AN ABSTRACT OF THE THESIS OF

Elizabeth A. Morrison for the degree of Master of Science in Geography presented on July 29, 2016

Title: Post-Aggregate Aggregation: A Geographic Evaluation of Enhancement Reclamation at Aggregate Mines in the Western United States

Abstract approved: ____

Todd W. Jarvis

The aggregate industry is responsible for the extraction and production of crushed stone, sand, and gravel— the literal building blocks of our society. Across the U.S. there are tens of thousands of quarries and sand and gravel pits, the majority of which are left abandoned or with minimal reclamation efforts. However, the combination of population growth, increased permitting difficulties for the aggregate industry, growing environmental concerns, and land use competition has spurred the enhancement reclamation of some sites in the U.S. Enhancement reclamation is defined as the actualization of a quarry or sand and gravel pits' secondary beneficial use potential achieved through reclamation or restoration. There is currently no documentation of where these sites exist or how frequently such projects occur. This research addresses the broad question, "What is the status of enhancement reclamation in the western U.S.?" and takes the first step towards the creation of a nationwide enhancement reclamation database. Enhancement reclamation projects were identified in western states in the conterminous U.S. and their geographic location(s) and reclamation type(s) were documented. These data are analyzed by region (pacific vs mountain), state, geographic environment, and enhancement reclamation type. The discussion is framed using the adaptive cycle to explain the frequency of enhancement reclamation projects between states and identifies population density, land use competition, and the geography of amenity as key drivers of enhancement reclamation.

Post-Aggregate Aggregation: A Geographic Evaluation of Enhancement Reclamation at Aggregate Mines in the Western United States

by
Elizabeth A. Morrison

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented July 29, 2016
Commencement June 2017

Master of Science thesis of Elizabeth A. Morrison presented July 29, 2016

APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Elizabeth A. Morrison, Author

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to all those who supported me during “round two.” After my first thesis I hubristically thought another would an easier endeavor— I was so wrong. If it were not for my advisor, family, and friends my foolhardy confidence may have kept me from finishing this second round.

First and foremost (and ideally for the rest of my career), I would like to thank Dr. Todd Jarvis. After my first degree you told me you thought I may not come back for the second— I admit that with another advisor I may not have. But working with you and having the opportunity to tap into not only your academic knowledge, but life wisdom is a privilege I could not pass up. It has been professionally rewarding and, frankly, *fun* sharing the excitement about this research. My time at OSU and work with you has laid the foundation for my future career and I undoubtedly would not be here without your belief, encouragement, flexibility, and support over the last four years. Thank you.

Dear family. More so than last time you came on this journey with me (sorry!). Mom: you are my guardian angel, rock, inspiration, best friend, confidante du jour, and so much more I literally cannot put it all into words… Dad: you are infinitely grounded, practical, patient, understanding, and the hardest worker I have ever met— many times during the process of this thesis I believed I could finish simply because I am related to you. I’ve leaned on you so many times over the last few months and you never faltered and I’ve felt so supported. Thank you.

My friends. Somehow from one side of the country to the other you’ve created a 3,000-mile net that I feel supporting me every day. I am so blessed to call you my chosen family and I would pick you again in every life time. Thank you for the calls (especially at inconvenient times or for inconvenient lengths of time), adventures, time, messages sent just to make me laugh during the writing phase, and understanding while I was M.I.A. hiding in my “thesis cave.”

Finally, I would like to thank all those at CEOAS, the IWW/INR, and my committee members. Dr. Lisa Gaines, Dr. Shireen Hyrapiet, and Dr. Dominique Bachelet thank you for the support in all its forms, and particularly on such short notice! Everyone has been incredibly supportive of my goal to complete this second MS… from helping me find funding to well-wishes and lunches, none has gone without notice. Thank you.

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1 INTRODUCTION

The aggregate industry is one of the largest and most lucrative businesses in the United States. It is defined by the U.S. Geological Survey (USGS) as all those companies that mine and process crushed rock, sand, and gravel resources (aggregates). In 2016, across all fifty states, the USGS valued construction sand and gravel at $7.2 billion across 4,100 companies and government agencies operating 6,300 operation sites; crushed rock was nearly double this value at more than $13.8 billion across 1,430 companies operating roughly 4,000 sites (including quarries, mines, and sales/distribution yards). From 2011 to 2015, annual U.S. sand and gravel production increased from 809 to 931 million metric tons, a 15% increase. Over the same time period, annual U.S. crushed stone production increased from 1,160 to 1,320 million metric tons— an increase of just under 14% (U.S. Geological Survey, 2016).

U.S. aggregate production growth is largely attributed to increased construction demands. Both commercial and residential construction have been, "experiencing a level of growth not seen since late 2005" (U.S. Geological Survey, 2016), due to both population increase and economic recovery following the 2008 financial collapse. According to U.S. census reports, the U.S. population is projected to increase by 31% (from 319 to 417 million) between 2014 and 2060 (Colby & Ortman, 2014). If these projections are accurate, demand for aggregate will continue to increase and the industry will remain dominant in the U.S.

While growth brings continued business to the aggregate industry, it also drives environmental and societal issues that have plagued mining for decades. Concern for the environment surged in the U.S. in the 1970s— a wave that has continued and strengthened in the new millennium. Top environmental concerns about the mining of aggregates include pollution (e.g., sedimentation, air pollution from equipment emissions, altered aquatic thermal regimes), erosion, changes in surface and groundwater movement (e.g., diminished aquifer recharge), decreased biodiversity, and aquatic and terrestrial habitat alteration (e.g., fragmentation and vegetation removal leading to dominant invasive species), which can harm local threatened and endangered species (Langer & Arbogast, 2002; Meador, 1998; Markle & Schincariol, 2007).

Social concerns vary based on local land use. Top concerns include noise pollution from machinery and trucks, increased local truck traffic, aesthetics, land use conflicts, impacts to groundwater including water quality impacts and depletion due to dewatering of pits so mining can occur below the level of the water table (e.g., conflicts between the agricultural and aggregate industries in areas where high-value agricultural land and aggregates overlap) (Achterman et al., 2005; Morrison, 2015; Drew et al., 2002; Arbogast et al., 2000).

The combination of these concerns, heightened permitting requirements, population growth, and subsequent development has made opening new aggregate mines (i.e., getting an approved permit) more difficult over time in many locations. Permits typically require a reclamation plan, which is a written plan describing how the mine will be closed following operations. Common practices include sloping the sides of a pit to a ratio of 3:1 to reduce safety hazards and spreading seeds to revegetate the disturbed area around the pit. However, over time plans have gotten more sophisticated and reclamation requirements stricter (e.g., requiring greater secondary beneficial uses prior to approval). Development of these plans increases the time it takes to approve a permit and can also be more expensive than a simple sloping and seeding reclamation plan. Population growth and development, while keeping the aggregate industry in business, can also hinder the opening of new sites. Aggregates can only be extracted where deposits naturally exist and when buildings or roads are constructed overlying a deposit, that source is no longer available to be mined (Campbell & Roberts, 2003).

With increasing challenges to sourcing aggregate materials in some regions and growing environmental concern, the time is ripe to focus on the reclamation and restoration of aggregate pits and quarries— including abandoned, currently operational, and future sites. However, much of the research done on aggregate mining has focused on its economics, environmental impacts, and social issues. A smaller subset of the literature concerns reclamation and restoration, and within this subset specific projects and techniques are often highlighted. Little research has been done on the reclamation and restoration of aggregate pits on a larger scale, and there is little documentation of specific enhancement reclamation projects across a large geographic area. Enhancement reclamation is defined as the actualization of a quarry or sand and gravel pit's maximum secondary beneficial use potential, achieved through reclamation or restoration (Morrison, 2015). This research seeks to begin to establish an inventory of enhancement reclamation projects in the U.S., beginning with contiguous western region states (see Figure 1).

1.1 Rules and regulations

There are currently no federal rules or regulations that instruct the permitting or reclamation of aggregate pits or quarries. There is, however, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), which is the primary federal law addressing the reclamation of coal mines and abandoned mine lands. As stated in 30 U.S.C. § 1202, it is the purpose of the SMCRA— with respect to coal mining— to:

> Establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations … assure that adequate procedures are undertaken to reclaim surface areas as contemporaneously as possible with the surface coal mining operations … [and] wherever necessary, exercise the full reach of the Federal constitutional powers to insure the protection of the public interest through effective control of surface coal mining operations.

The SMCRA established the Office of Surface Mining Reclamation and Enforcement (OSMRE) to help achieve these goals. The SMCRA does mention aggregates, but they are an afterthought when compared to the primary focus given to coal mining. First, their inclusion in the SMCRA can be inferred in 30 U.S.C. § 1202 (h). Here, another stated purpose of the chapter is to:

> Promote the reclamation of mined areas left without adequate reclamation prior to August 3, 1977, and which continue, in their unreclaimed condition, to substantially degrade the quality of the environment, prevent or damage

> the beneficial use of land or water resources, or endanger the health or safety of the public.

Therefore, aggregate pits and quarries left without adequate reclamation before passage of the SMCRA (i.e., that satisfy the definition of “abandoned mined lands”) are included, but are lower priority than lands disturbed by coal mining. Second, another purpose of the SMCRA addresses “other minerals,” the definition of which includes stone, sand, and gravel (30 U.S.C. § 1291 (14)). It is the stated purposed of 30 U.S.C. § 1202 (j) to, “provide a means for development of the data and analyses necessary to establish effective and reasonable regulation of surface mining operations for other minerals.” Pursuant to this goal, the SMCRA calls for a study of reclamation standards for surface sand and gravel mining with legislative recommendations to be submitted by 1978. This proposed study of reclamation standards for minerals other than coal is the most definitive reference to the reclamation of aggregate pits and quarries in federal law.

There is an inconsistency between this lack of federal regulation of aggregate mining and the recognition of issues associated with surface mining operations, which are enumerated in the congressional findings of the SMCRA (30 U.S.C. § 1202 (c)):

> Many surface mining operations result in disturbances of surface areas that burden and adversely affect commerce and the public welfare by destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural, and forestry purposes, by causing erosion and landslides, by contributing to floods, by polluting the water, by destroying fish and wildlife habitats, by impairing natural beauty, by damaging the property of citizens, by creating hazards dangerous to life and property by degrading the quality of life in local communities, and by counteracting governmental programs and efforts to conserve soil, water, and other natural resources.

Although aggregate mining is not federally regulated, it is addressed at the state and county level, and reclamation requirements vary from state to state. However, landowners often have substantial latitude when it comes to how the land is mined and how it is reclaimed following operations. Furthermore, there are many forms that ownership can take. Mining companies and operators frequently own a parcel of land outright. However, land is also often leased from another party (e.g., a farmer or other landowner), which gives that individual or group influence over a site's final form.

1.2 Geography of aggregate mining in the U.S.

The USGS divides the U.S. into four general geographic regions and divisions, which are based on U.S. Census Bureau definitions (Figure 1).

U.S. Census Bureau Geographic Regions and Divisions

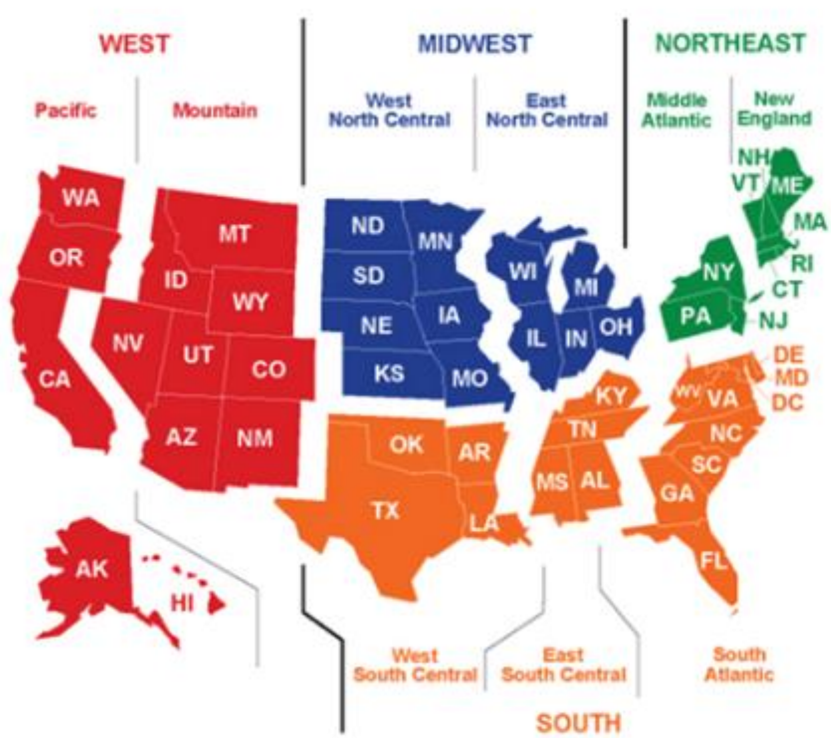

Figure 1. U.S. states organized by region and division (U.S. Census Bureau).

Aggregates are generally subdivided into: (1) construction sand and gravel, and (2) crushed stone. Percentages of construction sand and gravels sold or used in the U.S. by region and subdivision are shown in Figure 2. Percentages of crushed stone sold or used in the U.S. are shown in Figure 3. For quantities used or sold and value of the commodities by region and division, see Appendix A.

The Northeastern region produces the least of both commodities, largely because it is the smallest geographic area (10.9% of U.S.-produced construction sand and gravel;

14.5% crushed stone). The Midwest represents roughly one third of the U.S. production and sales of each (31.6% construction sand and gravel; 28.2% crushed stone). The west produces and sells the most construction sand and gravel (32.6%), but the least crushed stone (10.6%). Finally, the South represents the greatest overall percentage of aggregate production, including almost half of all U.S. production and sales of crushed stone (46.8%) and 24.7% of all construction sand and gravel (USGS, 2012).

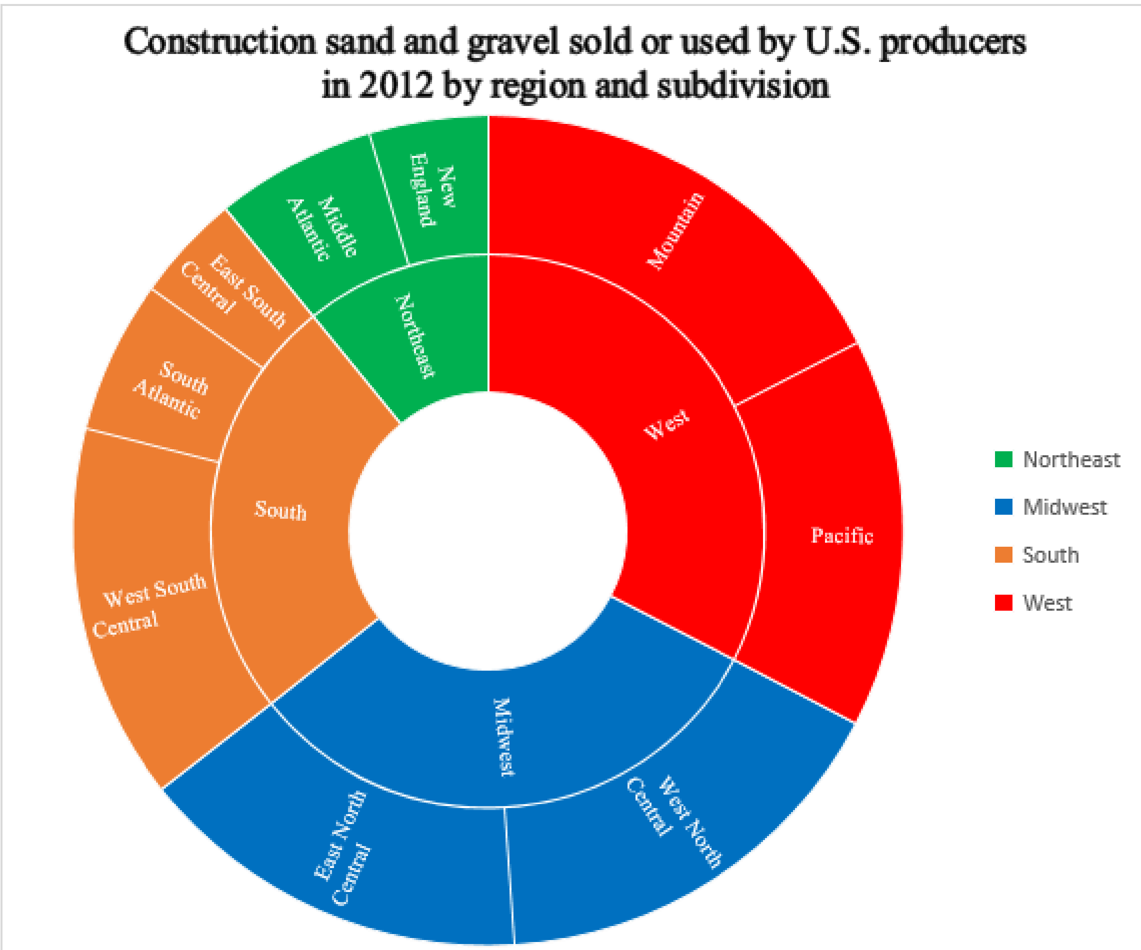

Figure 2. Percentage of construction sand and gravel produced or used by U.S. producers shown by four general geographic regions and subdivisions.

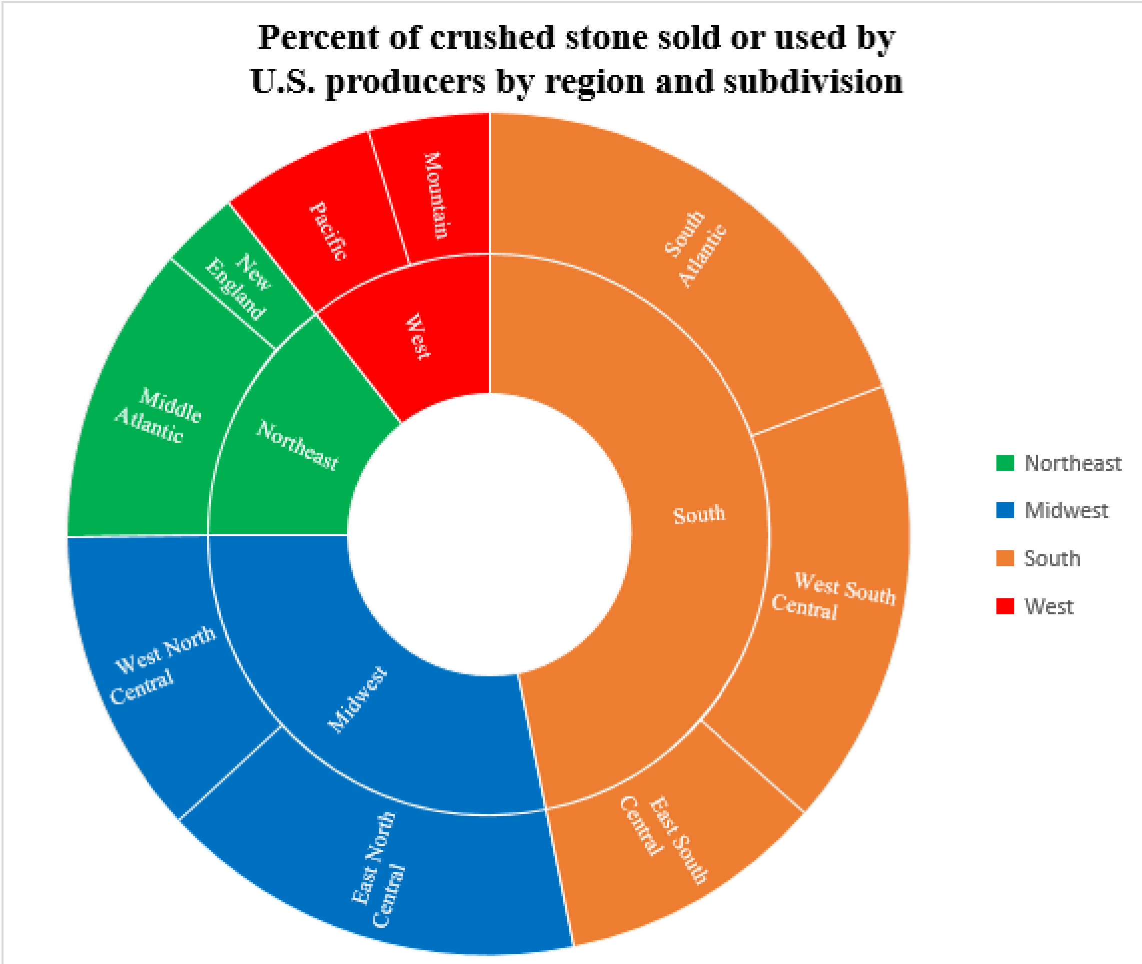

Figure 3. Percentage of crushed stone produced or used by U.S. producers shown by four general geographic regions and subdivisions.

