Applied Geography 88 (2017) 1–14

Contents lists available at ScienceDirect

Applied Geography

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

Quantifying the sustainability of urban growth and form through time: An algorithmic analysis of a city's development

Jared Ogle [a,*], Donna Delparte [a], Hannah Sanger [b]

[a] Department of Geosciences, Idaho State University, 921 S. 8th Avenue, Pocatello, ID 83209, USA
[b] Department of Science and Environment, City of Pocatello, 911 N 7th Avenue, Pocatello, ID 83201, USA

A R T I C L E I N F O

Article history:
Received 1 August 2016
Received in revised form
20 August 2017
Accepted 29 August 2017

Keywords:
Sustainability
Urban sprawl
Suburbanization
Ecological footprint
Urban form

A B S T R A C T

Throughout the latter half of the 20th century, households and cities have changed dramatically. Dense urban developments have given way to lower density suburbanization, while the changing face of the typical family has led to different household makeups. Analyzing how changing urban form influences the sustainability of cities is important for planning future ways in which society aggregates itself. Using current data layers, such as urban boundaries and building footprints, along with past aerial photographs of the city and census data, a detailed reconstruction of the city of Pocatello, Idaho was possible for 1941 for both urban form and population. Using these data sources an algorithmic analysis of various aspects of the city, clustering, compactness, connectivity, and density, was performed on a decadal basis. Results showed an overwhelming trend toward less sustainable development for the city, larger blocks, measured by intersection density, larger distances between houses, fewer people utilizing more space, a more irregularly shaped urban form, an average greater distance from the city center for development, and decreased connectivity, as measured by intersection density. Because the data sources used for this study are readily available to most planning municipalities, the same analysis could be performed on various cities and metros across the United States.

1. Introduction

Modern city growth must take into account the environmental stress caused by the ecological footprint imposed on nature by humanity. Ecological footprint analysis is a method first developed by Rees and Wackernagel that examines the demands placed on the world's ecosystem services for use in planning and sustainability (Rees, 1992; Wackernagel & Rees, 1996; Wackernagel, 1994). Core components of ecological footprints are Earth's area used for buildings, roads, and other infrastructure, typical of development (Palmer, 1999). Ecological footprint analysis has evolved to view a footprint in units of global hectares.

An alternative way of analyzing these aspects of ecological footprints is evaluating an urban area's efficiency of form, the characteristics of the developed area that allow for efficient utilization of ecosystem services and delivery of goods and services, while minimizing the impact on the surrounding environment. Inefficient forms are often due to housing choices and lead to increased energy use for transportation through fossil fuel emissions, losses of energy from residential electric transmission and distribution, and increased energy usage from urban heat islands (Ala-Mantila, Heinonen, & Junnila, 2013; Ewing & Rong, 2010; Stern, 2006; Zhang et al., 2013). Development of areas with inefficient forms often cause automobile reliance and increased costs for the delivery of services. One type of inefficient city form developed in modern times is dubbed "urban sprawl." Definitions of urban sprawl vary, but common spatial characteristics include, larger lot size, predominantly single-family residential areas separated from commercial development, and growth away from the central business district (Ewing, Pendall, Chen, & America, 2002), all of which creates insufficiently dense, auto-dependent areas, built away from the traditional central business districts.

As human spatial development patterns in the United States have changed since the middle of the last century, with individuals living further from city centers due to the advent of suburbanization (Fishman, 2000), a growing concern has been measuring urban sprawl (Cutsinger, Galster, Wolman, Hanson, & Towns, 2005; Ewing et al., 2002; Forsyth, 2003; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Jia, Tao Jiang, 2000; Laidley, 2015). Sprawl has many

* Corresponding author.
E-mail address: oglejare@isu.edu (J. Ogle).

http://dx.doi.org/10.1016/j.apgeog.2017.08.016

negative economic, social and ecosystem impacts. Economic impacts include increased costs for infrastructure maintenance (Henríquez, Azócar, & Romero, 2006) and increased consumer fuel cost associated with time spent commuting. Decreased socioeconomic mobility based on increased commute times and less centralized job opportunities can contribute to higher unemployment, poorer health, and shorter life-expectancy (Smart Growth America, 2014). Negative environmental effects consist of climate change due to increased fossil fuel use (Bart, 2010) and anthropogenic land cover change, which can contribute to local temperature increases (Parshall, Hammer, & Gurney, 2013) and resulting habitat loss and fragmentation (Schneider & Woodcock, 2008). These effects inform a methodology for data collection and quantification of different aspects of efficiency of form, a component of sprawl to plan for more sustainable growth. Four important, quantifiable aspects of efficiency of form over time—density, compactness in urban form, clustering, and connectivity—will be applied to analyze and offer recommendations for urban planning decisions for the city of Pocatello, Idaho.

