Beaver, A Natural Solution to Urban Stream Restoration

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Abstract

Water quality is imperative to sustained human health. Human existence, although reliant on unimpaired water, has largely altered watersheds with urbanization and has negatively impacted water quality. In response to our adverse effect on water and surrounding ecosystems, humans have attempted ecosystem restoration with the goal of establishing sustainable environments that support human, flora, and fauna life. Many studies within scientific literature present the importance of stream restoration or rehabilitation that is not so narrowly focused on human engineering solutions but that also incorporates ecological components. Ecological components include the living organisms within the ecosystem and if managed appropriately these organisms can be a catalyst for restoration. One such organism that can create positive change is beaver. The role of beaver within the context of stream restoration or wetland creation is discussed briefly throughout scientific literature, but a case for the use of beaver within an urban setting is not well documented. With a firm scientific understanding of the positive impact beaver activity has on watersheds, creating complex, bio-diverse fluvial ecosystems, we should begin to consider the implications of introducing beaver to urban stream systems as a viable "engineering" restoration solution.

Introduction

Water is necessary to support all life on earth, moving nutrients through air and soil, fueling bodily functions, and providing a resource necessary for flora and fauna functions. Unimpaired, healthy water systems are necessary to support these life-giving functions. Scientific and public interest in water quality was born of concern for drinking water quality and water-borne pathogens such as cholera (Scholz, 2016). However, drinking water, although essential to human existence, is not the only function of water imperative to all life. Both surface and groundwater, even when not necessarily safe for human consumption, are necessary to create aquatic habitats that support a rich and diverse array of aquatic species. It follows that watersheds, therefore, are not only a complex system of drainage paths and aquatic habitats, but healthy, vibrant watersheds are advantageous to human, animals, and plants alike.

Humans have historically stripped watersheds of the things that create complex, stable, and resilient natural environments such as well-established riparian vegetation, naturally sloped channels, and biodiverse aquatic biota (Fouty, 2008). Especially in urban settings, humans have removed many of the natural resources provided by aquatic ecosystems for our own use and have developed the land in such a way that generates excess stormwater runoff and increases the subsequent pollutant load. Urban watersheds, in fact, are often characterized as having unhealthy, flashy, and erosive streams and waterways (Walsh et al., 2005). These waterways often have poor water quality, as they are impaired with contaminants and void of healthy aquatic organisms. Anthropogenic impact on watersheds has therefore necessitated restoration of streams, for they are the terminus of the negative effects of urban development. Streams that drain urban areas are proxies of the activity within the surrounding area and are often assemblages of the pollutants and wastes within urbanized settings.

Water quality, a measure of the chemical, physical, and biologic condition of water as it relates to the requirements of biotic need (Diersing, 2009), is naturally impacted by many factors. Factors such as a thick riparian zone that filters incoming stormwater or an aquatic species that cleans suspended pollutants influence ecosystems in a way that effects its overall health and the subsequent water quality. One such naturally occurring phenomena is beaver inhabitation. Known as ecosystem engineers, beaver have the ability to completely alter the structure of their surroundings (Bailey et al., 2018). These organisms create, modify, and maintain habitat for themselves and other species within the surrounding environment in a way that transforms the watershed and changes the water quality (Jones et al., 1994). Beaver inhabitation, in fact, is documented to create wetland habitats that support a diverse and rich community of aquatic and non-aquatic species alike (Bailey et al., 2018; Bouwes et al., 2016; Dittbrenner et al., 2018; Fouty, 2019; Naiman et al., 1988; Pollock et al., 2014). Their dams slow sediment transport downstream and establish a stable water table, positively effecting water quality upstream and downstream of dam placement. Overall, beaver inhabitation is well documented in scientific literature to positively effect water quality and change the surrounding watershed (Gurnell, 1998; Krueger and Johnson, 2016; Naiman et al., 1988; Persico and Meyer, 2009; Rosell et al., 2005).

Many studies understand the importance of stream restoration or rehabilitation that is not so narrowly focused on human engineering solutions but that also incorporates ecological components (Booth, 2005; Booth et al., 2004; Scholz, 2016). Fewer studies, however, address the role of beaver within such systems, especially in the context of urban stream restoration or wetland creation. With a firm scientific understanding of the positive impact beaver activity has on watersheds, creating complex, biodiverse, stable fluvial ecosystems, we can begin to consider the implications of introducing beaver to urban stream systems as a viable “engineering” solution.