These statistics demonstrate the wide variation in aggregate materials produced in different areas of the U.S. on a macro-scale. There are also unique geographic features at the meso-scale (e.g. counties) that directly impact aggregate mining and site reclamation and (or) restoration.

Geographic features that can have the greatest influence on enhancement reclamation include land surface forms (Figure 4) and terrestrial ecosystems (Figure 5).

Land Surface Forms in the Conterminous U.S.

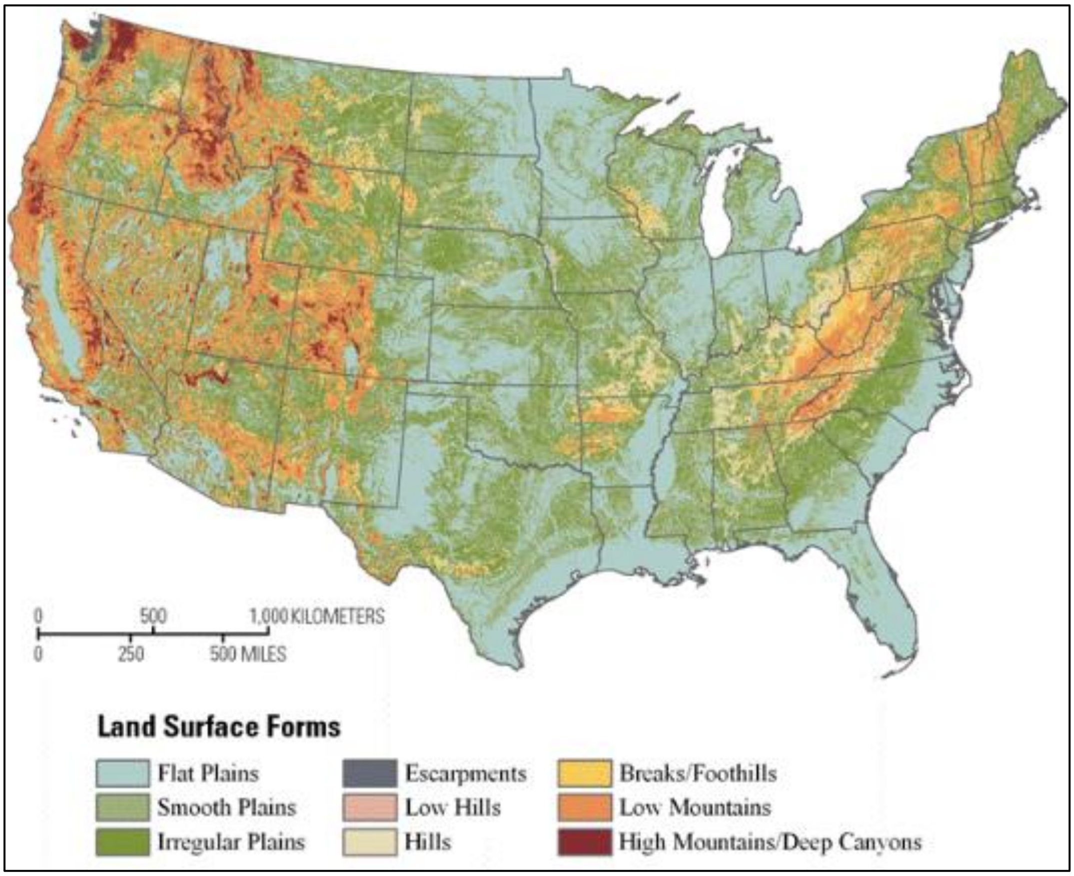

Figure 4. Land surface forms in the Conterminous U.S. (USGS).

Land surface forms directly influence the types of enhancement reclamation possible at a given location. For example, mountainous regions do not lend themselves to farmland reclamation, but are much better suited to an amphitheater or reforestation. The opposite is true of the plains. Furthermore, land surface forms strongly influence whether or not sand and gravel or crushed stone will be extracted in a particular area— flatter areas generally produce the former and more mountainous areas the latter. Similarly, the ecosystem in which a pit or quarry is located will help guide an enhancement reclamation plan. For example, drier ecosystems do not have the same capacity as wetter ones to support certain aquatic secondary beneficial uses (e.g., wetlands).

The western U.S., as can be seen in Figures 4 and 5, is highly diverse in its composition of both land surface forms and terrestrial ecosystems. This diversity is why the western region was selected for this analysis. This selection process is discussed further in Section 3.

Terrestrial Ecosystems in the Conterminous U.S.

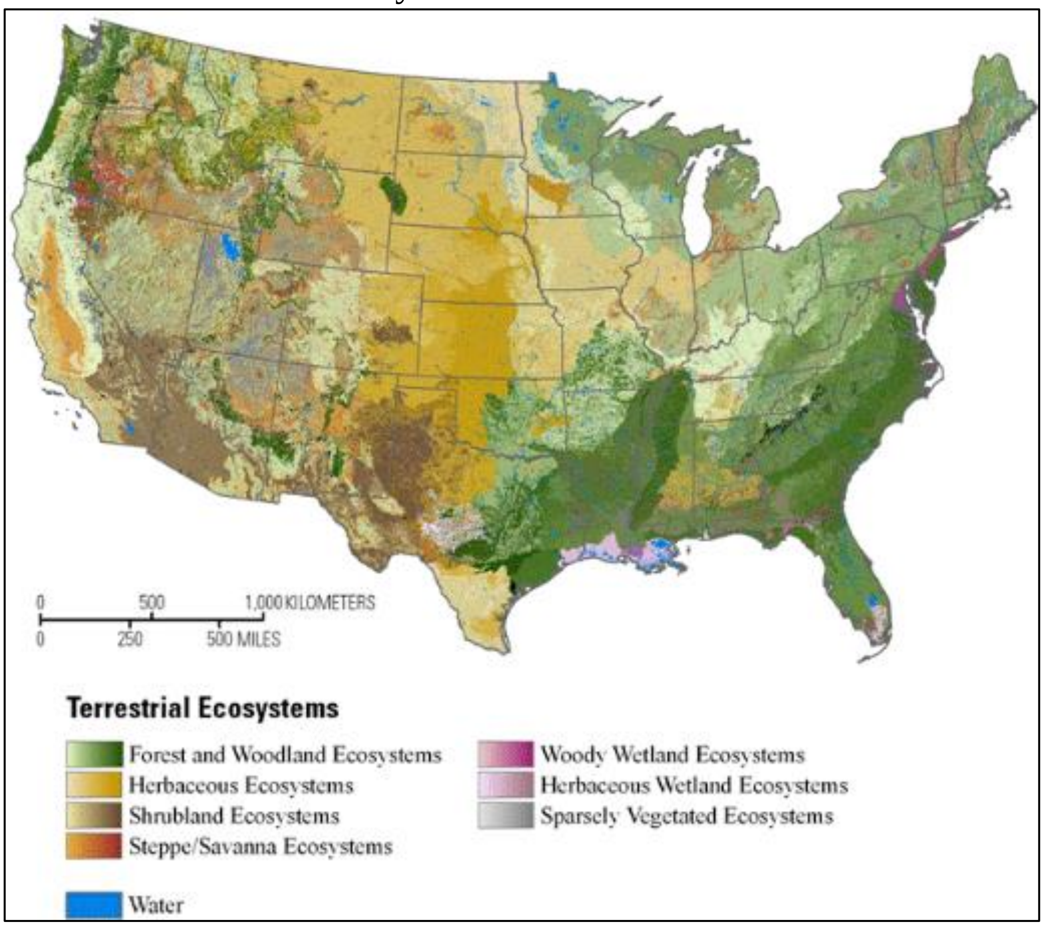

Figure 5. Terrestrial ecosystems in the Conterminous U.S. (USGS).

Broad geographic environments to be addressed in this study were determined by considering land surface forms and terrestrial ecosystems in the western US alongside an aggregate issues map (Figure 6), created by a 2004 Oregon Consensus Group meeting focused on mining issues on farmland in the Willamette Valley, OR. Despite the group's emphasis on the intersection of the aggregate and agricultural industries, they also identified a broader range of geographic environments impacted by aggregate mining in Oregon: (1) urban; (2) in streams; (3) farmland; and (4) forested/non-farmland (see Figure 6). Because the current research project extends beyond Oregon, and aggregate mining and enhancement reclamation are unique to each state and region, two alterations have been made to these geographic environment designations: "forested/non-farmland" is called "non-farmland" (further specified by ecosystem), and "in streams" is designated "aquatic". Thus, four broad geographic environments will be addressed in this study: (1) urban; (2) aquatic; (3) farmland; and (4) non-farmland (specified by ecosystem e.g., forest, steppe, etc.).

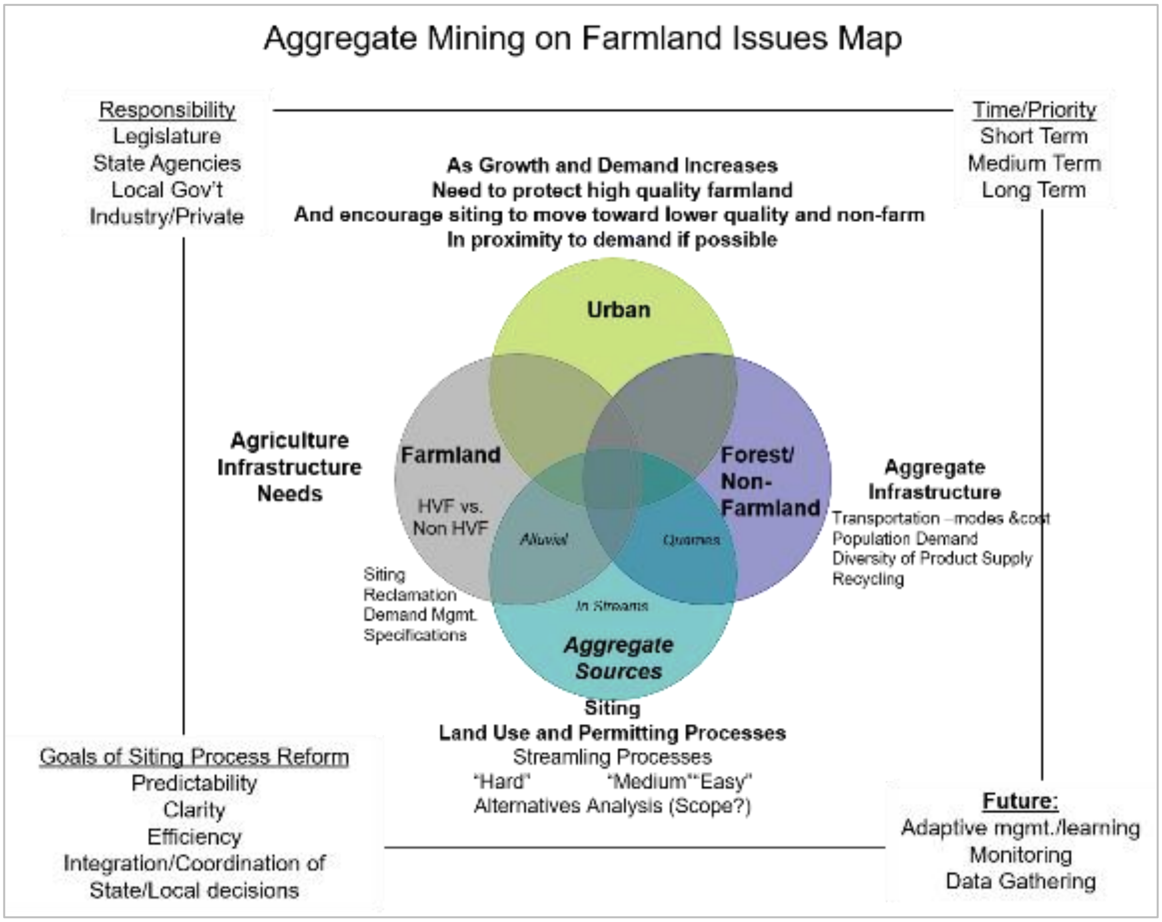

Figure 6. Aggregate mining land use issues map developed by 2004 Oregon Consensus group (unpublished).

In the following paragraphs, each of these four geographic environments are discussed in greater detail. This will include subcategories, common social and environment issues, and any unique characteristics associated with aggregate mining.

Urban

The term "urban" has many definitions. Here, urban follows the U.S. Census Bureau's classification system: urban areas (UAs) have 50,000 or more people, urban clusters (UCs) 2,5000-50,000, and rural areas encompass all population, housing, and territory outside of urban areas (U.S. Census Bureau, 2010).

Many aggregate pits are located within urban areas because shipping costs are the greatest expense for the aggregate industry. In other words, the closer the source is to the market (most commonly urban areas), the lower production costs will be (Robinson et al., 2004). Therefore, pits in urban areas are economically desirable for both the aggregate industry and consumers. However, the closer sites are to population centers, the greater potential for social conflicts due to increased local pollution, noise, traffic, and damaged view sheds. The simultaneous existence of these two facts is one of the major conflicts surrounding the aggregate industry: consumers want cheap sand, gravel, and crushed stone, but they do not want pits near their homes.

Aquatic

Aquatic sites have two main subcategories: instream and floodplain. Instream mining occurs within a river or stream itself and mining is typically shallow. This type of mining is the most controversial because it can severely damage aquatic habitats, and its frequency has decreased in many states over time due to these issues.

Floodplain aggregate mining occurs within the floodplain of a river or stream (the low-lying ground adjacent to a river or stream that is subject to flooding). While it does not have the same direct effects as instream mining, floodplain mining also has associated environmental effects.

Floodplain sites often overlap with farmland sites and thus experience additional pressures from environmentalists and environmentally minded citizens, to be discussed below.

Farmland

Farmland designation is typically controlled at the state and county levels via land use zoning. This geographic environment poses unique challenges for aggregate mining because it is in direct competition for land with the agricultural industry. Land use conflicts commonly occur where desirable alluvial aggregate deposits, which are smoother and cleaner than crushed rock and therefore easier to process following extraction, underlie the highest value soils (Class I or II, ranging from I-VIII). Class I soils incur only “few” and Class II “moderate” farming limitations (Hulse & Gregory, 2002). Alluvial aggregates and prime soils are often layered with one another because they were historically deposited by the same processes (commonly flooding; e.g., the Missoula Floods). Therefore, land use conflicts between the aggregate and agricultural industry are common because the most desirable sites for both parties are overlapping, scarce, and diminishing due to encroaching development and resource exhaustion.

Non-farmland

Non-farmland sites are those that are not classified as “urban” or “farmland” and are specified by their unique ecosystem; ecosystems include forest, grassland, scrub/savanna, steppe, and desert. Of the four geographic environments, non-farmland sites are met with the least resistance because they do not compete as frequently with other high-value land uses and are located outside of highly populated areas. Quarries, which produce crushed rock, are most commonly non-farmland sites and are specifically located in mountainous areas (generally forested or sparsely vegetated).

1.3 The reclamation and restoration of aggregate pits: Costs and opportunities

Reclamation and restoration, both addressed in this study and defined collectively here as “enhancement reclamation” (Morrison, 2015), differ mainly based on their motivation. Reclamation is mandated by law, planned as part of an approved permit (where applicable), and is typically carried out by the mining operator. There is also a bond associated with reclamation. A reclamation bond is an amount of money attached to a mining permit, which is either returned upon completion of reclamation or used by the permitting agency to carry out reclamation practices if the operator cannot complete them (e.g., due to bankruptcy). Additionally, reclamation that goes beyond the legal requirements is called voluntary reclamation.

By comparison, restoration is not mandated by law, but is taken on by outside parties with a future vision for a given site. Restoration projects are usually carried out by non-operators; common restoration parties include non-government organizations

(NGOs; e.g., The Nature Conservancy) and city or state government organizations (e.g., parks and recreation departments).

Both reclaimed and restored aggregate pits and quarries are included in this research because each process can help a site actualize its maximum secondary beneficial use potential, and therefore satisfy the definition of enhancement reclamation. The following paragraphs will discuss common, associated issues and practices in each of the four geographic environments.

Urban

Urban sites are commonly used for recreation and development. Although spent aggregate pits are not historically desirable places for building, their value is becoming more apparent. Typical enhancement reclamation projects include housing developments, commercial real estate, and city parks. Depending on the depth of the pit, locally desired amenities, and community affluence, pits may also be backfilled and built upon or left as a water feature. While utilization of aggregate pits for real estate is common in urban environments, projects are limited only by the imagination. Examples include schools, churches, and even homes featured in the "Street of Dreams."

Aquatic

Over time there has been growing pressure to pursue ecological enhancement reclamation projects (discussed further in Section 2) at aquatic sites— both instream and floodplain— largely due to increased data and information about environmental issues caused by these types of mining. This is furthered by growing concern over diminishing fisheries and threatened and endangered native species of salmonids in many states. Aquatic enhancement reclamation projects are often restoration projects, because outside parties (e.g., National Marine Fisheries Service or NGOs) get involved to increase system complexity and enhance habitat for local species of concern. Furthermore, projects with such goals (e.g., enhance habitat for an endangered species) often meet criteria for national and state level funding and their realization can be bolstered by these critical funding sources.

Farmland

Enhancement reclamation at farmland sites is often contentious. Although aggregate companies do reclaim farmland sites in accordance with their agricultural land use zoning, agricultural interests believe the end result of reclamation is often inadequate. Ideally, reclamation in agricultural areas should return the land to its previous, farmable condition ("farmland" reclamation). However, there is controversy surrounding whether or not it is possible to return agricultural land to its previous productivity. In reality, pits are often left open to be utilized in various ways ("farm use" reclamation; e.g., watering cattle).

Non-farmland

Non-farmland sites cover the widest array of ecosystems. However, they are often located in more rural areas, therefore pressure to reclaim and restore these sites is lower than the other geographic regions, due to less land use competition. On the other hand, economic drivers can increase the land value in these regions, making it affordable to fill in pits and build on them. Due to the diversity of ecosystems and landforms of non-farmland sites, many unique projects can be attempted. These regions are more likely to contain quarries, which offer more unique geographic features (e.g., large exposed quarry walls) that can be built into a project design. Examples range from garbage dumps to amphitheaters.

1.4 Research questions and objectives

The main question underlying this research is: what is the status of enhancement reclamation in the U.S.? This is addressed by the following specific research questions.

(1) How does enhancement reclamation differ regionally and state-by-state in terms of frequency and geographic environment?
(2) How does enhancement reclamation differ among geographic environments, including urban, aquatic, farmland, and non-farmland (e.g., forest or steppe)?
(3) What is the frequency of different types of reclamation (in total and among geographic environments)?

To address these questions, this research will create a dataset of enhancement reclamation projects in western states of the contiguous U.S. These data will provide a preliminary understanding of how and where quarries and sand and gravel pits have been reclaimed and restored in the U.S. and will provide the inaugural data for a future nationwide database of enhancement reclamation projects.

2 LITERATURE REVIEW

This literature review begins with an overview of social ecological systems (SESs) theory (i.e., coupled human natural systems), which provides a framework for the discussion (Section 5). Other relevant literature includes studies addressing (1) reclamation and restoration and (2) reclamation and restoration of aggregate pits and quarries.

2.1 Social-ecological systems (SESs)

As stated by Redman et al. (2004), "It is no longer tenable to study ecological and social systems in isolation from one another. Humans are an integral part of virtually all ecosystems" (161). All natural resources are part of a complex web of social-ecological systems (SESs), which are composed of numerous biophysical and social subsystems and variables. Therefore, it is appropriate to analyze aggregate mining operations and subsequent reclamation and restoration projects with SESs theory, or coupled natural human systems, as these are well suited for analyzing complex systems.

