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MODELING SUSTAINABILITY, ECOSYSTEM SERVICES, AND URBAN FORM FOR MEDIUM-SIZED CITIES IN IDAHO

by

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ABSTRACT

In a world that is reliant on finite natural capital to provide for ecosystem services, approaches to analyze landscape and environmental use over time and across space are imperative. This study takes a smart growth approach for determining sustainability of urban form for mid-sized cities in Idaho (Pocatello, Coeur d'Alene, and Idaho Falls). A contemporary cross-city comparison highlights the differences in growth and form of these cities using spatial metrics that include clustering based on building footprints, road connectivity, land use and zoning diversity, population and household density, along with centrality based on distance from urban core, city compactness, and fragmentation within the built area. Smart growth metrics are typically calculated based on regional datasets. The approach here uses commonly available city planning datasets at higher resolution to reproduce smart growth metrics for small to medium sized city analytics and comparisons that can be applied across the nation and beyond.

CHAPTER ONE. INTRODUCTION

Urban form in America has changed coinciding with the advent of mass transit in the post-World War II era (Salvati & Sabbi, 2014) and the construction of the Eisenhower interstate system. Cities once built for pedestrians and horse and buggies expanded around the needs of automotive culture (St. Antione, 2003). This change ignored many of the traits that create thriving American cities: streets that accommodated pedestrians, demand for inner city property, affordability of properties through differential age in building infrastructure, small blocks, and a mix of land use types in close proximity (Jacobs, 1961). The post-World War II period led to city growth marked by lower density development, less centralization of economic and social activities, higher unemployment, decreased social mobility, increased commute times, decreased industrial productivity (Fallah, Partridge, & Olfert, 2011), poorer health (Smart Growth America, 2014), increased infrastructure cost (Henríquez, Azócar, & Romero, 2006), decreased public transit, and greater socio-economic stratification and gentrification (Burton, 2000). This transition in urban form occurs in the study area, Pocatello, ID, as it developed outward in a less dense, less compact, more dispersed, and less connected fashion.

The use of ecosystem services is inevitably wrought with conflicts between services. For example, overuse of ecosystem services in an economy for provisioning of fuel, water, food, etc. can lead to a decrease in a habitat's ability to provide supporting services, regulating services, and cultural services from aesthetics to recreation.

Pocatello is a prime case study as it developed from subsistence use prior to western settlement, to a hub for the mass provisioning of resources across the region through the development of the railroad. Changes within the riparian habitat zone along the Portneuf River due to the development of the railroad and city have had costs and trade-offs, one being a departure of the Portneuf River and its surroundings from their natural state.

To analyze trade-offs in socio-ecological systems, Idaho EPSCoR's Managing Idaho's Landscape and Ecosystem Services (MILES) interdisciplinary research team focuses on studying socio-ecological-systems (SES) within Idaho. As part of this team, my research efforts are focused on analyzing urban land use as a form of natural capital through sustainability of form metrics and riparian ecosystem service analysis.

Before Pocatello's founding, the Portneuf River corridor acted as a winter camp for the Shoshone-Bannock Tribes (Franzen, 1983). In 1869 the United States Government officially recognized this area as part of the Fort Hall Indian Reservation. It was later purchased by the Oregon Short Line Railroad, and by 1882 tracks had been laid and Pocatello Junction formed. This was an important time of transition for the riparian ecosystem in Pocatello. Used for subsistence by the Shoshone, the Portneuf River was untouched by modern engineering and industrial development. With the purchase of the area by the railroad, the character of the river and riparian area changed. It carried passengers, acted as a gateway to the northwest, and provided for mass provisioning of resources rather than subsistence. Coal and timber became important commodities mined and shipped across it from other areas (Wrigley, 1943).

This change had dramatic effects on ecosystems nearby being developed to deliver these commodities. Locally, these changes led to the removal of river meanders and installation of rip-rap levees and 1.5 miles of concrete channel that reduced the river by a length of 4.1 miles and riparian habitat by 166 acres by 1968 (Capurso et al., 2010). These developments of the city infrastructure occurred at the cost of degradation to riparian habitat quality.

Additionally, changes in the river's form and amenities along the corridor affected recreation. The installation of greenways and parks are meant to meet the need of that ecosystem service. Future plans to improve parks and extend and link disconnected greenways have potential to increase access and available area to meet this cultural ecosystem service. Measuring connectivity, length, access, and amenities within and between parks can give metrics for recreation service improvement analysis.

Changes in habitat quality, the source of natural capital for ecosystem services and a yardstick for ecosystem health, is imperative in an ecosystem service analysis (Nagy et al., 2012). Similarly, recreation is an ecosystem service imperative for human well-being. Habitat quality must balance supporting, provisioning, regulating, and cultural aspects, while recreation is primarily cultural. Pocatello and the Portneuf River's changes and proposed changes offer a prime example to examine these: past, present, and future. This thesis addresses ecosystem services to measure the potential of a city's efforts to revitalize ecosystem services along a river corridor.

Research Objectives

The research objectives of this thesis are twofold. The first objective is to analyze the sustainability of urban form for Pocatello, ID from 1941 - 2013 and further build upon this analysis to complete a modern-day comparison of urban form between three medium sized cities in Idaho (Pocatello, Coeur d'Alene and Idaho Falls). The second objective is using proxies of change in river characteristics and amount of riparian vegetation to quantify deterioration in riparian ecosystem services for the Portneuf River between a pre-channelized and post-channelized condition.

Visual inspection of historical images and maps indicates Pocatello has become more dispersed and less compact through time. To answer the question of how Pocatello's urban form has evolved from 1941, a temporal analysis based on metrics indicative of sustainable urban form was performed. Metrics included density of people and buildings, clustering of urban features (nearest neighbor), centrality, compactness of built area (convex hull versus built extent), fragmentation (shape index), and connectivity (street connection density). When combined these factors provided quantitative decadal index values. Additionally, cross-site comparison with two contemporary cities in Idaho (Coeur D'Alene and Idaho Falls) provides an indication of how sustainable the modern day polycentroidal area of Pocatello and Chubbuck are, and begins a library of index scores for other cities to compare themselves.

For the second research objective of this thesis, I conducted a natural capital comparison analysis of three time periods along the section of the Portneuf River in Pocatello, Idaho. These time periods are a) prior to the building of railroads (pre-1900),

b) around the time of construction of the river levee (1968), and c) current day, including possible natural capital gains if the Portneuf Vision Study restoration plan is implemented. The analysis includes measuring river length, sinuosity, and meander count for the entire river, while also comparing loss of vegetation between pre- and post-levee construction using historical imagery from 1963 in comparison to imagery from 2013.

Intellectual Merit

Sustainability of urban form is based on previous research performed by Galster (2001) and Jia and Jiang (2000). The methodology presented here combines metrics for different aspects of urban form using Pocatello, ID, as a case study and elaborates further by producing a street connection density algorithm. Together these analyses produce results normalized and scaled relative to one another to facilitate comparison of urban form for Pocatello over time and for comparison to two additional medium sized cities in Idaho (Idaho Falls and Coeur d'Alene).

These algorithmic analyses are available as a toolkit for planners to use to quantify metrics for sustainability of form with data readily available to any planning department in a municipality. These include roads, building footprints, census data, enumeration boundaries, and built extents. These tools can give planners an idea of how their city has changed over time or as a comparison of their city's form with other contemporary cities of similar size. Models for future growth scenarios can be evaluated with these tools to make the most prudent and sustainable decisions.

One important component of a human's well-being is produced using ecosystem services derived from natural capital. The ecosystem service analysis of change in natural capital of the Portneuf River pre- and post-channelization and how the Portneuf Vision Study's recommendations for renewal of the Portneuf and adjacent areas show not only if the recommendations the city is making are needed, but also to what extent they produce a more sustainable city with the Portneuf River's ecosystem services and the current and future inhabitants' well-being in mind.

Broader Impacts

Comparatively measuring, quantifying, and modeling sustainability for a geographic area's development gives decision makers, planners, legislators, officials, community stakeholders, business owners and private citizens, the information they need to understand the repercussions of development. Also, depicting environmental effects through time lays the groundwork for giving decision makers relevant data upon which they can make plans. Zoning, land use policy, infrastructure development, as well as ways to preserve and protect and sometimes even return natural landscapes to healthier more sustainable states reminiscent of former times can occur through investigating built urban form, land use, land cover and infrastructure change that invariably comes therefrom.

CHAPTER TWO. LITERATURE REVIEW

Theoretical Basis of Sustainability Analysis

The U.N. Brundtland Report (1987) provides one of the first and foremost ways of evaluating sustainability. The report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 16). Following this landmark report, various authors expanded upon the concept of what creates and constitutes sustainability. Important paradigms for sustainability include ecological footprint analysis (Wackernagel & Rees, 1996), ecosystem services (Costanza et al., 1997), and the sustainability triangle and its conflicts (Campbell, 1996).

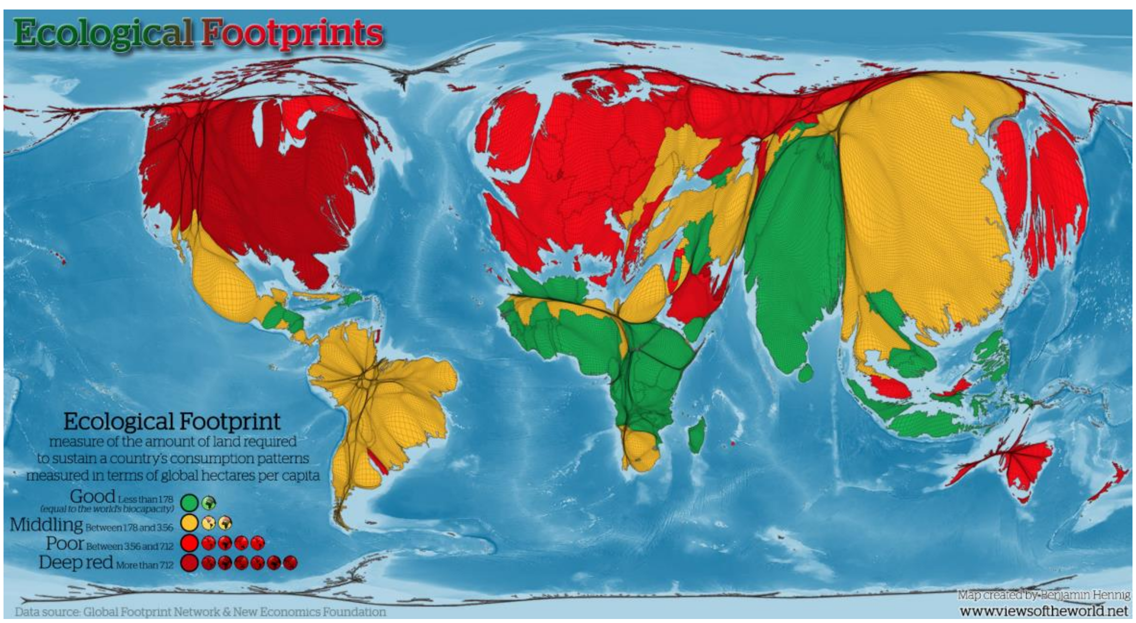

Figure 1. Ecological footprints indicate the United States and other Western Countries consuming many more resources than are renewed in a year, while green shows areas that consume on a sustainable level (www.viewsoftheworld.net).

A groundbreaking and important innovation for the analysis of sustainability introduced by Wackernagel and Rees (Wackernagel & Rees, 1996) was the concept of ecological footprint (EF; Figure 1). This is a method of analysis that evaluates the demands placed on the world's ecosystem services that includes a unit of measure, the global hectare (Amin, 2009). Area of land used for ecosystem services ranging from food, timber, fossil fuels and other raw materials are included in ecological footprint, and so is the area of Earth used for buildings, roads, and other infrastructure typical of development (Palmer, 1999). Critics of EF analysis find fault in the concept: energy use and matter is accounted in hectares and matter that exceed that which is present on earth. Such an impossible scenario shows EF to be a construct that groups real land usage with negative externalities of unsustainable development, such as pollution, that have been converted to land. For example, one global hectare of road usage is treated the same as 1 hectare of carbon sequestration of forest (Bergh & Grazi, 2013). For this reason, decision makers need measure of sustainability of urban form that considers efficiency of usage.

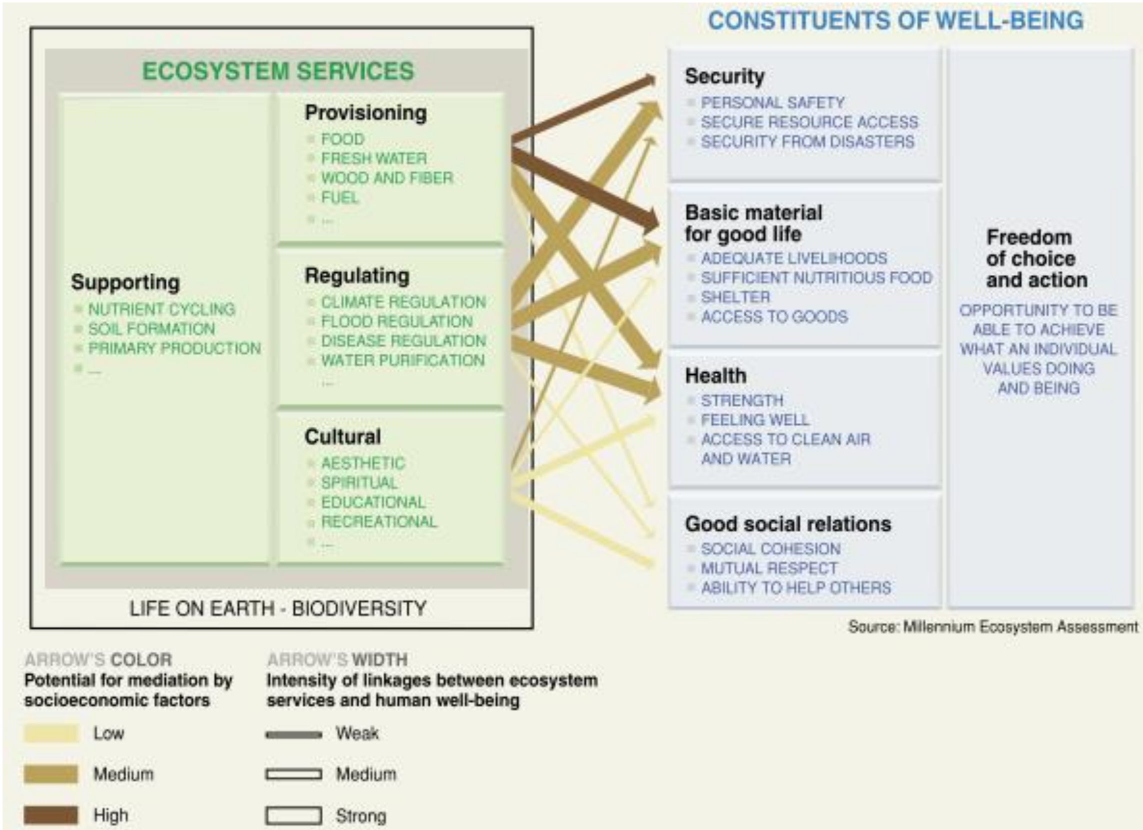

Figure 2. Supporting ecosystem services underlies all others: provisioning, regulating, and cultural. Together these services are linked to the constituents of human well-being that when satisfied provides freedom of choice. Source: Ecosystem Change and Human Well-being (2008)

Ecosystem services are provided and utilized for human wellbeing at the cost of various habitats' natural capital (Figure 2). Costanza (Costanza et al., 1997) defined ecosystem services as the "flow of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare." These two interlinked, but separate spheres lie within the social domain, which itself is only a part of all-encompassing nature, the container of all capital (Figure 3).

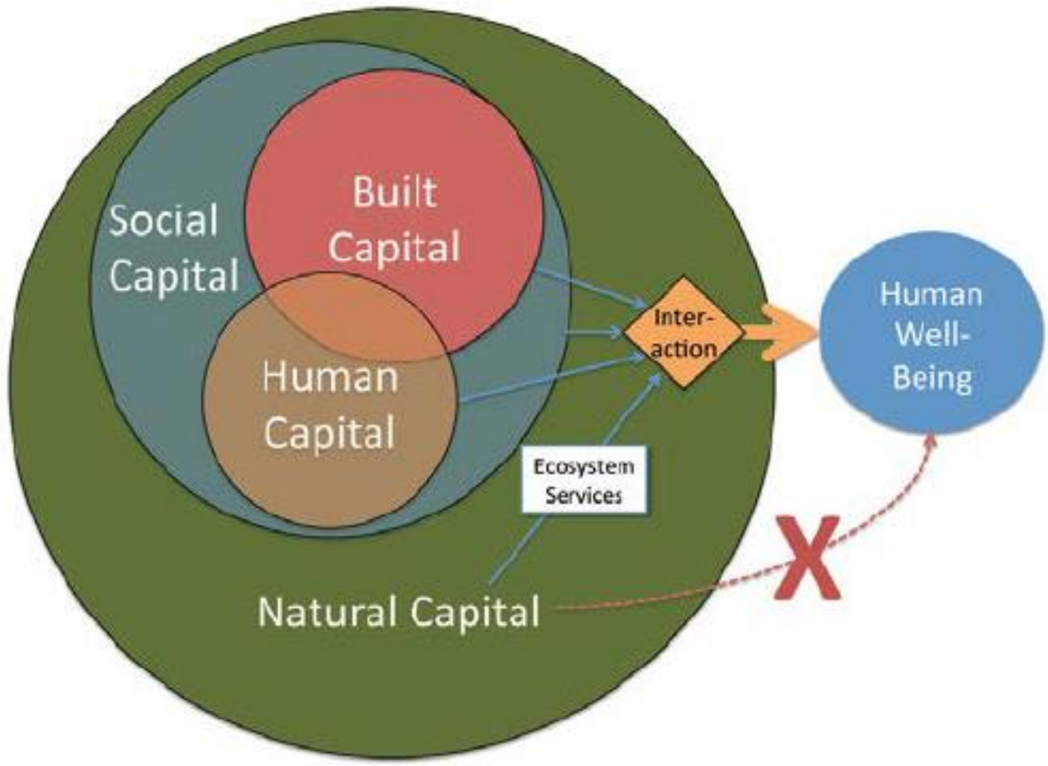

Figure 3. Natural capital does not inherently lead to human well-being, rather its relationship to social, built and human capital and how they interact produce human well-being (Costanza et al. 2014a).

Ebersole and Friselle (1997) noted that the landscape within ecosystems through time have a potential capacity. Despite the direction a habitat and ecosystem would have taken within a landscape, human actions have suppressed the expression and full development of a habitat due to development decisions. Natural capital analysis is one way of estimating this deviation.

Ecosystem services are broken down into four main aspects: basic supporting services (e.g. soil formation, nutrient cycling, and primary production), provisioning (food, water, fuel, etc.), regulating (climate, flood, disease, water purification, etc.), and cultural (recreation, education, aesthetics, etc.) services (Millennium Ecosystem Assessment, 2004). Because of the exploitation of these resources, an important component of ecosystem services analysis is that of habitat quality analysis. Habitat quality is most easily defined as the deviation of a particular habitat from an ideal reference state. Inherent in a habitat's deviation due to the unsustainable use of natural capital comes a corresponding deviation in its ability to deliver specific ecosystem services (Bálint, Ildikó, Miklós, Ferenc, & András, 2008)

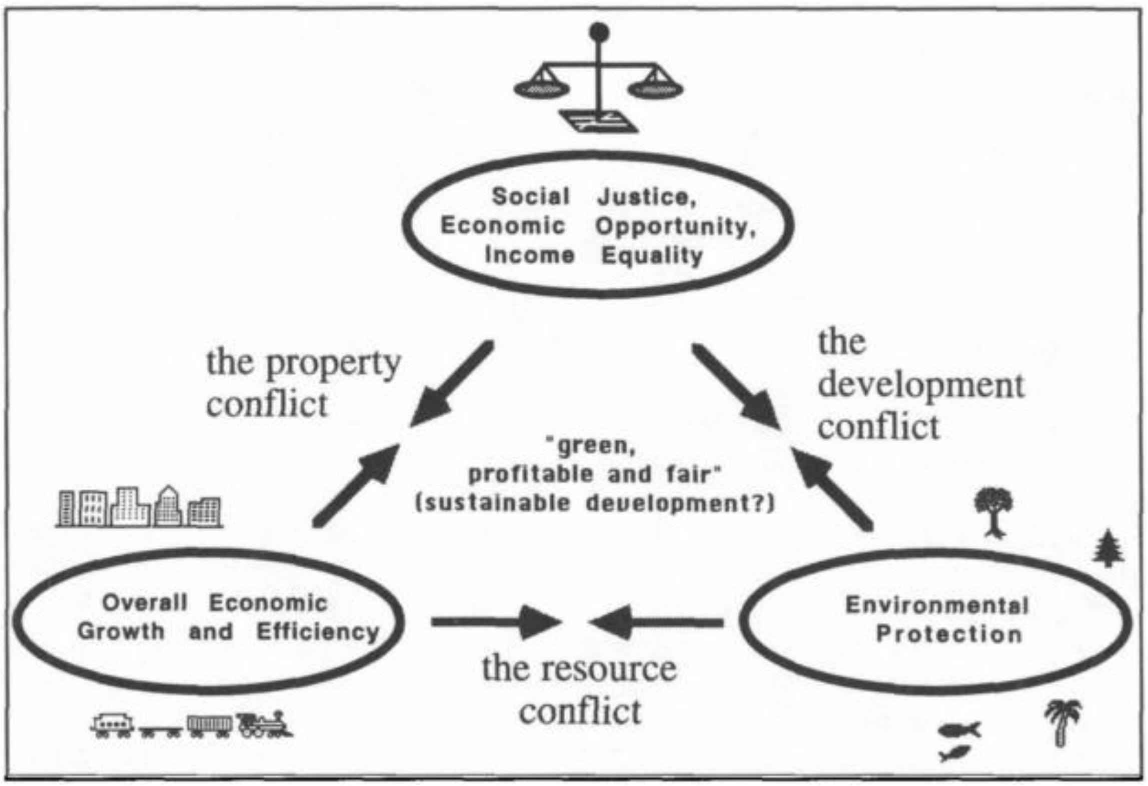

Figure 4. Sustainable development pillars and conflicts

According to Campbell (Campbell, 1996), there are three pillars of sustainability: environmental protection, socio-economic equity, and economic growth and efficiency.

