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Understanding Ecosystem Services Along Urban Streams Using Citizen Science, Social Media Data, and Expert Input

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Understanding Ecosystem Services along Urban Streams Using Citizen Science, Social Media Data, and Expert Input

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Environmental Science
and Engineering

by

Yareli Sanchez

2022

ABSTRACT OF THE DISSERTATION

Understanding Ecosystem Services Along Urban Streams Using Citizen Science, Social Media Data, and Expert Input

by

Yareli Sanchez
Doctor of Environmental Science and Engineering
University of California, Los Angeles, 2022
Professor Richard F. Ambrose, Chair

About 75% of the streams and rivers in Southern California are biologically degraded. Widespread development and flood control have created an urban river condition known for geomorphic simplification, reduced societal value of stream systems, and ecological simplification. The global degradation of streams has resulted in a freshwater biodiversity crisis that, by many measures, eclipses terrestrial biodiversity loss. However, while responsible for many pressures to ecosystems, cities can enhance aspects of ecosystem health and aid in reducing biodiversity loss. Cities can also host the ecosystem services, however degraded, that enhance community cohesion, resilience, and well-being. A growing urban river revitalization movement in the region, in various states of implementation, offers an opportunity to critically examine the opportunities and challenges that are presented by our local urban rivers. In this dissertation, I identify cultural ecosystem services (CES) along the Los Angeles River using FlickR data and examine the relationship between CES and site attributes using Maxent, a presence-only species distribution model. I find that I am able to identify 5 typologies of CES using FlickR text and photos, that two reaches of the Los Angeles River, a completely channelized and a semi-natural, soft-bottom reach of the River, host the highest CES intensity, and that relative suitability of CES occurrence is related to the presence of historical bridges, access, and median flow. Then, using a more traditional application of Maxent, I examine avian species habitat relationships at the catchment scale for species found along urban and semi-natural streams in Southern California. I find that I am not able to identify predictors of habitat suitability for generalist species at the catchment scale, in part due to contradicting model evaluation metrics, and describe limitations with the use of citizen science data, catchment scale analysis, model valuation, and the application of Maxent to highly urban settings. Finally, following statewide investments in green infrastructure projects that enhance water quality and water capture and recognizing the opportunity to support urban biodiversity in distributed multi-benefit projects, I make use of the Delphi method and the expertise of biodiversity experts to identify habitat goals for green infrastructure projects and associated metrics. I describe the Delphi process and the difficulty in reaching consensus due to disagreement in the feasibility and likelihood of success for several goals and objectives. I describe a preliminary framework to capture the habitat value of green infrastructure projects and compare it to established biodiversity frameworks.

The dissertation of Yareli Sanchez is approved.

Thomas Welch Gillespie

Elizabeth C. Koslov

Victoria Kelly Turner

Richard F. Ambrose, Committee Chair

University of California, Los Angeles

2022

Dedication

I dedicate this work to my loving family that made many sacrifices to support me in this endeavor. I specially dedicate this to my supportive husband that helped in countless ways, particularly when I needed that last push across the finish line.

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Acknowledgements

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Vitae

Yareli Sanchez

Education

- University of California, Los Angeles **In progress**
  Doctorate of Environmental Science, Environmental Science and Engineering
- San Diego State University **2013**
  Master of Science, Ecology
- California State University, Fullerton **2009**
  Bachelors of Science, Biology

Select Research

- Impact of Inundation on Salt Marsh Plant Productivity and Stress, UCLA July'14-Dec '15

Graduate research. Research aimed at facilitating monitoring and restoration of salt marsh ecosystems by linking the early eco-physiological stress response to increased flooding by salt marsh plants to specific reflectance regions. Developed expertise in eco-physiological methodology and the impact of sea level rise on coastal ecosystems.

- Use of Bio-filter Systems for the Improvement of Stormwater Quality, UCLA June'13-Oct'13

Graduate research. Preliminary research exploring the use of bio-filter systems for the treatment of storm water via plant uptake, microbial processes, and filter media. Developed expertise in application of ecological principals to engineered systems.

