict and map how future patterns of recreational use will be affected under different management scenarios. Keeler et al. (2015) found correlations of 0.65 and 0.70 between empirical visitation and Flickr photo-user-days in, respectively, Iowa lakes and Minnesota state parks. A photo-user-day represents a unique combination of user and recreational site. In this context, multiple photographs taken by one individual user at a single site and in the same day amount to a single photo-user-day. In an analysis of visitation in 836 parks worldwide, Wood et al. (2013) found a correlation of 0.386 between empirical and Flickr-based visitation rates.

This paper is the first to explore the use of geotagged social media information for the evaluation of the intensity and spatial patterns of public use in natural treatment systems. The suitability of photo counts as a proxy for visitation rates is explored in application to an extended version of the database by Ghermandi and Fichtman (2015). Spatial statistics analysis tools are implemented to map hot and cold spots of public use in two highly visited natural treatment systems. Photo counts are investigated for 273 distinct natural treatment systems worldwide. The predicted visitation frequencies in 139 systems are analyzed in terms of statistically significant differences in visitation across system types and influent water qualities. Beyond its practical implications for the understanding of the recreational and educational ancillary benefits of natural treatment systems, the paper advances the state of the art in the use of social media information as a tool to evaluate cultural ecosystem services by investigating the predictive power of four alternative univariate proxy calibration models and the potential increase in precision and geographical coverage derived from combining information from different photo sharing websites. Such results may have wider implications for the applicability of the technique to both man-made and natural ecosystems.

2. Material and methods

2.1. Database of natural treatment systems with public use

The database developed by Ghermandi and Fichtman (2015) provided the basis for the present investigation. Such database identifies 166 natural treatment systems worldwide with confirmed recreational and/or educational visits and provides observed or reported yearly number of visitors for 60 of them. The number of treatment systems with observed visits was enlarged for this study to include the waste stabilization ponds of the Western Treatment Facility in Melbourne, Australia (Morrow, 2015) and the Anton Crescent Wetland in Sutton, England (Featherstone, 2015).

For the purpose of identifying public use and predicting visitation rates in other natural treatment systems, the database was further enlarged, primarily relying on information provided in the North American Treatment Wetland Database version 2.0 (NADB2; CH2M-Hill, 1999) and the database of the Global Wetland Technology consortium (http://www.globalwettech.com/en/). In order to be selected for this study, the systems have to include water quality improvement as one of the primary declared objectives or be fed by an influent stream that exclusively or predominantly consists of (pre-treated) wastewater. Moreover, the ability to spatially characterize the extent of the systems was a necessary condition for inclusion in the database. In its final version, the database includes 273 systems.

The identified systems are located in 33 countries, with US (89 systems), France (61 systems), Great Britain (25 systems) and Italy (20 systems) being the best represented ones. Constructed wetlands (CWs) of the free-water surface (FWS; 115 systems) or subsurface flow type (SSF; 83 systems) account for the majority of the systems. A total of 23 and 38 systems are, respectively, waste stabilization ponds or combined pond-constructed wetland systems. The average system is extended over 143 ha (±639 ha). A median extension of only 5.9 ha testifies to a wide variability between the largest (Stormwater treatment area STA-3/4 in Florida; 7430 ha) and smallest systems (constructed wetland in Sarphati Park, the Netherlands; 0.5 ha). Most systems receive municipal effluents after preliminary or primary treatment (96 systems) or after secondary or more advanced treatment (65 systems). Stormwater runoff and surface waters are the main influent in, respectively, 52 and 17 systems. The remaining ones treat water from other sources, including water of agricultural and industrial origin. Additional information on the 273 natural treatment systems is provided in Table S1 in the Supplementary Material.

2.2. Estimating annual photo-user-days from geotagged social media data

The spatial boundaries of each of the sites in the database were characterized with one or multiple polygon shapefile(s) relying on Google Earth imagery and the ESRI ArcGIS 10.2.2 software.[1] Metadata of photographs taken within a 30-m buffer from the site boundaries were extracted from the Flickr and Panoramio photo-sharing websites using the respective application program interfaces (APIs). The metadata that are relevant to the present analysis are directly accessible through the APIs. Given that the APIs only allow to retrieve information for a rectangular box and not for a shapefile, the information was first retrieved for a rectangular envelope around the sites' shapefiles and subsequently processed in ArcGIS to eliminate photographs that lie outside the areas of interest. Photographs taken within 30 m from the site boundaries were also included to account for recreation-related uses from outside the perimeter fence, such as birdwatching (Keeler et al., 2015; Orlowski, 2013). Data were retrieved on October 12, 2015 and October 22, 2015 from Panoramio and Flickr, respectively. In the calculation of user days, care was taken not to incur in double-counting of multiple photographs taken by the same user in the same day or uploaded by the same user to both photo-sharing sites. Photographs that were taken before the actual construction of the natural treatment sites were removed from the analysis. All personally identifiable user information was removed. The analysis was limited to the photographs' metadata (including location) and did not involve the photographs' content. An average number of photo-user-days per year between 2004 and 2015 was calculated for each site. In an attempt to control for different accessibility to online photo-sharing services across countries, the most recent available estimate of the Internet penetration rate at the country

[1] The geographical coordinates of the center-points of the investigated sites are provided in a KML format, which is accessible in the online version of the paper.