# Incorporating the digital footprints of visitors in protected area use and impact monitoring: Case studies from the USA and Australia

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## Introduction

Advances in mobile and internet-based technologies haveencouraged examinations of non-traditional spatial data products and innovative data collection methods for research in a variety of disciplines. User-generated spatial content (UGSC) is increasingly leveraged to help address questions involving human-environment interactions (Sui, Elwood, & Goodchild, 2013). Protected areas (PAs) are an especially relevant context in which to explore the capacity of UGSC given the central role PAs represent in biodiversity conservation and ecosystem service provisioning, including recreation and tourism. To fulfill management objectives designed to minimize use-related impacts to natural resources, while providing opportunities for visitors, managers require timely and accurate data on not only the extent of different resource impacts, but also the precipitating or contributing factors such as visitor use activities, densities, and distribution (Hammitt, Cole, &Monz, 2015).

The time needed to collect systematic visitor data in PAs, as well as challenges associated with sampling in large, open systems, can serve as a barrier to obtaining such data. Additionally, staffing or financial constraints may necessitate the need to prioritize other research objectives or concentrate monitoring to select locations of concern. This prioritization is vital in protecting ecological and site integrity and ensuring adequate sample sizes, but may not always capture emerging trends or seasonal variations. Emerging trends may lead to unintended negative impacts as research has shown such impacts can happen quickly and after disproportionally small amounts of use (Hammitt et al., 2015). The purpose of this research is to explore one UGSC product, geotagged photographs, as a source of publicly-available spatial data to quantify and model visitor use distributions within PAsas a function of environmental and managerial factors.

## Relevant Literature and Methods

Geotagged photos are often created and shared by users not formally part of a research effort. Research applications are relevant to many disciplines, including transportation, urban planning, recreation, and tourism (García-Palomares, Gutiérrez, &Mínguez, 2015; Wood et al., 2013). Many studies havefocused onurban or developed area applications (García-Palomares et al., 2015), with emerging research involvingmore natural locations, like PAs (Wood et al., 2013). Wood and others (2013) useddata from Flickr, an online photo sharing website, to estimate visitation rates at 836 natural and cultural recreation sites in 31 countries. They found the number of uploaded photos was positively correlated with empirical visitation counts, contending that geotagged photos can serve as a reliable proxy for PA visitation rates. Geotagged photos have also been used to approximate visitor movements and distributions within a PA. Orsi and Geneletti (2013) employed a gravity model to estimate visitor flows for the Dolomites UNESCO World Heritage Site, Italy, based on popular locations determined through high densities of geotagged photos validated with on-site counts.

As applications of geotagged photos continue to growin both urban and natural locations, so too is there a need to further investigate the capacity of geotagged photos as a source of visitor use data for integrated human-environment interaction analyses. Maximum entropy (MaxEnt) models have recently been applied to visitor distributions using geotagged photos to identifysignificant environmental and managerial factors (Westcott & Andrew, 2015). The ranking of factorsidentifieswhich variables most greatly influence distributions and how changes may affect subsequent distribution patterns and resource pressures. This study contributes to the understanding of UGSC and MaxEnt modeling for PA managementby askingthe following research questions:

1. Does the spatial distribution of visitor use within a PA, as estimated using geotagged photos, change significantly at varying temporal scales and;
2. What environmental (e.g., land cover, topography, water bodies) and managerial (e.g., trails, visitor centers, campsites) factors most influence visitor distributions within a PA?

## Study sites

Hawaii Volcanoes National Park, USA (HAVO) and Kosciuszko National Park, Australia (KOSC) were selected for inclusion due to their global conservation significance (e.g., designations as UNESCO Man and Biosphere Reserves), unique landscapes protecting endemic and endangered species, and year-round and com-

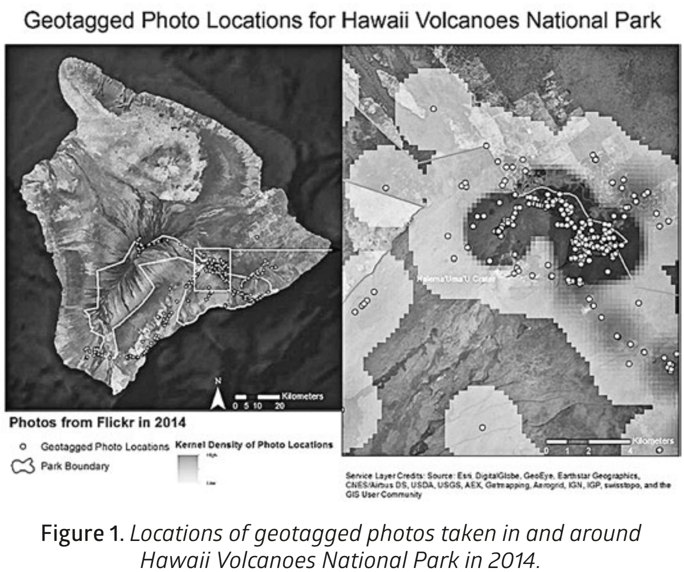


Figure 1. *Locations of geotagged photos taken in and around Hawaii Volcanoes National Park in 2014.*

plementary recreation and tourism appeal. Using the statistical software program R to query data from the Flickr application programming interface (API), all publicly-available geotagged photographs taken between 2011 and 2015 within a search area containing the park boundaries were selected for inclusion. Key attributes associated with the photos included geographic coordinates, date and time taken, and camera/device type. Figure 1 illustrates the preprocessed data for HAVO from 2014. Additional geospatial data, including locations of visitor infrastructure for distribution modeling and empirical tests of mobile device spatial accuracy, will be collected between July and October, 2016.

## Results

Results include visualizations and statistical assessments of visitor clustering and distribution at varying spatial and temporal scales. Preliminary findings from MaxEnt distribution models leveraging publicly-available data will provide a ranking of which environmentaland managerial factors contributed significantly to visitor distribution, as well as and inform discussions for additional variables in subsequent model iterations.

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