These values often conflict (Figure 4), however, a proper functioning (i.e. sustainable) socio-ecological system needs to balance these pillars. The paradigms for representing sustainability of nature between Campbell (1996), Costanza (1997), and Wackernagel and Rees (1996) differ; however, they all agree that there should be a balancing of the inputs of nature, society, and economy (built and human components) to achieve sustainable human well-being.

Urban Form Analysis

Jacobs' The Death and Life of Great American Cities (1961) is a seminal work in the planning literature, being one of the first to analyze the de facto conditions on the ground and how cities work. Through her research, she gives a detailed account of how public planners and the private finance sector weakened and caused abandonment of inner cities. Jacobs condemns idealism through paradigms devised by individuals such as Ebenezer Howard, proponent of the Garden City, and LeCorbusier, who formulated the Radiant City, within city planning that became orthodoxy to the planning community and gave rise to low-density suburban culture (Røe & Luccarelli, 2012). Rather than a utopian approach to planning based on ideals, Jacobs advocates for a data based approach to planning, though many of her conclusions come from personal observation. She eschews the wisdom of the time that high-density development needs remedying and instead sees how the older, higher density areas in cities exist as lively and dynamic places worthy of appreciation on their own merits. Jacob's (Jacobs, 1961) examination describes the factors (density, connectivity, mixed uses, and various aged buildings) that have made cities succeed or fail, and her prescriptions for denser, more walkable cities anticipates modern best practices, shorter blocks, adaptive reuse, and infill for sustainable development (Steyaert, 2012).

Data Driven Analysis of Sprawl's Effects

Analysis of development shows that low density urban sprawl, a phenomenon decried by Jacobs, is shown to increase income disparity, social, and racial gentrification (Squires, 2002). A drawback of denser development is the increased prices for housing and smaller living space. Despite the increased equity within the city, the downside to compact development cost is a measure of livability (Burton, 2000).

Maintaining a vibrant and sustainable city where personal interactions and commerce thrive relies on many streets and small blocks. Large blocks decrease the opportunities to choose varied paths and lead to monotonous stagnation with the same route repeated by a pedestrian (Jacobs, 1961). Recent studies, such as one from MIT empirically confirm this insight (Nadai, Quercia, Larcher, & Lepri, 2016).

Comparing block size across an urban area, and measuring the relative differences becomes an important metric in quantifying one aspect of sustainable urban form. Dill (2004) notes block size, and the corresponding intersection density, are important factors for measuring across a city for connectivity.

Block size and connectivity are important because of the increased contact among humans, increased pedestrian access to amenities, freedom of navigation, increased exercise, and sense of community improves livability by having a walkable city fostered by the local council, which in turn amount to an increase in quality of life.

Quantifying Sprawl

Jacobs identified and defined problems created in post-war trends in city development. Since Jacobs, planners and geographic information scientists have tried to come up with various methods for measuring the sustainability and sprawl of a city. Many sprawl analyses rely on analyzing population and various aspects of urban form ranging from buildings to infrastructure analysis. One of the pioneering methods for quantifying and measuring urban sprawl emerged from the work of Galster (Galster et al., 2001). He proposed that sprawl was composed of a lack of multiple measures: density, concentration, clustering, centrality, nuclearity, and proximity (Galster et al., 2001; Laidley, 2015). By using these comparisons, an idea of how to compare cities in the era of geographical information systems was born. Later, Galster, in conjunction with others, included an important mixed use component for measuring one aspect of sprawl (Cutsinger, Galster, Wolman, Hanson, & Towns, 2005; Laidley, 2015).

Other studies use different metrics when analyzing urban form. Fenkel and Ashkenazi (2008) measured sprawl and concentrated on population density within an area, shape irregularity, fragmentation of built area, and land use. Fenkel and Ashkenazi's study ignores building clustering, housing density, in favor of focusing on the shape of the developed area and concentration of individuals. Jaegar and Schwick's (2014) analysis of sprawl includes a metric that examined built up area, dispersion of development, and utilization intensity, which is a metric that combines persons and jobs per unit area developed. Weighted Urban Permeation (WUP) is the product of: urban permeation (built extent/reporting area) * weighted dispersion * weighted utilization density.

$$WUP = UP * {}_{w1}(DIS) * {}_{w2}(UD) \tag{1}$$

These variables multiplied give the area of analysis an overall sprawl score. Salvati and Sabbi (Salvati & Sabbi, 2014) take detailed population, census, and other metrics available for cities defined by enumeration boundaries and use principle component, cluster, and discriminant function analysis to identify clusters of varying urban form within sprawling cities. Some of the variables include houses per building, stories, year built, etc. This study gives a good measure of vertical profile, building density, population density, building use, and construction material, and uses a multivariate analysis that bins indicators into groups, such as percentage built between x and y years and percentage that are x stories. This creates many indicators by subdividing categories. However, Salvati and Sabbi avoid measuring other spatial components, such as compactness of the developed area, and spatial relationships between buildings, such as clustering or block size (Salvati & Sabbi, 2014).

An analysis by Jia and Jiang (Jia, Tao Jiang, 2000) found that street node (intersection) number is heavily correlated with population and through the use of search radii can define the areal extent of sprawl. This measure catches the natural city, extent of an urbanized area, rather than arbitrarily defined municipal boundaries. The fact that street nodes bear a remarkable correlation to population makes an estimation of the population within natural cities possible without more advanced dasymetric mapping techniques that require census aggregate data. However, this methodology underestimates leapfrog development, discontinuous developments emanating from a core, a sure sign of sprawl. Despite this, street node analysis is especially important because it can also give a measure of connectivity and block size. Table 1 shows a short summary of the development of GIS analysis of sprawl.

Table 1. Methods for analyzing urban form and sprawl

Author(s)	Method	Year
Jia and Jing	Street Node Analysis	2000
Galster	Density, Concentration, Clustering, Centrality, Nuclearity, and Proximity	2001
Cutsinger, Galster, Wolman, Hanson, & Towns	Included Mixed Use	2005
Fenkel and Ashkenazi	Density, Fragmentation, Land Use Mixture	2008
Jaegar and Schwick	**Weighted Urban Permeation**	**2014**
Salvati and Sabbi	Principle Component/Discriminant Function Analysis	2014
Laidley, Thomas	Census-based Density Cut Point Analysis	2015

A real breakthrough came with Galster's (Galster et al., 2001) spatially based analysis of density, concentration, clustering, centrality, nuclearity, and proximity. These early spatial studies of sprawl laid the foundation for later writers. Ideas of including mixed use within an area (Cutsinger et al., 2005) and job density along with individuals (Jaeger & Schwick, 2014) changed the quantification of sprawl. Many recent studies rely on census or similar data and enumeration boundaries and analyze large metropolitan cities. A time series analysis of a mid-sized city such as Pocatello, with fine resolution housing footprint and infrastructure data requires approaches similar to those implemented by Galster (Galster et al., 2001) and Jia and Jing (Jia, Tao Jiang, 2000).

Ecosystem Service Software Programs

Ecosystem service programs exist with multiple modeling methods with emphasis on various facets of ecosystem service ranging from provisioning and regulating services to socio-cultural. Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is a program released by the Natural Capital Project that has been widely peer-reviewed, often integrated with other GIS software such as ArcGIS (Esri), and addresses many different types of services (Bagstad, Semmens, Waage, & Winthrop, 2013).It utilizes deterministic modeling and assigns biophysical units to evaluate ecosystem services in its provisioning and regulating models, while its socio-cultural models receive relative units (Bagstad et al., 2013). This is a sensible modeling methodology because beauty, aesthetics, and pleasure from recreation do not lend themselves well to biophysical valuation, while provisioning and regulating services contribute directly to commodities (food, fiber, etc.) or their proliferation (clean water, air, genetic diversity, etc.) (Millennium Ecosystem Assessment, 2005). Biophysical quantification lends itself to conversion to market value in monetary terms in some analyses when paired with expert opinion performed by models in this software suite (Bagstad et al., 2013).

Artificial Intelligence for Ecosystem Services (ARIES) is an ecosystem services program based on probabilistic modeling (Villa, Ceroni, Bagstad, Johnson, & Krivov, 2009) that can be more data intensive than InVEST depending on the model, but uses artificial intelligence to apply deterministic modeling and gives biophysical units to provisioning and regulating and relative ranking to socio-cultural, like InVEST. InVEST's approach to uncertainty is through varying input, whereas ARIES employs Bayesian networks and Monte Carlo simulation. (Bagstad et al., 2013). ARIES allows for user interaction that chooses from ecological processes and other agents effecting a phenomenon, determined by user query, and builds a model therefrom (http://aries.integratedmodelling.org/).

ENVISION is another GIS platform for analyzing ecosystem services, particularly urban development. It was originally named EvoLand and works as an actor-agent decision support toolset (Bolte, Hulse, Gregory, & Smith, 2006). It can be used and integrated with other modeling software, like InVEST, or can be used with ad hoc user created models. Though it an be integrated with other software, most of its case studies have been developed in the Pacific Northwest and takes great effort to produce new case studies. It is cost effective in regions implemented, such as the Pacific Northwest, but less so otherwise. Like ARIES and InVEST it supports monetary and non-monetary quantification but has not been as widely used (Bagstad et al., 2013).

One way of determining values for natural capital change is to analyze ecosystem loss and degradation from a formerly recorded or idealized area. The remaining area is multiplied by its quality, or degradation from its reference state. The product provides an estimation of the remaining natural capital in an area and can give an idea of environmental loss and degradation for a particular ecosystem (Nagy et al., 2012). The InVEST model for Habitat Quality elaborates on this model and summarizes habitat quality by relying on area and LULC ranking, while also incorporating threats from the nearby environment. This is both a strength and a weakness. Though more elaborate with additional outputs for threats, biodiversity, and rarity than the natural capital index, data needs are much greater. The model assumes all threats are additive, though this may not be the case: multiple threats on the same ecosystem could be greater than the sum of their parts, a problem noted by the model's creators. A heavily studied area with high-resolution data of the ecology, including biodiversity, infrastructure, invasive species, and other threats, is best suited for this model. In the context of riverine landscapes and ecosystems, restoration's goal should be to increase the stream's potential for fulfilling as many possible desirable capacities as the ecosystem might have expressed naturally. To do this, anthropogenic change needs reducing or eliminating, particularly the aspects of human development that inhibit desired restoration expression. One particularly important aspect for renewing and restoring an area, such as a riparian ecosystem, is to reintroduce native species and eliminate undesirable invasive species.

Johnson and Buffler (2008) noted that to have a properly functioning riparian habitat there needs to be thriving natural species and a lack of invasive species, an adequate water table (20 inches or less subsurface), and a lack of channelization. Reduced stream flow and usage threaten river survival and riparian habitats; this includes for Pocatello. Crop producing land cover takes up a mere 14% of total land in the watershed; however, the vast majority (95%) of this water irrigates farms and fields, which in turn reduces stream flow 35%. Modelling future scenarios show lower flows, increased eutrophication, and, at worst case, a completely dry Portneuf River (Marcarelli, Van Kirk, & Baxter, 2010).

CHAPTER THREE. QUANTIFYING THE SUSTAINABILITY OF URBAN GROWTH AND FORM OF POCATELLO (1941 TO 2013) AND COMPARISON TO TWO CONTEMPORARY MID-SIZED IDAHO CITIES

Introduction

Modern city growth must consider the environmental stress caused by the ecological footprint imposed on nature by humanity. Rees and Wackernagel (1992; 1994; Wackernagel & Rees, 1996) developed the concept of ecological footprints that examines the demands placed on the world's ecosystem services for use in planning and sustainability analysis. 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 developed to view footprints in units of global hectares. An alternative way of looking at these aspects of ecological footprints is evaluating an urban area's sustainability 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. Development of areas with inefficient forms often leads to automobile reliance and increased costs for the delivery of services. One type of inefficient city form developed in modern times includes "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 create 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, a growing concern has been measuring urban sprawl. Sprawl has many negative economic, social and ecosystem impacts. Economic impacts include increased costs for infrastructure maintenance (Henríquez et al., 2006) and increased consumer fuel cost associated with time spent commuting. Decreased socio-economic 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 habitat loss and fragmentation (Schneider & Woodcock, 2008). These factors inform a methodology for data collection and quantification of different aspects of sustainability of form, a component of sprawl to plan for more sustainable growth. Several algorithms for important, quantifiable aspects of sustainability of form over time, including density (persons and households per unit area), fragmentation (shape index), and compactness (enclave analysis), are measured on a global, city-wide level, while other algorithms, such as centrality, clustering (nearest neighbor), development density, and connectivity (street connections), are measured locally within the city using grid analysis. Together, these local and global analyses will be applied to analyze and offer recommendations for urban planning decisions for the city of Pocatello, Idaho.

Historically, many measurements of sprawl and sustainability of urban growth have concentrated on large cities and Metropolitan Statistical Areas (MSAs) or county-wide analysis (Ewing & Hamidi, 2013; Ewing et al., 2002; Hamidi & Ewing, 2014; Smart Growth America, 2014) utilizing census and spatial metrics on a block-group macro level. These studies have produced sprawl rankings from aggregated variables.

Others have relied on land cover classification data derived directly from satellites with low spatial resolution (30m). Many planners examining changes in land cover over time have used America's National Land Cover Dataset (NLCD), (Irwin & Bockstael, 2007). The poor resolution of this data has proven insufficient for capturing low-density development, a predominant factor associated with sprawl. In one study recording low-density development, results yielded only 26% accuracy, while recording high density development was correct 83% of the time (Irwin & Bockstael, 2007). In contrast, an investigation of urban growth in Maryland by Irwin and Bockstael (Irwin & Bockstael, 2007) used planimetric data derived from building footprints in conjunction with parcel data to analyze urban growth. Of interest in this study was the finding that the NLCD classified low-density developments as undeveloped, which indicated the 30-meter resolution of the NLCD was inadequate and created misclassification. The greater spatial resolution of planimetric data and derived classification for low-density developed areas revealed a more accurate analysis of environmental fragmentation.

I used a similar methodology in this case study for Pocatello, Idaho, a medium-sized city, situated in the Portneuf River Valley in southeast Idaho for a time series (1941 to 2013) analysis to measure changes in sustainability as the city developed and to compare between cities. This methodology was undertaken to build upon the methodology of other's work at an MSA level and extend it to small and medium sized cities across space and time. From a cursory view of the gridded small blocked city of 1941 to the winding suburban streets of 2013, I hypothesized that the city would follow the path of less dense, less connected, and more sprawled out. Surrounding mountains and another municipality to the north, Chubbuck, limit Pocatello's long-term development options. This study quantifies the increase or decrease in sprawl, measured through sustainability of form metrics over time. Using census data in combination with historical aerial imagery, python scripts calculated measures of density, compactness, fragmentation, connectivity, clustering, centrality on a roughly decadal scale for the past 70 years. A second hypothesis was that this approach could be used to quantify the sustainability of two other medium sized cities in Idaho in comparison to Pocatello. By viewing physiographic boundaries, I conjectured three main possible responses. First, cities have tended to sprawl when they have had the ability, so Idaho Falls would be less dense and connected due to its location (Snake River Plain). Second, Coeur d'Alene would be denser because it was situated near a lake with high natural capital to attract more individuals. Lastly, Pocatello's fragmentation and compactness scores would be greater because of its physiography (bounded elongated valley along the Portneuf river).

For a comparative analysis between similar sized cities using contemporary datasets, I executed the same workflow to, acquired the same metrics, standardized and normalized the datasets for Coeur d' Alene, Idaho Falls, and the modern-day

Pocatello/Chubbuck area. 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.

Methodology

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. Designers of the city of Pocatello demarcated and built it around an accompanying railway within the Portneuf River Valley. The city, railway, and Portneuf River flow southeast to northwest, constrained by steep valley sides (Figure 5). Founded in 1893, Pocatello's 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, while the neighboring city of Chubbuck, once a mere farm village, has a population of 14,428. To show spatial change of the built environment and population over time, I created a workflow for data collection and analysis for Pocatello that is transferable to other areas. 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. I calculated linear regressions from census data to estimate population, household, and people-per-household for non-census years.

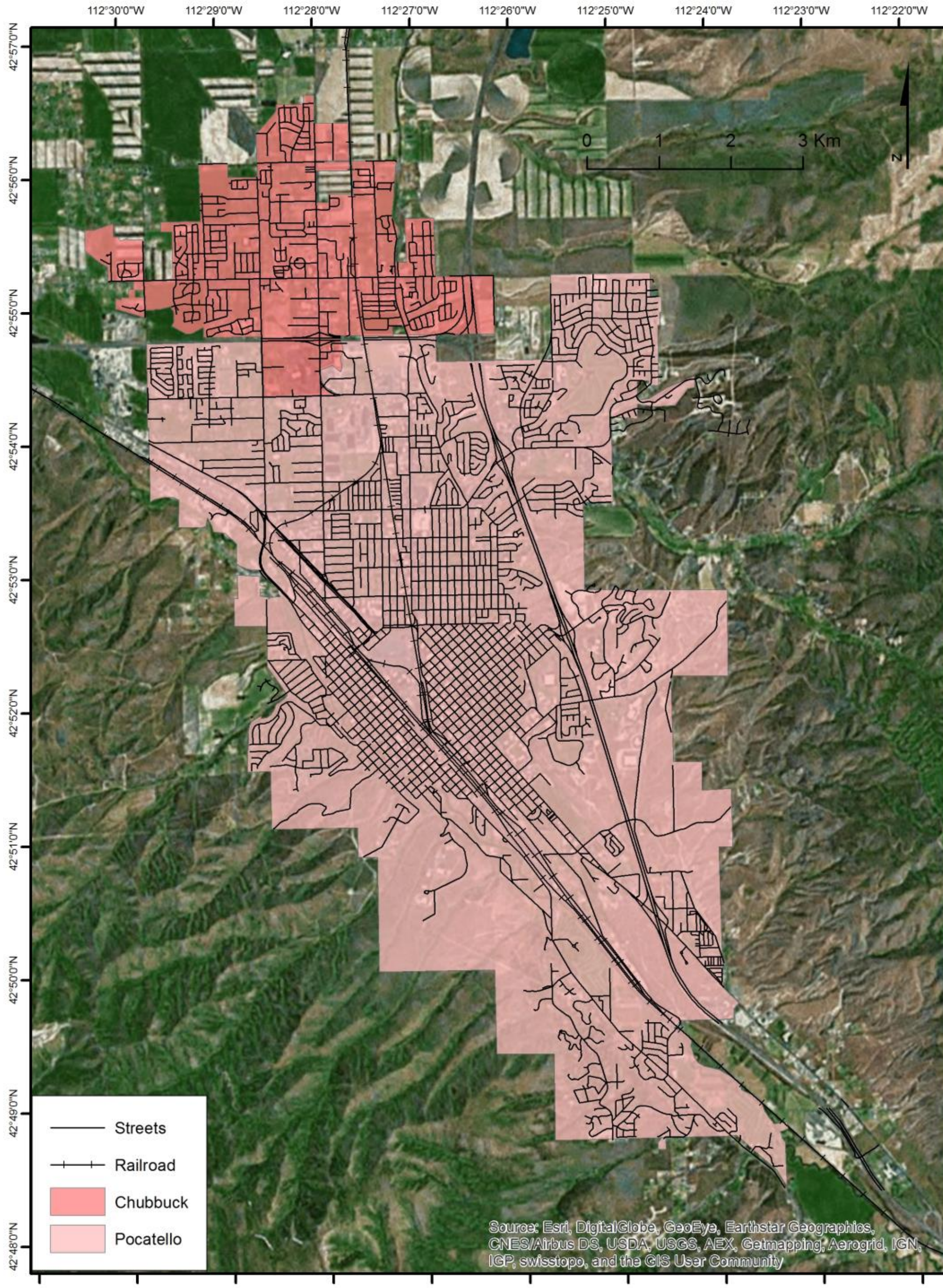

Figure 5. The study area of Pocatello and Chubbuck

Many types of geospatial data were used for this analysis (Figure 6). Main sources of spatial data utilized were Pocatello city boundaries, available from the city's founding until the present day. Historical aerial photographs were available for 1941, 1959, 1963, 1968, 1975, 1984, 1994, 2004, and 2013. Images were obtained at a scale of 1:30,000 for 1941 and scales of 1:12,000 and 1:24,000 for the years 1941 through 1994 through the United States National Archives, Idaho State Historical Society and the private sector firm, Valley Air Photos, Caldwell, Idaho. Images from 1941 to 1994 were converted into orthomosaics using structure-from-motion (SfM) technology complemented with highly accurate ground control points (Lipple, 2015). SfM technology uses camera orientation to align overlapping photos and create a single three dimensional image (Fonstad, Dietrich, Courville, Jensen, & Carbonneau, 2013). I used the United States Department of Agriculture, National Agricultural Imagery Program (NAIP) datasets for 2004 and 2013 (Table 2). Aerial photographs were used to identify when buildings were present and confirmed data present in the parcel data for the year built. Buildings that are no longer extant were manually digitized and their presence noted from the first and last year they appeared in imagery. I created an annexation layer by manually digitizing a city map based on city ordinances (http://www2.cose.isu.edu/~oglejare/Urban_Form/Annexation_History.html). A built extent layer within the enumeration boundary (city's legal extent queried from the annexation layer) for each year for every image year was created by digitizing around built features within the enumeration boundaries.

Table 2. Years, scales and sources for aerial photos

Year	Scale	Obtained From	DOI/Source
1934	1:62,500	Perry-Castañeda Library Map Collection	USGS Topographic Map (Pocatello)
1937	1:62,500	Perry-Castañeda Library Map Collection	USGS Topographic Map (Michaud)
1941	1:30,000	US National Archives	United States Department of Agriculture, Soil Conservation Service
1959	1:12,000 (~1 m resolution)	Pocatello, Idaho Historic Orthoimagery for 1959	doi:10.7923/G4X63JT0
1963	1:12,000 (~1 m resolution)	Pocatello, Idaho Historic Orthoimagery for 1963	doi:10.7923/G4SF2T3P
1968	1:12,000 (~1 m resolution)	Pocatello, Idaho Historic Orthoimagery for 1968	doi:10.7923/G4J1012N
1975	1:12,000 (~1 m resolution)	Pocatello, Idaho Historic Orthoimagery for 1975	doi:10.7923/G4D798BC
1984	1:12,000 (~1 m resolution)	Pocatello, Idaho Historic Orthoimagery for 1984	doi:10.7923/G48G8HMN
1994	1:24,000	Valley Air Photos, Caldwell, ID	doi:10.7923/G44Q7RWX
2004	1:24,000 (~1 m resolution)	National Agriculture Imagery Program	US Department of Agriculture, Farm Service Agency
2013	1: 6,000 (0.5 m resolution)	National Agriculture Imagery Program	US Department of Agriculture, Farm Service Agency

A contemporary analysis of the urban form of medium-sized cities in Idaho compared the Pocatello/Chubbuck metro to Idaho Falls and Coeur d'Alene. The Pocatello/Chubbuck metro area lies within a valley and is bounded by hills to the Southeast and Northwest. It comes to a bottleneck in the South at Portneuf Gap, which limits growth (Figure 5). The Pocatello/Chubbuck area is also bisected by the Portneuf River and Union Pacific Railroad.