Within planning social sciences there are many ways of operationalizing composite indicators. Galster et al. (2001) proposed the use of density, concentration, clustering, centrality, nuclearity, and proximity as dimensions for sprawl analysis, which were equally weighted using z-scores and summed to obtain a sprawl score. Smart Growth America operationalized its measurement of sprawl by taking 22 variables that were then used as the basis for four factors of sprawl: residential density, neighborhood mix of homes jobs and services, activity centering, and street accessibility. For example, street accessibility is operationalized with the factors: average block size, average block length, and percentage of small blocks. The 22 variables are combined into 4 factors using principal component analysis. The four factors are standardized to a mean of 100 and standard deviation of 25. They are then combined to yield an index score (Ewing et al., 2002). Galster's methodology represents operationalizing sprawl analysis with several factors. Smart Growth America's goes a step further and operationalizes sprawl analysis by combining variables that are then once more combined into an index score.

The operationalization of composite indicators took a different avenue because of the lack of sample size in this study. Many social science studies rely on generating composite indicators for various phenomenon. This approach will be taken here. One popular form of creating a composite indicator, includes picking a reference time/place, assigning it a value of 1 as a benchmark (OECD, 2008). This method has been used by the EU which used 14 indicators to construct 3 composite indicators for environment, social cohesions, and economic growth (Ferdinandusse, Duca, & Coussens, 2008).

Data type analysis is also very important when analyzing sprawl. Historically, many measurements of sprawl have relied on land cover classification data derived directly from satellites with low spatial resolution, and the Landsat series of satellites have been particularly used for this purpose (Jat, Garg, & Khare, 2008; Ji, Ma, Twibell, & Underhill, 2006; Wu, Ye, Qi, & Zhang, 2012). Though it has poor resolution, Landstat's long term continuous coverage through time across the globe has prompted use in other sprawl studies. For example, many planners examining changes in land cover over time have used America's National Land Cover Dataset (NLCD). However, the poor resolution of this data has proven insufficient for capturing low-density development, a predominant factor associated with sprawl. Irwin and Bockstael (Irwin & Bockstael, 2007) demonstrated that using the NLCD to identify low-density development yielded only 26% accuracy, while high density development was correctly classified 83% of the time. Therefore, measurements relying solely on low resolution NLCD data are inadequate for capturing low-density development and accompanying environmental fragmentation. In contrast, an investigation of urban growth in Maryland by Irwin and Bockstael (2007) used planimetric data derived from building footprints in conjunction with parcel data to analyze urban growth. The greater spatial resolution of planimetric data and derived classification for low-density developed areas revealed a more accurate analysis of environmental fragmentation.

In this case study, a methodology similar to Irwin and Bockstael (2007) using high resolution data was applied to Pocatello, Idaho, a medium-sized city that is situated in the Portneuf River Valley. Surrounding mountains and another municipality to the north, Chubbuck, limits Pocatello's long-term development options. The primary goal of this study was to quantify the increase or decrease in sprawl, measured through efficiency of form over time. Using census data in combination with historical aerial imagery, Python scripts calculated measures of density, compactness, connectivity, and feature clustering, as well as, clustering around the urban core on a roughly decadal scale for the past 70 years. Index scores for density, compactness, connectivity and clustering were combined to yield an overall efficiency of form score. The methodology and metrics described in this paper are applicable to other cities to measure historical change in form and sprawl and for comparative analysis between similar sized cities using contemporary datasets. The Python scripts developed for this study have been bundled into an Esri ArcGIS® toolbox for public download making them readily accessible to other researchers and city planners.

2. Methods

2.1. Study area and data sources

Located in southeastern Idaho, Pocatello lies along the Snake River Plain just north of the Basin and Range physiographic province. By viewing the city's early layout of building type and footprint, the city of Pocatello was designed around an accompanying railway within the Portneuf River valley. The city, railway, and Portneuf River flow southeast to northwest and are constrained by steep valley sides (Fig. 1). Founded in 1893, Pocatello's original 5.14 km^2 land base is now over 30.36 km^2. Its population has increased similarly, from 4046 residents in 1893 to 54,292 in 2015. In order to show spatial change of the built environment and population overtime, a workflow for data collection and analysis was created for Pocatello that is transferable to other areas (Fig. 2).

The main sources for population data for this project included population and total households taken from decennial census data over the period 1940 to 2010. A Linear interpolation was calculated from census data to estimate population, household, and people-per-household for non-census years. Spatial data utilized were Pocatello city boundaries, available from the city's founding until present day. Individual sequences of historical aerial photographs were available for 1941, 1959, 1963, 1968, 1975, 1984, and 1994. These images were obtained at scales of 1:12,000 and 1:24,000 through the Idaho State Historical Society and the private sector firm, Valley Air Photos, Caldwell, Idaho. Using structure from motion software (Agisoft Photoscan) the images were stitched together into orthomosaics for each year and georeferenced using GCP (ground control points) collected in the field with a mapping grade Global Positioning System (Lipple, 2015). The United States Department of Agriculture, National Agricultural Imagery Program (NAIP) datasets were used for 2004 and 2013.

A comprehensive annexation layer was created from the city ordinances. Built area within the city was identified using aerial imagery and building footprints. Due to the construction of city roads prior to settlement of every parcel, a large footprint with gridded roads existed that took years to settle. The city annexed