Traditionally, ecological and social sciences have been studied independent of one another. Coupled human ecological systems have been gaining more traction recently as a means to further understand complex human-nature interactions. For example, the National Science Foundation (NSF) created a program in 2001, The Dynamics of Coupled Natural and Human Systems (CNH) Program, which awards grants to interdisciplinary teams researching these systems. Appropriate projects must analyze the dynamics of each chosen natural and human system, and how they affect each other. The growing field of SESs research has developed a number of key concepts that demonstrate how coupled natural human systems interact. This discussion of SES theory will use the example of an old growth forest, including governance structures that manage it, as an analogy.

SESs are often discussed in terms of resilience, which can be defined as the how much disturbance a system can absorb while maintaining its basic ecological function (e.g., the level of disturbance a system can withstand, like intermittent wildfires in an old growth forest) (Holling, 1996; Folke, 2006).

Three characteristics of SESs generally determine their future trajectories: resilience, adaptability, and transformability. Resilience is how well a system can absorb disturbance while maintaining its overarching functions. Adaptability corresponds to how well the actors in a system manage its resilience. Transformability is the ability of a system to begin anew if a regime shift occurs (Walker et al., 2004). All of these three characteristics can be influenced by the natural state of a system and human management or influence.

A central aspect of SESs is their lack of linearity. This is due to their size, complexity, unpredictability, and interplay between systems of varying scales (e.g., a stand of trees vs the whole forest vs state-wide management vs federal rules and regulations). Key processes used to understand and analyze SESs include feedback loops— the reciprocal influence of people and nature on one another—, temporal variations— including legacy effects and time lags—, and spatial variations. Legacy effects are how previous human-natural connections impact the current systems and time lags are delayed observable responses to change in SESs. For example, the implementation of forest management practices decades before the study of a particular system is a legacy effect and a time lag could occur 20 years from now if a new management practice were put in place today (Liu et al., 2007).

In response to the multi-dimensionality of SESs, adaptive management strategies in particular have been lauded as essential to increase the resilience of SESs. Adaptive management calls for flexible government structures, the inclusion of multiple levels of involvement (e.g., landowners and local NGOs in addition to traditional government entities), and holds collaboration and learning-based management as core values (Bodin

& Crona, 2009; Boyde & Folke, 2012; Fabricius et al., 2007; Folke et al., 2005; Olsson et al., 2004).

Finally, SESs are associated with the interrelated concepts of the adaptive cycle and panarchy. The adaptive cycle (Figure 7) was introduced by Gunderson & Holling (2002) and describes the processes a SES system goes through. The different phases include growth and exploitation (r), conservation (K), release (Ω), and reorganization (α). The transition from the exploitation phase to the conservation phase is referred to as the foreloop and the transition from release to reorganization, the backloop.

The Adaptive Cycle

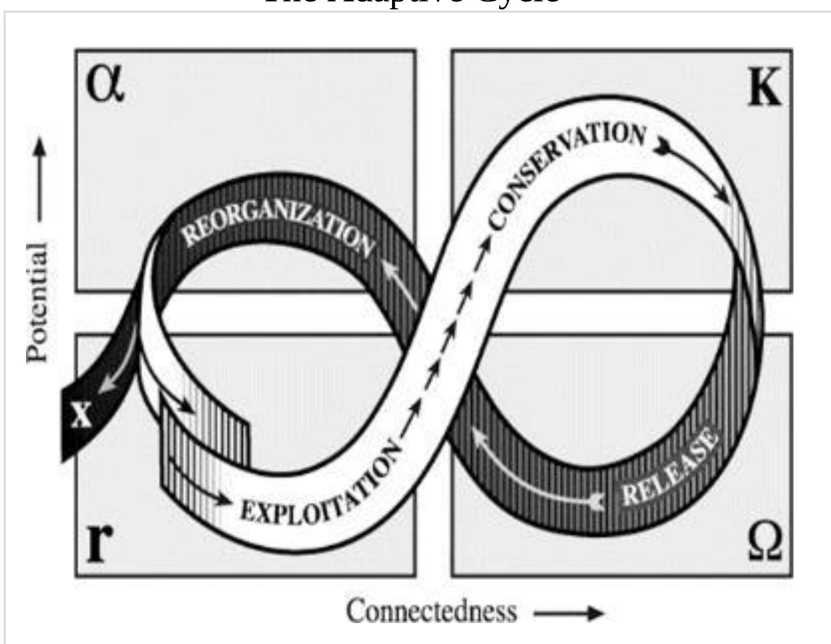

Figure 7. The adaptive cycle and its four interrelated growth and release phases (Gunderson & Holling, 2002).

The exploitation phase is characterized by growth and resource accumulation (growth and establishment of young shrubs, grasses, and trees), which leads to the conservation phase, also referred to as the equilibrium stage, which is characterized by stability (a mature old growth forest— a climax ecosystem), followed by the release - phase where a sudden collapse or extreme disturbance occurs (a forest fire), resulting in a rapid reorganization phase where the system reorganizes (reestablishment of grasses, shrubs, saplings, etc. which may be the same and (or) different from previous species).

Concept of Panarchy

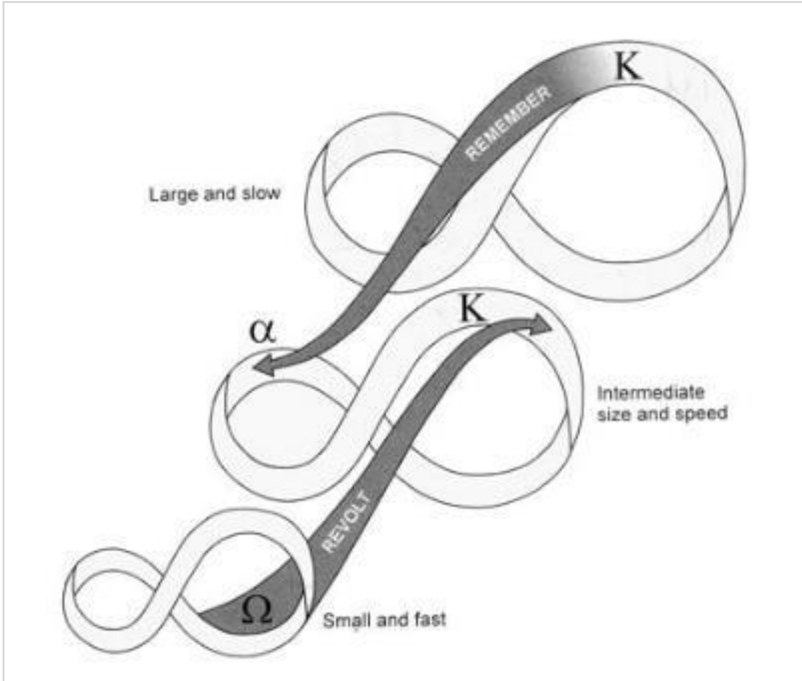

Figure 8. Panarchy: Nested, interrelated adaptive cycles at varying spatial and temporal scales (Gunderson & Holling, 2002).

The concept of panarchy (Figure 8) is that SESs interact and influence one another at varying scales (e.g., specific stands of trees can influence characteristics of the forest as a whole, and rules and regulations dictating forest management practices can influence the forest). SESs at varying scales move at different speeds— smaller SESs cycle more quickly and larger SES more slowly— and the collapse phase of smaller systems tend to influence those above, whereas the conservation phase of larger systems tends to have a more methodical influence on those below via system memory.

Following the heightened focus on SESs and call for greater understanding of these central concepts, Ostrom (2009) published a generalized framework for analyzing the sustainability of SESs. Four key interrelated subsystems— (1) resource systems, (2) resource units, (3) governance systems, and (4) users— are identified as relevant variables that can be used to understand and analyze SESs. Resource systems are the system being analyzed (e.g., the forest), resource units are the natural resources themselves (e.g., the trees), governance systems are the organizations and rules addressing resource extraction, and users are people who utilize the natural resource. Each of these core subsystems interact with one another and are additionally influenced by related ecosystems and social, economic, and political settings; each also consists of multiple second-level variables (e.g., user knowledge or size of a resource system).

Ostrom notes common second-level variables, and enumerates on the ten most frequently identified by studies that affect system sustainability, with a particular emphasis on the potential for a system to self-organizing: (1) size of a resource system, (2) productivity of a resource system, (3) predictability of system dynamics, (4) resource unity mobility, (5) number of users, (6) leadership, (7) norms/social capital, (8) knowledge of the SES, (9), importance of the resource to users, and (10) collective choice rules (ability of users to have a say in crafting rules governing the resource in question). While these are the select, most common second-level variables addressing system sustainability and self-organization, Ostrom also notes that variables chosen for analysis ought to be determined on a study-by-study basis.

2.2 Reclamation and restoration

The rehabilitation of natural areas has been increasingly recognized over time as valuable to our society. For example, “The Civil Works Program of the U.S. Army Corps of Engineers (Corps) recognizes habitat restoration as an important element in stewardship of our nation’s natural resources (e.g., Section 1135 of the Water Resources and Development Act of 1986, Section 204 of the Water Resources and Development Act of 1992)” (Pastorok et al., 1997). Reclamation and restoration projects can not only improve valuable ecosystem services and improve habitats, but they can also add cultural, ecological, social, aesthetic, and economic value to areas too.

Definitions and Perspectives

There are a number of reclamation and restoration strategies and definitions. The National Research Council (1992) differentiates between (1) restoration, the return of an ecosystem to approximately its pre-disturbance condition, (2) rehabilitation, the improvement of a system to ‘good working order,’ and (3) management, the manipulation of a system to maintain specific functions. While these strategies have isolated definitions, they are interconnected and are more appropriately viewed as part of an ecosystem improvement continuum.

Specific to this research, enhancement reclamation does not always fall into one of the aforementioned categories because non-ecologically based projects (e.g., commercial real estate) satisfy its definition because they maximize a site's secondary beneficial use potential. Ecologically-based enhancement reclamation projects, however, are many, and they ought to be considered with respect to this ecosystem improvement continuum.

There are four main ecological perspectives used for ecological restoration projects: (1) ecosystem, (2) key species functional, (3) bet-hedging design, and (4) adaptive management. The ecosystem perspective highlights the structure of an ecosystem at varying spatial and temporal scales (e.g. watershed scales and within a regional context). Key species, including threatened and endangered species and those that drive certain ecosystem functions must be taken into consideration during project planning. A bet-hedging design takes into consideration natural and anthropogenic disturbances that may occur at a given site and take such events into consideration during planning. Finally, adaptive management highlights the long-term plan of a site and recommends the implementation of a project in tiers that can be assessed over time as phases are implemented. The assessment of these phases ought to help further inform subsequent actions throughout the restoration process (Pastorok et al., 1997).

Processes and Evaluations

The process of reclamation and restoration can be broken down into three major parts: planning, implementation (strategies/techniques), and evaluation.

Many researchers agree that the planning stage of any restoration project is crucial to its success (Wyant et al., 1995; Hobbs and Norton, 1996). Specifically, end-goal (or vision) formulation at the onset of a project is essential for success in restoration projects in any geographic environment (Thom, 1997). Effective planning helps produce on-budget projects, while poor planning can curb restoration potential or, at worst, result in sites that do not provide the minimum necessary ecological functions (Westman, 1991). Due to the importance of planning, numerous decision frameworks for environmental restoration projects have been developed in the last two decades (e.g., Pastorok et al., 1997). Such frameworks attempt to standardize restoration work by laying a foundation for its initial stage; many are specific to particular environments like Thom's model (2000), which is directed at coastal restoration projects. A foundational part of the planning process is outlining ecological restoration goals, which Ehrenfeld (2000) breaks down into three categories: restoration of species, restoration of whole ecosystems or landscapes, and the restoration of ecosystem services.

Once primary goals are established, there are a number of strategies and techniques that can be utilized; the two fundamental paths restoration can take are active and passive. Traditionally, active techniques have been favored over passive (i.e., natural regeneration), but research has demonstrated that some ecosystems can recover quickly without human intervention and therefore a multitude of restoration approaches should be considered on case-by-case basis (Holl & Aide, 2010; Prach & Hobbs, 2008). However, the effectiveness of passive versus active restoration has been debated, with some of this debate centering on terminology (Clewell & McDonald, 2009). This ultimately leads to questions about the effectiveness and evaluation of such projects.

A large body of literature examines the assessment of restoration projects (e.g., a discussion of which characteristics ought to be measured to deem a project "successful"). However, it is generally thought that the monitoring and evaluation of projects overall happens too infrequently. Wortley et al. (2013) conducted a literature review focusing on the assessment of restoration projects following their completion. This review found that evaluation frequency has recently substantially increased, that the age of projects being evaluated has also risen, and that the majority of such research is being conducted in the U.S. and Australia. Wortley et al. also concluded that, while more ecologic projects are being evaluated following completion, socioeconomic characteristics are not being adequately addressed.

2.3 The reclamation and restoration of aggregate mines

Aggregate reclamation and restoration also has specific planning frameworks. Many states and other groups have published Best Management Practices (BMPs) for restoring sand and gravel pits and quarries. These publications tend to be aimed at reclamation in particular states (e.g., Norman et al., 1988; Wright, 2005), reclamation practices in a particular landscape or types of pit, such as within a 100-year floodplain or small gravel pits (Wright Water Engineers, 2013; Banks et al., 1981), or reclamation of pits for a particular purpose or land use, e.g., reclamation to cropland or for wildlife (Schroeder, 1997; Armitage, 1992). Furthermore, there is a particularly robust body of literature on the reclamation of alluvial sand and gravel pits for the purpose of creating fish habitat. In the last decade, there has been a particular interest in pit capture. This is when fish become trapped in pits adjacent to waterways during high flows and cannot get back to the main channel once flows recede. This can result in carnivory of threatened or endangered species by warm water species that can be dominant in such pits (Norman, et al., 1998). Therefore, many alluvial reclamation studies have called for the inclusion of safe fish passage in and out of pits to reduce the risk of pit capture as well as the expansion and widening of floodplains.

In addition to broad guidelines addressing reclamation techniques, the other dominant body of research on the reclamation and restoration of aggregate pits and quarries focuses on individual sites. Research has examined the outcomes of particular, often large-scale, reclamation and restoration projects (e.g., Delta Ponds in Eugene, OR, Butchart Gardens in Victoria, BC, or Chambers Bay golf course in Tacoma, WA). Projects such as these have demonstrated the value of having a champion— an individual or particular group with a dedicated vision for the site— and shown that to successfully complete projects of this magnitude, both funding and involvement should cover a wide spectrum. For example, John Ladenburg is lauded for the creation of the Chambers Bay golf course in Puget Sound, WA and is widely accepted as the “champion” of that project (e.g., Carson, 2015). The Delta Ponds in Eugene, OR brought together federal and state agencies, NGOs, and the local public as well as numerous sources of funding to achieve restoration success (e.g., the Delta Ponds).

Research has also been conducted on the success of particular types of reclamation and restoration techniques. In terms of mining, contemporaneous, segmental, and post-mining reclamation are three techniques that can be applied. Contemporaneous reclamation involves the transport of material directly from a newly opened mine to the mine being reclaimed. This method is desirable for aggregate operators because it reduces material transportation (material from the newly opened mine is only moved once), thus reducing overall costs. Segmental reclamation (i.e., concurrent) divides a site into portions that are methodically mined and then reclaimed. This method allows for the continuation of mining activities while reclamation occurs and reduces the amount of time from mining onset to the site's final reclaimed state. Finally, post-mining reclamation occurs after mining operations have concluded. This is typically the most expensive reclamation option, but it also requires less up-front planning (Shannon & Wilson, Inc., 2012).

The body of research that addresses specific projects includes work on revegetation success at gravel pits (Polster, 1989; Prach & Hobbs, 2008; Řehounková & Prach, 2008), establishment of native vegetation through natural seedfall (Roelle & Gladwin, 2002), the integration of reclamation into landscape design (Berger, 2008), and, — most often— the use of gravel pits as fish and wildlife habitat (Blomberg, 1982; Matter & Mannan, 1988; Harrison & Whitehouse, 2012).

While literature about reclamation and restoration of aggregate pits and quarries covers broad methodologies and outcomes of specific projects, there is a lack of literature addressing broad geographic patterns of reclamation and restoration; there are no known studies that document and compare a multitude of specific projects. The Minerals Education Coalition does have a selection of reclamation success stories on their website, which includes coal, industrial, and metal mine reclamation projects (see Minerals Education Coalition). Furthermore, there are no known studies that identify specific enhancement reclamation sites. The foremost publication about enhancement reclamation of aggregate mines comes from Arbogast et al., (1999), which includes a table of possible secondary beneficial use outcomes for both wet and dry mine sites. Arbogast et al. additionally frame reclamation and restoration from a human perspective, which helps integrate the process of mining (before, during, and particularly after) into the realm of social acceptance by demonstrating the restorative value of aggregate pits.

This research expands of the work done by Arbogast et al. by identifying enhancement reclamation outcomes based on their table of potential secondary beneficial uses. It additionally fills a research gap by conducting a geographic analysis of enhancement reclamation projects across a broad geographic area. This research is the first assessment of the status of enhancement reclamation in the Western U.S. and identifies what types of enhancement reclamation have occurred in various regions, states, and geographic environments. It will also lay the foundation for the creation of a nationwide database of enhancement reclamation projects.

3 METHODS

This research is the first step in the creation of a national database of enhancement reclamation projects at aggregate quarries and sand and gravel pits in the U.S. While this database will ultimately include projects in all fifty states, the current project addresses western region states (see Figure 1) in the contiguous U.S., hereafter referred to as “states of interest”. The western region was chosen for three reasons. First, it has the most diverse assemblage of unique ecosystems and land surface forms of any region in the conterminous U.S. (see Figures 4 and 5). Therefore, this region provided the greatest potential for providing diverse enhancement reclamation techniques and outcomes, and was assumed to provide an extensive sample of projects completed at quarries and sand and gravel pits. Second, the western region produces the highest percentage of sand and gravel of all regions in the U.S. (see Figure 2), which is key for this research because there are more reclamation and restoration options at sand and gravel pits compared to quarries. Third, the western U.S. is generally known for its social commitment to environmental welfare—particularly states in the pacific division. Specific to aggregate reclamation and restoration, this can be seen by the number of awards programs offered by states throughout the U.S. Seven of the eleven states of interest (64%) either have an active annual awards program or had such a program in the past, as indicated by this research. In contrast, just fourteen of the thirty-seven states (38%) in all other regions of the contiguous U.S. indicated the existence of such programs.

3.1 Data Collection

Snowball sampling was used for this research. Therefore, enhancement reclamation projects were selected purposefully, not randomly, and acceptable projects were selected based on the following essential criteria.

Inclusion Criteria

Three main criteria were taken into consideration when selecting projects for inclusion in the database: (1) satisfaction of the definition of enhancement reclamation, (2) project completion, and (3) the reclamation or restoration process.

Enhancement reclamation is defined as the actualization of a quarry or sand and gravel pit's maximum secondary beneficial use potential, achieved through reclamation or restoration. Therefore, sites with a clear secondary beneficial use (e.g., habitat for a particular species, public park, housing development) satisfied this definition. Abandoned or reclaimed sites that simply met minimum, permitted standards (e.g., pit edges sloped and site reseeded) or underwent natural succession and became e.g., a pond, were not included in this study.

Acceptable projects had to be completed, nearing completion, or practicing ongoing, concurrent reclamation. There are many barriers to reclamation and restoration projects and not all completed proposals come to fruition. Therefore, only projects that were confirmed completed or ongoing were included in the database.

Reclamation or restoration projects occur either because they are required by law or through voluntary action by e.g., a private landowner, NGO, or public organization. The former process is referred to as "permitted" and the latter "voluntary." Reclamation or restoration projects undertaken via either process were considered acceptable because either process can achieve the definition of enhancement reclamation

Identifying Enhancement Reclamation Projects

Enhancement reclamation projects were identified through personal communication and Internet searches, the latter providing several sources of information.