Coeur d' Alene lies adjacent to a lake, which shares its name. Its central business district lies along Sherman Avenue near the lake, ranging from 300 m to approximately 1.5 km from the shore. The city extends from its central business district, or CBD, up to 16 km northward, and has a population of 49,122 (Figure 6).

Idaho Falls has a similar diameter to Coeur d'Alene measuring 18 km across in some places, but differs because it has a centrally located CBD. It has over 10,000 more people than Coeur d'Alene (59,184) and is located along the Snake River (Figure 7).

County data supplemented by the city of Pocatello allowed datasets to be combined for cross site analysis against Coeur d'Alene and Idaho Falls. Building footprint centroids, roads, parcels, and enumeration boundaries for Idaho Falls and Coeur D'Alene were obtained from the University of Idaho's data repository, Inside Idaho (www.insideidaho.org). Contemporary aerial imagery and feature layers produced the built extent.

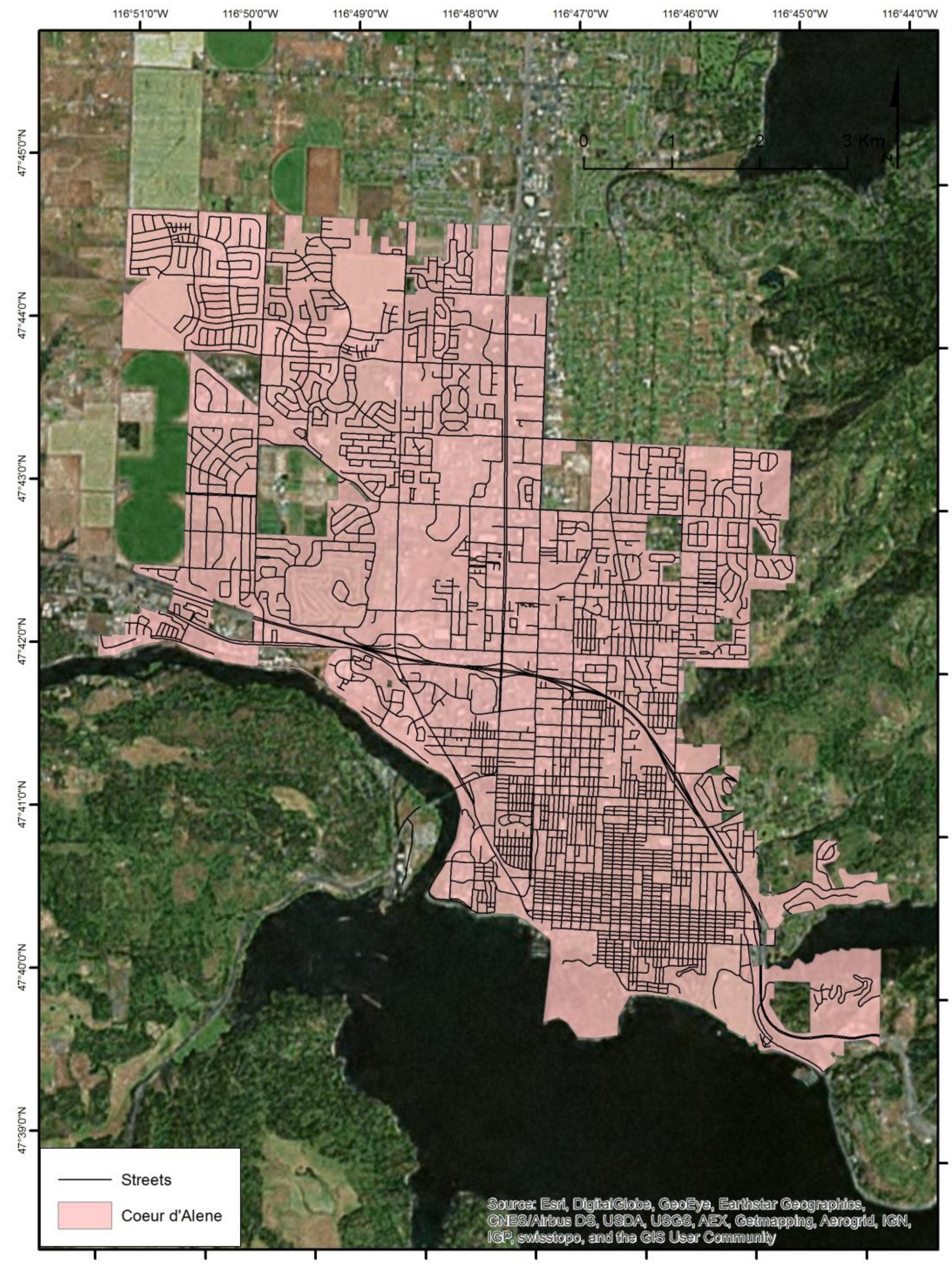

Figure 6. Study area of Coeur d'Alene

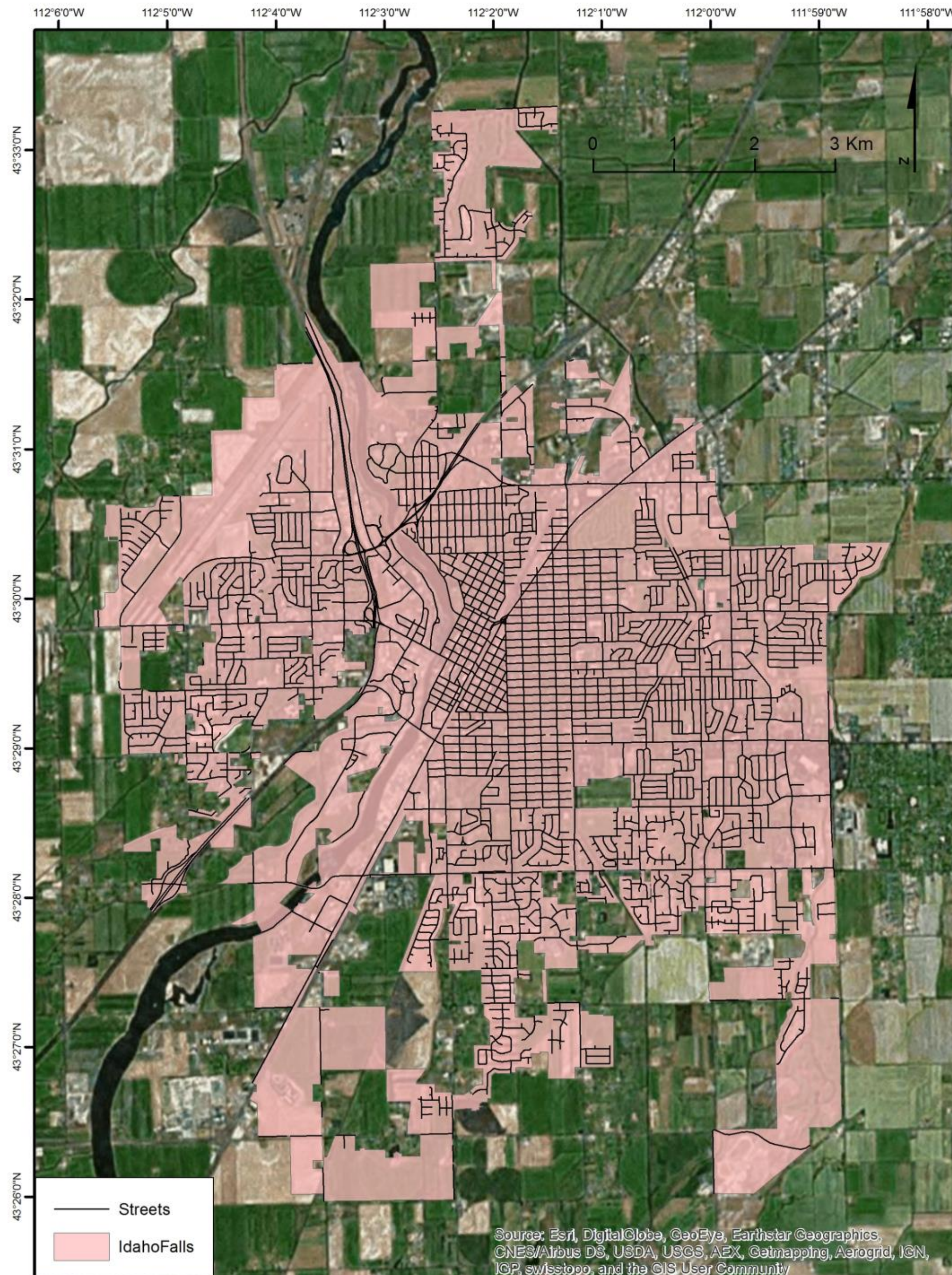

Figure 7. Study area of Idaho Falls

Scales of Analysis: Global (City) and Local (Grid) Analysis

I performed global analysis on the cities at a city level, where finer resolution was unavailable. These global variables include compactness (convex hull versus built extent), fragmentation (shape index), and density measures (population density, household density, and persons per household).

For fragmentation, I compared the buildings' standard deviational ellipsoid major to minor axis ratio, or a/b, which yielded a shape index (Alexander, Hubers, Schwanen, Dijst, & Ettema, 2011). For compactness analysis, I compared the area of the convex hull to the built area within to identify undeveloped enclaves (Chen, Zhao, Li, & Yin, 2006), and for density analysis I utilized census data for overall household, population density, and persons per household (Galster et al., 2001).

Local analysis was done on a grid basis and analyzed: clustering (nearest neighbor per grid), feature density (buildings per grid), connectivity (connections per grid), and centrality to the core. Grid analysis has been used previously by Galster et al. (2001), who used 1 mile by 1 mile grids and analyzed the Metropolitan Statistical Areas (MSAs) across America to analyze eight dimensions of sprawl. This was too large a cell size for small to mid-sized Idaho cities, therefore we needed to identify a smaller cell size that would be better suited to medium-sized cities. To determine the grid size for local analysis a spatial autocorrelation was performed on intersections, features that define blocks, street layout, and neighborhood form; 402 meters had the highest spatial autocorrelation across the study areas. Before analysis, grids were clipped to the built extent and for calculations clipped grids that deviated from the 402-meter standard were normalized for area.

Density Analysis

To start the workflow for density analysis, I joined the historical city extent with the census population and household data for each decennial year. For years in which aerial photos, but no census data, were available, population data was determined from the regression calculation of census data from all available years. I combined these statistics into the attribute tables for the non-census years. To Jacobs (Jacobs, 1961), density consists of high numbers of dwellings per acre and persons per dwelling units were an integral piece to consider when analyzing density. To others, density consists of high numbers of people per unit area, independent of dwellings and household size (Frenkel & Ashkenazi, 2008). To integrate all aspects of density within the city I considered household per unit area, population per unit area, and persons per household for density. Though households per unit area and people per unit area can lead to a derivation of people per household, it is important for a time series analysis to show the change over time in this statistic for planners and policy makers because adjustments to zoning and parcel size need consideration when persons per household changes. I calculated a density for each year for each data layer by dividing the population by the historical built extent footprint within the city boundary. I discounted the railroad infrastructure within the city from the city's "built area" for calculation in these algorithms, because of the pre-existing nature of the railroad and its vital nature to the city. Also, green space was removed because, though it may be within a developed area, it serves a great public purpose, according to MacKerron & Mourtato: it increases health outcomes, happiness, and improves social cohesion (2013). Factors affecting population density in an area are dwelling density (often synonymous with households) and household size (Forsyth, 2003). It is thus important to factor in household density, people per household, as well as overall population density into any city density analysis. For density, the total population in the enumerated boundaries was abbreviated T(p)enum, the total houses in the enumerated boundaries T(h)enum, and the area of the built extent, Abe.

$$\text{Density (population density)} = \frac{\text{T(p)enum}}{\text{Abe}} \tag{1}$$

$$\text{Density (household density)} = \frac{\text{T(h)enum}}{\text{Abe}} \tag{2}$$

$$\text{Density (persons per household)} = \frac{\text{T(p)enum}}{\text{T(h)enum}} \tag{3}$$

Compactness: Enclave Analysis

The area of the built extents was compared to the convex hull for every year and study area. An area ratio comparing the built (Abe) to convex hull's potential area (Ach) to be infilled gives an indication of potential space that could be developed versus what is. This type of analysis is often performed for least distance path and was used for enclave infilling analysis by Chen et al. (2016) when investigating types of growth in sprawl within China.

$$\text{Compactness (enclave)} = \frac{\text{Abe}}{\text{Ach}} \tag{4}$$

Fragmentation Analysis

A measure of fragmentation and dispersion noted by Alexander et al. (Alexander et al., 2011) was the ratio of the minor L(y) and major axis L(x) of the standard ellipsoid. Values closer to 1 indicate less fragmentation, with more compact shapes for development (nearly circular), while those closer to zero are more dispersed and fragmented linearly. . The shape index, which uses the standard deviational ellipsoid, considers all features and returns the trend in development for features.

$$\text{Fragmentation (shape index)} = \frac{\mathrm{L(y)}}{\mathrm{L(x)}} \tag{5}$$

Connectivity Analysis

To measure connectivity within and spanning various parts of a city, I used a methodology using a readily available layer: roads. The method of street node analysis for defining “natural cities” was pioneered by Jia and Jiang (Jia, Tao Jiang, 2000). They used streets nodes (intersections) and a search distance defined through examination of distances of spatial autocorrelation to define a search distance for other nodes. When no nodes were found it defined a “natural city” (Jia, Tao Jiang, 2000). This study utilized street node analysis, but rather than trying to merely define cities through this analysis it attempted to define connectivity within a city. Small blocked grid-patterned cities have been seen since Roman times and during expansion of America as efficient forms that allow for easy movement (Batty & Longley, 1994). Also, theorists such as Jacobs (1961) saw small blocked cities as more connected and indispensable to an economically vibrant city. Smaller blocks inevitably lead to more intersections, an increase in possible routes. Because I wanted intersection density within the city on the scale of neighborhoods, I chose a prominent peak (400 meters) from the output of Esri ArcMaps' Incremental Spatial Autocorrelation (ISA) tool to apply across time and cities. This tool helps identify distances where spatial data have high z-scores due to patterns in the underlying data. ISA is often used for hotspot analysis and other analyses where clustering of values is important. Here it was used to identify adequate grid size.

I intersected a polyline road layer of the city with the output type being "point." This created point features wherever roads crossed or met. Dissolving these based on X, Y fields removed possible duplicates where roads ended at intersection street nodes, and this yielded only one point per intersection. Next, I split the roads into individual features and performed a spatial join on the previously produced point layer with the road that I split at the intersection point features. This produced a point layer with a join count, which worked to record whether it was a three, four, or rarely five way or more intersection. Any intersected feature that produced a value of two was a 90 degree intersection or a bend in roads at the edges of town. I queried these values from the dataset and removed them because they did not indicate the geometry of any polygon or additional roads. The density of street connections per grid cell was calculated and compared across time and space. Here the T(c)m, the total count of connections at intersections with connections greater than or equal to three, was divided by (a), the summation of which was divided by the total, (T) number of grid cells (m) in the grid (u).

$$\text{Connectivity} = \frac{\sum_{m=1}^{M}((\frac{\mathrm{T(c)m}}{\mathrm{a}}))}{T(m)u} \tag{6}$$

Cluster Analysis

Another component used to analyze the change in the sustainability of form for Pocatello was the clustering of houses and other buildings within the city. Galster (Galster et al., 2001) used clustering of features to measure sprawl within his analysis and defined it as “the degree to which development has been tightly bunched to minimize the amount of land in each square mile of developable land occupied by residential or nonresidential uses.” Here I utilized the near tool in ArcMap with built structures (houses or commercial) as the input and near feature. This produced a distance (F) for each feature (i) to its nearest neighbor (n). Statistics for the average distance between houses were compiled for each grid cell (m), normalized for the cell area, (a), and averaged for the total (t) number of grids (m) in the study area (u) for local analysis and scoring.

$$\text{Clustering} = \frac{\sum_{m=1}^{M}((\sum_{i=1}^{I}(\mathrm{F(i,n)})\mathrm{m/a})}{T(m)u} \tag{7}$$

Centrality Analysis

Additionally, clustering around the core is also used within this metric and is referred to as “centrality” by Galster (2001). He defines this as “the degree to which residential or nonresidential development (or both) is located close to the central business district (CBD) of an urban area”. This study reconstructed building footprints for 1941, 1959, 1963, 1968, 1975, 1984, 1994, 2004, and 2013 for historical comparison.

Using this data, I measured clustering around the core for Pocatello. Data for centrality measurements for modern Pocatello-Chubbuck, Idaho Falls, and Coeur d'Alene was from parcel information. Pocatello parcel information had land value and improvement value in its attribute indicating built capital on the land. Though Idaho Falls and Coeur d'Alene lacked this field, structure data overlapped the parcels indicating the parcels which had been developed. Clustering around the core employed Galster's centrality equation (Galster et al., 2001), which utilized the number of structures and their average distance from the core. He defined the core from city hall and measured housing units and other forms of land use. Rather than solely looking at one type of land use (residential, commercial, etc.) clustering and the municipal core, this analysis chose the central business district and used all structures except railroad infrastructure. To do this I created grids with labels for each year and city. This grid was 402 m by 402 m for each square covering the entirety of the occupied area for each year. The fishnet "label" acted as the centroid for each individual grid square. The distance from these grid labels to the centroid of the CBD was calculated. The number of structures within each grid square was extracted to the grid. The polygon grid and the point feature labels were then spatially joined to create an output feature class containing the distance from the core centroid and number of structures within each grid square. A weighted distance from the core was calculated by multiplying units in any every given centroid times the distance from the core. For the final calculation of centrality for each city the total number (T) of structure units (i) in the entire grid (u), (T(i)u) was standardized by the square root of the total area ($A^{1/2}$) the product of which was divided by the sum of (Σ) the distances (F) cell centroid (m) to core] (k) weighted by total (T) observations (i) per grid cell (m), (T(i)m), standardized by area, (a).

$$\text{Centrality } = \frac{\mathrm{T(i)u}\left(A^{1/2}\right)}{\sum_{m=1}^{M}\left(\frac{\mathrm{(F(k,m)(T(i)m))}}{\mathrm{a}}\right)} \tag{8}$$

The contemporary analysis of Pocatello-Chubbuck allowed for polycentroidal core/CBD feature classes and measured the proximity to the nearest core. This differed from the historical analysis of Pocatello, which used monocentroidal proximity analysis. Chubbuck's emergence as a second central business district or core is relatively recent, and for this reason was only enacted in the contemporary cross-site analysis.

Development Density

Galster (2001) defined density as residential or commercial units per unit area. Neighborhood density was determined by measuring built structures within each 402 m by 402 m grid cell clipped to the built extent. A spatial join between the structure and grid cell layer produced a count per cell for each year and study area. Normalized girds made cell counts sufficient to produce a density metric across the city and on a local basis.

$$\text{Development Density} = \frac{\sum_{m=1}^{M}\left(\left(\frac{\mathrm{T(i)m}}{\mathrm{a}}\right)\right)}{T(m)u} \tag{9}$$

Mixed Use Analysis

The exposure index developed by Massey and Denton (1988) was used to measure the presence of a minority group within a majority population. This index has uses beyond statistical analysis of racial and ethnic populations for which it was first designed. Here is was modified by Galster (Galster et al., 2001) for a mixed use index and is utilized in this workflow. To calculate mixed use the density (D) of a land use (i) in a given grid cell (m), is multiplied by the quotient of the density (D) of another land use (j) and the total (T) count of land use (j) in the entire study area (u). The sum of this product is divided by the density (D) of land use (i) in the entire study area. In these analyses land use (i) refers to residential and (j) commercial (Galster et al., 2001).

$$\text{Mixed Use} = \frac{\sum_{m=1}^{M}((\mathrm{D(i)m}*[\frac{\mathrm{D(j)}m}{\mathrm{T(j)u}}])/\mathrm{a})}{D(i)u} \tag{11}$$

