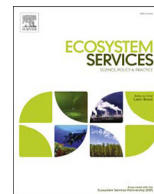




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Quantifying the visual-sensory landscape qualities that contribute to cultural ecosystem services using social media and LiDAR

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ABSTRACT

Landscapes are increasingly recognized for providing valuable cultural ecosystem services with numerous non-material benefits by serving as places of rest, relaxation, and inspiration that ultimately improve overall mental health and physical well-being. Maintaining and enhancing these valuable benefits through targeted management and conservation measures requires understanding the spatial and temporal determinants of perceived landscape values. Content contributed through mobile technologies and the web are emerging globally, providing a promising data source for localizing and assessing these landscape benefits. These georeferenced data offer rich *in situ* qualitative information through photos and comments that capture valued and special locations across large geographic areas. We present a novel method for mapping and modeling landscape values and perceptions that leverages viewshed analysis of georeferenced social media data. Using a high resolution LiDAR (Light Detection and Ranging) derived digital surface model, we are able to evaluate landscape characteristics associated with the visual-sensory qualities of outdoor recreationalists. Our results show the importance of historical monuments and attractions in addition to specific environmental features which are appreciated by the public. Evaluation of photo-image content highlights the opportunity of including temporally and spatially variable visual-sensory qualities in cultural ecosystem services (CES) evaluation like the sights, sounds and smells of wildlife and weather phenomena.

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1. Introduction

Landscapes are increasingly recognized for their provision of valuable cultural ecosystem services (CES) as they support recreation and leisure activities linked to educational, inspirational, and spiritual values, and improved overall mental and physical health and well-being (Sandifer et al., 2015; van Zanten et al., 2016a). Highly valued landscapes often include cultural features (e.g., historical monuments) and potential activities (e.g., local foods, kayak rentals) that synergistically enhance and contribute to their uniqueness as special locations (Hausmann et al., 2016). Planning, environmental management, and tourism fields have

long recognized the effects of values and perceptions on the way landscapes are used (Dorning et al., 2017). These perceptive lenses shape how different individuals use and appreciate the numerous non-material benefits of nature (e.g., for an overview of CES see Plieninger et al. (2013), Chan et al. (2012)). Significant advances have been made evaluating CES using respondents' assessment of landscape photographs (Van and Verburg, 2014; van Zanten et al., 2016b), immersive virtual environments (Appleton and Lovett, 2003; Smith, 2015; Tabrizian et al., 2018), and participatory techniques (Brown and Fagerholm, 2015). Rarely do such surveys capture the diversity of appreciated landscapes as they are confined to specific locations and small samples of the population (van Zanten et al., 2016a; Sherrouse et al., 2011). Moreover, such studies may miss the multiple non-material factors that contribute to the way a landscape is valued and experienced, including iconic features, cultural and ecological elements (e.g., monuments or

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wildlife), and other sensory attributes (e.g., sounds or smells). Assessing landscape-scale variation in a wide range of values would improve our understanding of the diversity of specific locations that are appreciated for their CES.

The full range of CES provided by a landscape is notoriously difficult to evaluate at the landscape-scale due to the absence of detailed data regarding the cultural values people associate with a specific place and the diversity within the landscape mosaic (Plieninger et al., 2013; Chan et al., 2012). Data mined from social media show promise for evaluating these benefits by serving as empirical evidence of visited and appreciated landscapes at broad spatial scales. For example, social media have been leveraged to map and quantify CES (Sonter et al., 2016; Richards and Friess, 2015; Oteros-Rozas et al., 2017; Casalegno et al., 2013; Richards and Tunçer, 2017), characterize landscapes (van Zanten et al., 2016b; Tieskens et al., 2017), and estimate the number of visitors to protected areas (Wood et al., 2013; Heikinheimo et al., 2017).

While social media posts can provide information regarding cultural services, photos have the added benefit of documenting appreciated features in the photo content itself and sensory qualities that can be inferred through photo content (e.g., smell of the ocean, the song of a bird). Surprisingly, this photographic content has scarcely been investigated, with the exception of a few studies (Dunkel, 2015; Oteros-Rozas et al., 2017). For example, Oteros-Rozas et al. (2017) demonstrated that photographs volunteered via social media could be classified according to CES categories. Dunkel (2015) similarly found that volunteered photos offered unique insights into the photographers' values, which could be inferred through the subject matter and composition of captured images (Dunkel, 2015). Assessing social media photographic content could add a new level of richness in our understanding of what constitutes a CES, by providing greater detail of appreciated features.