Objectives

The purpose of this review and analysis is to recognize the abilities of beaver as ecosystem engineers and suggest that their engineering capabilities can aid humans in our watershed restoration projects. I seek to summarize beaver effect on the surrounding ecosystem and document past research and scientific studies that address beaver and urban stream restoration. Continuous efforts have been made in recent human history to restore environments that have been damaged either directly by human means or indirectly as a result of human activity in the surrounding area. These damaged ecosystems often necessitate repair of some sort to avoid continued impairment. Beaver, as will be discussed at length, have an innate ability to positively impact water quality and should be considered for restorative aid.

I seek to show the connection between our anthropogenic efforts to restore ecosystems and the comparable abilities of beaver to naturally restore their environments. Specifically, in urban environments, the action of beaver can improve degraded hydrologic regimes and geomorphology while enhancing habitat for native plant and animal communities (Bailey et al., 2018). This paper introduces documented scenarios in which beaver inhabitation within an urban watershed was and continues to be viable. These case studies show varying examples of management strategy along with varying degrees of stream restoration. Beaver habitat suitability is described, as is the management necessary to maintain a balanced human, beaver relationship in a densely populated project area. Using published case studies and scientifically established knowledge of the effect of beaver colonization as support, this review hopes to rationalize the ways in which beaver can be introduced and sustained for the purposes of creating better water quality and positively effecting stream function concerns within an urban environment.

Methodology

Literature Review

To understand the effect of beaver inhabitation on urban stream systems, I performed a thorough literature review. These efforts included studying and documenting scientific literature that discusses the impact of urbanization on streams, the impact of beaver activity on streams, and case studies or other scholarships that suggest the management techniques necessary to support beaver inhabitation in urban stream systems. By searching databases provided by the George A. Smathers Library off-campus access platform and using knowledge I have from previously studying beaver for my undergraduate thesis, I was able to gather information that documents the positive impact of beaver colonization on water quality and the surrounding ecosystem. Search terms such as “beaver”, “urban stream restoration”, “ecosystem engineers”, and “reintroduction” were used while conducting the literature search.

I also noted literature that documented the impact of urbanization on waterways, defining Urban Stream Syndrome and the negative effects of increased imperative surface coverage and other factors of urban development. Moreover, it would be unrealistic to document only the positive parts of beaver inhabitation without pointing to the reputation they have as being a nuisance to landowners. Beaver are notorious for damaging private landscapes, downing trees and flooding lands where their activity is unwelcomed. Many of the case studies I will discuss record the potential negative impacts and attitudes towards beaver within an urban setting. Restoration projects that seek to implement beaver will continuously be faced with human versus wildlife management issues. These issues and potential solutions will be discussed as well.

Analysis

I carefully examined the sources identified through my literature for data regarding beaver effect on habitat, urban stream syndrome, beaver use for restoration, and other water quality and urban stream restoration related information. Data included the effect of urbanization on watersheds, documenting the ways in which ecosystems are altered by changes in increased impervious surface and pointing to the need for restoration efforts. I also analyzed the effect of beaver inhabitation on stream ecology, showing data to support increases in biodiversity, species richness, and overall stability. Moreover, I examined management strategies for implementing beaver in an urban environment as to further understand the ways in which restoration efforts with beaver could be implemented in a sustainable manner. Without documentation of past successes, beaver colonization within urban watersheds would be difficult to support. Overall, the analysis portion of this paper is to synthesize the data collected through research and provide a breakdown of the pros and cons of beaver habitat within an urban context.

Results

Urban Stream Syndrome

The term “urban stream syndrome” describes the consistently observed ecological degradation of streams draining urban land (Walsh et al., 2005). The Handbook of Urban Studies suggests that the definition of urban is contested, for urban environments are multi-faceted and include complex and ever-changing spatial, economic, socio-cultural, and political factors (Paddison, 2001). For the purposes of our discussion, however, I will leave the definition of urban relatively loose, as it refers to areas within or adjacent to cities, towns, or other densely populated areas. The characteristics of which include increased amounts of impervious surface coverage, watersheds that are largely delineated within urban land-use categories, and a centrality of political and economic power (Paddison, 2001).

Watersheds that drain urban areas see alterations to their physiochemical and ecosystem processes (Walsh et al., 2005). Urban streams have a “flashy” hydrograph, meaning they experience large pulses of water moving through the system (See Figure 1). The symptoms of urban stream syndrome also include altered channel morphology, increased pollutant load, and reduced biotic species. Changes in hydrology are often the most obvious symptom. The amount of water moving through the system is largely affected by increased stormwater runoff from impervious coverage, smaller riparian zones, and a large amount of stormwater infrastructure that moves water from within the urban areas via pipes and ditches to the stream in question.