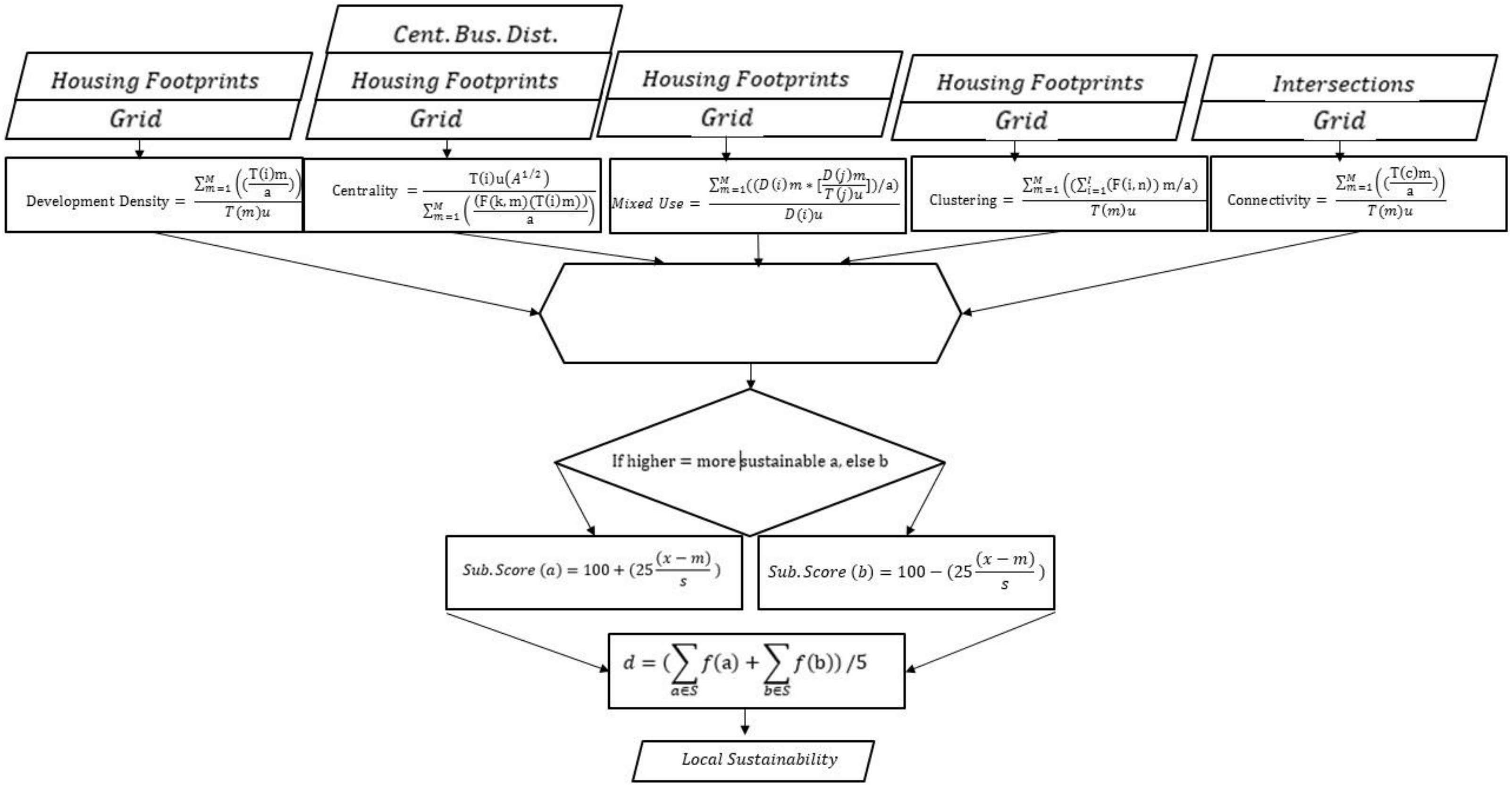

Figure 8. Workflow for local sustainability algorithm

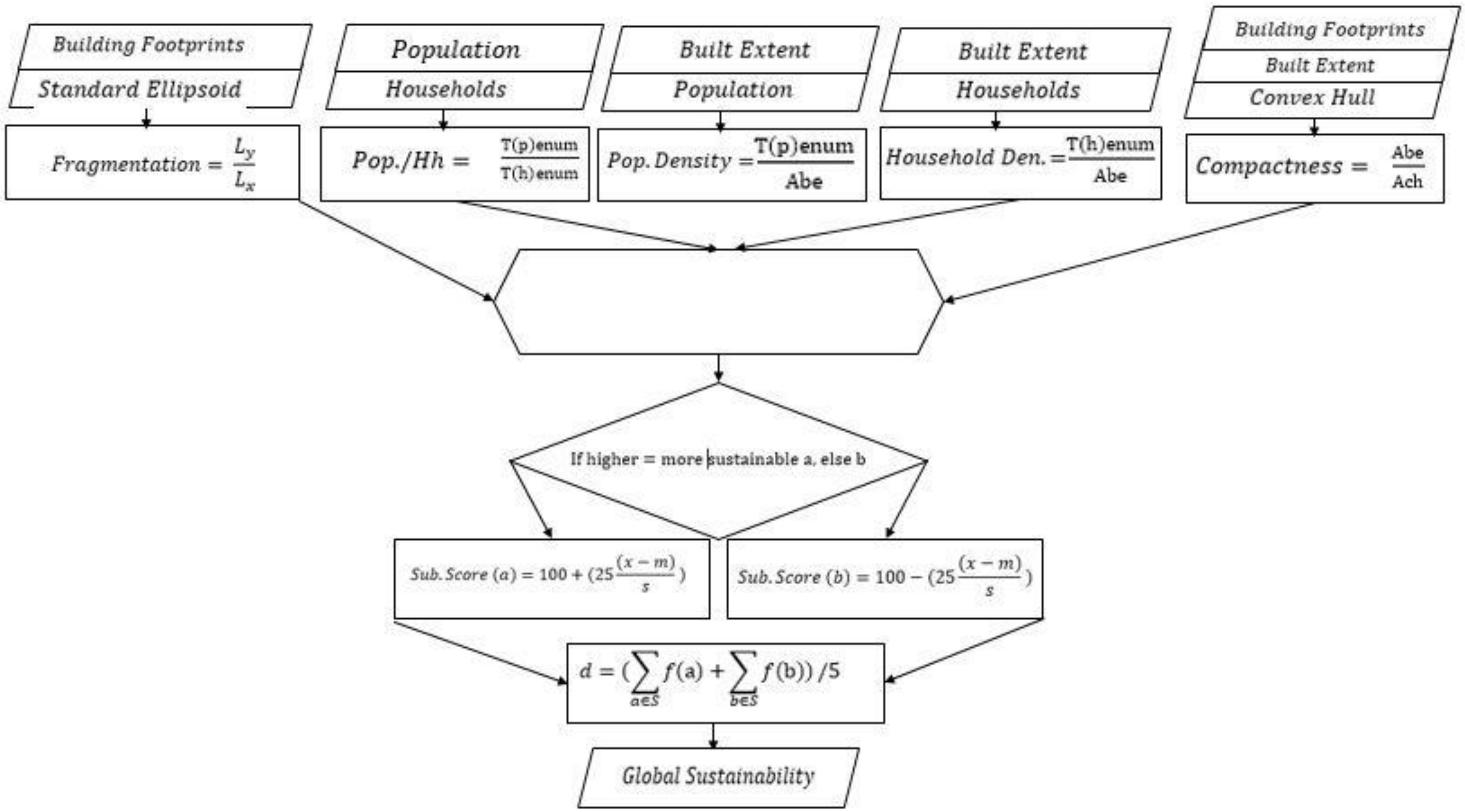

Figure 9. Workflow for global sustainability algorithm

Variables were broken into two groups, global and local, with algorithmic analyses performed (Figures 8 and 9). Global statistical categories were only applicable on a city-wide level (population and household density, as well as people per household, compactness, and fragmentation) and local statistical categories (connectivity, clustering, development density, and centrality) were available on a cell by cell basis. Scores for each category were standardized and normalized against all other values in their study cohort (Pocatello across time or cross-site comparison) with means adjusted to 100 and standard deviations 25 (Ewing et al., 2002). Nearest neighbor and centrality values were the only values in which lower values meant less sprawl. Therefore, after normalizing, the values along the distribution were transformed across the y-axis (mean). Finally, from these normalized scores were used to produce global and local sprawl index scores. All global categories were evenly weighted to produce a final global sprawl index score, while all local categories were evenly weighted to produce a final local sprawl index score (Ewing et al., 2002; Hamidi & Ewing, 2014).

Results

Global Analysis (Pocatello through Time)

For Pocatello, the first 50 years many parcels were vacant and were slowly in-filled. Its historical built-footprint grew from 5.14 km^2 in 1893 to 7.63 km^2 by 1941. From 1941, the first image year comprehensively analyzed with sustainability of form metrics, built-footprint more than quintupled in size from 1941 to the present day. Its largest growth occurred between 1941 and 1963, during which time it tripled in size to a little over half of what it is today. From 1963 onward, it grew at a relatively steady pace, annexing and developing land on a regular basis (Figure 10). Today the historical built extent is about 32.4 km^2 (Figure 11).

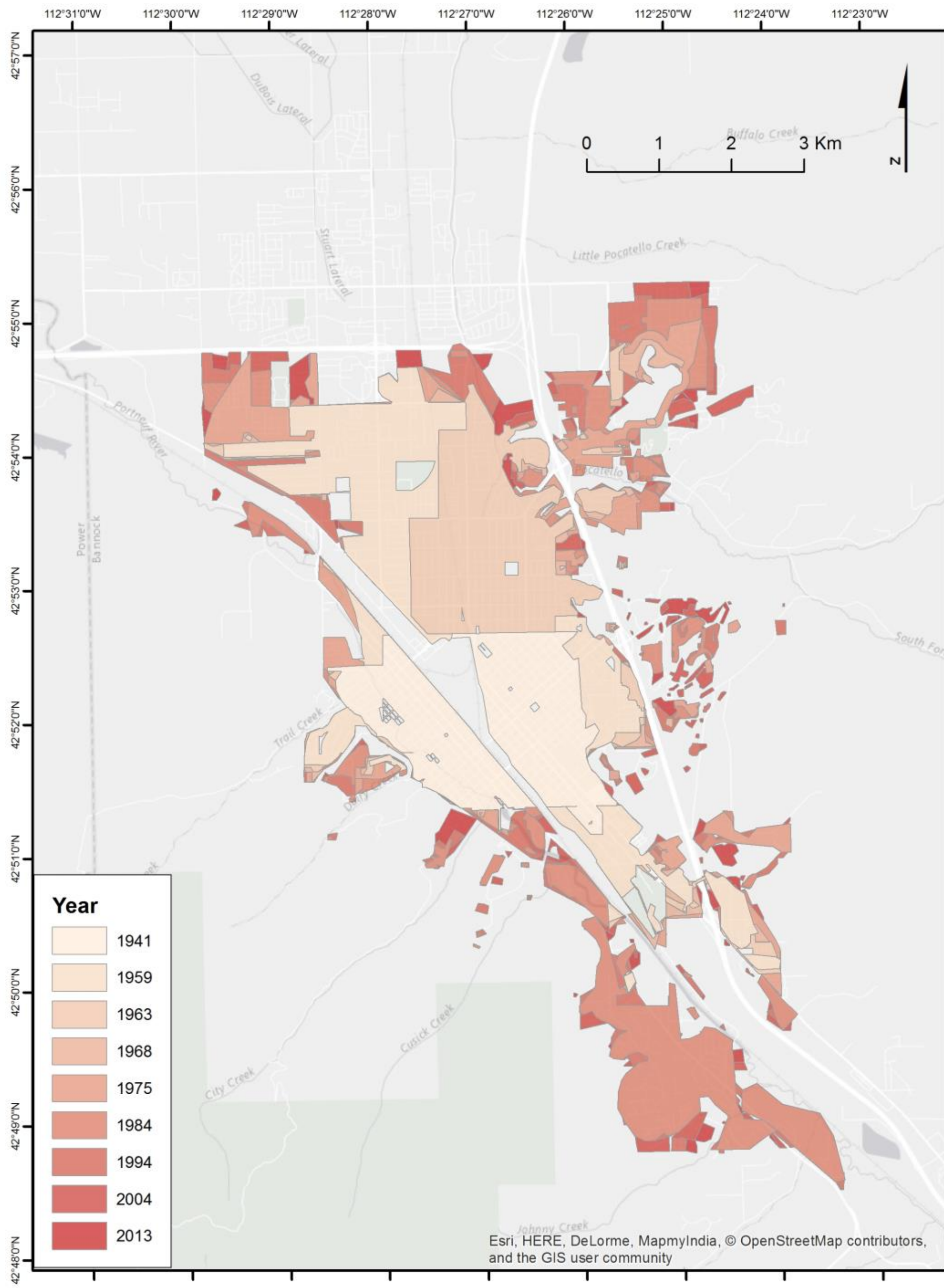

Figure 10. Pocatello Development 1941 to 2013. Light to dark shading indicates gradual development as the decades progress.

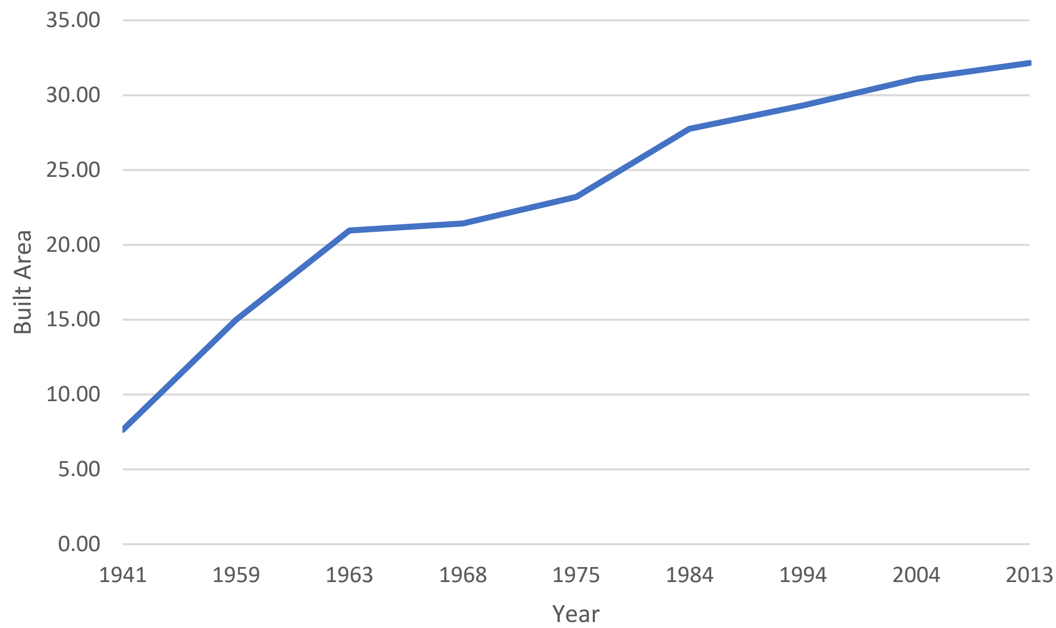

Figure 11. Built area of Pocatello in km². Through successive annexations of expanding development, the city of Pocatello has quintupled in size since 1941.

The change in city population and number of people per household differ dramatically. Pocatello's population increased linearly throughout the course of its history. However, people per household was highest in the first image year, 1941, and was 4.6; following the Second World War, a drop of approximately 1/3 occurred from its height of 4.6 in 1941, down to 3.1 by 1959. People per household continued to drop reliably at every data point from 1959 forward reaching its lowest in 2013 at just barely over 2.6 people per household (Figure 12).

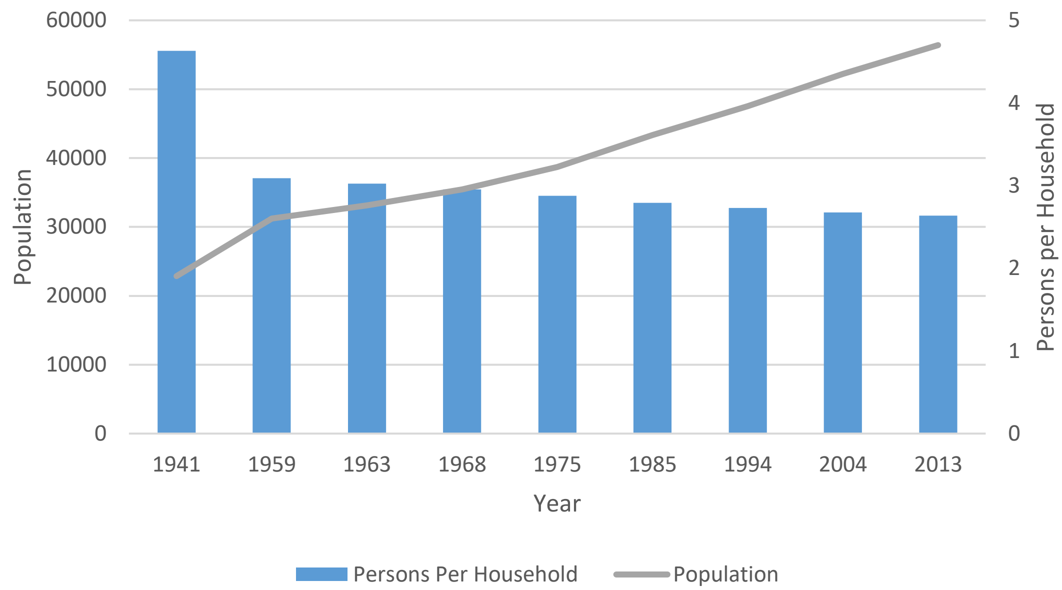

Figure 12. Displayed above are the persons per household and total population for Pocatello, ID 1892 – 2013. A trend of increasing population, illustrated by the line, and decreasing people per household, indicates more people living in smaller households.

When I analyzed population and household density per square km, a peak in density appears in 1941 with 2,994 persons per km^2 with a decrease of nearly 50% to 1580 per km^2 by 1963. This drop is particularly apparent in population density. The changes occurring in urban form nearly cuts population density in half. After 1963, both statistics oscillated slightly but stayed relatively stable.

A useful way of showing comparative change within the data is to standardize and scale the city's scores through time. Population density and people per household peaked in 1941 with values much higher than the average observed through time. Household density peaked in 1959, which is important to note because this was the post war boom period known for rapid urban expansion. However, 1963 overall scores were lower than the present day in both population and household density, largely due to the annexation of land not yet urbanized. Household and population density reached their lowest in 1984 with values of 76 and 84. Remarkably, household density has risen to 117 today, though population density is still below average. This is particularly due to a record low currently in persons per household.

Other global analyses at the city level relied on measuring the form of the city, rather than the density of individuals within. Fragmentation, or shape index, was measured by the ratio of the minor to the major axis of the directional ellipsoid for the city (Alexander et al., 2011), and showed that the city had the least fragmented development in 1941 with an index of .75. The optimal value is 1. By 1959 annexation and development along the valley led to a drop to .48, follow by a subsequent rise to .60 by 1968. By 1984 it dropped to .56, the value it has remained since.

When comparing the convex hull of the city's area to the actual built area, values peaked in 1941 also with a value of .87 with 1963 having the second highest value of .65. For subsequent years, values have remained in the mid .40s. This indicates significant concavity in various parts of the city (Table 3).

Table 3. Global metrics for Pocatello, ID (1941-2013)

Year	Household Density	Population Density	Persons per Household	Compactness	Fragmentation
1941	646.72	2993.89	4.63	0.87	0.75
1959	674.37	2083.94	3.09	0.52	0.48
1963	522.49	1580.35	3.02	0.65	0.49
1968	559.42	1653.39	2.96	0.47	0.60
1975	579.64	1667.52	2.88	0.48	0.59
1984	560.00	1562.42	2.79	0.45	0.56
1994	594.45	1622.68	2.73	0.45	0.56
2004	627.41	1679.18	2.68	0.45	0.56
2013	665.24	1754.37	2.64	0.46	0.56

Local Analysis (Pocatello through Time 1941-2013)

Development density within Pocatello fell approximately 15 percent from 1941 to 1968 (Table 4). By 1984, it had fallen another 9.5 percent before rebounding slightly. Though it has oscillated thereafter, it has failed to reach density of the level in 1968 and before.

Connectivity has fallen from 1941 to 2013 a total of 44.6 percent (Table 4). Its largest decline was between 1941 and 1959, in which it fell a total of 25.5 percent, as old town Pocatello grew in area noticeably for the first time since its founding. By 1963, the connectivity of Pocatello dropped an additional 10 percent. Drops in connectivity continued but were no longer as great, with the greatest drops between 1975 and 1984 and between 2004 and 2013 decreasing connectivity by 7 and 6 percent, respectively.

Centrality around the core has also decreased with greater dispersion from the core. Centrality was greatest in 1941 at 0.25, and subsequently decreased to 0.19. It has oscillated with annexations and infilling through the years but has hovered between 0.17 and 0.19.

Analysis showed features were most clustered for Pocatello in 1941 and 1959, thereafter features became more dispersed from one another as a dense core gave way to that were incorporated into the city. Below the chart shows how an increase in grid count is accompanied by dispersion (Table 4).

Table 4. Local metrics for Pocatello, ID (1941-2013)

	Grid Count	**Clustering**	**Developed Parcel Density**	**Connectivity**	**Centrality**
1941	55	0.80	711.25	310.97	0.25
1959	131	0.83	569.32	231.59	0.19
1963	185	2.82	605.36	209.10	0.18
1968	195	3.53	608.50	206.96	0.17
1975	226	2.12	556.32	205.48	0.19
1984	313	5.81	541.03	191.57	0.17
1994	325	1.94	537.28	187.69	0.18
2004	342	3.81	540.02	176.10	0.18
2013	347	2.58	540.02	172.21	0.19

Global Analysis (Pocatello/Chubbuck, Idaho Falls, and Coeur d'Alene)

Persons per household had very little variation between the three cities with values ranging from 2.59 (Coeur d'Alene) to 2.83 (Idaho Falls). Pocatello/Chubbuck had 984 persons per km^2, whereas Coeur d'Alene had 1032 and Idaho Falls 948. Household density had similar proportions in density because of the limited range of the persons per household. Density within homes varied little between the cities, however, households and population density was quite different with Coeur d'Alene nearly 15% and 20% less dense in the latter metrics. Pocatello/Chubbuck and Coeur d'Alene had nearly identical shape indexes scoring .46, though Idaho Falls had an index approximately 40% higher, .65, indicating the distribution of features within Idaho Falls are closer to circularly dispersed than linearly (Figure 13).