- Tidal Effects on Trace Gas Flux in a Mangrove Forest in B.C.S., Mexico, SDSU Jan'10-May'13

Graduate research. Research aimed at understanding variables controlling trace gas flux from mangrove ecosystems focusing on effect of tidal and zonal variation. Developed expertise in the biological, physical, and chemical processes governing wetland ecosystem functioning and trace gas emissions.

- Genetic Variability of the Endangered Santa Ana River Woolly Star, CSUF June'07-May'09

NSF-Undergraduate Mentoring in Environmental Biology project. Research quantified the genetic variability in a federally endangered plant species. Assessment necessary to inform restoration and future research efforts. Optimized methodology in assessing genetic variability

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Publications

- Rosencranz J.R, Brown L.N., Holmquist J.R., Sanchez Y., MacDonald G.M., Ambrose R.F. (2017) The Role of Sediment Dynamics for Inorganic Accretion Patterns in Southern California's Mediterranean-Climate Salt Marshes. Estuaries and Coasts.
- Romero M.R., Walker K.M., Cortez C.J., Sanchez Y., Nelson K.J., Ortega D., Smick S.L., Hoese W.J. and Zacherl D.C. (2012) Larval diel vertical migration of the marine gastropod. Journal of Marine Biology.

Select Work Experience

- Senior Scientist, Council for Watershed Health 2017-Present

Technical lead on CWH's applied research projects. I provide technical expertise on stream monitoring and on measuring the performance of green infrastructure projects. I manage the Los Angeles River Watershed Monitoring Program, the refresh and monitoring efforts for one of the first regional neighborhood retrofits, Elmer Avenue, and the monitoring, outreach, and educational components of the Drought Response Outreach Program for Schools (DROPS).

- NOAA Knauss Legislative Fellow, U.S. Senate Feb'16-Jan'17

Year-long fellowship where I worked to advance legislative environmental priorities related to watershed management, water quality, and Great Lakes issues. I translated technical scientific information to better inform office activities. I engaged with stakeholders, researchers, and local leaders to assess funding and programmatic gaps. I gained exposure to the appropriations process, national coastal resilience efforts, agriculture policy and programs, programs supporting innovation in water issues, as well as cross agency approaches and regulations relating to water quality and habitat conservation.

- Graduate Research Assistant, UCLA Sep'15- Jan'16

Facilitated and carried-out experimental set-up and planning for a research project investigating the use of sediment augmentation as a restoration strategy to combat the impacts of sea level rise. Organized and led teams of undergraduate students in field efforts.

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Rain or Shine, Soaking up Success. Panel. **2020**
Green Infrastructure – Indices, Metrics, and Monitoring

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Watershed Monitoring – Informing Los Angeles River Restoration

State of the Los Angeles River Watershed Symposium. Talk. **2017**
Monitoring the Los Angeles River From 2008 to Today

Annual Conference of the Ecological Society of America (ESA). Talk. **2012**
Trace Gas Flux in Mangrove Forest Ecosystem in B.C.S., Mexico

Annual Conference of the American Society of Plant Biologist. Poster. **2009**
The Genetic Variability of a Federally Endangered Plant Species

Annual Conference of the SACNAS. Poster. **2009**
The effect of Anthropogenic Runoff on the
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Cota Robles Fellowship	**2013**
Mabel Myers Memorial Scholarship	**2012**
Farris/EPEF Travel Award, used to attend ESA's 2012 Conference	**2012**
Jordan Meyer Memorial Scholarship	**2012**
Sussman Fellowship	**2010**
Outstanding Poster Presentation, Biology, SACNAS	**2010**