Personal communications were pursued in each state of interest and snowball sampling was utilized to achieve an exhaustive sampling frame (Bernard, 2011). Parties with direct influence and involvement in the reclamation and restoration of aggregate sites were contacted in each state of interest. These parties included: state agencies and county offices with aggregate permit responsibilities, aggregate trade associations, and selected aggregate companies (contacted based on personal recommendations and/or a review of reclamation data, e.g. previous projects presented on a company website). Parties were emailed or, if necessary, contacted by telephone. Individuals and groups contacted were asked for information about local reclaimed or restored aggregate sites that satisfied the definition of enhancement reclamation. Requested information included project name, location, a brief history, involved parties, and enhancement reclamation outcome(s).

Projects were also identified via an Internet search. This technique yielded four main project sources. First, state-based reclamation award programs were identified in seven of the eleven states of interest. Award-winning projects were further researched to determine if they met the aforementioned criteria. Second, local newspapers were utilized to identify enhancement reclamation and restoration projects. Often projects were reported on during their proposal and (or) planning stages, rather than following their completion. In such cases, personal communications via email or phone, if necessary, were conducted to determine the status of the proposed project. Third, relevant journals and magazines (e.g., Pit & Quarry) were searched for projects. Fourth, white papers, management plans, and similar resources published by parks and recreation districts, city councils, watershed councils, engineering firms, and similar groups were also utilized to identify projects.

Primary data sources included publications and personal communications with individuals and groups who were directly involved in the enhancement reclamation projects— archival data retrieved from permitting agencies were sometimes primary sources, but only when they pertained to site reclamation specifically, not when they only covered the mining history (in particular this occurred when a private group outside the mining company purchased a site and then restored it). Secondary sources included information that came from an outside source (e.g., newspapers or individual who knew about certain projects but were not directly involved.

3.2 Documenting Project Characteristics

Project characteristics (defined in Table 1) were chosen prior to the beginning of data collection. The four geographic environments were selected based on the Aggregate Mining on Farmland Issues Map (see Figure 6).

Table 1. Definitions of project characteristics collected

Characteristic	Explanation			
State	WA; OR; CA; MT; ID; WY; NV; UT; CO; AZ; NM			
Division	Geographic division as defined by the U.S. Census Bureau (Pacific and Mountain in the western region)			
City and County	Nearest city to project site and county.			
Population	Population of nearest city.			
Coordinates	Geographic coordinates of project site.			
Project Name	Name of the project or pit.			
Geographic Environment	Urban (project is within city limits)	Aquatic (project is within 0.5 miles of a lake, river, or stream)	Farmland (project is within 0.5 miles of farmland)	Non-farmland (e.g., forested, steppe, desert)
Reclamation Type	Secondary beneficial use(s) or project outcome(s). See Table 2.			
Geology	Quarry or sand and gravel pit.			

Reclamation types (Table 2) were adapted from Arbogast et al.'s (1999) table of after-uses for sand and gravel pits and hard rock quarries. Types included in the table presented here only include outcomes that were identified in this research, although other types and outcomes were considered during data collection (based on Arbogast et al.) and should included in future research. Public facilities, commercial/industrial, and residential were separately documented during data collection, and then combined into one category (development) for analysis. The same was done with storage and recycling (ecosystem services).

Table 2. Enhancement reclamation types and outcomes

Reclamation Type	Reclamation Outcome	
Conservation	Fish spawning	Stream restoration
	Passive lakes (aquatic habitat/waterfowl habitat)	Threatened/endangered species
	Riparian habitat	Native plant revegetation
	Wetland habitat	Wildlife habitat
Recreation	Swimming	Trails (hiking/biking/horse trails/pedestrian)
	Fishing	Public parks
	Boating/kayaking/paddleboarding	Camping
	Waterslide resort	Disc golf course
	Golf course	Athletic fields
	Dog park	Waterskiing
Public Facilities	Amphitheater	Sculptural
	School	Hospital
	Church	Restaurant
	Fire station	Landfill
Commercial/ Industrial	Office	Light manufacturing
	Shopping center	
Residential	Housing	
Recycling	Groundwater recharge	Water quality improvement
	Wastewater treatment	Sewage treatment
	Stormwater treatment	Aggregate recycling
Storage	Flood control	Water supply
Agriculture	Cropland (crops/vineyard)	Pasture
	Forestry	
Education/ Outreach	Historical/cultural	Educational events
	Interpretive signs	Heavy equipment training
	Nature center	

Reclamation types and outcomes were documented based on available source information and all types of enhancement reclamation activities were recorded, not just a project's primary purpose. For example, a quarry reclaimed to a public park that included a small wetland and the intentional preservation of a quarry wall would include: recreation (public park), conservation (wetland habitat), and education/outreach (historical/cultural).

3.3 Methodological limitations

There are three main limitations present in this study: data quality and availability, situational biases (institutional, social, and economic), and researcher's personal bias.

Data Availability & Quality

This study cannot hope to include all enhancement reclamation projects in the states of interest. There are currently no sources that document reclamation and restoration nationwide, meaning comparison against an existing inventory— to ensure the inclusion of all enhancement reclamation projects— would be impossible. Furthermore, documentation has historically been sparse (although improving over time), and was non-existent before rules and regulations were established in the 1970s. Mining began in the 1800s, so the stories of many pits have been lost to time.

Second, data availability also dramatically differed state-by-state. Certain states prioritize reclamation and restoration of aggregate sites more than others. The former states had more extensive and readily available information compared to the latter states. Some states also give reclamation awards for aggregate mines; others do not. Further differentiating between those with such awards programs, some states have a well-maintained, publicly accessible documentation of winning projects, while others do not and information is scattered.

Finally, the level of documentation and amount of information about each project varied greatly. Some sources provided only the essential information, while others included meticulous documentation about the project from start to finish. This was largely due to the varying source types from which projects were identified (e.g., newspaper articles versus technical project reports).

Situational Biases

There are three main forms of bias inherent in this research: (1) institutional, (2) social, and (3) economic bias.

Across the U.S. there is an institutional bias toward the reclamation and restoration of coal mines, due to the SMCRA, resulting in a possible bias against the reclamation of aggregate quarries and sand and gravel pits. Furthermore, because there is no federal law dictating the process of aggregate mining, regulation occurs at the state and county level. Therefore, states and counties that prioritize reclamation and restoration (i.e., have stricter rules and regulations) are more likely to have projects that satisfy the definition of enhancement reclamation. For example, states that exempt sand and gravel from reclamation have an institutional bias against enhancement reclamation. Additionally, rules and regulations about reclamation were not created until the 1970s. Therefore, there is an institutional bias towards the reclamation and restoration of younger pits— rather than those opened prior to the passage of reclamation laws. Reclamation is also largely dictated by land use zoning. Therefore, zoning regulations directly influence the planning and final outcome of reclamation projects.

Social bias is inherent in this research because individuals and groups— commonly landowners and vocal interest groups— can stimulate enhancement reclamation. Landowners or "champions" with an enhancement reclamation vision are often cited as examples of why projects get started. The power given to landowners to dictate land use (not zoning) is a form of institutional bias, but it is also social because one's motivations to reclaim are personal. Vocal groups (e.g., farmers, environmental advocates) can also influence reclamation and restoration. For example, enhancement reclamation to farmland is more likely to occur in an area with a vocal agricultural community that is in conflict with the aggregate industry. Finally, local social norms can bias reclamation and restoration; more environmentally conscious areas are more likely to pursue enhancement reclamation and have publications (e.g., newspaper articles) discussing such projects.

Last, economic bias exists in this research in two main forms. First, transportation costs are the greatest expense for the aggregate industry. Consumers prefer cheap aggregates, which increases demand for local materials and the likelihood of aggregate mines in urban areas. The cost of transportation is so great that locating mines close to the market has also been suggested to outweigh other potential land uses (i.e., agriculture) (Jaeger, 2006). Second, there is a bias toward the enhancement reclamation of urban sites because land values are more likely to increase as populations increase and development becomes more widespread. For example, a now abandoned sand and gravel pit, which was located on the edge of town when it was in operation, may become prime real estate over time as urbanization spreads. This may bias enhancement reclamation towards urban environments because with the increasing development, building at aggregate pits becomes not only cost effective, but lucrative.

Researcher's Personal Bias

Personal researcher bias was of most concern when (1) determining whether or not a project satisfied the definition of enhancement reclamation and (2) documenting geographic environment. To address the first, projects were deemed acceptable if a clear secondary beneficial use was present regardless of scale (e.g., a one-acre pit restored for the purposes of migratory bird habitat was treated the same as a one-hundred-acre pit with the same reclamation type). To address documentation of geographic environment, specific parameters were chosen and strictly adhered to for each geographic environment (see Table 1).

4 RESULTS

The results are divided into three main categories: (1) total identified sites, (2) identified sites by geographic environment, and (3) types of enhancement reclamation. The first section includes how many sites were identified in each state of interest, state-wide geographic distribution, number of quarries compared to sand and gravel pits identified, and number of identified sites by population. The second section addresses the frequency of enhancement reclamation by each of the four geographic environments, including how often each of the geographies overlap with one another. The final section displays the frequency of different types of enhancement reclamation (recreation, conservation, development, education/outreach, ecosystem services, and agriculture) identified overall and by geographic environment. Furthermore, the three most common types of enhancement reclamation are further broken down by specific activity.

4.1 Identified Enhancement Reclamation Sites

Roughly twice as many enhancement reclamation projects were identified in the Pacific subdivision (82 sites) compared to the Mountain subdivision (46 sites). Furthermore, the most enhancement reclamation sites were found in California (37), Oregon (33), Colorado (26), Washington (11), Idaho (7), Nevada (5), New Mexico (3), Arizona (2), Wyoming (1) and Utah (1). Figure 9 illustrates the total number of sites by state and regional subdivision (Pacific and Mountain).

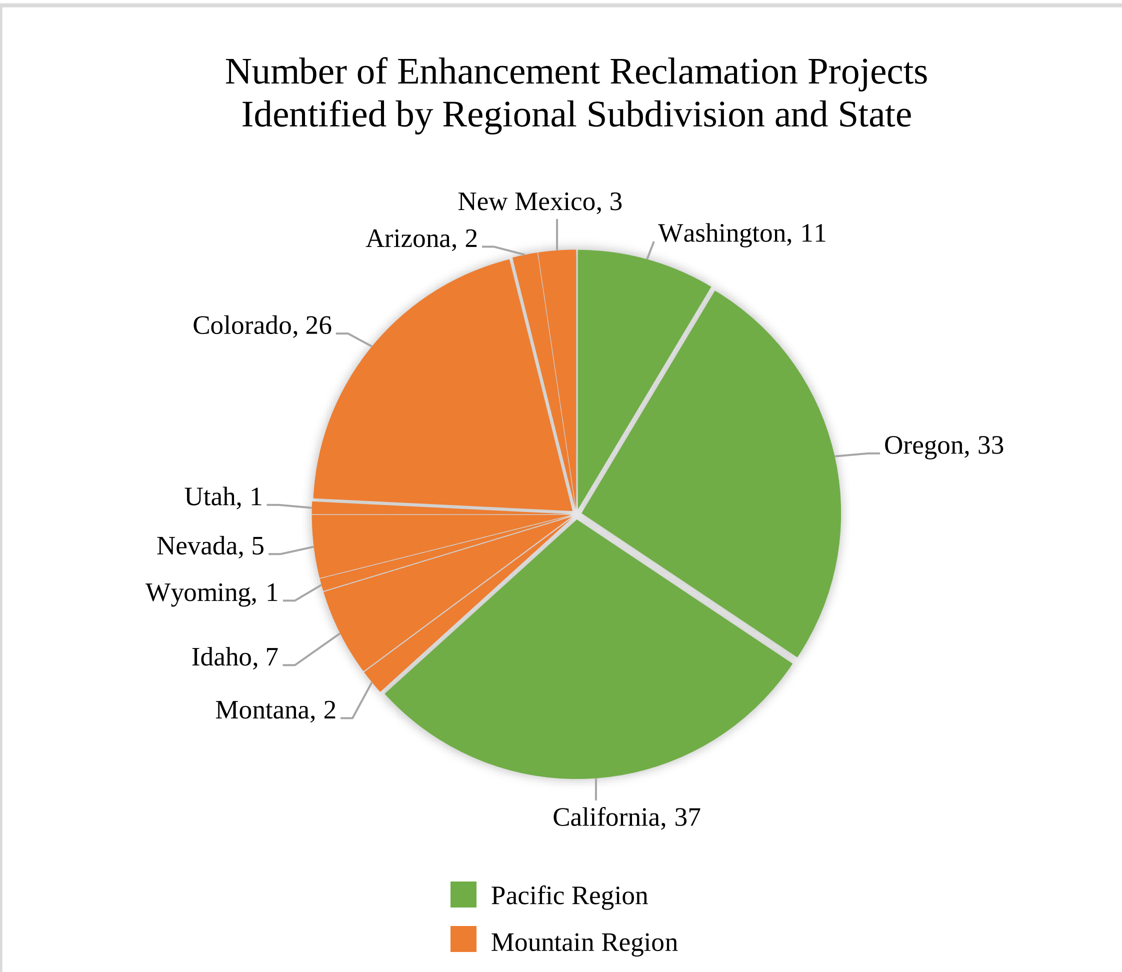

Figure 9. Number of enhancement reclamation sites identified in the Pacific and Mountain regions and in each state of interest.

More populated counties tended to have more enhancement reclamation sites than less populated counties (social factors including race, income, etc. are addressed in the discussion). To better understand the distribution of enhancement reclamation in each state, Figure 10 shows the percentage of counties in each state where at least one enhancement reclamation site was identified. When normalized by county, the same states that had the greatest number of total sites also had the greatest geographic diversity in where these sites were located. The greatest difference was seen in Colorado because fourteen sites were all located within the same county. Nevada and Idaho, too, showed less geographic diversity because all five sites identified in Nevada and four of the seven sites in Idaho were in the same county.

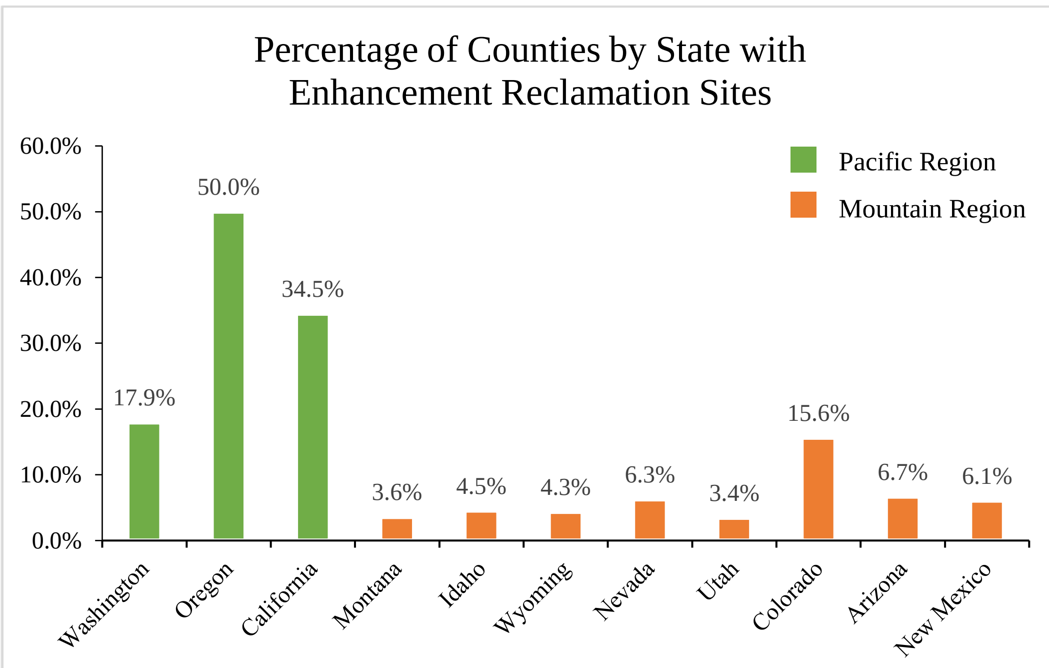

Figure 10. Percentage of counties within each state where at least one enhancement reclamation site was identified.

The number of sand and gravel pits compared to quarries was compared (Figure 11) and enhancement reclamation was vastly more common at the former.

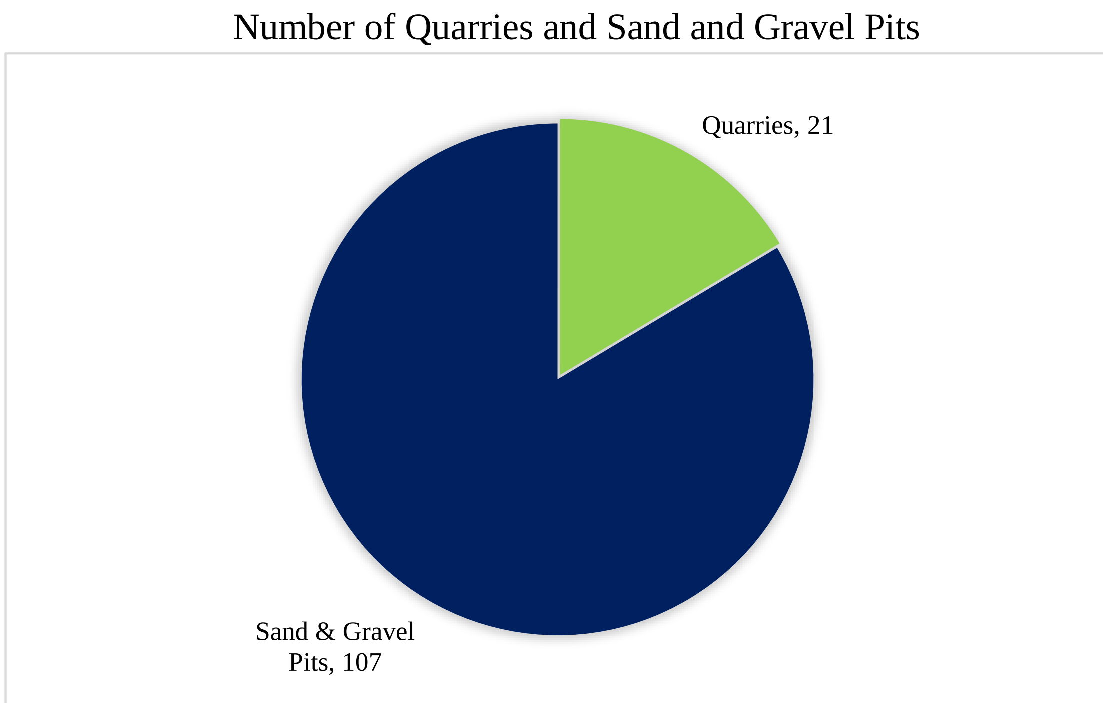

Figure 11. Number of identified quarries compared to sand and gravel pits

Finally, the population of the city each site was in or nearest to was noted. Figure 12 shows the number of sites identified based on local population. Urban areas (population greater than 50,000) had the most sites (49% of identified sites), followed by urban clusters (population 2,500 – 50,000; 35%), and rural areas (population < 2,500) the least (16%).