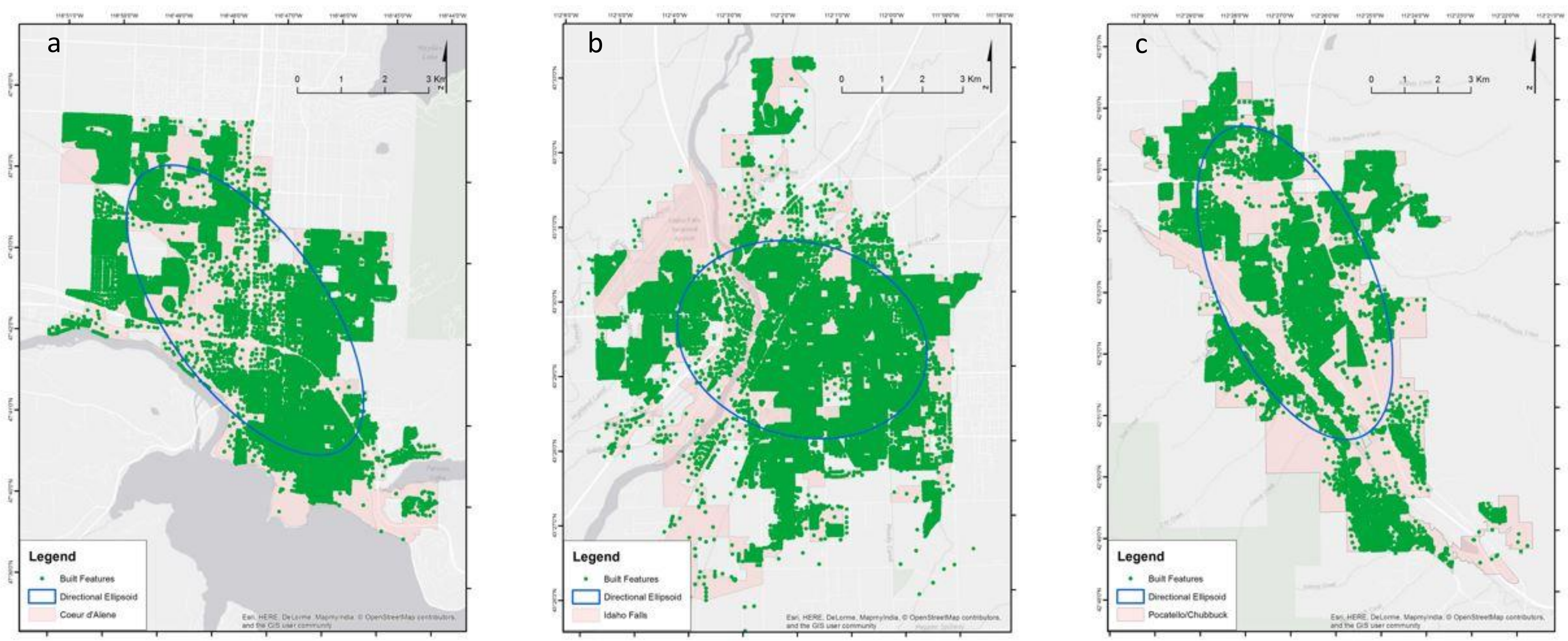

Figure 13. Fragmentation of a. Coeur d'Alene, b. Idaho Falls, and c. Pocatello-Chubbuck indicated by the major and minor axes of the ellipses

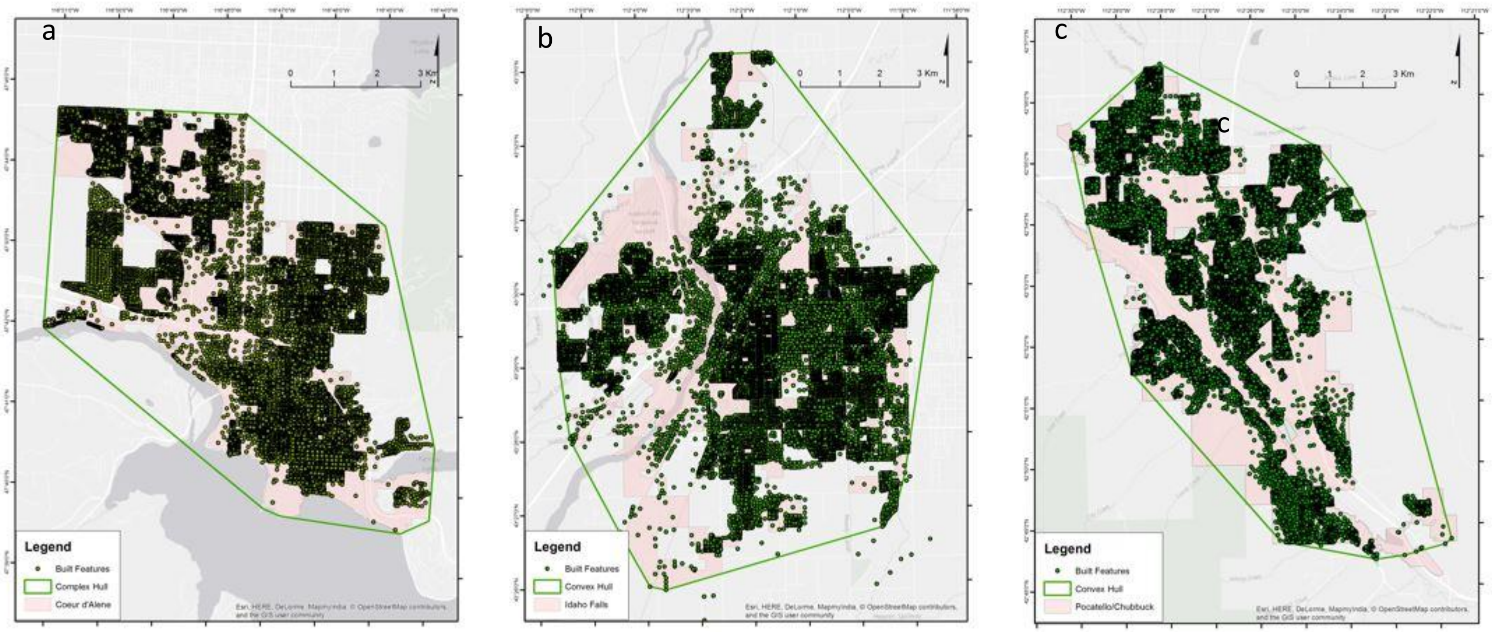

Figure 14. Compactness of a. Coeur d' Alene b. Idaho Falls, and c. Pocatello/Chubbuck using built area compared to the convex hull of the city's polygon.

Coeur d’Alene scored higher on the convex hull to built extent metric (Figure 14) than it did on its shape index. Its convex hull to built extent value was 0.65, Idaho Falls scored 0.62, and Pocatello/Chubbuck scored 0.64 (Table 5).

Table 5. Global Analysis of Coeur d'Alene, Idaho Falls, and Pocatello/Chubbuck

Study Area	Household Density (households per m^2)	Population Density	People per Household	Compactness	Fragmentation
Coeur d'Alene	303.34	785.36	2.59	0.65	0.46
Idaho Falls	365.36	1,032.40	2.83	0.62	0.76
Pocatello Chubbuck	348.33	948.44	2.72	0.64	0.47

Local Analysis (Coeur d’Alene, Idaho Falls, and Pocatello/Chubbuck)

From parcel and structure data counts of developed parcels revealed a density of development within each grid. Combined the three study areas produced 1082 grids with a total of 76,158 developments between them.

Coeur d’ Alene had the greatest development density, and scored 9.5 percent greater than Idaho Falls and 7.2 percent greater than the Pocatello/Chubbuck area. Coeur d’Alene had the greatest connectivity as well. It had 16.45 percent greater connectivity than Idaho Falls and 20.3 percent greater connectivity than Pocatello (Figure 15). When examining clustering, values were weighted by grid area and not feature count (Figure 16). Coeur d’Alene had a 0.41 value, Idaho Falls had a 0.53, and Pocatello/Chubbuck 2.38 (Figure 17).

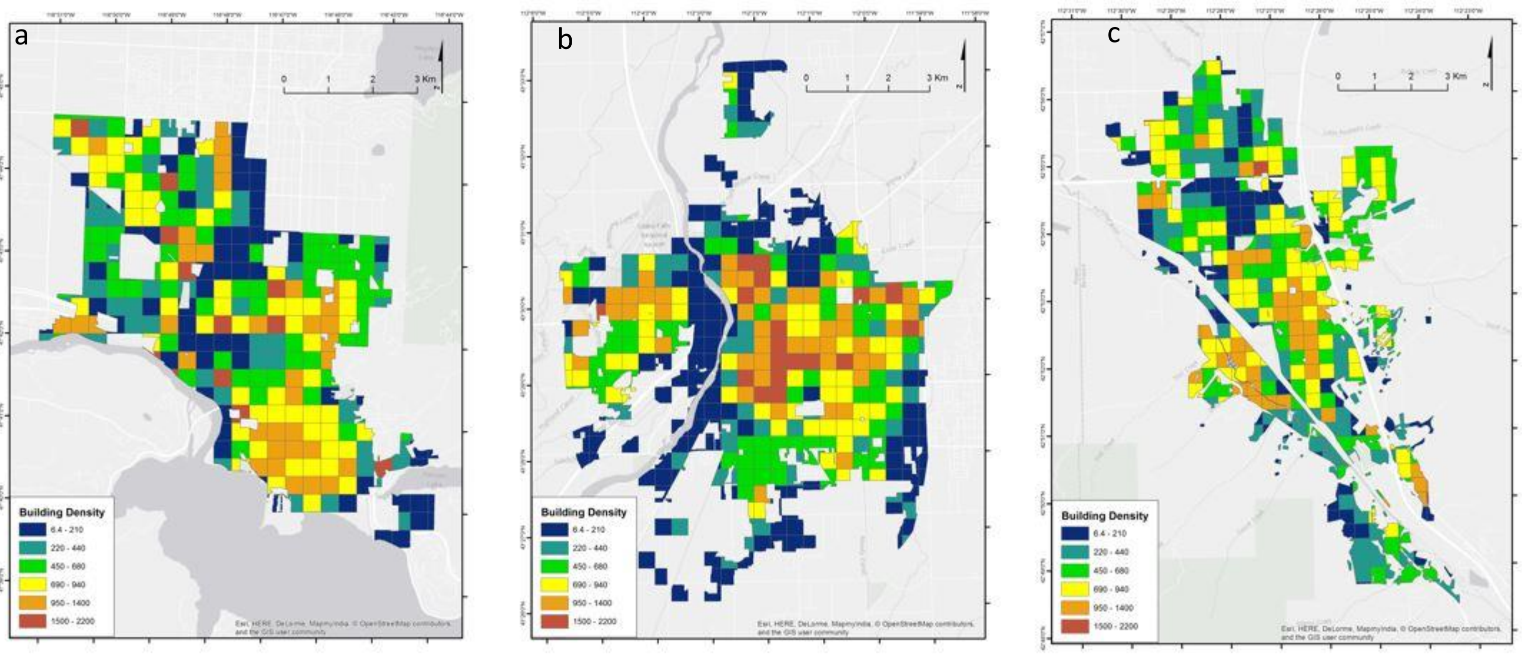

Figure 15. Development Density across a. Coeur d’Alene, b. Idaho Falls, c. Pocatello/Chubbuck

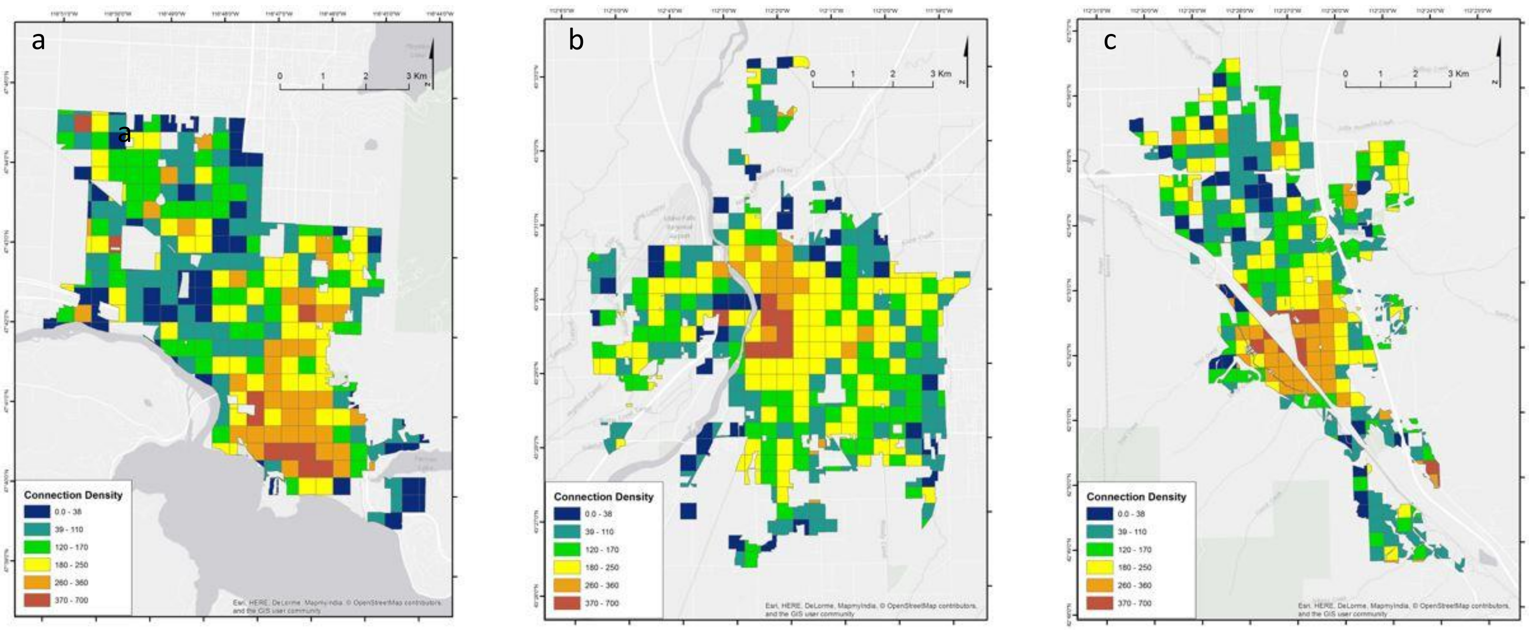

Figure 16. Connectivity across the three study areas as measured by connection density for a. Coeur d'Alene, b. Idaho Falls, and c. Pocatello/Chubbuck.

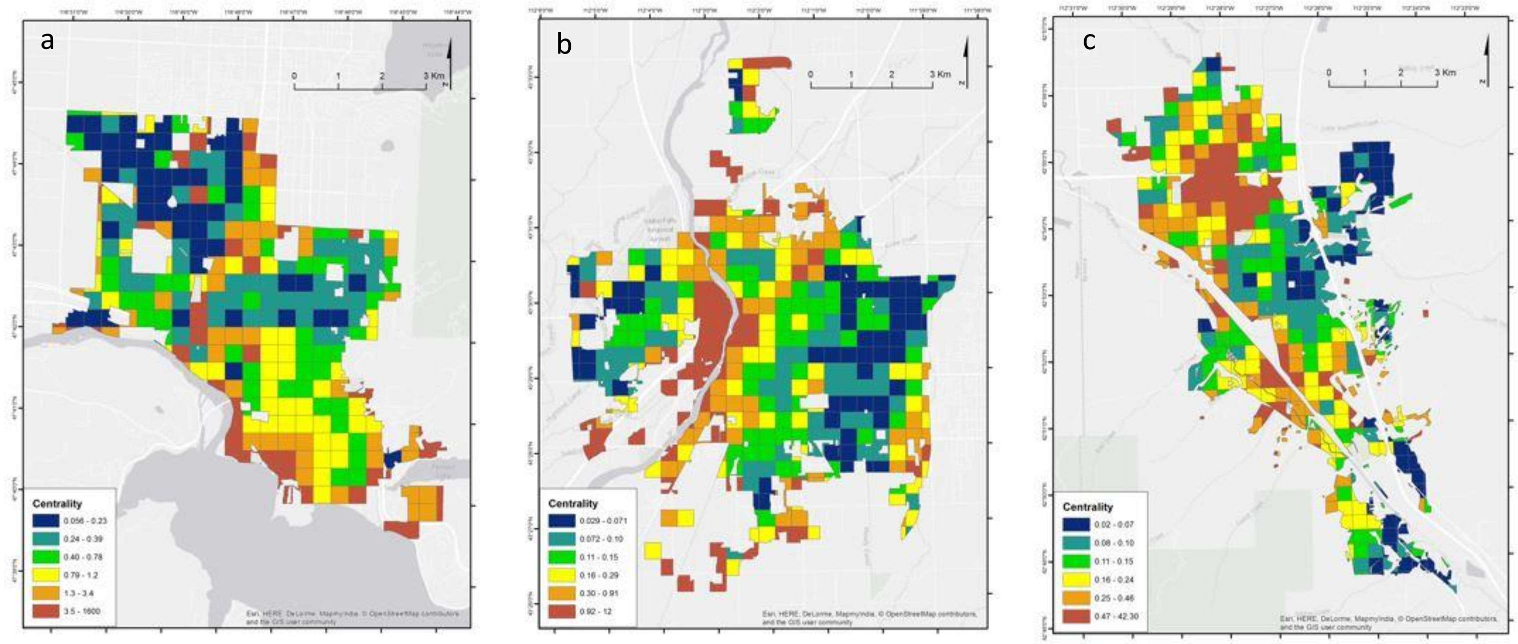

Figure 17. Depicted here is centrality, for a. Coeur d’Alene, b. Idaho Falls, and c. Pocatello/Chubbuck.

For Centrality, Coeur d'Alene had the lowest score at 0.21 followed by Pocatello/Chubbuck (2.9), and Idaho Falls (3.4). Centrality's weighting yields outcomes where lower values equal greater sprawl. Therefore, Idaho Falls was least sprawled followed by Pocatello/Chubbuck and then Coeur d'Alene (Table 6).

Table 6. Local metrics for Coeur d'Alene, Idaho Falls, and Pocatello/Chubbuck areas

Cities	Grid Count	Clustering	Developed Parcel Density	Connectivity	Centrality	Mixed Use
Coeur d'Alene	290	0.41	576.63	143.19	0.21	5.39
Idaho Falls	375	0.53	526.40	122.96	0.34	5.18
Pocatello/ Chubbuck	417	2.38	537.76	118.22	0.29	5.71

Final Scores

Both global and local metrics indicate that Pocatello was at its least sprawled in 1941. In total, the global index had a score 54 points above the mean (Table 7). All sub-indices indicate 1941 scored over 50 points higher than global variables except household density, with which scored over 25. The last year in which global index scores are higher than the mean is 1959 with the lowest scores occurring in 1984 (Figure 18).

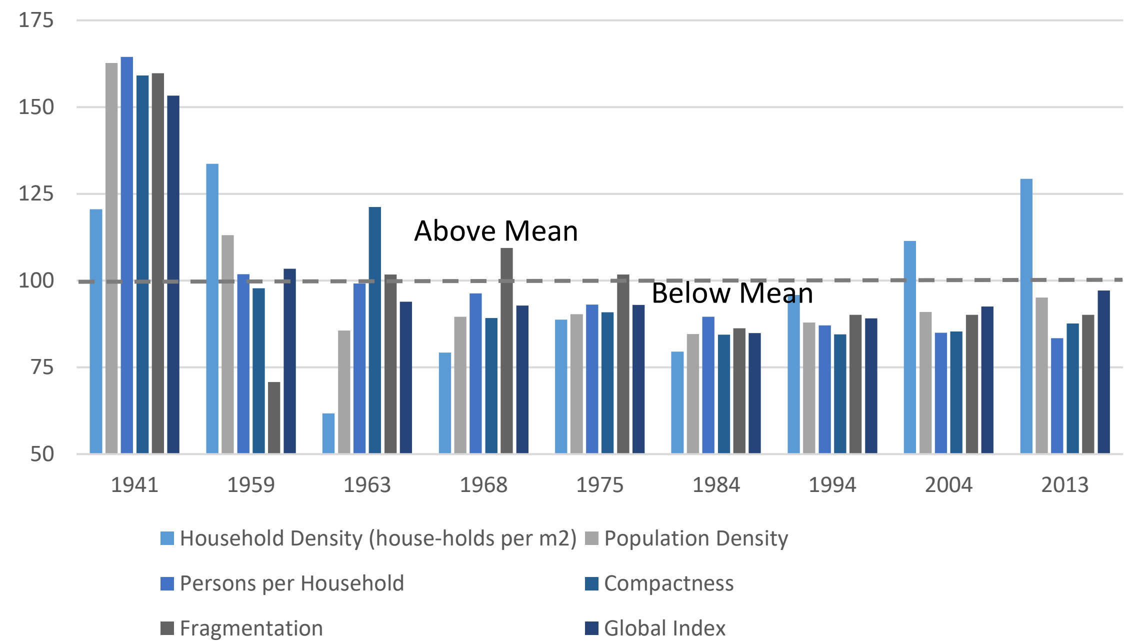

Figure 18. Global metrics for Pocatello, ID (1941-2013) normalized and scaled

Table 7. Global metrics for Pocatello, ID (1941 - 2013) normalized and scaled

Year	Household Density (house-holds per m^{2})	Population Density	Persons per House-hold	Compactness	Fragmentation	Global Index
1941	120.55	162.72	164.49	159.09	159.74	153.32
1959	133.63	113.08	101.82	97.75	70.78	103.41
1963	61.75	85.61	99.15	121.24	101.72	93.89
1968	79.23	89.59	96.34	89.23	109.45	92.77
1975	88.80	90.36	93.13	90.84	101.72	92.97
1984	79.50	84.63	89.60	84.40	86.25	84.88
1994	95.81	87.92	87.14	84.50	90.12	89.10
2004	111.41	91.00	84.97	85.32	90.12	92.56
2013	129.31	95.10	83.37	87.62	90.12	97.10

Local index scores indicate Pocatello scored highest and was least sprawled in 1941 (Table 8). Its sprawl index value dropped from 153 to 103 within an 18-year time span in these two decades. It continued to drop reaching its low in 1984, mirroring the phenomenon seen in the global statistics reaching its low in both composite indices at this time. It recovered thereafter, but never to pre-1984 levels (Figure 19).

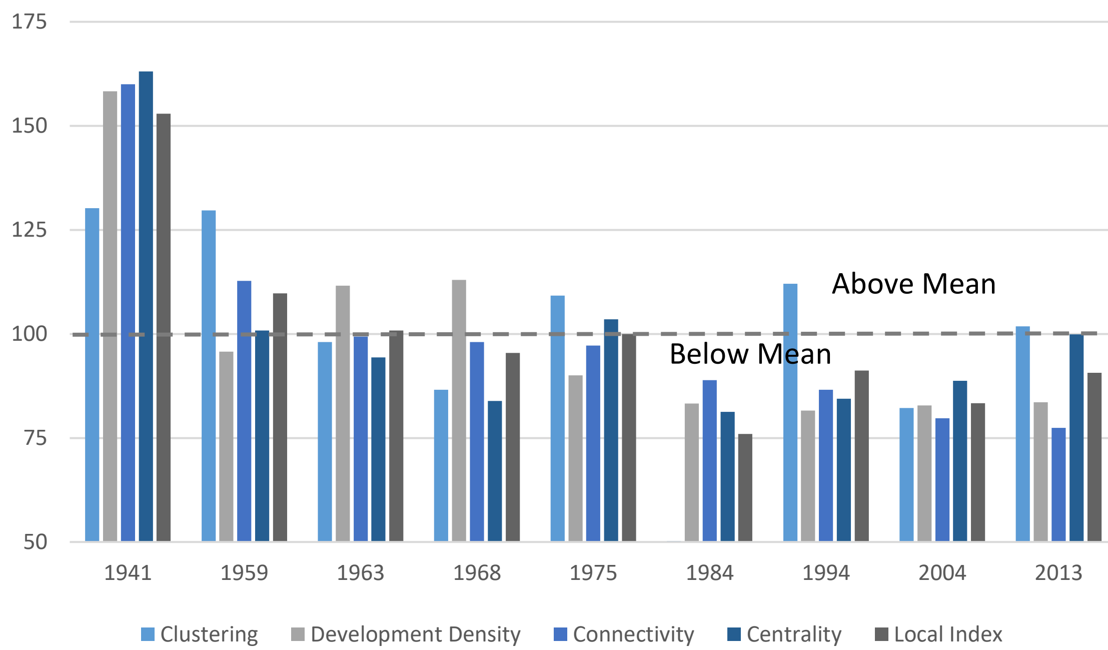

Figure 19. Local Metrics for Pocatello, ID (1941-2013) normalized and scaled

Table 8. Local Metrics for Pocatello, ID normalized and scaled

	Grid Count (unscaled)	Clustering	Development Density	Connectivity	Centrality	Local Index
1941	55	130.1814	158.28	160.00	163.06	152.88
1959	134	129.6863	95.74	112.74	100.79	109.74
1963	189	98.02668	111.62	99.36	94.38	100.85
1968	199	86.6169	113.01	98.08	83.89	95.40
1975	229	109.173	90.01	97.20	103.54	99.98
1984	316	50.24546	83.27	88.92	81.29	75.93
1994	328	112.06	81.62	86.61	84.40	91.17
2004	347	82.21055	82.83	79.71	88.76	83.38
2013	351	101.7997	83.61	77.39	99.89	90.67

Both global and local values were closer across sites than in the temporal analysis. Coeur d'Alene scored worse in every category except compactness than either of the other urban areas indicating it has the least infillable enclaves. Idaho Falls scored strongest in fragmentation, yet comparatively worst in compactness. This is because Idaho Falls has an inner configuration of houses that is quite circular, yet a few outliers that create infillable enclaves. Idaho Falls also has the highest population density, household density, persons per household (Figure 20). This indicates Idaho Falls to be densest in every population and household metric. The Pocatello-Chubbuck area scored average and near the mean (100) for every category (Table 9).