1 Introduction

Cities throughout the world are located next to rivers because they provide a dependable source of water, productive soils, and ease the movement of materials. The devastating loss of life and capital due to flood is a common element that has led to the channelization of urban rivers and the construction of dams and extensive storm drains systems. Widespread patterns of development and flood control have resulted in an urban river condition known for geomorphic simplification, reduced societal value of stream systems, and ecological simplification (Bernhardt et al., 2005; Walsh et al., 2005). The impacts of urbanization are so archetypical that the condition has been coined "urban stream syndrome" (Walsh et al., 2005), whereby impermeable land cover and highly effective storm drain systems quickly move large volumes of runoff, create a flashy hydrograph, allow for elevated nutrients and contaminant concentrations, reduce aquatic richness, and alter channel morphology. In urban streams flow magnitudes are higher, timing to peak flow shorter, and post-event flows reduced (Poff et al., 1997; White & Greer, 2006). Alterations in the flow regime and channelization create disconnection between aquatic life histories and the hydrograph (Schlosser, 1985), impact plant community composition (White & Greer, 2006), and biotic diversity (Bunn & Arthington, 2002). Invasive plant species, like *Arundo donax*, invasive amphibians, such as the American Bullfrog and red swamp crayfish, and fish, like bass and sunfish, expand their range and thrive under the perennial flow conditions of urban rivers (Bell, 1997; Fuller et al., 2011; Riley et al., 2005).

Communities have taken notice of the opportunities to rehabilitate local rivers and river revitalization is gaining steam as a means to improve urban waterways, waterfront economies, provide community amenities, and to potentially tackle the rapid loss of aquatic biodiversity (Abell, 2002; Sandercock & Dovey, 2002). Throughout the nation, once booming industrial cities have looked to their waterfronts to revitalize urban life. These cities have applied similar templates for revitalization. In an analysis of revitalization plans completed for the cities of Chattanooga, Columbus, Louisville, Pittsburgh, Portland, and Saint Paul, Tumbde (2005) found that public private partnerships are key to revitalization and include partnerships and funding entities as diverse as development agencies, private developers, non-profit organizations, local and state entities, and private investors. Despite the diverse economic development, recreational, and environmental goals these partnerships can introduce into planning processes, Tumbde (2005) found key common strategies across cities. For example, the need to boost local economies has resulted in heavily industrialized zones being transformed into mixed use and commercial development that encourage further development and generate the local revenue that can help maintain public amenities. Environmental remediation is also key to creating safe and inviting public spaces, creating momentum for compliance with the Clean Water and Clean Air Acts. Development of infrastructure creates the foundation for further investment and development. Connectivity, whereby derelict riverfronts are connected to business districts, civic institutions, and downtown areas, help boost visitation and the appeal of riverfront properties (Tumbde, 2005). The creation of parks, open spaces, trails and other recreational opportunities has also emerged as an objective of river revitalization. In cities like Louisville, open space was used as a flood buffer zones between development and the river's edge (Tumbde, 2005). Many cities have revitalized their waterfronts, and to an extent restored their rivers, to spur economic development. However, the benefits of these investments, particularly when comparing different models of revitalization, are poorly accounted for.

Though the benefits of river revitalization are considerable enough to draw many formerly industrial cities across the country into planning processes, the benefits have not been reviewed and quantified in a comprehensive manner. However, the value and benefits of ecological restoration, the process that support an ecosystem in recovery, which will vary depending on the prioritization of restoration efforts and ecosystem services within revitalization plans, has been quantified using various valuation methods. In Washington State, a survey tool was used to estimate the recreational, existence, and bequest value of dam removal and ecosystem restoration for an anadromous fishery, estimated at $138 million (J. B. Loomis, 1996). In California, hedonic pricing method was used to estimate the value of investment via the Urban Stream Restoration Program. Restoration activities resulted in a 3-13% increase in property value, though some aspects of restoration, like riparian tree buffers, reduced property values (Nicholls & Crompton, 2017; Streiner & Loomis, 1995). Households will pay an estimated $252 annually for the ecosystem services associated with restoration, such as recreation, erosion control, habitat creation, water purification (J. Loomis et al., 2000). In brownfield to green field conversion, a re-development strategy along formerly industrial waterfronts, survey assessments have found that projects enhance scenic beauty, increase neighboring property values, boost community pride, enhance neighborhood cohesion, enhance physical fitness, and provide access to recreational space and nature (De Sousa, 2004, 2006).