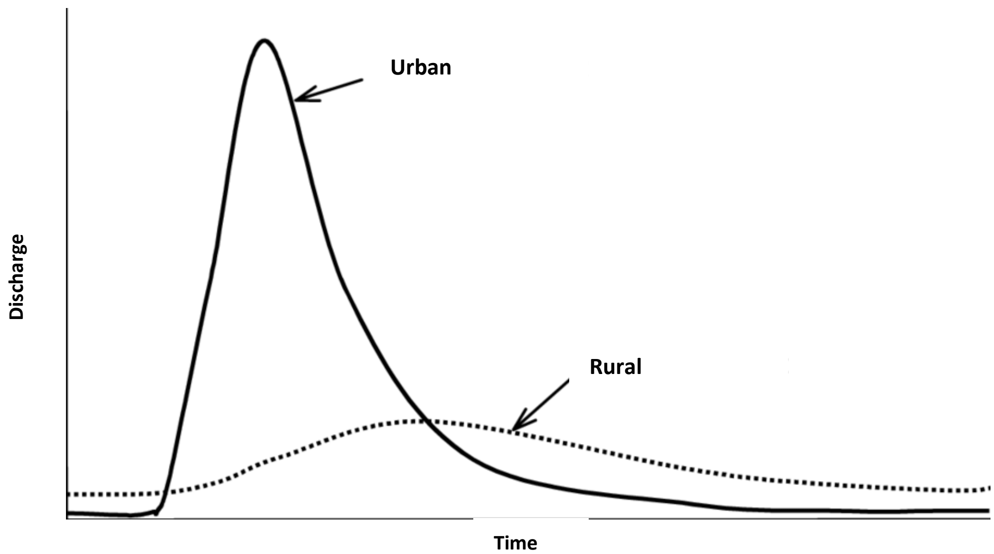

Figure 1: Urban hydrograph versus rural hydrograph showing a quicker response to precipitation within an urban stream and a slower, less energetic response within a rural stream. The pulse of water moving through the urban stream is due to less water infiltration and increased amounts of stormwater runoff from impervious surroundings.

The amplified response to precipitation and resultant flashy stream flow has other consequences such as increased concentrations of contaminants and subsequent changes to water chemistry. Further, the width and depth of the stream channel is forced to adjust to the increased energy moving through the system, marked by excess erosion within the channel. Increased nutrient concentrations effect the biological composition including macro and micro invertebrates. Table 1 was amended and adopted from Walsh et al. (2005) to illustrate both the consistent and inconsistent symptoms that characterize urban watersheds.

Stream Feature	Consistent Response		Inconsistent Response
Hydrology	Increased	Frequency of overland flow Frequency of erosive flow Magnitude of high flow Rise and fall of storm hydrograph	
	Decreased	Lag time to peak flow	
Water chemistry	Increased	Nutrient (N, P) Toxicants Temperature	Suspended sediments
Channel morphology	Increased	Channel width Pool depth Scour	Sedimentation
	Decreased	Channel complexity	
Organic matter	Decreased	Retention	Standing stocks/inputs
Fishes	Decreased	Sensitive fishes	Tolerant fishes Fish abundance/biomass
Invertebrates	Increased	Tolerant invertebrates	
	Decreased	Sensitive invertebrates	
Algae	Increased	Eutrophic diatoms	Algal biomass
	Decreased	Oligotrophic diatoms	
Ecosystem processes	Decreased	Nutrient uptake	Leaf breakdown

Table 1: Symptoms generally associated with the urban stream syndrome (Walsh et al., 2005). Consistent responses are effects of urban stream syndrome found throughout the majority of urban watersheds, and inconsistent responses are dependent upon the characteristics and activities of the urban area surrounding the stream.

Stream Restoration

The accumulation of the symptoms discussed above necessitate stream restoration. Urban streams have the potential to provide precious natural resources to humans who live near them (Meyer et al., 2005), but our treatment of stormwater has resulted in streams that are treated more like storm drains than biodiverse, healthy, and vital ecosystems. Urban streams often fit within the definition of ecosystems requiring restoration, meaning they are degraded, damaged, transformed or entirely destroyed as the direct or indirect result of human activity (Clewell, Aronson, and Winterhalder, 2004). Actions then taken to initiate or accelerate the recovery of such an ecosystem with respect to its health, integrity and sustainability are then considered ecological restoration and is an intentional activity necessary to create urban watershed environments that support human populations with the same health, integrity and sustainability.

Successful stream restoration requires a dynamic and creative approach. Especially in an urban setting, stream restoration projects are unique to their surroundings and the particular form of degradation or damage they face. A critical factor to be considered in restoration and conservation of urban stream and their watershed is the local human population (Booth, 2005). This truth suggests that effective management of these streams will require a broader perspective than traditional steam ecology, one that included social, economic, and political dimensions (Walsh et al., 2005).