Photo content may also help in validating the location of photographic capture. Geographic misclassification can occur due to inaccuracies in recording the user's position through mobile technologies (i.e., GPS signal loss) or errors in actual coordinate pin-pointing by users on older website mapping-interfaces (Zielstra and Hochmair, 2013). To date, such errors have been assessed primarily in urban settings by measuring the distance between the volunteered image position and the manually corrected camera position of landmarks (Zielstra and Hochmair, 2013). Such a measure is unlikely to be feasible in landscape scale studies with large numbers of social media locations that lack distinctive landmarks. Alternatively, error evaluation can potentially be achieved by comparing the photographic content captured at these locations with verifiable spatial layers depicting similar attributes (e.g., land use) (Oteros-Rozas et al., 2017).

While photographs may capture targeted aspects of appreciation, it is increasingly acknowledged that the entire surrounding landscape context or the experienced environment contribute to CES delivery (van Zanten et al., 2016b). Calculating the viewshed is a potentially useful geographic tool that can capture how the environment is experienced. A viewshed is the 360° area that is visible from a discrete location (Vukomanovic et al., 2018). It includes all surrounding points within the line-of-sight of an assumed viewer's location and excludes points that are obstructed by the terrain and other features (e.g., buildings, trees). Viewshed research has been instrumental in understanding scenic values associated with residential development (Vukomanovic and Orr, 2014) and the relationship between aesthetic values and landscape patterns (Schirpke et al., 2016). However, difficulty in identifying the subject of appreciation within the viewshed has unfortunately caused many studies to resort to a best guess regarding the precise location of appreciated areas (Schirpke et al., 2016; Yoshimura and Hiura, 2017). Combining georeferenced photos volunteered by

social media users with viewshed analysis presents a unique opportunity to evaluate the landscape qualities and visible attributes associated with high valued areas (Yoshimura and Hiura, 2017).

In this study, our objective is to demonstrate a novel multi-method approach for capturing and understanding the visible-sensory landscape qualities that contribute to CES. We aim to evaluate the experienced environments of visitors to coastal North Carolina through the locations they volunteer via social media. In doing so, we will (1) test the ability of high-resolution LiDAR to define the visible area of these locations; (2) assess the applicability of social media photographs to enrich our understanding of CES; and (3) characterize the natural and built environments and activities that are highly photographed. We assume that locations with high numbers of photographs deliver numerous CES and hypothesize that our multi-method approach can better contextualize the recreational potential, aesthetic character, and uniqueness that likely characterize these areas.

2. Methods

2.1. Study area

The Middle Atlantic Coastal Plain in North Carolina is a low-lying area comprising agricultural lands and approximately 484 km (301 mi) of coastline (Fig. 1). The area is home to a variety of ecological communities, including tidal and coastal marshes, floodplains, swamps, peatlands, and barrier islands. The coastal beaches, charismatic species and cultural history contribute substantially to the regional economy through tourism expenditures with an estimated 4.6 billion U.S. dollars spent annually (Association, 2013). These iconic landscapes are increasingly threatened by human population growth, amenity migration to coastal regions and unsustainable land-use practices (Bin et al., 2005). Compounding these stressors are additional factors related to climate change – particularly direct inundation from sea-level rise, saltwater intrusion and coastal forest retreat that are threatening terrestrial and non-terrestrial habitats (Chen et al., 2017; Engelhart et al., 2009; Hauer et al., 2016). Substantial public and private funds have been allocated to conserve tourist attractions that support local economies, for example, through beach nourishment and stabilization programs and the relocation of culturally significant structures (Bin et al., 2005). Identification of locations that are important to the public, and the characteristics associated with these special places, offers the opportunity for targeting projects that would enhance and conserve important cultural ecosystem services.

2.2. Data collection and processing

To assess highly visited locations, we collected all photographs uploaded to the Panoramio website for the years 2005–2015 using the website application programming interface (API). We collected all data using a python code that systematically mined the geographic coordinates included with the social media posts on the website (van Zanten et al., 2016a). This ensured that we captured all content uploaded for the case study region and the adjoining 3 km region that could possibly view our study site ($n = 16,582$). Unlike more popular platforms such as Facebook and Instagram, which have placed limits on content access, Panoramio data are accessible to the public. Panoramio also offers highly accurate locational data compared to alternative social media like Flickr (Zielstra and Hochmair, 2013). We sought this high accuracy to assure that viewsheds reflected the actual visible-sensory environment of photographers. In addition to collecting the geographic coordinates associated with content contributed by the public,

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