Criticisms of waterfront revitalization, however, abound. Sieber (1991) noted that revitalization has been largely reflective of social and economic changes that favor elite urbanites engaged in the creative or knowledge economy. Revitalized rivers host a core constituency that is decidedly different. Former uses of the waterway are often lost and there is a blanket erasure of a blue-collar industrial past and the social and environmental decisions that created persistent inequalities in the Nation’s cities (Hagerman, 2007; Sieber, 1991). In a river walk models of revitalization environmental benefits can be over-estimated. Citizens exhibit a higher willingness to pay for the restoration of a stream to its natural state rather than the creation of the artificial streams (Lee & Jung, 2016) that are often a template of revitalization plans. However, environmental movements grow with revitalization efforts and often seek to connect urbanites to nature and remedy the impacts of industrial activities (Sieber, 1991). While generally public health research has supported the goals of environmental movements, because green space can reduce noise, enhance recreational opportunities and even improve food access (Escobedo et al., 2011), cities are confronted with a paradox. Restoration and urban greening can lead to “green gentrification,” whereby historically underserved and park poor neighborhoods become more attractive, rent and housing cost rise, and the communities that were supposed to benefit from greening are displaced (Wolch et al., 2014). This paradox has led some to argue that design interventions should prioritize community perspectives, avoid the river walk model, and be ‘just green enough’ to remedy environmental and public health ills (Curran & Hamilton, 2012; Wolch et al., 2014).

Strategies recognizing the need for equitable revitalization and the value of socio-ecologically guided restoration have used largely bottom-up and community centered approaches. Along the Sacramento River scientist worked with stakeholder groups and local partners to identify restoration activities that would simultaneously enhance ecosystem health and ecosystem services, specifically flood protection and recreation, by explicitly joining ecosystem and societal perspectives and priorities (Golet et al., 2006). Using a “bottom-up” approach to revitalization, Hager et al. (2013) found that neighborhood revitalization and school greening improved water quality, engaged communities in outdoor recreation, improved student scores in environmental literacy assessments, created opportunities for social cohesion, increased access to municipal services, and created momentum for investment in ecological, social, and economic improvements. In Los Angeles after a 2007 River Master Plan was criticized for failing to consider economic and development policies that would benefit residents that long lived near the River, the communication infrastructure theory (CIT), a framework that incorporates multi-method research, field work, and partnership building between academic institutions and advocacy groups, was utilized as a bottom-up story-telling framework that garnered policy recommendations for revitalization efforts. Policies included local hiring, affordable housing, and the establishment of land trusts (Villanueva et al., 2017). Insight from revitalization projects throughout the country will continue to offer opportunities to challenge pre-existing assumptions of what revitalization should look like and to soberly acknowledge the constraints that can bind visions for a revitalized river.

As river restoration has grown in cities, the classic ecological philosophy focused on restoring ecological systems to a pre-European state by focusing on river fluvial processes, flood-pulse events, and target species (Lake et al., 2007) has, at times, been incongruent with the physical and spatial constraints and community preferences. Restoration will be limited along highly modified river channels due to flood risk and the large populations and human developments that abut river channels. Rivers are unlike other ecosystems in that they are very dynamic, and the high flows and water levels that come with sudden storms demand room for the river to swell. Additionally, novel ecosystems (Hobbs et al., 2009) will require new restoration strategies due to shifting species composition and ecosystem functioning caused by environmental alteration. A changing climate will also shift the selection of target species (Butterfield et al., 2017). As a result, the field of ecology has evolved to acknowledge the constraints of restoration and suggest that restoration guidepost shift from reference state to process based (sediment dynamics, flooding, succession). Ecologist have also begun distinguishing between the types of restoration and associated goals, ranging from restoring to a pre-disturbance state that can be defined and reconstructed to moving an ecosystem from degradation toward a more natural state, particularly when a pre-disturbance condition cannot be defined and reconstructed (Aronson et al., 1993; Dufour & Piégay, 2009). Since managing flood risks is the top priority and reference states are rarely achievable, restoration projects in many of the world's cities are heavily designed and engineered, such as terracing, sinuous low flow channels, and floating platforms (Martín-Vide, 1999). Additionally, urban ecologists have begun to develop frameworks for restoration that pay attention to social, cultural, and economic perspectives (Egan et al., 2012), acknowledging that human preferences and public understanding of ecosystems will play a central role in the future of rivers (Alberti et al., 2003a; Dufour & Piégay, 2009). Effective community engagement will therefore be key in future models of restoration (Alberti et al., 2003b; Golet et al., 2006; Villanueva et al., 2017).