Ecological restoration, including that of urban streams, includes one of several activities: reclamation, rehabilitation, mitigation, ecological engineering, and various kinds of resources management (Clewell, Aronson, and Winterhalder, 2004). These activities can overlap in many instances and all play a role within urban stream restoration projects depending on the degree of urbanization and specific complex of activities characterizing local development (Booth, 2004). This paper specifically addresses the practice of ecological engineering as a mean to manipulate natural materials, living organisms and the physical-chemical environment to achieve specific goals and solve technical problems (Clewell, Aronson, and Winterhalder, 2004). This practice most often relies on man-made materials and anthropogenic designs efforts to restore the ecosystem in question. However, non-humans, particularly animals, are agents with power and their ecosystem engineering capabilities should not be underestimated. Although ecological engineering is only one activity within the practice of ecological restoration, it often overlaps with other activities and is the portion or restoration that is potentially controlled by other, non-human players.

Beaver Inhabitation

Beaver are considered ecosystem engineers. Ecosystem engineers are organisms that alter the abiotic community within an ecosystem by physically altering the structure of the ecosystem itself, including modulating the availability of resources to other species (Bouwes et al., 2016). These organisms create, modify, maintain or even destroy habitat for themselves and other species within the surrounding environment (Jones, Lawton, and Shachak, 1994). Beaver maintain the structure of an ecological community and largely determine the types and numbers of species in a specific environment (Krueger and Johnson, 2016). A suitable beaver habitat, therefore, will experience great change throughout the lifespan of the organism.

Beaver prefer unconfined, low gradient alluvial channels, without steep, rocky or bedrock bottoms, and below a destructive, powerful stream water threshold (Gurnell, 1998; Persico and Meyer, 2009; Pollock, Beechie and Jordan, 2007; McComb, Sedell and Buchholz, 1990). A suitable habitat for beavers must contain all of the following: (1) stable aquatic habitat providing adequate water; (2) channel gradient of less than 12%; and, (3) quality food species present in sufficient quantity (Naiman, Johnston and Kelley, 1988; Persico and Meyer, 2009; McComb, Sedell and Buchholz, 1990; Polvi and Wohl, 2012). Beaver dams, just like any human-built dam, lead to aggradation and flooding within the stream system. They either partly or completely block the flow of water and can alter channel longitudinal profiles, create localized sediment storage in backwater ponds, and increase the extent and duration of overbank flooding and associated alluvial groundwater recharge (Polvi and Wohl, 2012). Dams change the stream discharge regime, decrease water velocity, result in a stair-step stream gradient profile, and enlarge the area of flooded soils (Persico and Meyer, 2009). Beaver activity is likely to produce increased variability in channel width and depth, in-channel morphological features, and patchiness of bed sediments (Gurnell, 1998).

Beaver are key in developing complex and highly stable ecosystems essential for species survival (Fouty, 2008). Beaver dam formation and the subsequent wetland formations can create fish habitat, diversify vegetations in riparian zones, and aggrade sediment to increase stream productivity (Bailey et al., 2018). The pictures below (Figure 2) show two types of beaver dams, the first (A) along a stream low enough in gradient to support a series of dams and the other (B) along the width of a bog that has transformed to a large wetland environment. Both of which we assumed were actively used by beaver. Both the pictures show a clear decrease in streamflow volume, an increase in wetted areas, and a wide riparian zone.

Figure 2: Evidence of beaver inhabitation along a stream (A) and within a wetland environment (B).

Case Studies

The following case studies were discovered during the literature review process and present varying scenarios in which beaver positively impact their surrounding environment, are successfully introduced and managed in an urban setting, or where both of these circumstances are true.

Fairfax County, VA

Huntley Meadows Park (HMP) is located in the southeastern portion of Fairfax County, Virginia (McCrea, 2016). The part is located within a suburban area outside of the populous and growing urban area of Washington D.C. The restoration project within HMP was targeted at a large pre-existing wetland within the park. The wetland was created in the mid-1970s by a beaver colony that subsequently abandoned the centralized wetland once their food source depleted (McCrea, 2016). The abandoned dam allowed the wetland to drain and the area went dry. These changes resulted in a decreased level of biodiversity in the park and a project was established to address this loss, focusing on maximizing biodiversity while working with the existing hydrology, topology, and wildlife ecology (McCrea, 2016).