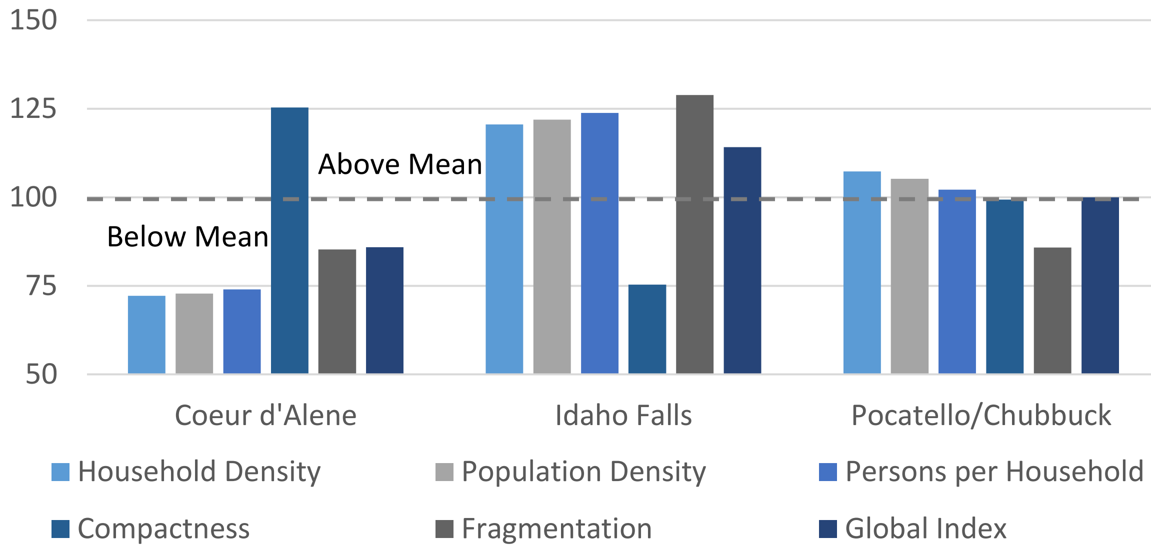

Figure 20. Global metrics for Coeur d'Alene, Idaho Falls, and Pocatello/Chubbuck areas normalized and scaled

Table 9. Global metrics for Coeur d'Alene, Idaho Falls, and Pocatello/Chubbuck areas normalized and scaled

Study Area	House-hold Density	Population Density	Persons per House-hold	Compact-ness	Fragmentation	Global Index
Coeur d'Alene	72.17	72.79	73.98	125.34	85.31	85.92
Idaho Falls	120.56	121.96	123.84	75.35	128.87	114.12
Pocatello/ Chubbuck	107.27	105.25	102.17	99.31	85.83	99.97

Local Index scores indicated more decisive scores on final index measures. Coeur d'Alene had above average nearest neighbor scores, development density, and connectivity higher than the mean, yet centrality and mixed use values lower than the mean (Figure 21). The poor centrality scores are due to city growth being one-directional due to the bounding lake to the south on which the CBD was adjacent. High connectivity was due to smaller blocks. Pocatello/Chubbuck had the greatest mixed use values, while Idaho Falls led in centrality. Overall, Coeur d'Alene had the highest composite local index score, followed by Idaho Falls, and finally the Pocatello/Chubbuck area (Table 10).

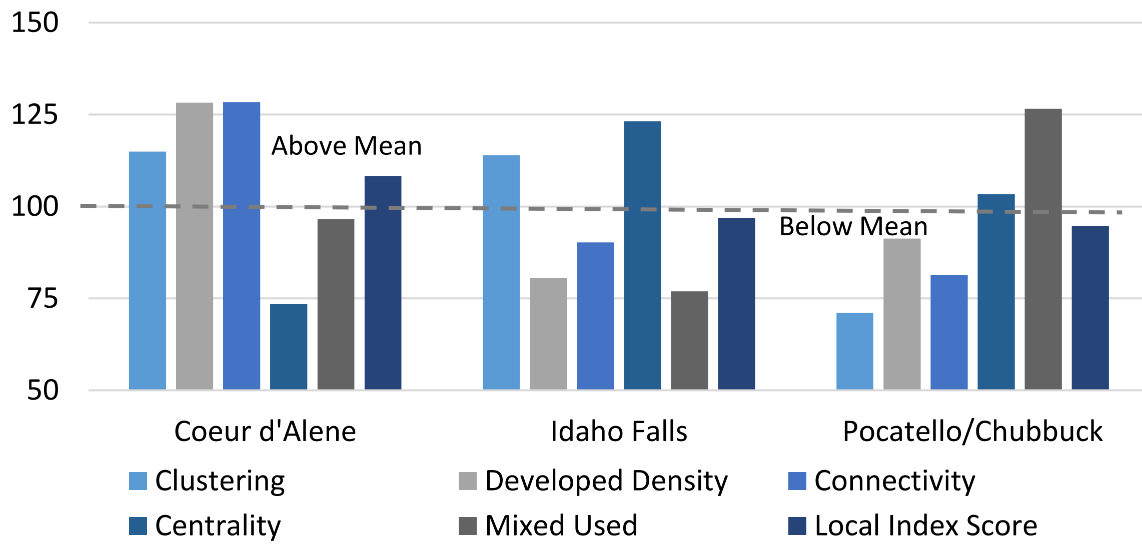

Figure 21. Local metrics for Coeur d'Alene Idaho Falls and Pocatello/Chubbuck areas normalized and scaled

Table 10. Local metrics for Coeur d'Alene, Idaho Falls, and Pocatello/Chubbuck areas normalized and scaled

Cities	Clustering	Developed Parcel Density	Connectivity	Centrality	Mixed Use	Local Index
Coeur d'Alene	114.90	128.19	128.40	73.49	96.57	108.31
Idaho Falls	113.96	80.51	90.27	123.15	76.89	96.96
Pocatello/ Chubbuck	71.14	91.30	81.33	103.35	126.54	94.73

Discussion

Previous studies have concentrated on these Idaho areas on a county-wide level and aggregated variables in different ways. One example is Smart Growth America's 2014 analysis of Idaho counties. Smart Growth America had four main categories for sprawl variables, consisting of density (percentage of population living in suburban low-density tracts, percentage living in medium to high density tract, density within built areas), land use, activity centering, and street accessibility.

The local analysis here contains the same elements as Smart Growth, adds an additional clustering category (Figure 22), has a similar scoring mechanism, and has much greater resolution more applicable to small and mid-sized cities. The resolution used here for the local analysis is less than a half of a square km, whereas the global approach analyzes the city footprint, structures, and overall population within a city, rather than county or metropolitan level. Herein, lies the comparative strength of this algorithmic toolset.

Smart Growth America's 2014 county wide analysis showed a substantial difference in index values for the counties. To compare Smart Growth America's county results to city results clustering was removed before indexing. (Table 11). The final index values were the same for the local county level analysis as the Smart Growth analysis (Smart Growth America, 2014).

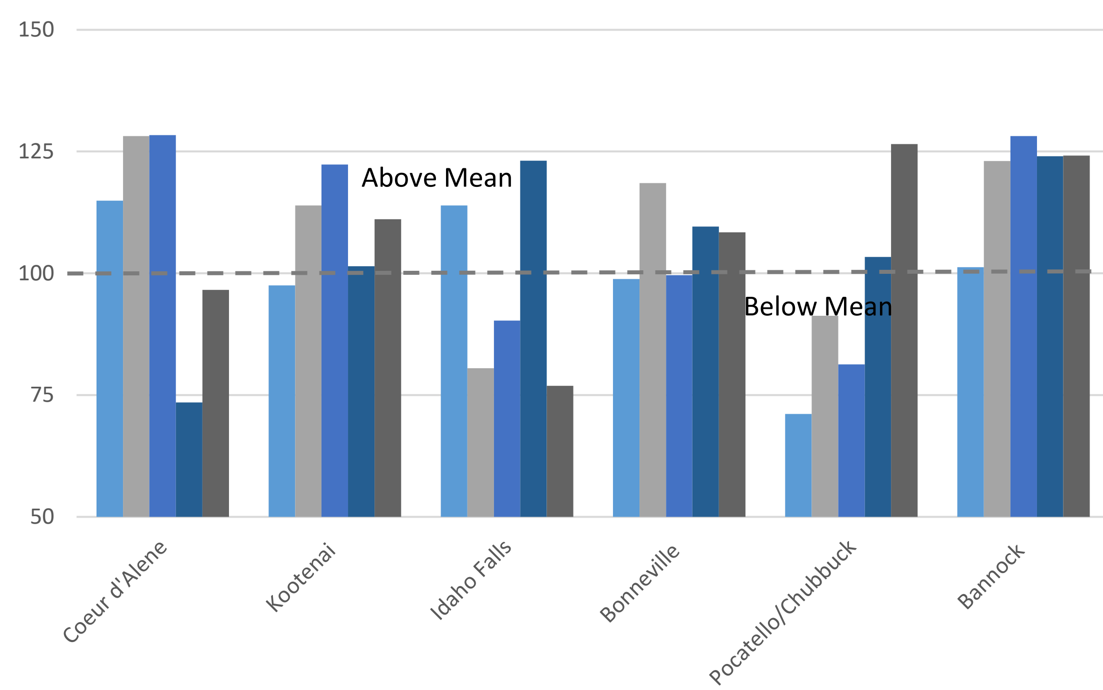

Figure 22. Smart Growth America's sprawl scores by county compared to city

Table 11. Smart Growth America's sprawl scores by county compared to city

County	Density	Land use mix	Activity Centering	Connectivity	Index
Bannock (Pocatello/Chubbuck)	101.28	123.06	128.18	124.04	124.18
Pocatello/Chubbuck	91.30	126.54	103.35	81.33	100.63
Bonneville (Idaho Falls)	98.84	118.52	99.62	109.57	108.39
Idaho Falls	80.51	76.89	123.15	90.27	92.71
Kootenai (Coeur d'Alene	97.55	113.96	122.32	101.44	111.14
Coeur d'Alene	128.19	96.57	73.49	81.33	94.90

Here, different methods for sprawl analysis produced results indicating each city was more sustainable in some respects, less in others, and had greater resolution than Smart Growth's County-wide analysis. Main differences in the algorithms were: 1) whether they were global (census density measures, compactness, and fragmentation) or local (grid analysis methods), 2) whether they rewarded concentration near the core (centrality and shape index) or punished isolated outliers (grid nearest neighbor and compactness), and 3) whether the algorithm weighted for the count per grid (connectivity, development density, and centrality). Average nearest neighbor values when comparing grids without weighting the variable for the features is useful because it indicates efficient or inefficient growth at the periphery. Often services must be provided (e.g., water, sewer, roads, fire, rescue), which increases costs to isolated peripheral areas. Methodologically weighting for feature count per grid might bring nearest neighbor values closer together, however, algorithms that illuminate low density development are imperative for sprawl and sustainable cities research. The Pocatello-Chubbuck area, for example, had only a half meter difference in nearest neighbor value than Coeur d'Alene and scored nearly half a meter better than Idaho Falls. On a grid level, Pocatello-Chubbuck and Idaho Falls both averaged five meters more than Coeur d'Alene. This indicates both cities had outlying, sparsely developed areas which could potentially be costly for a city to service per capita. This became evident in the clustering values for the Pocatello/Chubbuck area, 71.1 compared to Idaho Falls, 114.0, and Coeur d'Alene, 114.9.

A global analysis comparing an area's built extent to its convex hull is similarly useful to grid analysis using nearest neighbor because they punish outliers, one on a local (average nearest neighbor) and one on a global (area of convex hull versus built extent). Convex hull analysis has been applied to least cost path analysis to figure the most efficient way to traverse data points. Here, its use in enclave analysis avoids the problem posed by measuring the area to perimeter ratios that change depending on the method of measurement and fractal scale. Because of the increased distances a city must service, quantifying the paths between the edges of development versus the cities area shows infill-able areas, which let planners and stakeholders know what needs developing and what type of growth has added superfluous length to areas the city must service.

Pocatello-Chubbuck scored highest in compactness (convex hull to built extent ratio). This indicates Pocatello-Chubbuck had few enclaves, likely a result of the physiographic boundaries. Measuring compactness has previously been accomplished by area to perimeter ratios of a city's built up area with the ideal form that of a circle (Frenkel & Ashkenazi, 2008); this punishes cities whose growth is physiographically limited and cannot possibly grow in a radial form. This method also avoids the dilemma of fractal dimension of measurement.

Grid Analysis is useful because grid resolution can be adjusted appropriate to the scale of city or metropolitan area being studied and the data available. Galster (2001; 2005) used 1 mile by 1 mile units, while analyzing metropolitan areas across the United States in conjunction with census. In this study, mid-sized cities were used. To avoid edge effects a smaller grid was employed. Four hundred and two meters was chosen for its high spatial autocorrelation with the smallest extent analyzed within the study. Also, grid cells here were clipped to the developed extent of the city, and statistics calculated by normalizing the remaining clipped grid cells.

Grid analysis allows comparison across the city, one area can be compared to another, and between cities. For example, Galster (2001) compared cities' densities, and those who had over 2 standard deviations over Galster's entire United States M.S.A. aggregation were considered grid squares of concentration. The use of grid squares can create an adequate number of samples between and within cities so statistical analysis can be performed in greater detail. These grids can be represented cartographically to show differences on a local level.

Global measures for a city or metropolitan area are indispensable for understanding sprawl as well because grid units are not separate entities capable of self-sustenance, rather they are linked to the greater developed area physically, economically, socially, infrastructural, and municipally. Local measures based on a grid can indicate what parts of a city are more isolated and less sustainable, while global indices such as fragmentation indicate aspects of a city's sustainability. Galster's (2001) grid analysis compartmentalized sprawl into six dimensions: density, concentration, clustering, centrality, nuclearity, and proximity. Here clustering, centrality, connectivity, mixed use, and development density are used. Several of these overlap with Galster's analysis, yet some like mixed use and connectivity provide a different perspective on sprawl. Some aspects of a city are not suited to grid analysis, such as, compactness (enclave analysis) and fragmentation (shape index). Here they are captured on a global level.

The results of this case study reflect trends occurring nationwide, though in some periods, the city charted its own course. In Pocatello's early days, planners arranged the city with a street grid built systematically, while leaving many parcels fallow or vacant. From 1893 to 1941, population and household numbers within the city increased as the vacant lots were developed. Pocatello's enumerated boundaries grew by little more than half a square km, approximately 13%, in its first fifty years, though the population grew over 600% in this same time. The infill of the city caused a peak in population density and persons per household in 1941, a milestone for the city with household density peaking in 1959. Though households-per-unit-area decreased from a peak by more than 50%, the decrease in persons-per-household experienced a pronounced drop: 4.6% in 1941 and 2.6% in 2013. Decreased density within households is not necessarily an indicator of unsustainable development. In fact, Jacobs (Jacobs, 1961) drew a difference between high density and overcrowding to illustrate this point: "High densities mean large numbers of dwellings per acre land. Overcrowding means too many people in a dwelling for the number of rooms it contains" (p. 205). However, the 50% drop in households per acre shows a shift within the city's boundaries toward a less sustainable form using this metric.

The 43% drop in persons-per household also corresponded to a noticeably larger increase in house size over this period. Fewer people living in larger homes has created a domestic situation representative of a larger phenomenon at the national level.

Persons-per-household have decreased similarly over time across the U.S. In 1940, the average U.S. household was composed of 4.18 members, and had dipped to 3.07, by 2000 (Salcedo, Schoellman, & Terlitt, 2009). A factor at work is a divorce rate that has increased from 4 in 1,000 around the time of the founding of Pocatello to approximately 10 per 1,000 in 1941. In 2008, the divorce rate was 23 per 1,000. Correspondingly, the marriage rate has decreased from 211 per 1,000 single females in 1950 to only 82 by the year 2000. Greenwood and Guner (2008) proposed that sociological changes, such as married women's changing economic roles as wage earners are associated with this phenomena. Pocatello illustrates a larger phenomenon of decreasing household size nationwide as housing size and families changed over the time studied.

Coeur d' Alene and Idaho Falls had comparable scores in persons per household. However, population and household per unit area were much less dense. While persons-per-household have decreased each year, the average house size has increased since 1941 for Pocatello. The average house size was approximately 141 m^2 in 1941 and dipped to its lowest, 131 m^2, around 1963, which was shortly after the annexation of the neighboring town of Alameda. Since that year, the area of the average building has increased for every year analyzed, peaking in 2013 (average building size was approximately 166 m^2). This decrease in household size, concurrent with increases in building size, could represent the suburban phenomena of elites and non-elites wishing to be perceived as having greater affluence with large houses serving as status symbols in the newly built neighborhoods, phenomena common to other suburban developments nationally (Chase-Dunn & Kwon, 2011).

The marked decrease in centrality in Pocatello illustrates growth away from the core in an uneven fashion. Two factors contributed to the decreases in previously mentioned metrics (e.g. connectivity, density, and clustering): (1) the natural physiographic layout, which limits natural circular expansion (Harari, 2016) and (2) the location and type of neighborhood developed. The city and its planners can do little about the first factor. However, disconnected, winding, and fragmented residential suburbs in the north part of the city make commuting for residents a necessity; these characteristics are hallmarks of sprawl and an inefficient and unsustainable urban form. The change in the cities' clustering scores reflects this change. According to Forman (2014), "large single-use rather than mixed-use residential areas, auto dependence by residents, loss of farmland, loss of natural habitat, fragmented disconnected land" (p.79) characterize sprawl. The development of northern Pocatello, Johnny Creek, Mink Creek and other developments share these characteristics. Areas that were farmland or natural habitat now have large residential areas that make commuting much more of a necessity compared to the historic Pocatello downtown (Old Town) district. These developments have shifted the centroid of Pocatello further northward as time progressed to the point that the center of Pocatello is no longer located within the original city boundaries, but rather Alameda, a city it merged with in 1962 (Figure 12). These newer developments lack the mix of amenities, businesses, and housing that the old city contained, such as pedestrian connectivity from residences to the historical Old Town urban core.

Jacobs (Jacobs, 1961) stressed the need for small blocks to enhance greater exposure to more businesses, people, and varied pathways. Krizek (2003) stressed how small blocks led to less commuting and greater pedestrian and bicycling activity. Old Town Pocatello was constructed in just this fashion, as indicated by higher street connection density values (indicative of smaller blocks). The contemporarily built larger blocks of Alameda and, much later, suburbs with even larger irregular blocks create a lower mean street connection density value indicating larger blocks within the city. This trend needs to change if a sustainable and vibrant urban form with varied opportunities for pedestrians and bicyclists is to emerge. Continued development of large irregular suburban blocks leads to decreased physical activity, pedestrian activity, and bicycling, while it relegates people to longer commutes and greater reliance on automobiles, contributing to poor health outcomes (Saelens, Frank, & Behav, 2003). A vibrant, lively city requires greater intersection density than has been the trend in recent years. One phenomenon is that once streets are constructed and houses built the on the ground, the spatial configuration is unlikely to change. Comparing maps and metrics, such as intersection density, of the original Pocatello town site from 1892 to today shows that the block and street layout of old town has changed very little. When looking at an inefficient and unsustainable trend in urban form and growth in Pocatello, this phenomenon can be problematic due to the resources and capital needed to redevelop an area in a more sustainable manner. For this reason, it is important that future growth incorporate small dense blocks, rather than large or irregularly shaped blocks typical of today's suburbs.

It is important to note that this case study analyzed the urban form within the enumeration boundaries. Since the 1950's, Pocatello aggressively annexed land that was then developed or annexed neighborhoods soon after they were developed. However, the past decade has seen smaller, less frequent annexations, as practical concerns of providing services farther from the core become an issue. The greater metropolitan area of Pocatello contains fragmented neighborhoods built on the slopes of Pocatello's southwestern and northeastern benches. The city has not annexed or extended the urban services boundary, due to the prohibitive costs and low density of these developments. A larger analysis of the metropolitan area using different built extents, census data, and dasymetric mapping techniques would present a different picture for the metropolitan area. Future analyses of the larger area might also enable stakeholders, from taxpayers to planners to decision makers, with supplemental data to make important decisions, such as whether to annex or not.

These Sustainability of Form GIS tools available for download from Github (https://github.com/delparte/UrbanForm.git) in the form of a stand-alone Python script and an ArcGIS toolbox so that planners may be able to use the data they have on hand to analyze their own cities. The resulting data can inform stakeholders, allowing them to make decisions on how they can grow in a more sustainable fashion. Additionally, cross-city comparisons with readily available data will provide an online dataset where planners can judge their cities' scores against others. Rather than relying solely on overall score, analyzing the sub-scores is highly important when interpreting results and giving information to decision-makers for feedback.