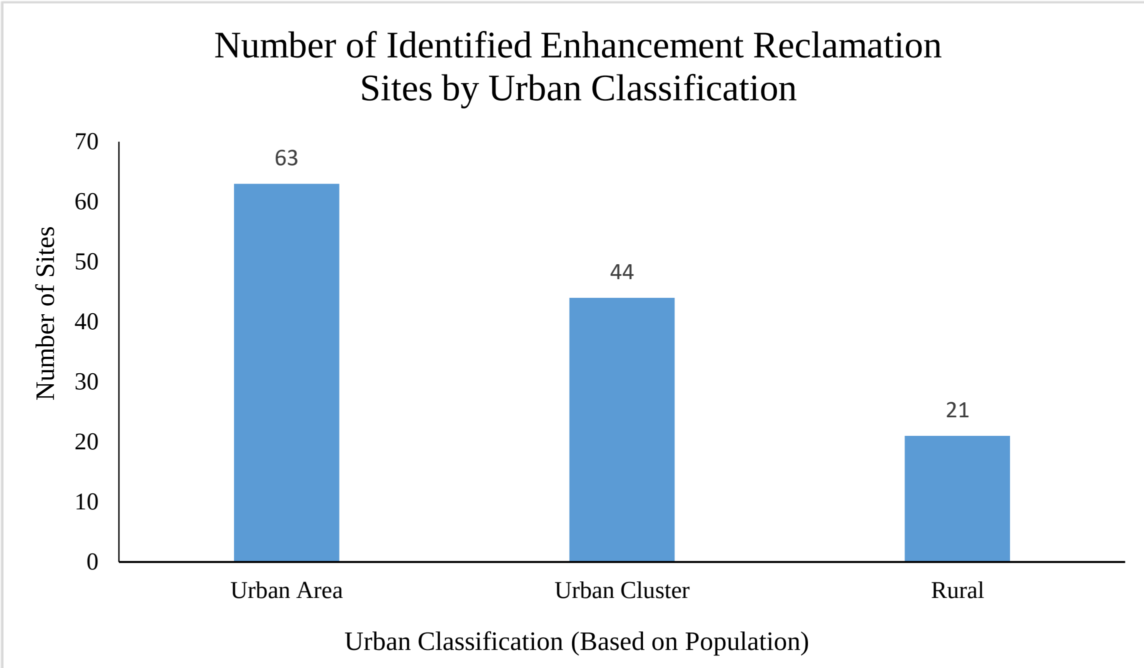

Figure 12. Number of sites identified by urban classification. Classifications are based on U.S. Census Bureau definitions (see Section 1.2) based on population.

4.2 Frequency of Enhancement Reclamation by Geographic Environment

Identified sites were categorized by their geographic environment. Non-farmland sites were further divided by ecosystem (forest, grassland, steppe, scrub/savanna, or desert). Sites occupying more than one geographic environment (i.e., overlapping) were also recorded. Overall, 41 sites (32%) were in single environments, 81 were in coupled environments (63%), and 6 were in three overlapping environments (5%).

Based on this methodology, the number of identified geographic environments is greater than the total number of sites. Figure 13 shows where enhancement reclamation sites were identified: aquatic (61% of all sites), urban (53%), non-farmland (31%), and farmland (24%).

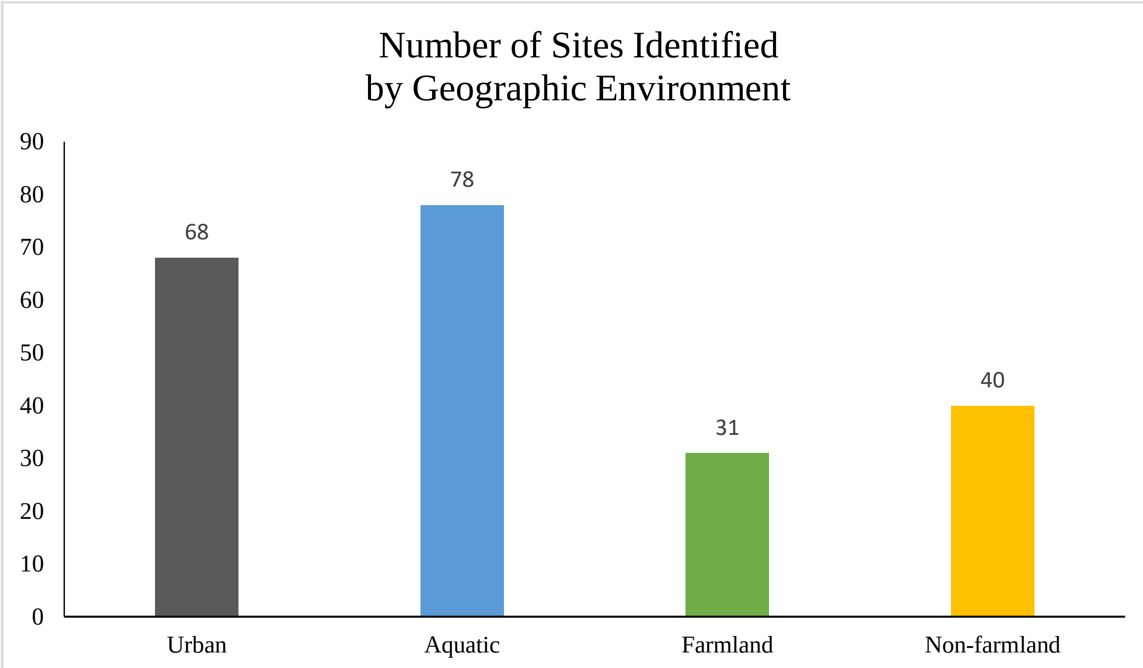

Figure 13. Number of sites identified within each of the four geographic environments. Number of sites does not represent total number of sites identified because many sites were in more than one geographic environment.

Figure 14 shows in greater detail where enhancement reclamation sites were identified by ecosystem at non-farmland sites. This geographic environment is separated by quarries and sand and gravel pits because the majority of quarries (95%) were identified as non-farmland. The most frequently identified non-farmland ecosystems were: forest (13% total sites; 42% non-farmland sites), steppe (7% total sites; 22% non-farmland sites), grassland (4% total sites; 13% non-farmland sites), desert (4% total sites; 13% non-farmland sites), and scrub/savanna (3% total sites; 10% non-farmland sites).

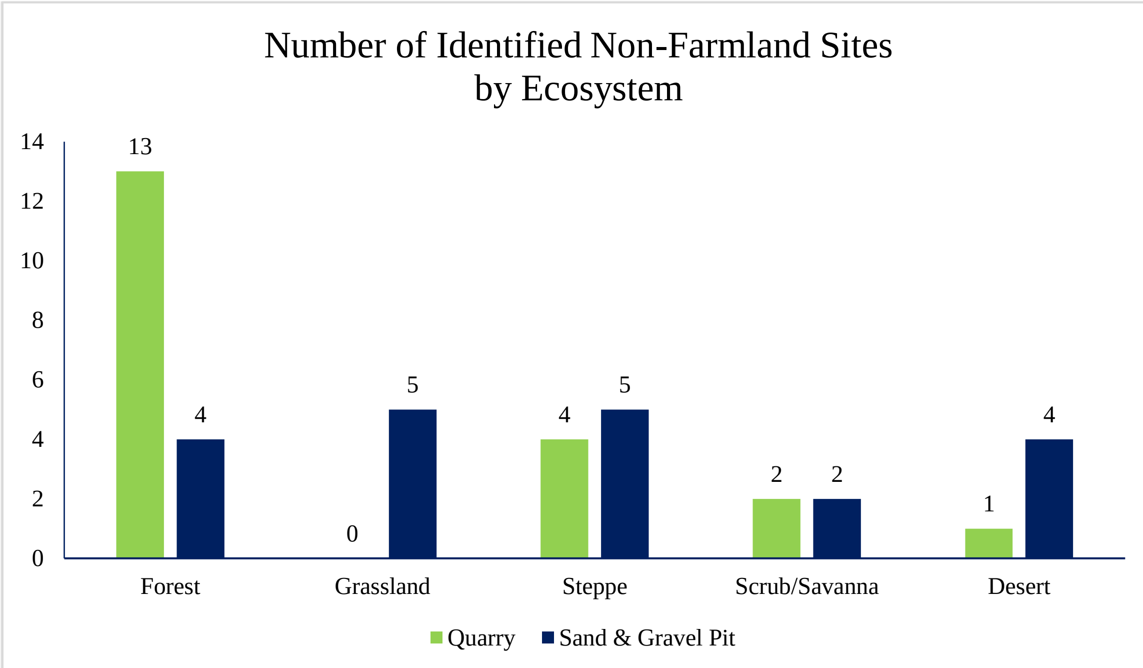

Figure 14. Number of identified non-farmland sites by ecosystem and geology (quarry or sand and gravel pit).

The number of sites identified by geographic environment were also compared by population of the nearest city and broken down by the U.S. Census Classification (Figure 15). Similar to the total number of sites identified, sites identified in urban, aquatic, and farmland geographic environments were most frequently found in urban areas, followed by urban clusters and then rural areas. Non-farmland sites, however, were most frequently found in urban clusters, followed by rural areas, and finally urban areas.

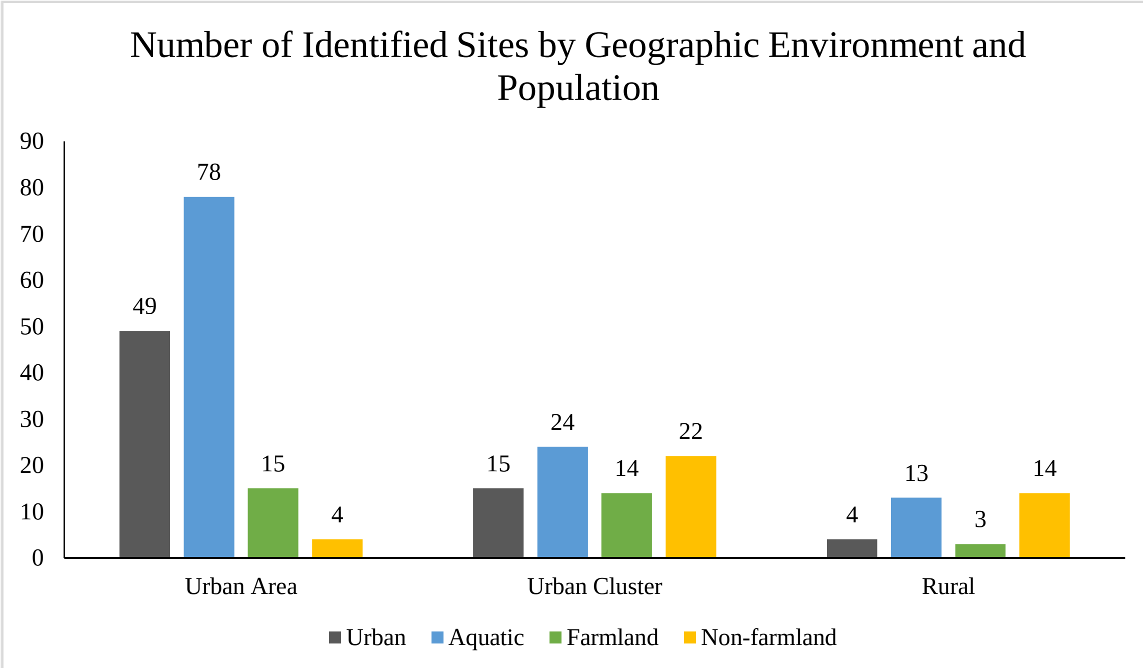

Figure 15. Number of enhancement reclamation sites identified by geographic environment and population (based on U.S. Census Urban Classifications).

4.3 Types of Enhancement Reclamation

Types of enhancement reclamation at all identified sites are shown in Figure 16. Figure 17 breaks down types of reclamation by geographic environment. All graphs are separated into quarries and sand and gravel pits. Types of enhancement reclamation identified at non-farmland sites are further broken down by ecosystem in Figure 18.

The most common types of enhancement reclamation (percentages by total number of identified sites) were conservation (65%), recreation (42%), development (20%), ecosystem services (19%), education/outreach (18%), and agriculture (10%).

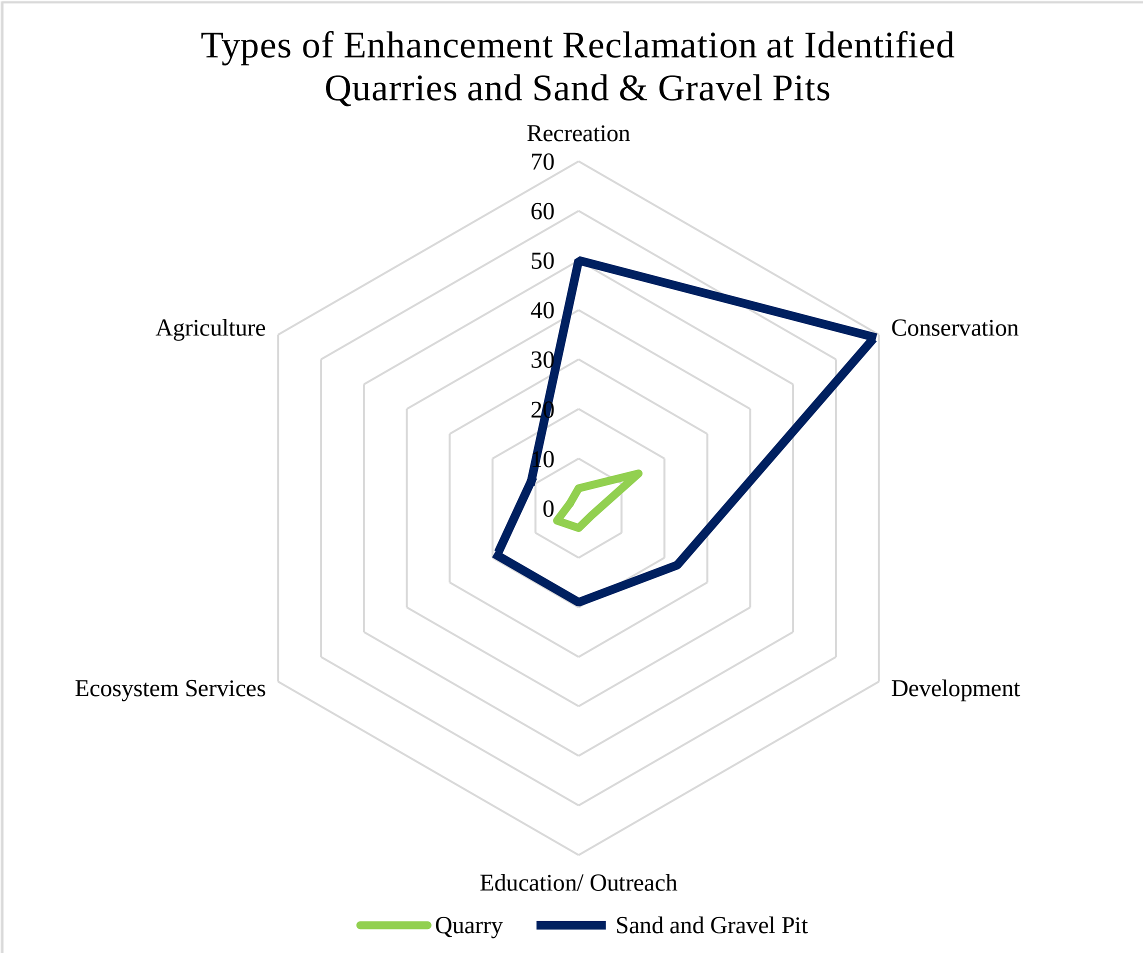

Figure 16. Total number of enhancement reclamation sites identified by reclamation type.

Sites identified in urban environments were most often reclaimed to recreation (40 sites, 59% of urban sites), conservation (39 sites, 57% of urban sites), development (30 sites, 44% of urban sites), education/outreach (17 sites, 25% of urban sites), ecosystem services (16 sites, 23.5% of urban sites), and agriculture (1 site, 1.5% of urban sites) uses.

Sites identified in aquatic environments were most often reclaimed to conservation (61 sites, 78% aquatic sites), recreation (40 sites, 51% of aquatic sites), education/outreach (18 sites, 23% of aquatic sites), ecosystem services (18 sites, 23% of aquatic sites), development (10 sites, 13% of aquatic sites), and agriculture (6 sites, 8% of aquatic sites) uses.

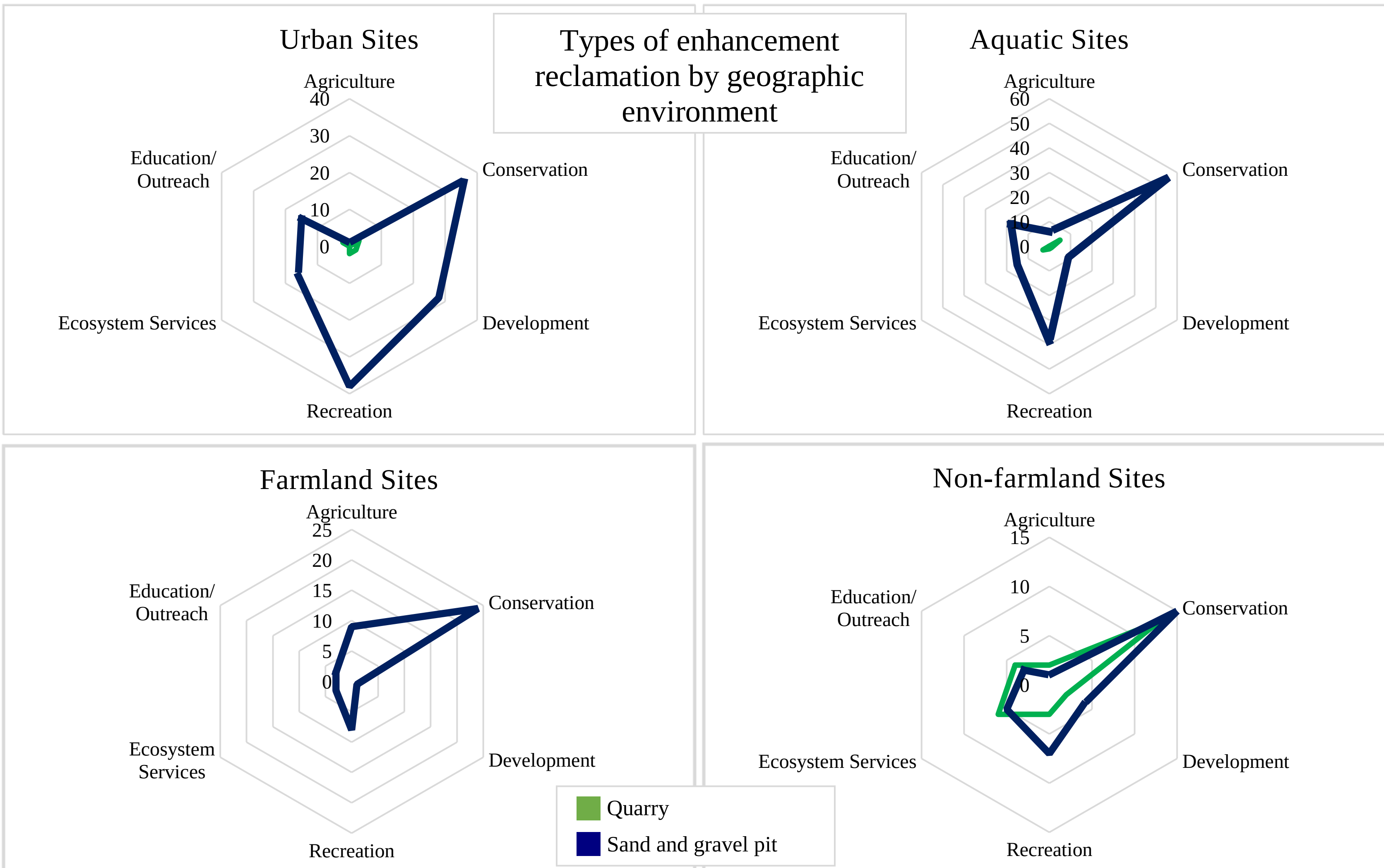

Figure 17. Frequency of different types of enhancement reclamation found at identified urban, aquatic, farmland, and non-farmland sites.

Sites identified in farmland environments were most often reclaimed to conservation (24 sites, 77% farmland sites), agriculture (9 sites, 29% farmland sites), recreation (8 sites, 26% of farmland sites), ecosystem services (3 sites, 10% of farmland sites), education/outreach (3 sites, 10% of farmland sites), and development (1 site, 3% of farmland sites) uses.

Sites identified in non-farmland environments were most often reclaimed to conservation (28 sites, 70% non-farmland sites), ecosystem services (11 sites, 27.5% of non-farmland sites), recreation (10 sites, 25% of non-farmland sites), education/outreach (7 sites, 18% of non-farmland sites), development (6 sites, 15% of non-farmland sites), and agriculture (3 sites, 8% of non-farmland sites) uses.