Prior to implementation of the chosen project plan, research was conducted that included interviews, participant observations, field site observations, and document analysis. The results of these efforts formed a governing strategy that involved beaver by familiarizing personnel with beaver ethology and the development of biodiversity via the required wetland restoration, modulating beaver behavior so that they could co-exist in a space by initiating human-controlled water levels and by making beaver activity visual for park goers (McCrea, 2016). In this way, beaver became environmental subjects that were described as “partners in wetland management” (Fairfax County Park Authority, 2013). This urban wetland park connects elements of scientific knowledge, such as the innate ability of beaver to create biodiverse wetland environments, with environmental ethics and material elements such as urban hydrology (McCrea, 2016).

Seattle, WA

Golden Gardens Park

Golden Gardens Park is located on the shores of Puget Sound within Seattle, Washington. In the late 1990s Seattle Parks and Recreation converted a parking area into a wetland complex with the goal of restoring historical waterfowl habitat, cap an area of contaminated soil, and provide handicap and recreational access to the beach (Bailey, Dittbrenner, and Yocom, 2018). The design originally included an engineered pond habitat with a weir as the outlet, but in 2014 beaver colonized the site.

Although beaver colonization was not initially included in the project design, long-term management strategies are being implemented in order to make the inhabitation sustainable. Beaver have increased site complexity and augmented design goals by expanding wetted edge and water storage capacity, while enhancing aquatic and avian habitat (Bailey, Dittbrenner, and Yocom, 2018). The pond area was originally meant to add water storage and provide some stormwater filtration, but site managers are working to retain beaver on-site by altering management strategy and adapting design goals to the physical changes. Since realizing the further benefits for wildlife habitat and increased surface water area, this project has set new goals to embrace beaver inhabitation (Bailey, Dittbrenner, and Yocom, 2018).

Magnusson Park

Magnusson Park is located on the shore of Lake Washington in Seattle, Washington. The park includes a wetland complex on the site of decommissioned military airfield mean to provide wildlife habitat and support passive recreational opportunities (Bailey, Dittbrenner, and Yocom, 2018). The intensely engineered system was designed to provide filtration of stormwater from local neighborhoods and it was suspected that beaver would eventually colonize the area. The designers displayed flexibility by reducing site constraints and creating broad berm-style weirs that functioned like beaver dams to achieve ecosystem function before colonization (Sheldon and Gresham, 2007).

Beaver inhabited the project in 2014, building two large dams that resulted in an increase of surface water area by 30% (Bailey, Dittbrenner, and Yocom, 2018). Despite an increased water table that flooded some walking trails and existing vegetation, beaver presence was perceived positively as the design team recognized the diversified wetland edge and an increase in shrub groundcover (Bailey, Dittbrenner, and Yocom, 2018). In order to sustain the recognized benefit of beaver inhabitation, pond-leveling devices to control water levels and reduce flooding and other beaver management approaches were employed. Managers of the park remained flexible, making site modifications as necessary to support beaver colonization and allowed beaver to improve the ecological function and habitat diversity of the site overall.

Thornton Creek

The Thornton Creek confluence is located within Seattle's largest catchment. The project aimed to improve riparian area surrounding single-family homes. The project site is located immediately above a reach of Thornton Creek that provides the highest quality habitat for Chinook salmon spawning of any stream within Seattle (Bailey, Dittbrenner, and Yocom, 2018). The project site manage plan anticipated the likely colonization of beaver due to known populations in the adjacent pond. In fact, certain design elements such as maximizing floodable area and instream woody vegetation were intended to provide ideal material to beaver dam building. As of 2018 beaver had not colonized the area, but the site managers are read to monitor and adaptively manage the site as beaver colonize and vegetation and hydrology evolves (Bailey, Dittbrenner, and Yocom, 2018).

Vancouver, Canada

Vancouver's Stanley Park is located at the end of a peninsula that protrudes into the Pacific Ocean. The park is surrounded by water on three sides and the downtown core on the fourth. Beaver moved into Beaver Lake in Stanley Park in 2008 which was devoid of beaver for most of twentieth century after the last beaver occupants were forcibly removed (Dean, Ingram, and Sethna, 2017). The return of beaver to the park plays into a new paradigm of urban park management that encourages indigenous animals and fosters their habitats as sanctuaries for wildlife observation (Dean, Ingram, and Sethna, 2017).

In order to sustain a peaceable human and beaver existence, the beavers within Beaver Lake at Stanley Park require daily management. While park visitors visit during the day, the beavers dam up the culvert with branches and mud every night. This requires that park wardens unclog the culvert every morning in order to manage the water levels within the lake. The beavers will be allowed to stay as long as the wardens are willing to unclog the culvert, which means that Beaver Lake remains a profoundly humanized landscape (Dean, Ingram, and Sethna, 2017).