Conclusion

One of the advantages of this algorithmic analysis methodology is that it utilizes data readily available to most municipalities and gives an individual breakdown of various facets of a city's form. Building footprints are often available from local municipalities, while satellite data can show the overall layout of a city. This enables individuals to derive built extent polygons from nationally available NAIP imagery, satellite imagery, or even the image library available within Google Earth Pro for worldwide coverage. Population data, available from sources such as the national census, is free to access. Planners and local stakeholders can make decisions on how to improve their city population density in a sustainable fashion. When time series data is available for a city's footprint, trends and growth trajectories are discernible, which enables analysis of comparative changes in form and density.

Another use of this algorithm is that it does not necessarily have to be time series analysis of one series, as it was for Pocatello in this study. A city's various metrics can be indexed to another's to see comparable statistics for different categories. This is illustrated through the processing and statistical comparison of the Pocatello/Chubbuck area with two other mid-sized cities in the state Coeur d'Alene and Idaho Falls. An interactive global and local comparison map can be found at http://www2.cose.isu.edu/~oglejare/Urban_Form/City_Comparison.html.

Utilizing urban sustainability of form metrics to analyze various aspects of cities' density, clustering, fragmentation, centrality, compactness, and connectivity, over time and indexing it to present day values effectively demonstrates how Pocatello has changed and the tools presented in this case study can yield concrete metrics to inform plans for urban sustainability. Planners can see trajectories of historic change and try to correct course toward a more sustainable future using this methodology. Planners cannot mandate sustainable living arrangements; however, they do have options. These could include choosing whether to develop multi-family dwelling units, integrating mixed-use zoning practices, or building vertically to take advantage of precious space. Pocatello has grown outward, taking little initiative to increase density. In Pocatello and the adjacent area, developable space is becoming limited because of the physiographic barriers surrounding the city. The cross-site comparison indicates that different cities have achieved more sustainable forms depending on the index and sub-indices examined. No one city outperforms all others across all indices, so they all have room for improvement. To allow for future growth, a sustainable urban form that is as compact as physiographic boundaries will allow a more connected city as measured by street connection density, which can be accomplished with smaller adjacent blocks, more clustering between structures and around the core that could be accomplished through infill and smaller parcel zoning, and increased density through more multi-family housing.

CHAPTER FOUR. MODELING RIPARIAN HABITAT CHANGE ALONG THE PORTNEUF RIVER

Introduction

Riparian zones are an important habitat because of the natural capital they contain and ecosystem services they provide. For example, in the western United States these areas provide habitat for one third of all total species, including 70% of all threatened or endangered species (Poff, Koestner, Neary, & Merritt, 2012), while only taking up between 1% and 2% of the land (Svejcar, 2016b). They also work to provide humanity with important ecosystem services, such as reducing nitrate and ammonia levels in rivers when flooded through the process of denitrification, while also protecting rivers from fertilizer and pesticides from farms or lawns (Svejcar, 2016a), and provide recreation services.

Human civilization is inextricably linked to the ecosystems within which it resides. The environmental context and ecosystem health determine the long-term sustainability of both nature and civilization. The ecosystem provides several types of basic needs, such as, supporting, provisioning, regulating, and cultural services. Provisioning services meet production needs from timber and fiber for goods, to food and water. Regulating services help control disease, water quality, and climate. Supporting services provide for basic underlying processes, such as formation of soil, nutrient cycling, and photosynthesis. Cultural services, such as recreation and aesthetic services, are important to the psychological health of civilization. Taken together, all of these are important in providing for human well-being (Millennium Ecosystem Assessment, 2005).

As a society it is important that these ecosystems services are used in a sustainable way, one in which society meets its needs without compromising future generations ability to meet theirs (World Commission on Environment and Development, 1987). To do this, estimates of how ecosystems change are needed. Previous studies, such as those by Costanza (Costanza et al., 2014b) and Nagy et al. (Nagy et al., 2012) estimate the ecosystem-wide changes among various habitats valuing one against another; such methodology is referred to as a natural capital index. Rather than looking at large biomes and judging one against another, this study aims to quantify riparian habitat loss, river change, and ecosystem service utilization in a riparian setting.

Research Questions and Hypotheses

Development of the city of Pocatello in the post-World War II boom and the channelization of the Portneuf River completed in 1968 have drastically changed the riparian land cover and its use. This is apparent from aerial photos taken from 1941 to today that show river straightening causing loss of meanders, some of which developers have subsequently filled in and developed over. While these changes tamed the river on its journey through Pocatello, important issues need addressing:

Research question 1. How has the river changed from its midcentury state to post channelization in 2013? With river shortening/straightening and installation of rip-rap the river length, ecosystem services are expected to have decreased.

Research question 2. Through a riparian land cover classification, how has the riparian land cover changed through time along the river? Riparian vegetation is expected to have decreased over time.

Study Area

Figure 23. Reaches along the Portneuf River: Northwest Pocatello, Concrete Channel, the Levee, and South Pocatello (source: Portneuf Vision Study Executive Summary, 2016).

The Portneuf River has changed through time and been heavily engineered to meet the needs of society. Prior to settlement by Western civilization, the Portneuf riparian corridor (Figure 23) was occupied by the Bannock and Shoshone tribes and was used for subsistence living (Franzen, 1983). Although the Portneuf was part of the tribes' reservation area, it was purchased by the Oregon Shortline railroad, tracks were laid by 1882, and mass provisioning of resources, such as coal and timber, from areas nearby (Wrigley, 1943), accompanied engineering of the fluvial environment. In addition to the early straightening of the river by the railroad, levee installation was followed by channel construction, finally completed in 1968 (Capurso et al., 2010). All of this led to a shortening of the river, change from natural river bank to compromised rip-rap, and introduction of uninhabitable concrete channelization. Today, the riparian ecosystem has been heavily compromised, with presumably much natural capital lost due to the needs of river engineering to allow for transportation of provisions along the adjacent railroad and flood prevention.

With recognition that the health of the riparian environment has been compromised and the need to balance immediate human needs for provisioning, regulating, supporting, as well as cultural services the City of Pocatello and US Army Corps of Engineers have embarked on a Portneuf Vision Study that aims to improve ecosystem services by restoring and protecting riparian ecosystems along the river while increasing recreation opportunities (US Army Corps of Engineers, 2016). Quantifying change in ecosystem services through time with proxies was one of the goals of this study. The results and data produced here can allow others to see the effects of river engineering on the Portneuf River and consider avenues for change.

Methodology

Four reaches were created along the Portneuf to analyze the change in natural capital over time. These stretched from Siphon Road to Fort Hall Mine Road. Data was created showing the state of the river and the adjacent vegetation. Within the study area, a time series analysis of over a century was created from before it was engineered by the railroad south of the city, prior to levee installation and channelization in the mid-20th century, up to the present day. Digitization of the Portneuf through time utilized various cartographic maps, aerial orthophotographs, and a proposed future scenario. Digitization of vegetation and levees were specifically confined to 1963 and 2013, just prior to levee installation and fifty years later with half meter resolution data (2013 NAIP). Within the riparian corridor, the Portneuf Vision Study's Executive Summary was utilized in conjunction with a high resolution DEM to estimate length once specific planned meanders had been restored (US Army Corps of Engineers, 2016).

Table 12. Proxies, study areas, and temporal frames

Ecosystem Service Proxy	Study Area	Temporal Frame
River Length	All reaches	Pre-Railroad – 2013
Sinuosity	All reaches	Pre-Railroad – 2013
Meander Amplitude	Levee Reach	1963 and 2013
Meander Count	Levee Reach	1963 and 2013
Riparian Vegetation	Levee Reach	1963 and 2013

River length and sinuosity were calculated for all reaches utilizing data across all time periods, including data prior to railroad installation, up until 2013. Sinuosity was calculated using a sinuosity index, or SI. This is the deviation of a river from its shortest possible path. Values above 1.5 and below 3.0 indicated normal sinuosity, while values below 1.5 indicated low sinuosity (Timár, 2003). Other proxies for ecosystem services concentrated solely on the Levee Reach prior to levee installation through contemporary times (1963 and 2013). Proxies for ecosystem services analyzed here include meander amplitude, meander count, and area of riparian vegetation (Table 12).

Data Sources

Historic reconstruction of Portneuf River length relied on a time series cartographic maps and rasters (Table 13), the first of which is a Union Pacific Schedule of Property circa 1917, which revealed its state then and prior to railroad infrastructure installation. The next dataset used in this study were topographic maps from the USGS of Pocatello and Michaud quadrangles from 1934 and 1937. For times series analyses subsequent to 1937, aerial photos from 1941, 1959, 1963, 1969, 1975, 1984, 1994, 2004, and 2013 were used for river length, meander calculations, and vegetation. The Portneuf Vision Study's plans were utilized to construct the future Portneuf River's proposed path, length, and meanders (US Army Corps of Engineers, 2016).

Table 13. Data Sources

Year	Reach Coverage	Scale	DOI/Source
River prior to Railroad Alteration	SP, L*	1:3,400	Union Pacific Railroad, 1917 Schedule of Property
1917	SP, L*	1:3,400	Union Pacific Railroad, 1917 Schedule of Property
1934/1937	SP, L, CC, NW	1:62,500	Perry-Castañeda Library USGS Topographic Map (Pocatello/Michaud)
1941	SP, L, CC, NW*	1:30,000	US National Archives United States Department of Agriculture, Soil Conservation Service
1959	L*, CC, NW*	1:12,000 (~1 m resolution)	Idaho State University doi:10.7923/G4X63JT0
1963	SP*, L, CC, NW*	1:12,000 (~1 m resolution)	Idaho State University doi:10.7923/G4SF2T3P
1968	SP*, L, CC, NW*	1:12,000 (~1 m resolution)	Idaho State University doi:10.7923/G4J1012N
1975	SP*, L, CC, NW*	1:12,000 (~1 m resolution)	Idaho State University doi:10.7923/G4D798BC
1984	SP*, L, CC, NW*	1:12,000 (~1 m resolution)	Idaho State University doi:10.7923/G48G8HMN
1994	SP, L, CC, NW	1:24,000	Idaho State University doi:10.7923/G44Q7RWX
2004	SP, L, CC, NW	1:24,000 (~1 m resolution)	US Department of Agriculture, Farm Service Agency, National Agriculture Imagery Program
2013	SP, L, CC, NW	1: 6,000 (~0.5 m resolution)	US Department of Agriculture, Farm Service Agency, National Agriculture Imagery Program
2026	SP, L, CC, NW	N/A	(US Army Corps of Engineers, 2016)

Results

Northwest Reach

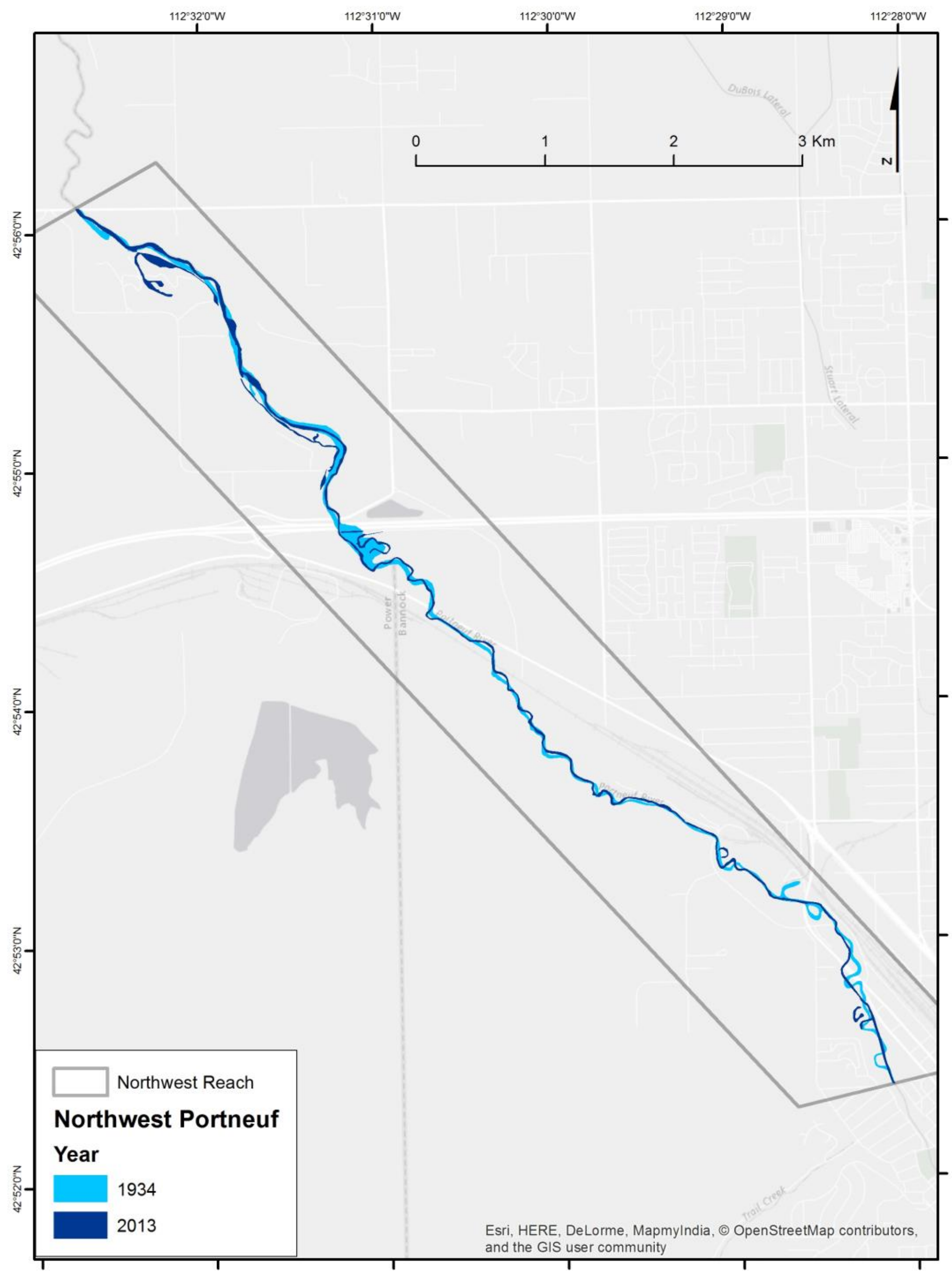

Figure 24 - The Northwest Pocatello Reach

The first dataset in this study, the 1934-1937 Michaud and Pocatello U.S.G.S. topographic quadrangles, cover the length of the entire Northwest Reach from Siphon Road to the Channel Reach (Figure 24). Following these years, aerial photography was lacking for complete analysis again until 1994, a 57 to 60-year gap (Table 14). During this time the Northwest Reach bank length decreased by 245.39 m with a corresponding loss of 0.05 percent loss in its sinuosity index (SI). The range of sinuosity seems confined within this period to a normal range with only a minor change. It has changed very little in length since 1994. The future depiction of the Portneuf Northwest Reach indicates slight shortening of the river, 180 m, but this is most likely due to inexact digitization within the Portneuf study than in actual plans to engineer the river to be a shorter length. There are currently 2.9 km of unconnected wetland meanders within this region, an important asset of natural capital and habitat.

Table 14. Changes in river length and sinuosity for the Northwest Pocatello Reach

Year	River Length	Change (m)	Sinuosity Index
1934/1937	11645		1.28
1994	11400	-245	1.23
2004	11405	5	1.23
2013	11432	27	1.23
2026	11252	-180	1.21
Total Change		-393	0.07

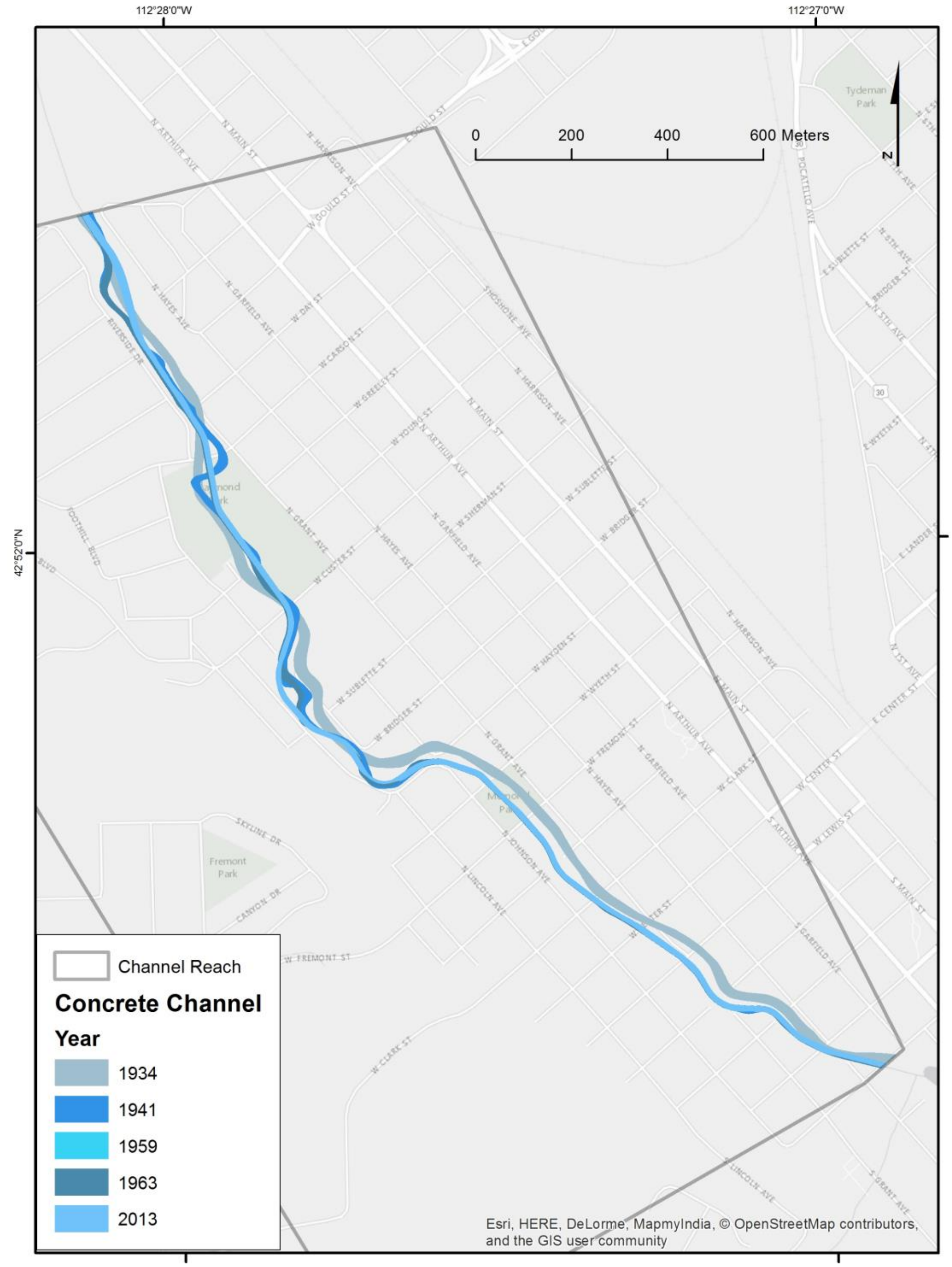

Figure 25. Concrete Channel Reach 1934 to 2013

Concrete Channel Reach

The Concrete Channel Reach is covered completely with map and vector data from 1934/1937 to present and beyond but lacks any cut off meanders present in imagery (Figure 25). The 1941 imagery depicted two of the meanders from the 1934/1937 imagery as much more sinuous with greater length. This could be due to engineering by the WPA which occurred as early as 1938 (Irland, 2016). The recording of this change increased the of the reach by approximately 118 m and increased the sinuosity index by 0.05. A decrease in length, 90 m with a corresponding decrease in sinuosity of 0.04, occurred within the next 17 years with the next largest drop between 1963 and 1968, due to channelization (Irland, 2016). From this point forward bank length decrease was negligible. Plans for 2026 seem to indicate no river lengthening, though the form of the channel may change with better aesthetic qualities and greater accessibility (US Army Corps of Engineers, 2016).

Table 15. Changes in river length and sinuosity for the Concrete Channel Reach

Year	River Length (m)	Change (m)	Sinuosity Index
1934/1937	2707.41		1.11
1941	2824.91	117.5	1.16
1959	2735.08	-89.83	1.12
1963	2735.08	0	1.12
1968	2717.50	-17.58	1.11
1975	2717.51	0.01	1.11
1984	2717.50	-0.01	1.11
1994	2713.71	-3.79	1.11
2004	2709.07	-4.64	1.11
2013	2709.07	0	1.11
2026	2709.21	0.14	1.11
Total Change (m)		1.8	0.00

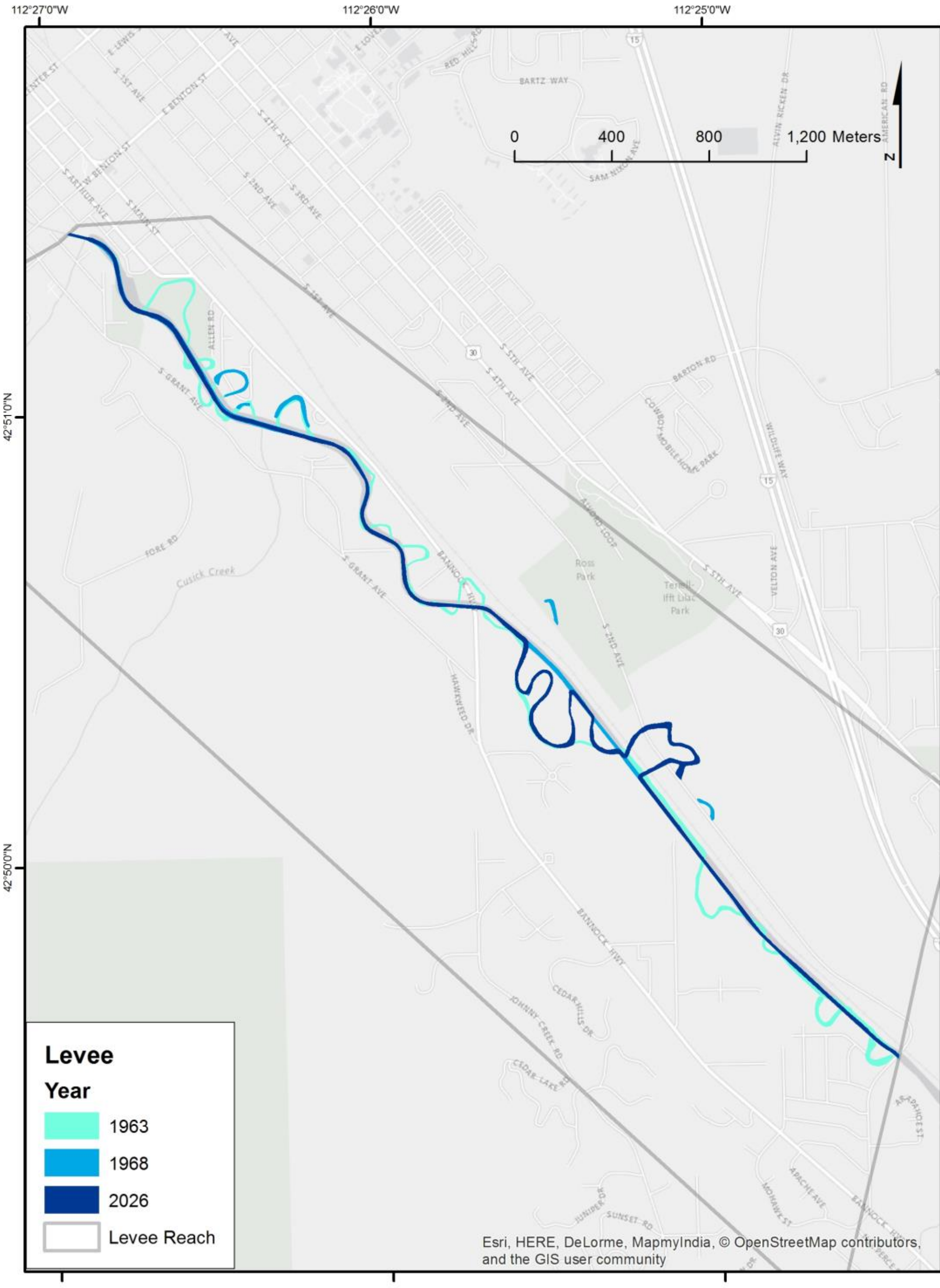

Figure 26. Levee Reach 1934 to 2026

Levee Reach

The Levee Reach (Figure 26) was the most mapped and photographed reach from 1934/1937 to the present of the Portneuf River in this study (http://www2.cose.isu.edu/~oglejare/Urban_Form/South_Portneuf_History.html). From 1934/1937 to 1941 it had an apparent increase in river length of 379 meters (0.08 SI), due mostly to increases in sinuosity. From 1941 to 1963 the river decreased 556.2 m, decreasing its 0.11, followed by another decrease of 2049.76 to 1968 meters. This was a 0.43 drop in sinuosity, the highest 2nd of any time across reaches. This 2.6 km decrease in river length is roughly the same as of 2013. Future proposed scenarios for bank length restoration would increase river length by 1.6 km and increase sinuosity .30, though this is still approximately 800 m less than its greatest length (Table 16). The decreases from 1941 to 1968 occurred due a series of river straightening culminating in the instillation of the Levee.