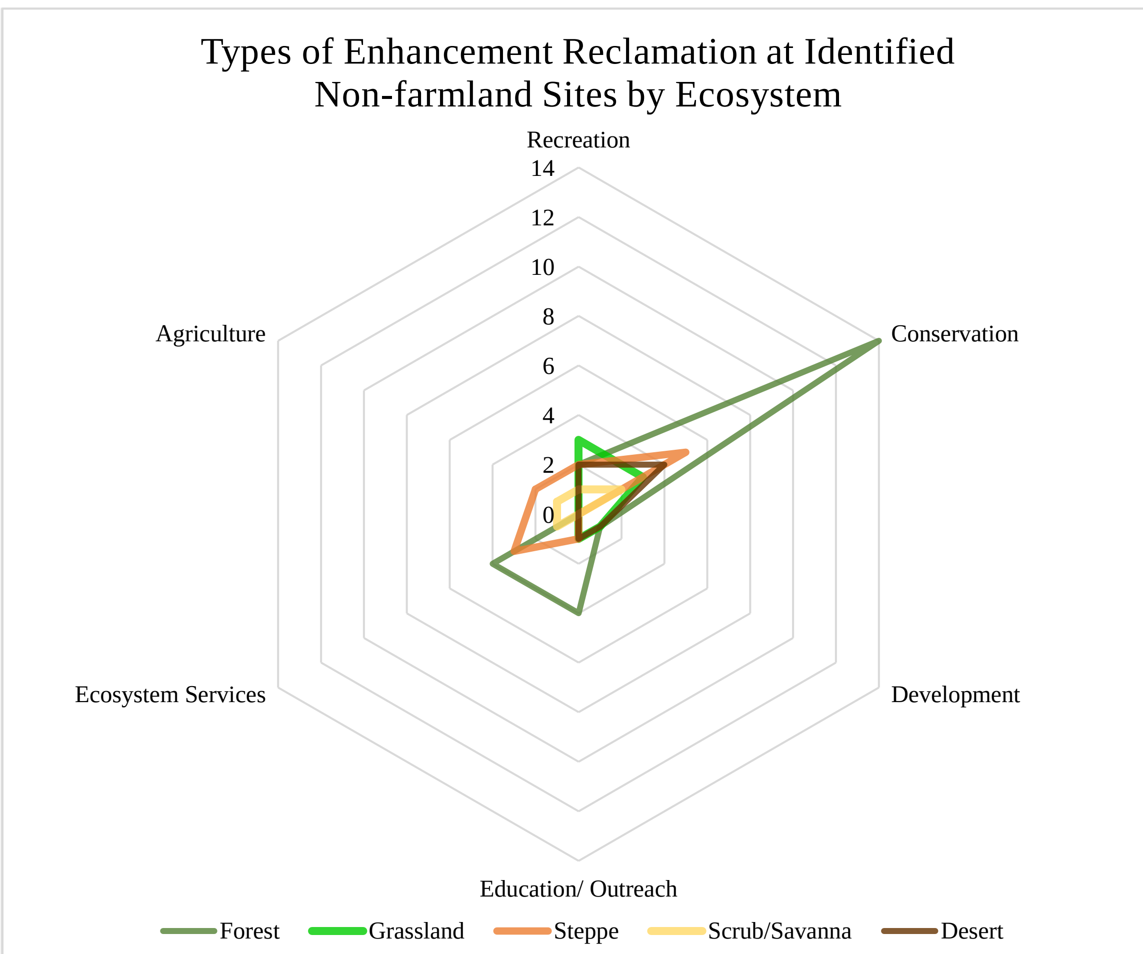

Figure 18. Frequency of different types of enhancement reclamation found at identified non-farmland sites by ecosystem.

Many types of enhancement reclamation were not identified at various non-farmland ecosystems. Identified types are enumerated below in order of most identified sites.

At forested sites: conservation (14 sites, 35% of non-farmland sites), education/outreach (4 sites, 10% of non-farmland sites), ecosystem services (4 sites, 10% of non-farmland sites), recreation (2 sites, 5% of non-farmland sites), and development (1 site, 3% of non-farmland sites) were the most common uses.

At grassland sites: recreation (3 sites, 7.5% of non-farmland sites), conservation (3 sites, 7.5% of non-farmland sites), development (1 site, 2.5% of non-farmland sites), and education/outreach (1 site, 2.5% of non-farmland sites) were the most common uses.

At steppe sites: conservation (5 sites, 12.5% of non-farmland sites), ecosystem services (3 sites, 7.5% of non-farmland sites), recreation (2 sites, 5% of non-farmland sites), agriculture (2 sites, 5% of non-farmland sites), and education/outreach (1 site, 2.5% of non-farmland sites) were the most common uses.

At scrub/savanna sites: conservation (2 sites, 5% of non-farmland sites) was the most common use and each recreation, ecosystem services, and agriculture had 1 site (2.5% of non-farmland sites).

At desert sites: conservation (4 sites, 10% of non-farmland sites) and recreation (2 sites, 5% of non-farmland sites) were the most common and education/outreach and development each had one site (2.5% of non-farmland sites).

5 DISCUSSION

The key findings of this study include the regional and state-by-state distribution of enhancement reclamation sites, frequency of enhancement reclamation sites by geographic environment, and frequency of different types of reclamation. This section explores geographic patterns at the meso (regional, states) and micro (geographic environment, reclamation type) scales and frames the findings within the scope of SES theory, including the adaptive cycle and Ostrom’s generalized framework for analyzing SESs. It also proposes the application of a “geography of amenity” pattern that emerged from the data.

5.1 High and Low Frequency States

The states of interest in this study can be divided into two categories in terms of enhancement reclamation: (1) high frequency and (2) low frequency. Table 3 compares high versus low frequency criteria and lists the states in each category. All of the high frequency states satisfied at least two of these criteria. It must be noted that, in every high frequency state, there are many non-enhancement reclaimed sites, and in low frequency states there are almost certainly enhancement-reclaimed sites that have not been identified in this study.

Table 3. Criteria dividing high and low frequency states

Criteria	High Frequency	Low Frequency
Number of sites	≥ 10	< 10
Number of data sources	≥5 unique data sources (e.g., each individual counted as a unique source) that provided at least one enhancement reclamation site.	< 5 unique data sources that provided at least one enhancement reclamation site.
Data access	Easily accessible online data; clear identification of contact individuals, agencies, and professional groups with knowledge of local enhancement reclamation.	Limited or no online data; greater difficulties identifying appropriate agencies and (or) individuals with knowledge of local enhancement reclamation.
States	WA, OR, CA, CO	MT, ID, WY, NV, UT, CO, AZ, NM

Number of sites

The definition of high vs low frequency states was based on the number of identified enhancement reclamation sites (Figure 9) and geographic distribution (Figure 10). Geographic distribution was included in high and low frequency designation because some states had numerous sites, but within just one or two counties. For example, Idaho and Nevada had 7 and 5 identified sites, respectively, but the sites in Idaho spanned two counties, and in Nevada only one. Furthermore, analyzing geographic distribution normalized Colorado, which had fourteen sites in one county. It is considered a high frequency state because 15.6% of its counties have at least one enhancement reclamation site; the next closest low frequency state (Arizona) included 6.7% of its counties.

Data sources and access

The process of data collection for each state of interest in this research is, in itself, a point of discussion because there was a clear division between states where information was readily available (high frequency) and those where it was not (low frequency).

High frequency states tended to have more readily available access and more unique data sources, including reclamation award programs, articles in newspapers, magazines and journals, research documents, and numerous individuals with knowledge about enhancement reclamation projects in their state. Generally, fewer agencies, companies, groups, and individuals needed to be contacted in high frequency states because those contacted at early stages of data collection had information about, and knowledge of, enhancement reclamation sites in their states. Additionally, a more diverse set of data sources were available (and utilized) in high frequency states. Therefore, more individuals (including not only professionals connected to the aggregate industry and reclamation, but journalists, researchers, and others) had knowledge of enhancement reclamation in these states, demonstrating an overall greater awareness of enhancement reclamation in these states. This may be partly attributed to environmental awareness as a social norm in these states, high levels of education about such issues, and subsequent availability of jobs in high frequency states.

Although this does not explain why high frequency states have more enhancement reclamation projects, it does help confirm the high-low categorization of these states. Bathelt et al., (2004) showed that firms located in clusters— a group of inter-connected, associated institutions in a particular field linked by commonalities, that can range from the city to country scale (Porter, 2000)— that were part of the local "buzz" had learning, networking and performance advantages over outsiders due to their proximity to one another; this is also referred to as agglomeration economics. Similarly, states where enhancement reclamation is more commonplace will display greater networking and learning— awareness— compared to states where it is infrequent.

5.1.2 SES theory and high and low frequency states

A common critique of Holling's adaptive cycle is its simplicity. It is applied to vastly complex human-ecological systems at varying temporal and spatial scales and such a modest concept cannot capture the intricacies of the systems it seeks to explain. Said another way, it is a two-dimensional model explaining a three-dimensional world with three-dimensional issues; this critique holds true with respect to this study. The incidence of enhancement reclamation cannot be fully explained with the adaptive cycle because there are so many factors at play that determine whether or not a pit will be reclaimed and how. However, the adaptive cycle's simplicity is also part of its utility as a metaphor for interactions and changes within SESs— it is even called a "tool for thought" by the Resilience Alliance. Therefore, the following discussion does not apply the adaptive cycle as a strict model, but rather a tool that helps explain in part why certain patterns emerge with respect to enhancement reclamation of pits in the western U.S.

In terms of the overarching theory of SES's, enhancement reclamation is most associated with the concept of transformability, which is the ability of a system to reestablish itself once a regime shift has occurred, and second with resilience, which is the ability of a system to absorb disturbance while still maintaining its basic ecological functions. Mining, at the local level of the pit itself and its immediate surroundings, can be viewed as a regime shift. Therefore, enhancement reclamation following mineral extraction increases the transformability of a system because it helps bring the site into a new regime. Furthermore, enhancement reclamation can also increase system resilience at the meso scale (e.g., county or state) because it increases the potential that mined lands may be returned to their pre-disturbance state. When applied to the adaptive cycle, enhancement reclamation fits into the innovation and new growth phases and encourages the latter because it helps move a system into a new status quo and regime.

Every SES can be placed along the continuum of the adaptive cycle (Figure 7). The adaptive cycle has most commonly been applied to more ecologically driven systems (e.g., an old growth forest), but the SESs of aggregate mining and enhancement reclamation are primarily human-driven. Therefore, this research can utilize the recent model of Fath et al. on the adaptive cycle as applied to social systems (Figure 19).

The Social Adaptive Cycle

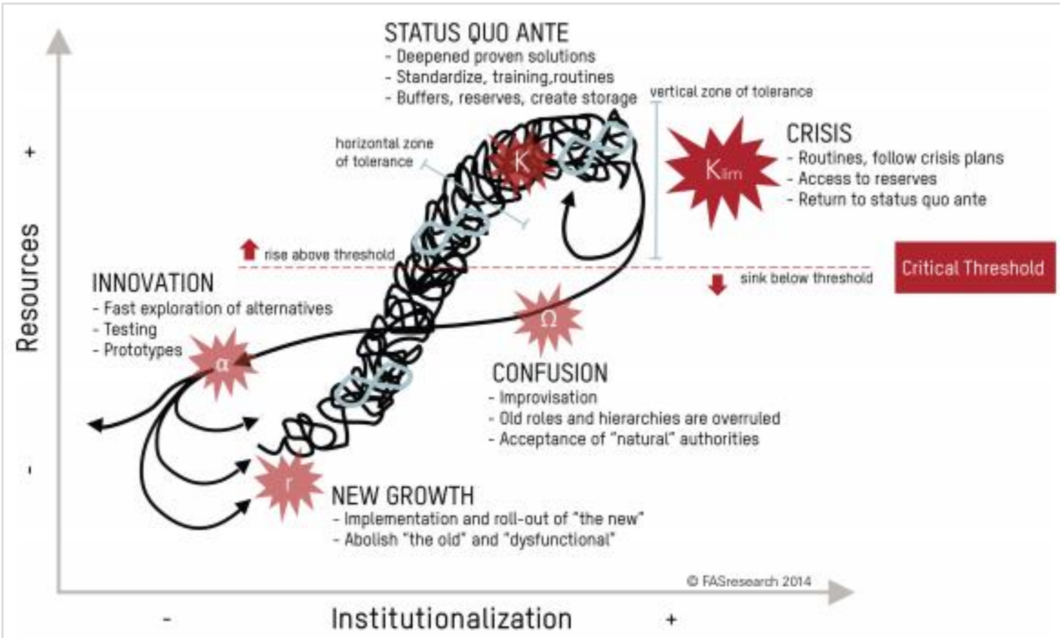

Figure 19. The adaptive cycle as applied to social systems (Fath et al., 2015).

The SESs in which aggregate mines and their enhancement reclamation exist contain four key interrelated variables: the aggregate industry, aggregate-governing bodies, local users, and mined lands. If each state of interest is examined as its own SES (in the context of aggregate mining and enhancement reclamation), then high frequency state SESs can be placed within the confusion (Ω) — innovation (α) portion of the continuum and low frequency states in the status quo ante (K) portion. These SESs ought to be regarded on a continuum rather than in a singular phase because SESs do not behave linearly, can go back and forth between phases, and each mine is also uniquely within its own individual adaptive cycle (e.g., each mine represents an embedded sub-adaptive cycle or can be viewed as a smaller, nested adaptive cycle within the panarchy framework; see Figure 8) (Gunderson & Holling, 2002).

The status quo ante phase in the aggregate mining – enhancement reclamation SES may be characterized by "business as usual" mining practices: aggregate resources are locally plentiful and little conflicts arise between competing land uses. In this scenario little enhancement reclamation occurs because few drivers exist. Low frequency states demonstrate this pattern.

In contrast, the confusion phase may be characterized by land use conflicts, increased societal demands and pressures (e.g., for improved environmental stewardship or local amenities), or newly implemented rules and regulations. The innovation phase may be characterized by the onset of enhancement reclamation practices. Finally, the new growth phase may be characterized by enhancement reclamation becoming the norm, whether by voluntary reclamation or through a stricter permitting structure.

Land use pressure is considered the driving variable in these SESs because the purpose of any enhancement reclamation is to produce a secondary beneficial use to degraded mine lands. If "land" is placed on the y-axis in Fath et al.'s social adaptive cycle, then, when it becomes a scarce enough resource and crosses the critical threshold, enhancement reclamation will begin to occur.

These concepts will be illustrated by comparing a high frequency state (Oregon) to a low frequency state (Wyoming).

Oregon

The late status quo ante phase (i.e., as a system approaches the resources threshold) is frequently characterized by "locked up" resources and system rigidity. Land use in Oregon's Willamette Valley (where the majority of enhancement reclamation projects were identified) exhibits such a "locked up" resource pattern. The state's most desirable aggregate resources are located within the Willamette Valley, which is the most densely populated region of the state (2.8 million, 70% of the state's population). This region has experienced considerable recent population growth and development, is home to much of the state's prime farmland, and its namesake, the Willamette River, hosts economically and socially valuable threatened and endangered salmonids. Furthermore, Oregon has some of the most innovative and strict land use planning laws in the country. Senate Bills 100 and 110 (1973) developed a statewide framework for land use planning and also required every city and county to develop a comprehensive land use plan. Environmental wellbeing is also a social norm in Oregon— particularly in the western part of the state— and issues surrounding gravel mining have been cited specifically in the Willamette Valley and in the southern coastal region (Jaeger, 2006; Ewing, 2010;

Morrison, 2015). Each of these variables contributes to the land becoming "locked up," which increases land use competition and scarcity of resources.

Over time land use conflicts surrounding aggregate mining have increased. Frequent conflicts included farmers fighting the aggregate industry over mine permitting on prime farmland, environmentalists fighting the permitting of mines near the Willamette River to limit impacts on salmonids, and local citizens fighting the permitting of mines, displaying a "not in my backyard" (referred to as "NIMBY") mentality. Permitting aggregate mines has become increasingly difficult over time as issues continually mounted. All of these circumstances constitute the confusion phase.

The innovation and new growth phases can be seen since the 1970s and are also marked by an increase in system resilience at the local scale. Innovation began with the formation of the Mineral Land Regulation & Reclamation (MLRR) program within the Oregon Department of Geology and Mineral Industries, which crafted statewide reclamation requirements for aggregate mines, and later implemented an annual reclamation awards program. The program has worked with mine operators to test new reclamation techniques (innovation phase), and reclamation requirements in permits have steadily gotten stricter over time. Today, it is not uncommon for enhancement reclamation to be the norm for newly permitted sites, which even indicates the early stages of the new growth phase. By creating secondary beneficial uses at mine sites, enhancement reclamation transforms disturbed lands and increases system resilience.

Wyoming

Wyoming is roughly 1,000 square miles larger than Oregon and has a total population of 584,153. It is the second least densely populated state in the U.S. However, in 2012 Oregon and Wyoming produced nearly the same quantities of both crushed stone and construction sand and gravel (USGS, 2012).

Wyoming's aggregate – enhancement reclamation SES is currently in the status quo ante phase because land is plentiful and there are few competing uses (e.g., farming, dense areas of development). "Land" as a resource has not crossed the critical threshold, so mines are generally not drive to enhancement reclamation. It can therefore be projected that when land crosses this threshold, the likelihood of enhancement reclamation will increase because it can help alleviate future land use tensions.

5.1.3 Self-organization and enhancement reclamation projects

While each state of interest has been classified as either high or low frequency, the completion of each individual enhancement reclamation project is ultimately what dictates a high or low frequency state. Therefore, variables that influence why or why not enhancement reclamation projects occur are key to understanding the differences between high and low frequency states. Ostrom's (1999) framework specifically addresses variables that influence the potential for SESs to self-organize, and enhancement reclamation projects can be viewed as the result of self-organization whether or not they are voluntary or permitted (see Section 2.1). Permitted projects can be viewed as the result of self-organization because there is no federal law mandating reclamation and individual permitting agencies have discretion over the level of reclamation they require. Four key variables identified in Ostrom's framework best explain the greater likelihood of self-organization (i.e., actualization of an enhancement reclamation project) in high frequency states compared to low frequency states: norms/social capital, importance of resource, leadership/entrepreneurship, and government organizations.

Norms/social capital

It has been shown that public support can be essential for the success of restoration projects. Cairns (2000) states this well: "Major ecological restoration will not be undertaken unless human society approves the goals and objectives of restoration" (171). The higher number of conservation-based enhancement reclamation projects in high frequency states, which are generally considered more environmentally conscious than low frequency states, supports the finding that stronger environmental values increase the likelihood of enhancement reclamation.

For example, the primary purpose of numerous projects in Oregon was to create spawning habitat for salmonids, which are of both economic and social importance in the Pacific Northwest. Societal environmental norms can also help explain the case of Colorado because Fort Collins, CO (where fourteen enhancement reclamation projects were identified— all conservation-based) strongly identifies with its local river, the Poudre (e.g., see England, 2011). This finding suggests that even in regions or states less likely to pursue enhancement reclamation, local pockets with particular social norms may drive its occurrence.

Finally, there is a long history of mining in low frequency states, and numerous very large, open pit mines. Therefore, mining is not only more commonplace in low frequency states, but the scale of aggregate mining is much less in comparison to what the region is used to. For example, a one hundred acre sand and gravel pit is dwarfed by Utah's Bingham Copper Mine, which has been in operation since 1906, is over 3,000 feet deep, covers roughly 1,900 acres, has caused local landslides, lead, arsenic, sulfur dioxide, and lead contamination, and was proposed for Superfund classification in 1994 (Arrington & Hansen, 1963; Linn & Thomas, 2008). This finding is consistent across low frequency states, where other types of mining (frequently associated with environmental hazards, e.g., coal and uranium) are prominent and the reclamation of these mines gets top priority (e.g., Smyth & Dearden, 1998; Tordoff et al., 2000; Chambers et al., 1994; WoldeGabriel et al., 2014).

Importance of resource

Ostrom also states that users are more likely to self-organize when they attach high value to a resource system or depend on it for their livelihood. High frequency states have more high value, desirable agricultural lands and attach greater value to sensitive habitats as compared to low frequency states. Additionally, high frequency states have larger, denser populations that rely on land for development. These factors all encourage enhancement reclamation in high frequency states because land is both valuable and scarce. The placement of value on land is driven by local land use. For example, in agricultural areas users are likely to place high-value on enhancement reclamation to farmland. In areas with high rates of population growth value will be placed on housing or industry to create jobs, or in more affluent areas value may be placed on entertainment-based amenities such as golf courses or shopping centers. Enhancement reclamation in relation to community demographics and other pertinent social factors are addressed at the end of the discussion.