Oregon, USA

Bridge Creek is a watershed located in the north-central portion of Oregon, USA. The project was aimed at species recovery for Steelhead fish. Prior to project start, the Steelhead habitat exhibited low complexity and poor quality (Bowes et al., 2016). Research suggested that beaver dams would aid in the sought-after project goals, but also revealed that beaver dams are often short lived within Bridge Creek due to lack of woody vegetation. The goal was to encourage beaver to build dams then on stable structures (i.e. beaver dam analogs) that would increase dam life spans to facilitate channel aggradation, and eventually floodplain creation and reconnection (Bowes et al., 2016).

After 2009, when beaver dam analogs were first placed within the creek, the total number of dams was on average four times more abundant than pre-manipulation (Bowes et al., 2016). Following the manipulation, habitat quantity and quality also increased, resulting in an increase in Steelhead juveniles within ponded areas. The addition of beaver dam analogs resulted in an overall increase in the number of natural beaver dams. This increase in beaver dams led to large changes in both fish and beaver habitat, and the Steelhead population response largely followed the hypothesized increase (Bowes et al., 2016).

Case Study Conclusions

These case studies show the varying degrees of management needed to sustain a beaver population within an urban area. The studies vary from showing instances in which beaver colonization was planned and prearranged and other projects where beaver inhabitation was likely, yet not an integral part of project completion. The use of beaver colonization for restoration efforts is far from mainstream, so understanding case studies such as these gives you a baseline understanding of the ways in which beaver reintroduction can be successful and lead to a stable and sustainable aquatic ecosystem. It is worth noting that the case studies presented here are mostly from parks within urban or suburban neighborhoods. This is perhaps an important note on the amount of land and management needed to implement beaver engineering successfully.

Discussion

Beaver in an Urban Environment

The beaver population within North America was estimated to be somewhere between 60-400 million individuals prior to European arrival (Seton, 1929). It is understood that at that time beaver were found in nearly all aquatic habitats throughout the continental US. Starting in the early 17^{th} century, however, more than 10,000 beaver per year were taken for the fur trade in Connecticut and Massachusetts alone; 80,000 were taken from the Hudson River (Moloney, 1867). As the fur trade continued and the beaver population declined, people moved westward sometimes with the sole intention of finding new trapping areas and continuing the fur trade. This westward mobility resulted in the nationwide near extinction of the North American beaver.

The overall decline in beaver population took place simultaneously with a decrease in wetland acreage throughout the US, undoubtedly related to changes in beaver habitat (Naimann et al., 1988). With this decline, streams and adjacent riparian zones shifted from systems dominated by ponds, wetlands, braided channels, marshes and wide riparian zones abundant in fish and wildlife to simple, incised, overly wide, single-thread channels with narrow strips of riparian vegetation (Fouty, 2008). Today, beaver population is rebounding, estimated to be between 10 to 15 million individuals, but is nowhere near its historical population (Muller-Schwarze, 2003). Identifying sites for continued reintroduction throughout North America will continue to require knowledge of habitat suitability factors as well as active management considerations (Dittbrenner et al., 2018).

In considering the introduction of beaver into an urban environment it is imperative to remember the complexity of urban ecosystems. As previously mentioned, urban ecosystems are highly variable and are often characterized as having degraded, damaged, and anthropogenically altered environments. Thus, the planned prolonged human-wildlife interaction resulting from beaver introduction to urban streams is a decision that will need to be reached with a flexible, dynamic, creative and well-informed approach. Decisions regarding beaver inhabitation will not only require a management plan but will also require support from stakeholder and local landowners. So not only is it imperative to find adequate habitat capable of supporting viable populations of healthy beaver, but it is just as important, perhaps even more so, that such populations will cause acceptable interference with existing land-uses (Baker et al., 2006).

The figure below provides a great way to visualize the approaches in consideration of beaver inhabitation. Introduced by Bailey et al. (2018), this figure suggests there are three ways in which you can approach beaver inhabitation within aquatic restoration projects: 1) no consideration of beaver colonization, 2) consideration of the potential for beaver colonization, and 3) requiring beaver colonization. The first method shows an ultimate outcome of design modifications and negative human responses along the way. The second method allows for beaver inhabitation, but does not require it, so the author suggests the project does not reach its potential for ecosystem services provision. The last method requires beaver colonization and suggests that although the beaver population will need to be managed, this is the best way to efficiently get a high level of ecosystem services from your restoration project.