Table 16. Changes in river length and sinuosity for the Levee reach

Year	River Length (m)	Change (m)	Sinuosity Index
1934/ 1937	7333.73		1.52
1941	7712.75	379.02	1.60
1963	7156.55	-556.2	1.49
1968	5106.79	-2049.76	1.06
1975	5103.37	-3.42	1.06
1984	5103.36	-0.01	1.06
1994	5105.90	2.54	1.06
2004	5105.89	-0.01	1.06
2013	5105.88	-0.01	1.06
2026	6530.03	1424.15	1.36
Total Change (m)		-803.7	-.16

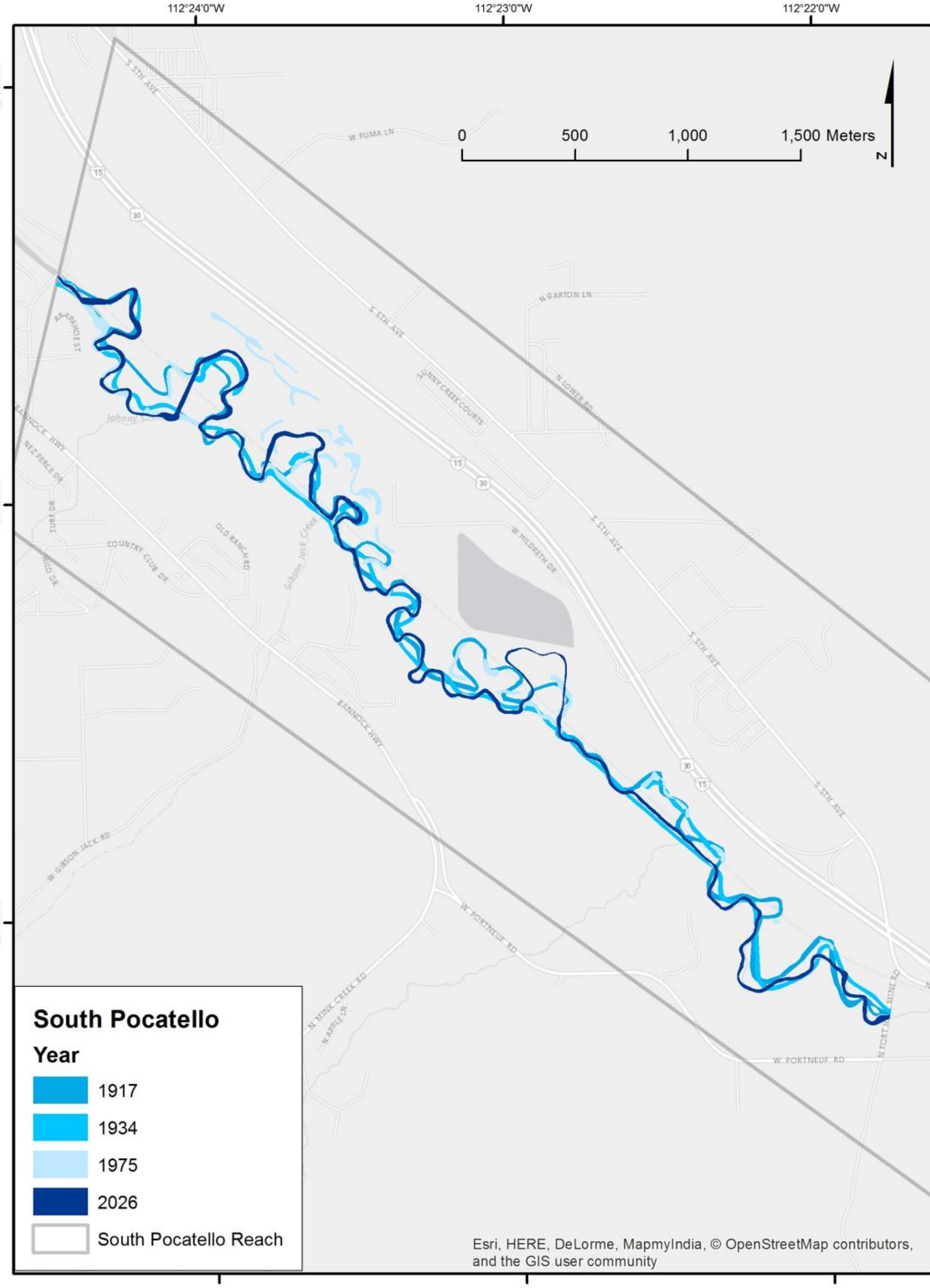

Figure 27. South Pocatello Reach 1917 - 2026

South Pocatello Reach

The South Pocatello Reach (Figure 27) was mapped from its natural state in 1917 to 1934/1937. Subsequently there was a 38-year gap and no aerial photography was available for the entire reach until the year of 1975 (Table 17). Also, the Union Pacific Railroad (UPRR) allowed for a reconstruction of the Pocatello River prior to railroad installation due to the labeling and drawing of the old channels and dikes/levees that cut old river channels from the newly straightened river. The un-engineered and un-straightened river was approximately fifty percent longer, or 3 km longer (0.63 SI) than its recorded length in 1917, according to the same Union Pacific Railroad map. The 1917 map indicated “old channels” in addition to the straightened river expanse along the railroad. It reached its low in 1934 at 5868.83 meters, with the greatest straightening. It had increased by approximately 1.2 km by 2013. Future meander restoration plans would restore over 5km within this reach increasing its length to 100-year record extents with a total SI of 1.97.

Table 17. Changes in river length and sinuosity for the South Pocatello Reach

Year	River Length (m)	Change (m)	Sinuosity Index
Pre-RR	9378.29		1.91
1917	6348.69	-3029.6	1.29
1934/1937	5868.83	-479.86	1.20
1975	7075.49	1206.66	1.43
1994	7099.87	24.38	1.44
2004	7112.63	12.76	1.44
2013	7128.06	15.43	1.44
2026	9728.05	2599.99	1.97
Total Change (m)		349.76	0.08

All Reaches

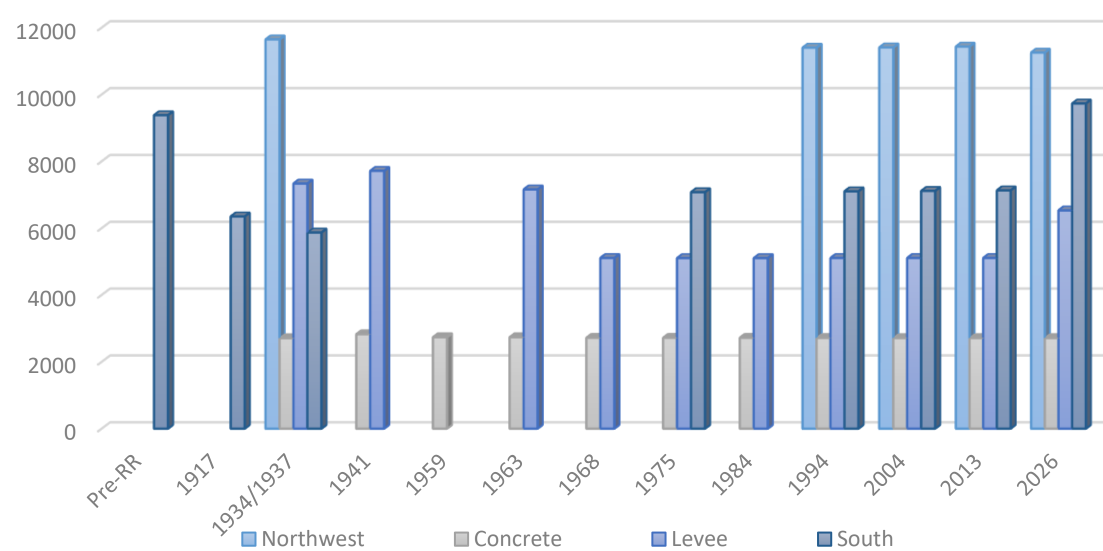

Figure 28. Change in river length through time for various reaches

The Portneuf River became less sinuous and shorter from 32749.20 m in 1937 to 27554.77 m in 2013 (Figure 28). One contributing factor was due to hydrological engineering causing shortening of river length. The largest decrease in river length has occurred in the South Pocatello reach prior to railroad development and 1917. This is followed by the Levee Reach which experienced the second most change in river length between 1963 and 1968. The third largest change was an increase in the South Pocatello reach between 1937 and 1975, with an increase of 1206.66 meters. Looking forward, if the plan put forth by the Portneuf Vision Study is implemented, river length in the Northwest and Concrete Channel Reach is expected to stay nearly the same. In the Levee Reach 1.4 km and in the Southern Reach nearly 2.6 km of river length is expected to be restored through meander restoration.

Riparian Classification - Levee Reach

For the land adjacent to the levee, a land cover classification was undertaken to indicate the presence or absence of vegetation. The vegetation was classified through manual digitization based off of aerial photos. Various vegetation types were not necessarily discernible, so canopies and the adjacent grass were classed together. In 1963, the Levee Reach contained 130,499 square meters of vegetation. Soon thereafter it was straightened causing a loss of meanders and vegetation (Figure 29). By 2013, the area containing vegetation had decreased to 49,292 square meters, a 2.65-fold decrease (Figure 30).

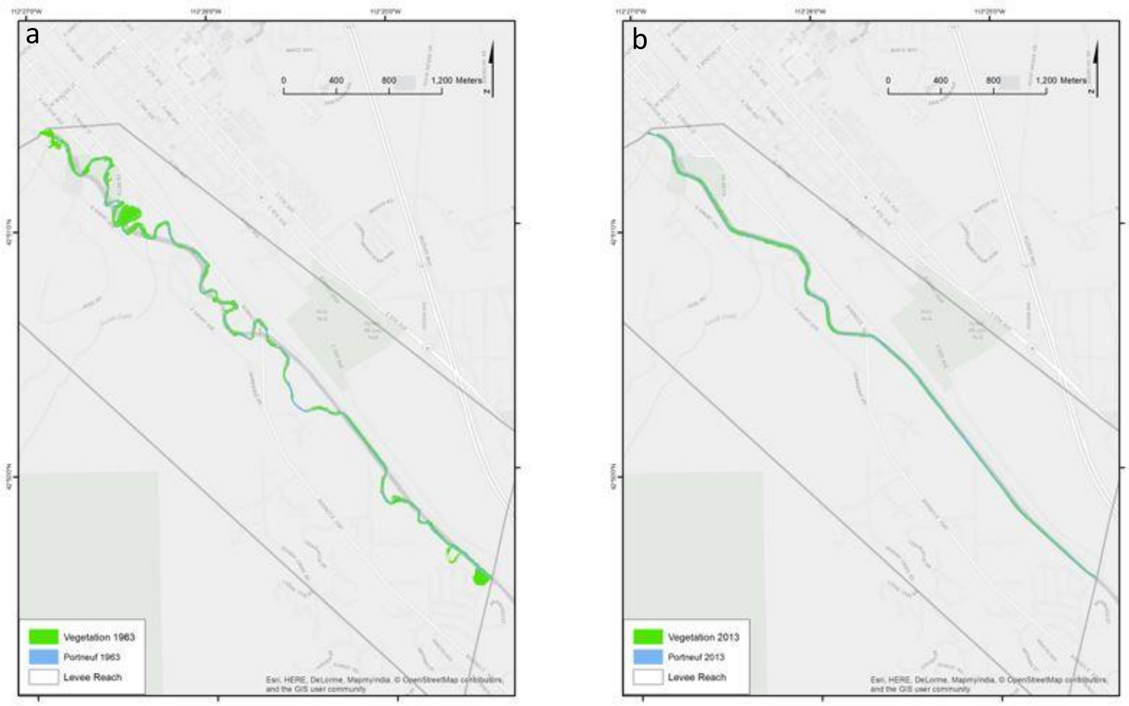

Figure 29. There is a decrease in vegetation due to straightening and levee installation between a. 1963 and b. 2013

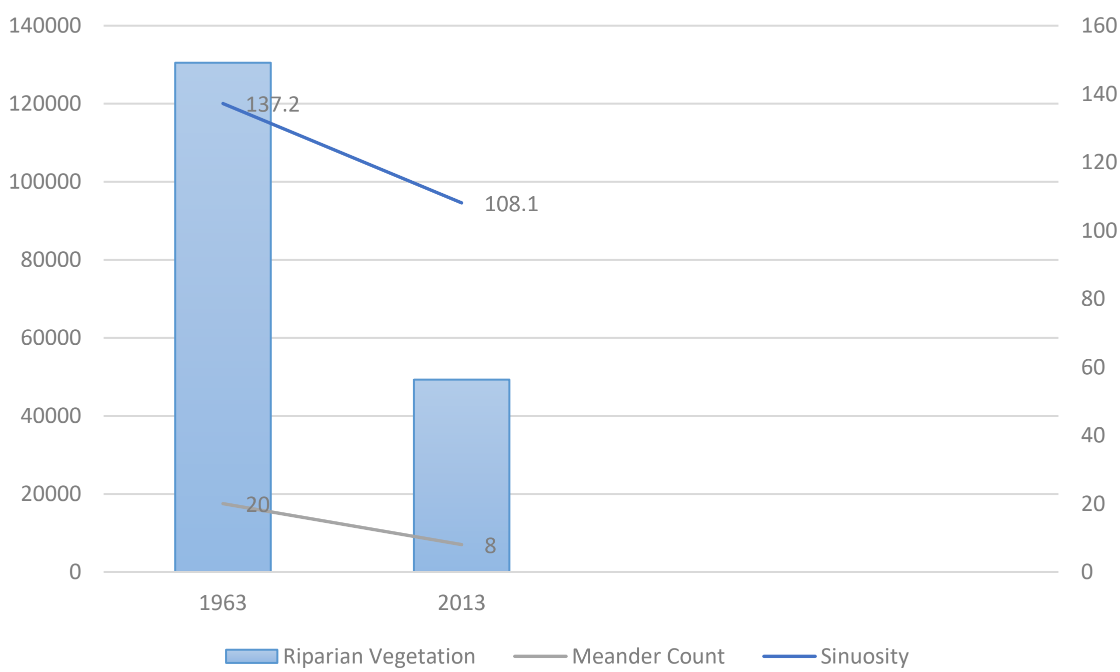

Figure 30. Decrease in vegetation, sinuosity, and meander count all correlated from 1963 to 2013

Table 18. Decrease in vegetation, sinuosity, and meander count all correlated from 1963 to 2013

	1963	2013	Change
Riparian Vegetation	130499	49292	81206.9 (sq. m)
Meander Count	20	8	
Meander Amplitude	137.2	108.1	19.9 (m)

Installation of the levee affected the form of the river by reducing the number of meanders from 20 in 1963 to 8 in 2013 (Table 18). These are gentle meanders with comparatively low amplitude, 19.9 meters less, that are much longer in width.

Discussion

Over an 80-year period from 1937 to 2017, the Portneuf River decreased nearly 16km between Siphon and Fort Hall Mine Road. However, it has been shortened considerably since railroad instillation as is evidenced on Union Pacific Railroad maps, particularly in the South Pocatello Reach. The primary cause of this has been hydro-engineering, first by the railroad for travel infrastructure, and then by the federal government for flood protection. Though flood protection and infrastructure for goods and services are important ways managing landscapes for ecosystem services, there are more efficient ways of managing this natural capital that does not hinder other ecosystem services. For example, river straightening for flood control served one purpose, yet harmed stream recharge, decreased riparian land cover, and decreased sediment deposition as an ecosystem service. The transfer of goods and services was once more relevant in the past, but with advances in infrastructure, technology, and modes of transport this is less and less relevant.

Much of the Portneuf River's record of change was due to hydrologic engineering for utilization of its ecosystem services. The Concrete Channel Reach and Levee Reach had great hydrological engineering with straightening to protect infrastructure. Yet today, since this is no longer as relevant for these may be better be used. For example, the Portneuf Study puts forth the restoration of river meanders in where it is currently straightened (US Army Corps of Engineers, 2016), which is good for recreation services (paddling), natural habitat, and fish pool regeneration (Tomscha, Gergel, & Tomlinson, 2017). Balancing the needs of humans and the needs of nature, or trying to see them as one in the same, is one of the keys to successful ecosystem service management and future looking restoration of the Portneuf River highlights this ecosystem service philosophy.

CHAPTER 5: CONCLUSION

Chapter three took a Smart Growth approach to sustainability of form. Algorithms examined various aspects of city form through time for Pocatello from 1941 to 2013. A comparison was also performed to validate methods between modern day Pocatello (2015) and two other mid-sized cities in Idaho: Coeur d'Alene and Idaho Falls. It was expected that the growth of Pocatello would mirror suburbanization that much of the United States experienced from the Second World War to today, even though it was a mid-sized city. Statistics such as intersection density, and other forms of density did change to mirror this hypothesis. Also, physiography was assumed to be the limiting factor on growth. Statistics like fragmentation reflect this conclusion.

Success in the Post World War II era has often been viewed as achieving the "American Dream," which includes a suburban lifestyle. The growth and form of suburbs is historically anomalous. This growth was fueled in the post war era by influential architects and planners at the local level, mass adoption of the automobile, and federal policy. Ebenezer Howard's "Garden City," LeCorbusier's "Radiant City," and other city planner's paradigms heavily influenced development in a modified form, mainly in the way of development away from the core. Local planners took a greater role in development and had stricter zoning with more single-use residential, a hallmark of the suburbs.

The federal government encouraged suburbanization in several ways. First, it encouraged it through direct funding via The Federal Housing Association (FHA) and Veterans Associations (VA), which subsidized mortgages. Secondly, it subsidized suburbia through tax breaks for developers and construction of the interstate system. Thirdly, it aided the development of suburbia through deed restrictions and civil rights decisions which effected the demographics (Hanchett, 2000). This new emerging type of city is not built for its utility, but rather for the automobile. Suburban developments can be seen as growing away from the core in the Post-war developments in Pocatello. These developments break with traditional urban form typical of Pocatello's history and mirror the development occurring across the country in cities just like Pocatello.

In suburbs, decreased connectivity stemming from the curvilinear suburban form combined with low density single-use residential areas separates individuals from amenities and increases auto dependency. For this reason, a neighborhood should be more organic. Rezoning areas from single-use to mixed use could decrease auto-dependency, commute times, and give access to amenities. Future neighborhoods should be designed and zoned that are connective with mix-use zoning. These areas should be more connected with more four-way intersections, smaller blocks, a smaller average lot size, and with a mix of residential and commercial.

The analysis of urban form is vastly important for identifying sustainable form for cities of all sizes. The difference between previous analyses of smart growth and the analyses conducted for this study lie in scale, types of data sets used for analysis, and replicability. Most analyses, such as Smart Growth America and others, differ from this study in scale. The data used for larger sized metropolitan areas is often county, micropolitan or metropolitan in resolution. The data for this analysis was of a finer resolution based on a four-block local grid or mid-sized city global analysis. Readily accessible data from a city's GIS department, such as building footprints, city streets, central business districts, and built extents, are widely available and can be used to replicate this effort for other mid-sized centers. This data and this work flow could be expanded with an online database and act as a decision support toolset. It could take available municipal files, integrate them into an online database, give comparative rankings on final and sub-indices for various cities in the database, as well as, provide. cartographic outputs for planners, decision-makers, and constituents the information needed to shape future decisions on growth and development.

Chapter four examined the Portneuf River by analyzing proxies for riparian ecosystem change between pre-channelization, post-channelization, and after a possible future scenario Hydrologic engineering for infrastructure use was the main impetus for change through time and the primary cause in changes in natural capital along the riparian corridor. Historic maps, air photos, and LiDAR data, were analyzed to produce metrics such as river length, meander count and amplitude, sinuosity, and vegetation area. Using these methods, comparative metrics for past, present, and future scenarios were created. Infrastructure to control flooding has played a critical role in diminishing key indicators of riparian ecosystem services along the Portneuf River. Data from this study can be used to generate scenarios to evaluate the impact of the proposed Portneuf River implementation plan on ecosystem service returns.

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