1.1 Urban Ecology and the Challenges and Opportunities within Cities

Cities present both opportunities and challenges for conservation and management of biodiversity. Rapid global urbanization and habitat fragmentation has contributed to the rapid loss of native species due to: the loss of native vegetation, stress and mortality associated with human activities, increased exposure to predation, and competition with non-native species (Grimm et al., 2008; Marzluff, 2001). Yet, green spaces and biodiversity in cities is important from a sociological and ecological perspective. Green spaces in cities shape aesthetic preferences, can help support the establishment of neighborhood social ties, and shape formative experiences with nature and conservation priorities (Dunn et al., 2006; Kuo et al., 1998; J. R. Miller, 2005). There is also some evidence of the health benefits of biodiversity, such as psychological and immune health (Aerts et al., 2018; Wall et al., 2015). Residents in cities also value the environmental and personal benefits that biodiversity offers (Clergeau et al., 2001). Cities may also have some conservational value. Australian cities were found to host heightened levels of biodiversity and threatened and endangered species (Ives et al., 2016). Research studies have found that gardens, depending on the taxa of interest, garden size, vegetation structure, and the inclusion of native plant species, contribute to urban biodiversity (Goddard et al., 2010; Loram et al., 2008; van Heezik et al., 2013). High levels of urban biodiversity can also be explained by a high density of adaptive and exploitive native species, intermediate levels of disturbance, species replacement by ornamental species, and environments that favor early successional natives and cosmopolitan species (Clergeau et al., 2001; McKinney, 2006). Urban areas cannot hosts all species types, however. Ecosystem complexity, biotic interactions, and species richness still decline along urban gradients, particularly for urban sensitive species (McKinney, 2006 for review). For example, the species associated with complex groundcover that human populations regard as untidy, such as ground, shrub, and cavity nesting birds, disappear from human dominated ecosystems (Marzluff & Ewing, 2018). The highly fragmented landscapes found within urban areas will likely only sustain a subset of species, likely generalist and urban tolerant species, but managers can work to maintain populations of these species (Marzluff & Ewing, 2018). A better understanding of species habitat relationships in urban environments can help with restoration, conservation planning, and to better inform reconciliatory management and urban design (Michener, 2004).

Unlike classic ecological approaches to ecosystem study, urban ecosystems are interconnectedness with socio-economic considerations. The multi-faceted nature of urban areas has led to the emergence of urban ecology and recognition of cities as heterogeneous, dynamic, complex ecosystems, and microcosms of global change that present the opportunity for enhancing human well-being (Grimm et al., 2000, 2008; S. T. Pickett et al., 2001). Though cities are heterogeneous within their boundaries, the common needs and preferences of human populations has meant that cities are globally homogenous and share common characteristics including: an increased amount of edge habitat, smaller patch sizes, high densities of urban tolerant and cosmopolitan species, an altered energy balance and levels of productivity (Grimm et al., 2008; McKinney, 2006). Approaches to studying these rapidly growing entities have largely been dominated by gradient or transect methods that span the urban core and exurban areas (McKinney, 2006) as well as landscape pattern metrics related to structure, function, change, and socio-economic factors (Alberti et al., 2001). Other frameworks for the study of urban areas have incorporated classic ecological approaches including: meta-population dynamics (Driscoll, 2007), patch dynamics (S. T. A. Pickett et al., 2000), and human ecosystem frameworks (McKinney, 2006; S. T. Pickett et al., 2001; S. T. A. Pickett & Cadenasso, 2006). Human ecosystem frameworks are relatively novel within a field that has historically left humans out of ecosystem models. The factors within a human ecosystem framework span beyond demographics and include social status, culture, networks and institutions to better model the human role in ecosystems (Machiis et al., 1994). Urban ecosystem frameworks can conceptualize cities from a socio-ecological perspective and create the foundations for biophysical research that enhance the design and management of cities and generate benefits for people and natural communities (S. T. A. Pickett & Cadenasso, 2006).