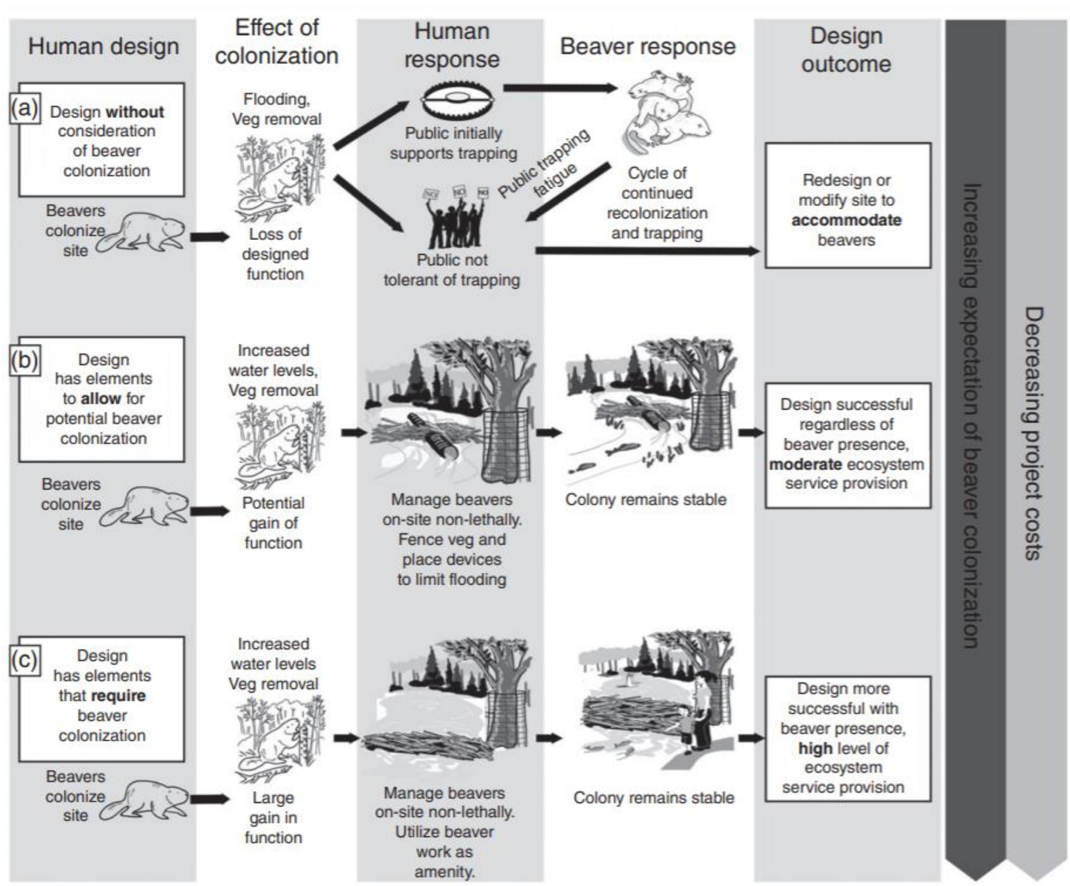

Figure 4: Pathways for integrating beaver into urban landscapes as is presented by Bailey et al. (2018).

Management of beaver ranges from lethal removal of nuisance individuals to reintroduction of individuals for habitat restoration, to increase wildlife and habitat diversity (Taylor, Bergman, and Nolte, 2008). This range of attitude towards beaver inhabitation is reflected in within urban environments as well. If managed properly, the conflicts that beaver sometimes create can be minimized, but it requires an anticipation and acceptance of the geomorphic and hydrological implications of beaver introduction (Bailey, Dittbrenner, and Yocom, 2018). Urban streams, then, are a probable candidate for beaver inhabitation, but it requires designers and managers to incorporate beaver behavior and perception into the governing apparatus (McCrea, 2016). The following case studies introduce scenarios in which beaver were successfully introduced into urban environments and/or were used for stream restoration.

Conclusions

In order for stream restoration to be successful, a shift from narrow analysis and management to an integrated understanding of the links between human actions and changing river health is necessary (Booth et al., 2004). The movement of people from rural to urban environments has accelerated in the Twentieth and Twenty-First Centuries, resulting in a continued reliance on urban watersheds to support life-giving processes and aquatic ecosystems (O'Driscoll et al., 2010). Urbanization alters river ecology and frequently creates stream systems plagued by urban stream syndrome. Humans have systematically and rapidly stripped watersheds of all the features that had historically provided complexity, stability and water retention capability (Fouty, 2008), including ecosystem engineers such as beaver.