Grassland, steppe, scrub/savanna, and desert environments, the greatest utility of which (outside development and mine use) is commonly grazing, are dominant ecosystems in low frequency states. While some users' livelihoods do depend on these lands for grazing, there is little scarcity, which does not incentivize enhancement reclamation, thus making it less common. This is supported by the low percentage of projects identified in these environments (18% of all identified sites).

Leadership/entrepreneurship and government organizations

Resilience literature frequently touts leadership and entrepreneurship as vital components of successful projects (e.g., Hahn et al., 2006). In all four high frequency states, multiple identified projects cited a particular individual or group who was viewed as essential to the project's success. Such "champions" were also recognized in low frequency states, but in far fewer numbers.

It is unreasonable to assume there are simply better leaders and entrepreneurs in high frequency states. First, the difference may be partly attributed to the level of detail provided by data sources. Second, such areas may be more economically prosperous overall and thus have greater funds to allocate to these projects. Third, economics may be linked to available education in these areas too— there may be more funding for education in general as well as greater opportunities for environmental or sustainability students. Finally, the stronger environmental social norms seen in high frequency states likely encourage more expansive networks of restoration experts, available educational resources, and previous projects to learn from and be inspired by. This is supported by the recent concept of industry clusters: tight connections that bind industries together by e.g., sources of innovation and geographic location (Bergman & Feser, 1999). Third, environmental education may be greater in these areas.

Government organizations can also be viewed as a form of leadership in the context of enhancement reclamation. Absence of a federal law dictating aggregate reclamation processes allowed states to develop their own reclamation management strategies, which resulted in the wide variety of aggregate governance structures seen today. Government organizations in high frequency states created more robust aggregate rules and regulations, which require greater degrees of reclamation, compared to low frequency states. For example, California's Surface Mine and Reclamation Act (SMARA) requires reclamation to a "productive use" (although reclamation outcomes do not always satisfy the definition of enhancement reclamation) and literature has recommended that permitted reclamation plans be crafted with the intent of integrating a site into the larger ecosystem, rather than considering a pit in isolation of its surrounding landscape— this is particularly true in the case of floodplain reclamation (Kondolf, 1993). This can be compared to government organizations in low frequency states: five of the seven either exempt the reclamation of aggregate sites or their main laws governing reclamation fall under the federal SMCRA, which prioritizes the reclamation of coal sites and addresses the reclamation of aggregate pits only if they were abandoned prior to 1977 (see Section 1.1).

5.1.4 The geography of amenity

The geography of amenity is the concept that enhancement reclamation is more likely to occur where project outcomes will benefit people. It suggests that the likelihood of enhancement reclamation depends on a site's location— in a high potential use area or not— and economic value.

High potential use areas

A mine's location in a high potential use area is one of the most influential variables dictating whether or not enhancement reclamation will occur. Literature has shown that communities tend to support reclamation and restoration projects that are perceived to add community value and (or) enhance local uses (Toffey et al., 1998; Damigos & Kaliampakos, 2003), and projects in more populated areas will add greater community value because there are more people who may use, for instance, a park, trail or swimming pool. This agrees with the observed division of high and low frequency states, because 84% of all identified enhancement reclamation projects were in urban areas or urban clusters (see Figure 12).

Farmland is another example of a high potential use area that is distinct between high and low frequency states. For example, 67% of the sites reclaimed to cropland were located in California's Central Valley, which is a vital agricultural region for California and the U.S., as it comprises 75% of the irrigated land in California (17% of the nation's irrigated land) and produces 25% of the food in the U.S. (U.S. Geological Survey, 2015). Finally, proximity of a site to valuable wildlife habitat is an indication of whether or not enhancement reclamation will occur. The geography of amenity helps explain the sole site identified in Wyoming because it is located just outside Yellowstone National Park. Yet the distinction between high and low frequency states was particularly noticeable where enhancement reclamation projects targeted habitat conservation for threatened and endangered aquatic species. Of the 36 identified sites, 28 (78%) were in Oregon and California where salmon habitat conservation is a top priority.

Economic value

Commonly, economic valuation in the context of aggregate mining depends on the resource itself. However, enhancement reclamation can turn what may otherwise become a desolate site into a lucrative business venture. As urbanization expands, property values of sites that would have otherwise been too costly to reclaim become cost-effective and are often turned into public amenities, housing developments, or shopping centers (e.g., McCullough, 2005). This is true in both high and low frequency states and the pattern is particularly strong among low frequency states (see Figure 20) where development was the most common type of enhancement reclamation. For example, every identified site in Nevada was in Las Vegas, in a solely urban geographic environment, and reclaimed to development. Furthermore, these sites were located on the edge of the city and were reclaimed as the city grew and expanded, which made enhancement reclamation a rewarding business decision.

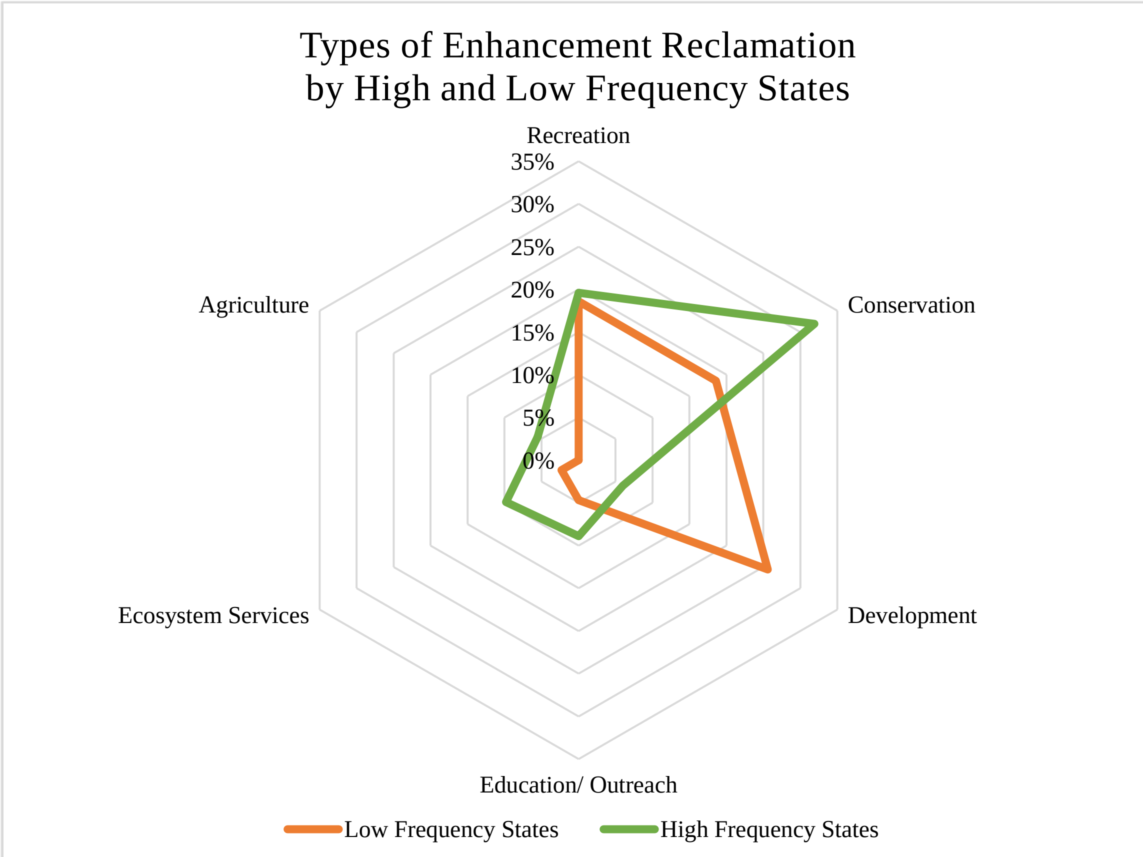

Figure 20. Types of enhancement reclamation identified by high and low frequency states

Outside of development, enhancement reclamation likely occurred more frequently in high frequency states because larger projects were seen as having a greater potential for economic success due to the state's larger populations. The scale of projects in high frequency states demonstrates this. For example, sites in California included reclamation to golf courses, waterslide parks, and upscale campgrounds, whereas these large-scale enhancement reclamation projects were not seen (with the exception of one golf course in Arizona) in low frequency states.

5.2 The Influence of Geographic Environment on Enhancement Reclamation

Geographic environments, while largely examined independent of one another, cannot be just considered individually, particularly in a SES. Of the 128 identified sites, only 41 (32%) were non-coupled environments (e.g., only urban or aquatic, rather than urban – aquatic) and 93% of those non-coupled sites were either urban or non-farmland.

Therefore, the following analysis of enhancement reclamation by geographic environment largely focuses on the interactions between environments as well as within a SES context.

5.2.1 Urban and Aquatic

Aquatic sites were the most frequently identified (61%) of all geographies. This is likely due to depositional resource geography, enhancement reclamation options at aquatic sites, and the coupling of aquatic and urban sites.

First, geography is the foundation of enhancement reclamation because mining can only occur where nature puts aggregates. Frequently, sand and gravel resources are found near present and past rivers and streams because they were historically transported and deposited aquatically (Langer et al., 2004). This historic deposition is why the majority of identified sites were found in an aquatic geographic environment.

Second, there are many enhancement reclamation options at aquatic sites, many of them relatively low cost. They can become aquatic recreation areas for fishing, swimming, and water sports (e.g. inlets for kayaking or paddle boarding) or hiking, with the addition of trails. They are often ripe for conservation of threatened and endangered species habitat (e.g., creation of spawning side-channel habitat for salmonids) or wetland habitat, and can add aesthetic appeal to planned housing areas, as well as commercial or industrial parks, which would also likely increase their property values. They can also provide education and outreach opportunities with the inclusion of historic interpretive signs. Furthermore, various grants are available to support projects that target the conservation of threatened and endangered species (e.g., Washington State Salmon Recovery Grants), which also likely promote the occurrence of aquatic enhancement reclamation projects.

Finally, while aquatic sites were the most frequently identified, they were almost never isolated (Figure 21), being most frequently coupled with urban, farmland, and then non-farmland environments. The two isolated aquatic sites identified were reclaimed historic instream mining sites. Over time, instream mining has decreased dramatically due to research on the impacts of sediment removal from streams (e.g., Kondolf, 1994;

Federal Interagency Working Group, 2006), which could also contribute to the small number of isolated aquatic enhancement reclamation projects.

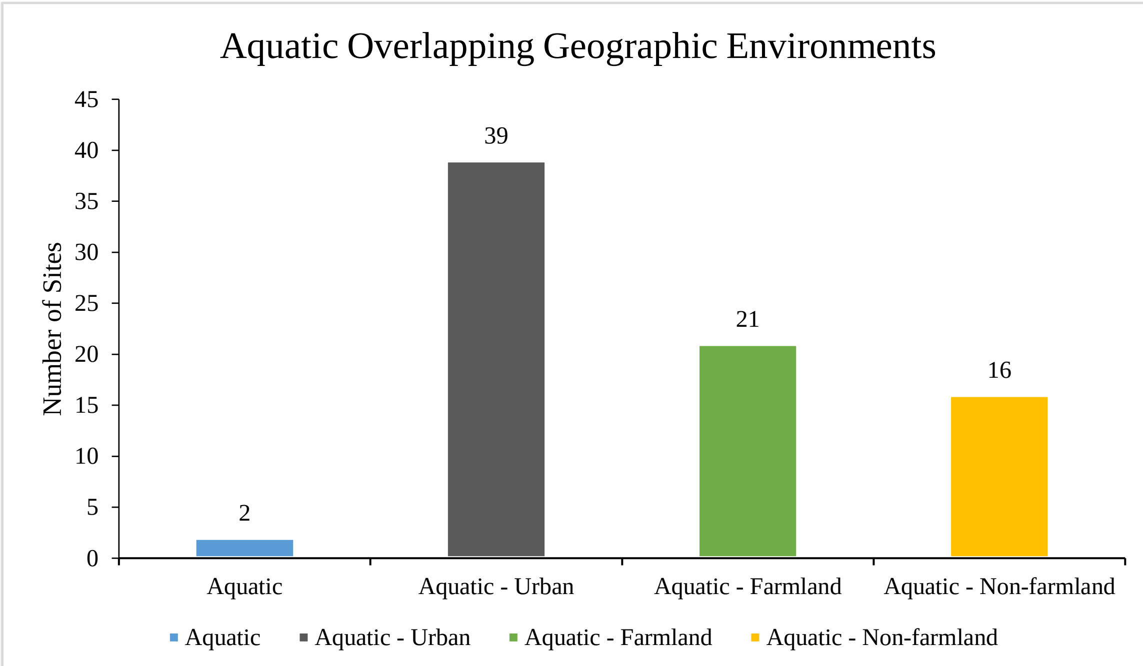

Figure 21. The number of aquatic identified sites by geographic coupling.

Although urban sites were the second-most identified, it is not just their frequency that combined them so often with aquatic sites— the physical coexistence of these two geographic environments bolsters the potential of enhancement reclamation at coupled aquatic-urban sites. There are a number of features that combine to make aquatic-urban sites ripe for enhancement reclamation and many are related to the geography of amenity: (1) Aggregate mines tend to be located within 30 to 50 miles of their intended market to limit transportation costs (Meador and Layher, 1998); (2) Markets tend to be urban areas or clusters (i.e., greater than 2,500 people) because they demand the most materials; (3) Cities and towns tend to be located near water sources; (4) aquatic sites have a high number of enhancement reclamation possibilities, as noted above. These four factors create demand for enhancement reclamation projects by local populations— particularly in environmentally minded locations— and present strong opportunities for enhancement reclamation success.

5.2.2 Farmland

As with urban sites, farmland sites also frequently overlapped with the aquatic geographic environment. Therefore, many reclamation activities at farmland sites were targeted toward conservation (e.g., stream restoration), rather than agriculture.

There were 31 sites identified as farmland sites. However, only 13 of these underwent agricultural reclamation. Furthermore, only 9 of these 13 were reclaimed to crops or vineyards; 4 were to grazing or pasture land.

A common concern among farmers is that, although the aggregate industry makes claims about returning mined land back to productive farmland, once farmland is disrupted by aggregate mining it is not adequately or frequently enough returned to land viable for raising crops. This study confirms this concern. Of the 31 sites designated as farmland, only 29% (9 of 31) were reclaimed, at least in part, back to arable farmland (in most cases, only part of the disturbed mining land, rather than the whole site, is reclaimed back to crops).

Overall, farmland sites tend to be a victim of geographic circumstances. High-value aggregates often underlie prime agricultural lands, which increases mining pressure on farmland. Rules and regulations have decreased instream mining, but this increases floodplain mining and encroaches on farmland. Urban sprawl itself encroaches on farmland and additionally buries potential aggregate resources, further encouraging mining on or near farmland. Farmland is pressed from all sides in terms of land use, yet greater food production is required in the future as populations grow. Mining on farmlands is likely to continue in the near future, and enhancement reclamation back to viable cropland can help alleviate some of the pressures felt due to mining.

5.2.3 Non-farmland

Quarries

The majority of identified quarries (95%) were in non-farmland geographic environments and 65% of these enhancement reclaimed quarries were in forested environments (Figure 12). While many quarries are located in mountainous, often forested areas, there is also a lot of aggregate mining in desert and steppe environments—

but enhancement reclamation does not occur as often in these places. The enhancement reclamation of quarries overall and at forested sites may be explained regionally.

First, because quarries are often larger than sand and gravel pits and require blasting, they typically are farther from population centers. Therefore, there is less pressure to reclaim them overall as there is little associated geography of amenity. Second, all but one of the identified enhancement reclaimed quarries were located in high frequency states where enhancement reclamation is more of a social norm than in low frequency states.

5.3 Types of Enhancement Reclamation and Frequency

Conservation, recreation, and development were the top three types of enhancement reclamation identified among sites in this study. Each will be broken down by specific reclamation outcomes and analyzed by geographic environment in the context of the geography of amenity. Finally, the scope (i.e., overall project goals and outcomes) of individual projects will be addressed.

The big three: Conservation, recreation, and development

Conservation practices were identified at 65% of all sites— recreation was the next closest at 42%— and was clearly the most common at all four geographic environments (see Figure 17). This standout frequency of conservation practices can be attributed mainly to the geographic occurrence of aggregate materials, local values, and the history of mining reclamation.

Sand and gravel were historically transported and deposited along waterways and many sites are still near modern bodies of water (Langer et al., 2004). The physical location of pits near rivers, streams, and lakes makes them ripe for conservation practices because they can add value to local ecosystems e.g., wetlands or salmon spawning habitat. This prior ecological knowledge can increase predictability of system dynamics, which is one of Ostrom’s ten key variables influencing the potential of self-organization.

Enhancement reclamation is a relatively new concept. The history of reclamation has shifted from no reclamation, to basic reclamation practices largely for safety purposes, and is now in its own innovation phase, where new techniques are being explored for a variety of purposes. One of the most common forms of early, basic reclamation was planting native vegetation and creating habitat for waterfowl and other wildlife, examples of which are frequently seen in early reclamation literature (Johnson, 1987; Svedarsky & Crawford, 1982), and such conservation techniques have been altered and improved over time. This demonstrates institutional learning and memory, both of which increase the resilience of SESs (Berkes et al., 2008).

The geography of amenity and economics can also be attributed to the frequency of conservation enhancement reclamation, as well as recreation and development projects.

Figure 22 shows that conservation, recreation, and development are most common in urban and aquatic environments and all have a similar rate of occurrence in urban environments. The geography of amenity encourages these three types of enhancement reclamation, particularly in more populous areas, because they each add distinct value to reclaimed areas. For example, a conservation project that recreates salmon spawning habitat can add cultural value and improve local fisheries. A constructed wetland— in addition to conservation benefits— increases ecosystem services and local aesthetics, and both recreation and development-based enhancement reclamation projects provide concrete public uses (e.g., public parks and housing).

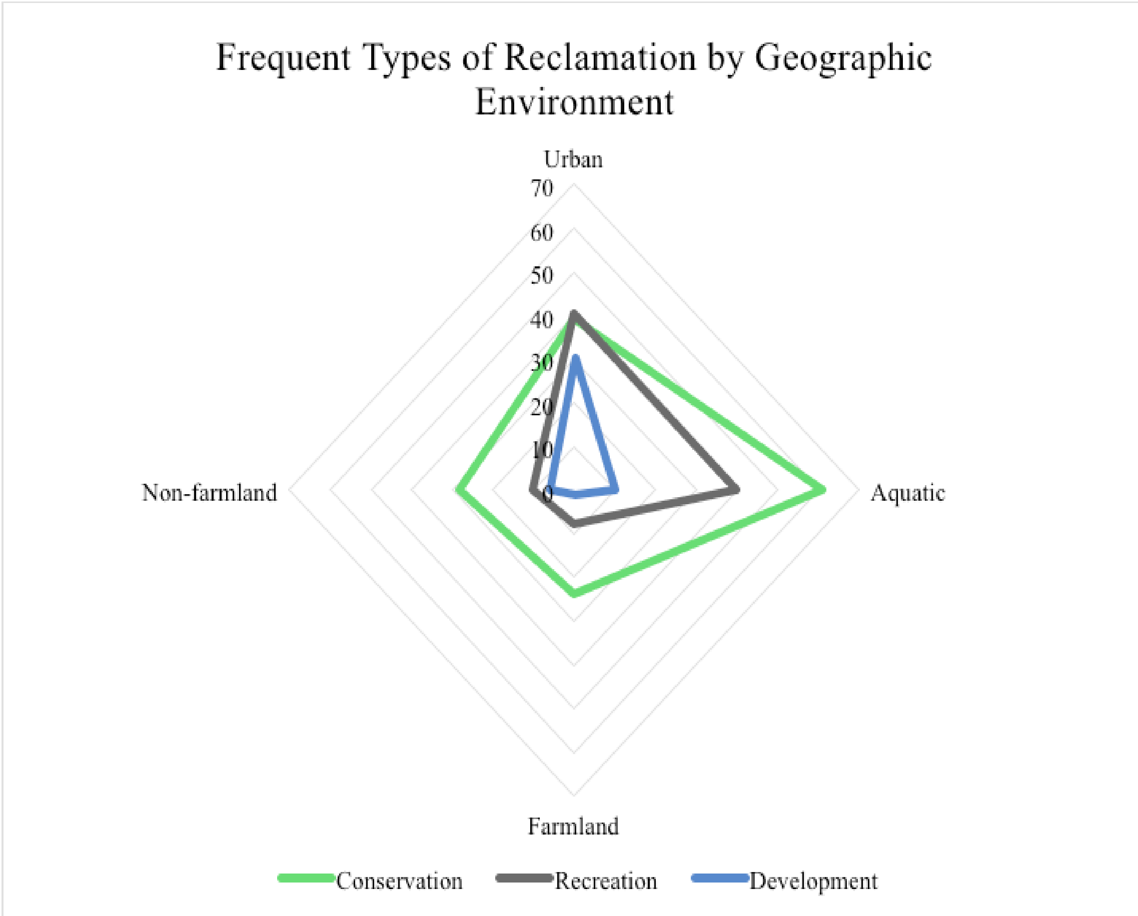

Figure 22. Frequency of the most commonly identified types of enhancement reclamation by geographic environment

Economics also play a role in the frequency of different types of reclamation. It has been shown how increasing land values encourage development projects and larger projects such as water parks and golf courses, both of which are more potentially lucrative in more densely populated urban areas. Simply put, development and recreation projects are more likely to occur if the price is right. Furthermore, the numerous grants available for projects that increase habitat for threatened and endangered species economically incentivizes conservation projects.