Beaver activity within urban stream systems has the potential to progressively effect the aquatic environment within an otherwise degraded system. Their presence as ecosystem engineers leads to an overall increase in habitat heterogeneity and structural complexity of the stream ecosystem (Polvi and Wohl, 2012). The recovery sequence, as seen in Figure 5, has the potential to incorporate beaver presence for the greatest level of ecosystem service and function (Polluck et al., 2014). Adopted from Polluck et al. (2014), Figure 5 illustrates the ways in which streams function with and without beaver presence, ultimately leading to a healthy, biodiverse, and stable ecosystem once beaver colonization is sustained.

There is, however, an inherent level of conflict between beaver resource use and land-use changes with humans. Beaver down trees and impound water in a way that completely alters the water table and effects the surrounding vegetation. Often times they clog outlet structures and can negatively impact human engineering. However, if managed properly, restoration projects that require beaver colonization can result in fully functioning wetland or stream ecosystems that will continue to provide healthy aquatic habitat and enhanced water quality. Projects will inevitably require some level of adaptive management, but the case studies discussed preciously suggests there are various ways to alter projects and address necessary changes to maintain an acceptable level of human-beaver interaction. Examples include, water levels adjustments with weirs or outfall structures, tree protection with wire for and the removal of woody debris from unwanted areas in order to continue to embrace the ability of beaver as ecosystem engineers.

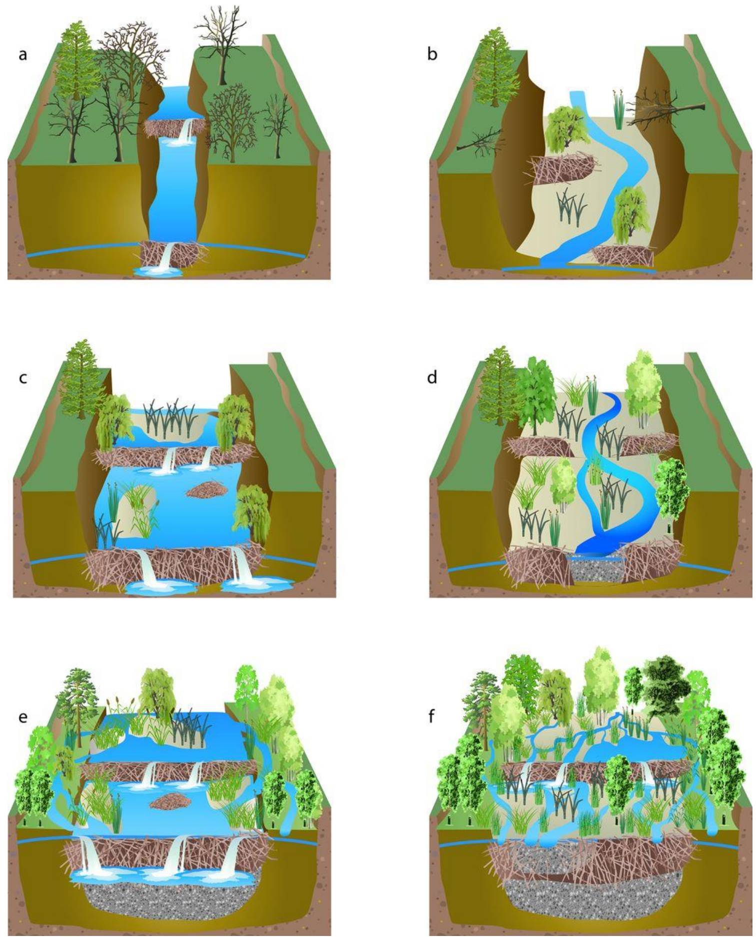

Figure 5: Sequence of ecosystem change with beaver colonization as is introduced by Polluck et al. (2014). A shows initial beaver colonization. B is the resultant stream profile after dams have been abandoned. The incised and widened stream then goes through another sequence of beaver inhabitation and abandonment in c-d. Pictures e-f show the wetland environment that is established after sustained beaver inhabitation. The resultant ecosystem is more biodiverse and stable than the previous pictures.

Human restoration designs within urban settings most often include highly engineered systems where we implement human-made construction materials and alter the channel so that the flashiness of the system is manageable. I argue, however, that the research shows we should introduce beaver into urban stream systems, especially in areas where there is space for a wetland ecosystem such as a park. The positive impacts that beaver have on the surrounding environment and water quality have been well documented within this paper as well as within the scientific world. The idea of reintroducing beaver into urban watersheds is nuanced and requires an amount of active management in order to maintain a good human/wildlife relationship, but with a flexible and creative approach the engineering ability of beaver can be harnessed and utilized to create sustainable natural aquatic environments that benefit humans and surrounding flora and fauna.

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