In addition to explaining the most common types of enhancement reclamation, economics can also help explain the types missing from Figure 22: ecosystem services, education/outreach, and agriculture.

First, the most common outcomes of ecosystem services reclamation projects were groundwater recharge, water storage/supply (i.e., reservoirs) and flood control, which are larger scale, costly projects that require particular funding strategies. For example, one recreation – ecosystem services combined project applied income from the recreation site to pay for the installed sewer and wastewater treatment facilities. Second, education/outreach projects do not provide significant post-use income. The majority of these projects included interpretive signs added to reclaimed recreation areas and mining relics left on site to inform about the location's history. While these items provide interest and culture, they do not add economic value and as such are often overlooked. This is demonstrated by the lack of projects including both development and education/ outreach— only two of thirty development sites (7%) also had an education/outreach component and both were residual mining relics left on display. Last, although reclamation to agriculture (crops) has been shown to be economically successful, its main expenses are land ownership and time. The most successful aggregate-agriculture examples in this dataset are on large tracts of land where reclamation is planned years in advance and the whole system is managed around reclaiming previous sites as new ones are opened up within the same property. This approach requires dedication, careful planning, and unified ownership.

Project scope: Single use versus multiple use enhancement reclamation

Enhancement reclamation projects can be generally divided into two types of projects based on their scope: individual use and multiple use projects. The former includes projects that add value based on the sum of their parts. For example, one site was revegetated with native plants around the pits (conservation), and a series of shops and apartments were built (development) overlooking the new man-made lake (because the pit was left to naturally fill with water) where a small fishing dock was installed (recreation), along with a small interpretive sign added recounting the site's history (education/outreach). Individual use sites include examples such as golf courses, theme parks, amphitheaters, and backfilled pits where public amenities (e.g., schools, churches) are built. Figure 23 shows the number of individual and multiple use sites identified.

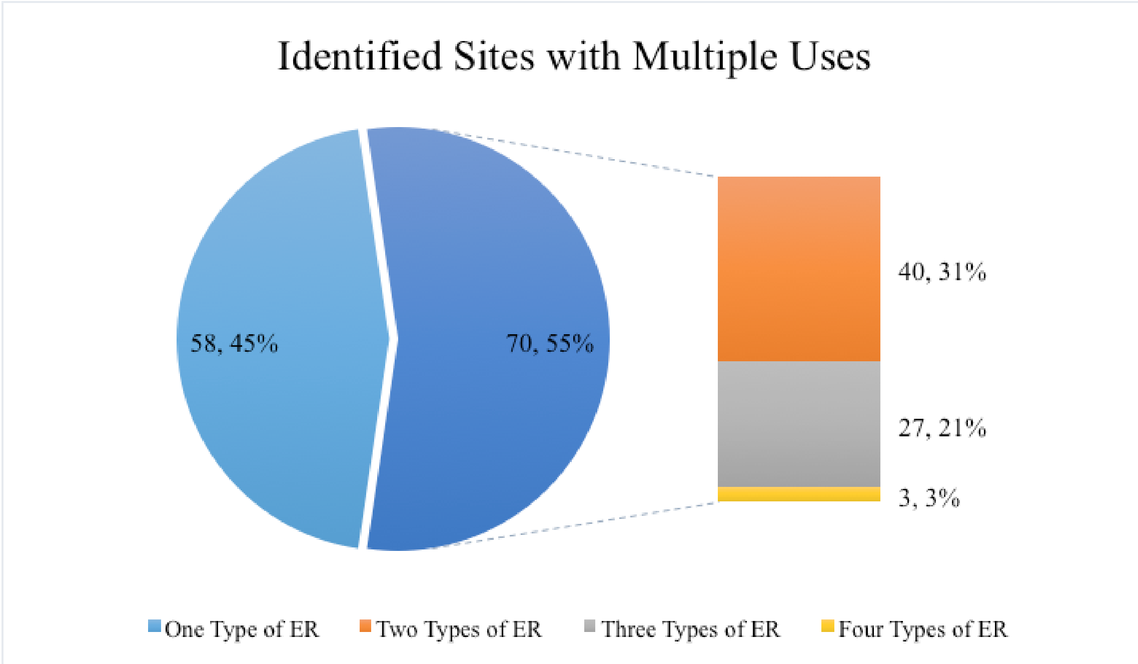

Figure 23. Identified sites by number of types of enhancement reclamation present.

Based on these results, multiple use sites are slightly more common than single use sites. However, numerous sites with multiple types of reclamation better fit the profile of a single use site. For example, two golf courses in the dataset were recreation and development sites. Similarly, many single use sites also completed smaller enhancement reclamation projects (e.g., a hiking trail built through a quarry to a popular local waterfall) that seem to better fit the definition of a mixed use site.

Therefore, while the designation of single versus mixed use does not provide information about individual projects, this evaluation demonstrates the diversity of enhancement reclamations projects in the west. Every project adds value on its own scale. Enhancement reclamation projects are best when evaluated individually and appreciated for their unique contributions to the local ecosystem, economy, and society.

5.4 Case studies, learning, inspiration, and future research

This discussion will conclude with an examination of case studies as potential models and sources of inspiration for the management of aggregate mining and reclamation in the west, and a reflection on concepts associated with enhancement reclamation not addressed in this study. First, Ontario, Canada’s Aggregate Resources

Act is examined, highlighting parallels between the province and high frequency western states. Second, the potential of non-aggregate mining reclamation case studies will be discussed. Third, questions about social justice in relation to aggregate mining and enhancement reclamation are posed as ripe questions for future research.

Ontario: A case study on aggregate management

Supported by Ostrom's framework, this study has demonstrated the value of appropriate governance systems in encouraging enhancement reclamation— Oregon is the best example of this in the west. However, improvements can always be made and enhancement reclamation is far from universal across quarries and sand and gravel pits in any U.S. state. For inspiration about how to improve local governance structures in the U.S. (particularly in high frequency states) there is no more appropriate model than Ontario, Canada.

Ontario's Aggregate Resources Act can be viewed as the ultimate result of the province's own "release phase," which consisted of heated conflicts in the late 1960s between the aggregate industry and residents in aggregate-rich municipalities. These conflicts (the release) resulted in a fundamental change in Ontario's land use planning and what is now known as the Aggregate Resources Act, which is internationally recognized as an effective aggregate management strategy (Yundt & Messerschmidt, 1979; Baker et al., 2008; Hanna, 2010). The story of high-density populations and land use conflicts is all too familiar in high frequency western states and Ontario's landmark aggregate legislation provides a good model for the U.S. to examine.

First, the Aggregate Resources Act covers Canada's most populous province in terms of both people (roughly 40% of the country's population resides there) and aggregate sites (roughly 5,300 active sites as of 2008). These factors make this a good case study on the implementation of an act governing aggregate across a large, highly populated area, which could translate to legislation at the state or even federal level.

Second, reclamation (referred to as rehabilitation in Canada) is a central feature of the Aggregate Resources Act. Two of its four main purposes are, "to require the rehabilitation of land from which aggregate has been excavated; and to minimize adverse impact on the environment in respect of aggregate operations." Furthermore, research about reclamation— including experimental rehabilitation projects— is prioritized and both progressive (i.e., concurrent) and final reclamation are required at every quarry and sand and gravel pit. Although the status of enhancement reclamation differs between western U.S. states, at least one example was identified in each state of interest— the concept of enhancement reclamation has been established in the west— and Ontario's emphasis on reclamation suggests that it is a key feature in effective aggregate management. Therefore, U.S. states ought to continue pursuing enhancement reclamation as part of their ongoing aggregate management strategies.

There are also key differences between Ontario and western states, revealing issues that ought to be addressed if a similar management strategy is to be attempted in the U.S. While the province parallels the west's reclamation-forward attitude, its government has historically strongly backed extractive resources industries (particularly forestry and mining), which has included the designation of prime aggregate resources lands, limiting the geographic expansion of municipalities and development— rather than moving mining around development (Chambers & Sandberg, 2007; Baker, 2008). This stronger pro-mining stance (compared to the U.S.) has encouraged criticism of the government for local issues incurred by mining. For example, Chambers & Sandberg (2007) note an issue with peripheralization— where particular isolated, economically marginal regions are prone to environmentally hazardous single-industry domination— and community pushback where aggregate mining expansion is attempted. The quality of rehabilitation has also been criticized as inadequate. Research has shown a net gain in disturbed land, and the government has been denounced for a lack of environmental protection and not enforcing adequate levels of rehabilitation (e.g., Dillon, 2006; Baker et al., 2008; Port, 2013).

These differences and difficulties should be treated as an opportunity to learn about the implementation of aggregate management. It is clear that reclamation/rehabilitation is a necessary piece of the management puzzle— it is a cornerstone of Ontario's Aggregate Resources Act— but also that the quality and level may be seen by the public as insufficient. Moving into the future, the U.S. can focus on stimulating enhancement reclamation— particularly at sites near communities— and increasing enforcement. Additionally, in order to strengthen mining laws, the social norms and views about aggregate mining, which are generally negative in the U.S., must be addressed. Because public support is essential to change rules and regulations, increasing awareness about the potential benefits of enhancement reclamation of aggregate quarries and sand and gravel pits is recommended.

Broad learning from reclamation

In SES literature, it has been suggested that integration of various knowledge systems— particularly the inclusion of traditional ecological or local knowledge— can help improve management of the system in question (McLain & Lee, 1996; Moller et al., 2004). The value of employing various knowledge systems in an enhancement reclamation context was seen in particular at sites in Washington, Oregon, and California. Of all identified projects, those that included interdisciplinary teams in all phases of reclamation and prioritized the inclusion of local experts and citizens tended to have the grandest outcomes and were highly successful in meeting— and often exceeding— their enhancement reclamation goals. However, the incorporation of local knowledge does not have to end at the physically local scale. Global connectivity is at an all-time high, and "local" is becoming a relative term.

To improve management of aggregate mining and strengthen the practice of enhancement reclamation, the exploration of case studies about *non*-aggregate mining reclamation and restoration processes is recommended. Furthermore, to capture the full value of local knowledge, these case studies should target regions at the forefront of reclamation in their respective fields. Suggestions include a review of the SMCRA managing reclamation of coal mines (see below) in the U.S. and the effectiveness of its federal awards program, methods used to evaluate reclamation success of oil sands to wetlands in Canada (e.g., Rooney & Bayley, 2011), and cases of successful brownfield site development in the U.S. (e.g., Lange & McNeil, 2004).

For example, the SMCRA of 1977 requires prime farmland disturbed by coal mining activities be returned to pre-disturbance productivity. Therefore, there are many examples of coal mines reclaimed to farmland, resulting in farmland reclamation guidelines, particularly in the Midwest, (e.g., Schroeder, 1997; Dunker et al., 2012;

Illinois Department of Natural Resources). These examples can be explored for applicable techniques and lessons learned that could address the lack of enhancement reclamation to farmland in the west.

Although enhancement reclamation of aggregate sites is not the norm in many places, the concepts of reclamation and restoration are. There are countless examples of projects and management strategies outside this field that can be learned from and applied to aggregates.

Social justice concerns

Social justice research has clearly shown that undesirable industries (including but not limited to ore and precious metal mining) are frequently located in close proximity to underprivileged populations and communities, which can lead to displacement, loss of access to natural resources, exposure to hazardous chemicals and activities, criminal undertakings or accusations, and environmental degradation (Martinez-Alier, 2001; Tschakert, 2009; Walker, 2009; Walker, 2012)

Specific to aggregate mining, the opening of new mines is of concern because it fits the pattern of extractive industries being located near vulnerable populations. The incidence of aggregate mining ought to be documented in relation to underprivileged communities. In particular, special attention should be given to *when* an area was originally permitted and when ground was first broken because pits can have very long lifespans and the character of a community may change thanks to development spurred by the local pit. Case studies are the recommended primary method of study because community characterization over time must be addressed.

Specific to the enhancement reclamation of aggregate mines, questions of social justice ought to contrast this research by asking where projects have not occurred, rather than where they have. Due to the great cost of enhancement reclamation projects and the geography of amenity, it could logically be hypothesized that enhancement reclamation occurs more frequently in more affluent communities— furthermore that the most prominent cases of enhancement reclamation (e.g., golf courses, parks or wetlands with well-installed and maintained trails, residential communities or shopping centers with the pit left as a water feature, etc.) are in such areas. An analysis of where and how pits are reclaimed at the meso scale (e.g., county or state) is recommended for this study. A database of all pits in particular area ought to be collected and their reclamation status documented— a ranking system of prominence (e.g., an enhancement reclamation scale from projects demonstrating minimal effort to the most grandiose) could be implemented to gauge how well a pit was reclaimed.

6 CONCLUSIONS

This section provides an overview of the research outcomes (Table 4) as they relate to the stated research questions and objectives (Section 1.4), distinguishes additional research outcomes, and closes with avenues for future research.

6.1 Research outcomes

This study, the first of its kind, documents specific characteristics of enhancement reclamation projects across a wide geographic area. The results demonstrated a division between high and low frequency states (pacific and mountain region states, respectively, with the exception of Colorado), and showed that the overall status of enhancement reclamation in the former is advancing, while the latter, is currently stagnant. This separation between high and low frequency states was attributed to population density, land use competition, and the geography of amenity. In addition to answering the driving question, “What is the status of enhancement reclamation in the U.S. west?” this research also:

- Compiled a list of types of enhancement reclamation in the west (Section 3.2);
- Identified key parties and resources that comprise the SES in which enhancement reclamation can increase resilience: aggregate industry + aggregate-governing bodies + local users + mined lands (5.1.2);
- Applied the concept of the adaptive cycle to enhancement reclamation (Section 5.1.2);
- Proposed the “geography of amenity” as a concept to predict the likelihood of future enhancement reclamation projects and their likely characteristics (Section 5.1.4);

- Recommended Ontario's Aggregate Resources Act as a case study on the management of aggregate resources and reclamation (Section 5.2);
- Recommended an examination of reclamation practices at non-aggregate sites to increase learning and improve enhancement reclamation of quarries and sand and gravel pits (Section 5.2);
- Began initial documentation for the first nationwide database of aggregate enhancement reclamation projects.

Table 4. Results relative to stated research questions and objectives

Objective/Question	Results	Section(s)
(1) Identify regional and state-by-state frequency of enhancement reclamation.	• Enhancement reclamation occurs more frequently in pacific subdivision states than in mountain subdivision states. • CA, OR, CO, and WA were found to be high frequency states. MT, ID, WY, NV, UT, CO, AZ, and NM were low frequency states.	4.1
(2) Identify frequency of enhancement reclamation by geographic environment.	• Enhancement reclamation most frequently occurs, by decreasing frequency, in aquatic, urban, non-farmland, and farmland geographic environments. • Enhancement reclamation projects frequently occur in coupled urban-aquatic environments. • Quarries undergo enhancement reclamation much less frequently than sand and gravel pits, but when they do, it is most often in forested ecosystems.	4.2
(3) Identify frequency of different types of enhancement reclamation.	• The most to least frequent types of enhancement reclamation in the west are conservation, recreation, development, ecosystem services, education/outreach, and agriculture.	4.3

6.2 Future research

Building off this research, future studies should address states outside of the western region and aim to increase documentation about specific enhancement reclamation projects throughout the U.S.

The states of interest addressed in this study represented a diverse set of landforms and ecosystems. However, it cannot be assumed that states in the midwest, south, or eastern U.S. share the same geographic pattern, because the frequency and type of enhancement reclamation are largely driven by social norms and land values, which differ from region to region. For example, although high frequency western states and eastern states have similar population densities, coal mining is more frequent in the East, which could decrease the likelihood of aggregate reclamation in favor of coal reclamation. Therefore, future research should include all states in the U.S. and make regional comparisons.

As addressed in the concluding paragraph of the discussion, future research should also be conducted on the influence of social factors on aggregate mining and the incidence of enhancement reclamation. Key factors should include race, ethnicity, education, and economics.

Finally, although this project was the first to examine specific characteristics across a multitude of enhancement reclamation projects, future research should build upon this dataset by including additional site characteristics that help illuminate the story behind each project (e.g., funding sources, enhancement reclamation parties, land ownership, and general history of each site). Land ownership— in particular a comparison between public, private, and tribal lands— ought to be highlighted as a key driving factor of enhancement reclamation because individuals' land use decisions are motivated by a wide range of values. Understanding the "how" and "why" behind successful projects would be invaluable information for those interested in pursuing enhancement reclamation projects. A database of enhancement reclamation sites would also be an educational resource for the aggregate industry to share with the public and legislators, demonstrating the little-understood potential of aggregate mining, and the positive outcomes that can result from successful enhancement reclamation.

Enhancement reclamation ought to be further studied, celebrated, and promoted—because every project, from one-acre tracts of arable farmland to prestigious golf courses and wetlands in Wyoming— adds value and gives new life to a site (and region) that may otherwise have been left barren.

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Appendix A. Quantities and values of construction sand and gravel and crushed stone sold or used by U.S. producers in 2012

Quantity and value of sand and gravel sold or used by U.S. producers in 2012

Region/Division	Quantity (thousand metric tons)	Percent of total	Value (thousand dollars)	Percent of total
Northeast				
New England	37,200	4.6	316,000	5.1
Middle Atlantic	51,400	6.3	454,000	7.3
Midwest				
East North Central	124,000	15.3	766,000	12.4
West North Central	132,000	16.3	780,000	12.6
South				
South Atlantic	49,300	6.0	409,000	6.6
East South Central	33,300	4.1	225,000	3.6
West South Central	119,000	14.6	930,000	14.9
West				
Mountain	142,000	17.5	1,110,000	17.9
Pacific	123,000	15.1	1,210,000	19.5
Total	811,200	99.8*	6,200,000	99.9*

***Data are rounded to no more than three significant figures; may not add to totals shown**

Quantity and value of crushed stone sold or used by U.S. producers in 2012

Region/Division	Quantity (thousand metric tons)	Percent of total	Value (thousand dollars)	Percent of total
Northeast				
New England	34,600	3.0	394,000	3.5
Middle Atlantic	134,000	11.5	1,420,000	12.5
Midwest				
East North Central	192,000	16.4	1,500,000	13.2
West North Central	138,000	11.8	1,250,000	11.0
South				
South Atlantic	225,000	19.3	2,850,000	25.1
East South Central	120,000	10.3	1,280,000	11.3
West South Central	201,000	17.2	1,550,000	13.7
West				
Mountain	53,700	4.6	403,000	3.6

Pacific	69,500	6.0	704,000	6.2
Total	1,167,800	100	11,351,000	100

All data obtained from USGS Mineral Yearbooks (2012)