Ecosystem services are the benefits people derive from the natural world and the concept has supported discussions and evaluations about an ecosystem's contributions to human well-being (MEA, 2005). Based on the difficulties of restoring some landscapes, particularly riverine landscapes within urban regions, there has been growing interest in restoring ecosystem services instead. However, approaches that narrowly focus on a few services and processes, such as reducing sediment loads or flows, can have unforeseen tradeoffs, resulting in loss or damage to ecosystems (Bullock et al., 2011; Palmer et al., 2014). As a result, multiple studies are seeking to understand distributional patterns of ecosystem services, their relationship to each other, and how to co-manage ecosystem services (K. M. A. Chan et al., 2006; Egoh et al., 2008; Naidoo et al., 2008). Cultural ecosystem services (CES) are the non-material benefits that ecosystem provide to human populations such as spiritual, recreational, aesthetic, and educational values (MEA, 2005). This category of services play a role in all human/nature interactions but have received less attention because their non-material nature make them more difficult to quantify (Díaz et al., 2018). Studies that have captured the value of CES, though often focused on the recreational CES typology, have often valued CES above commodity production, though these economic valuation exercises often ignore social perspectives (K. M. Chan et al., 2012; Hernández-

Morcillo et al., 2013). Andersson et al. (2015) note that because CES are interlinked with many ecosystem services, they may provide a gateway for managing nature in cities and connecting populations to the value of ecosystem services, more broadly. Managing cities and degraded rivers to maximize certain ecosystem services and using CES, and their assumed intuitive value, to connect communities to urban ecosystems is a compelling idea that, in the least, supports efforts to understand the distribution of ecosystem services and their relationships to the environment.

Human aesthetic preferences will impact project design, revitalization typologies and ecological value in managed ecosystems. Open spaces in urban environments often reflect the diversity of a city itself and the preferences of ethnic, class, user, and interests groups. However, the evolutionary and cultural values that come into play in human predilection for natural aesthetics do not predict ecological quality (Gobster et al., 2007) and designers face the tasks of accommodating human preferences while still maintaining some ecological value (Bernhardt et al., 2007). For example, trails can create edge effects that favor generalist and increase levels of predation (K. R. Miller, 1996). Heavy recreational use at sites can result in high trash levels and alter groundcover, soil, and tree condition (Cole & Marion, 1988). Gobster (1995) notes that users often have a distaste of features such as downed wood, dead material, and scattered clear cuts, and generally favor features that reduce habitat complexity, biodiversity, and increase habitat edge. User groups differ in their aesthetic and stewardship values for rivers. Among hydrologists, farmers, and the general public, the latter two preferred the aesthetic of well-maintained and straightened river channels (Nassauer et al., 2001). Landscape architects attuned to the impact of aesthetic preferences and keen to survey community inclinations have found techniques to provide “cues to care.” Such techniques include: co-designing less appreciated ecologically beneficial features with features that are more widely valued, such as open water, using publicly accessible points strategically, providing information to help communities interpret forest management and, installing features such as weirs and deflectors to create the auditory and visual aesthetics communities value (Gobster, 1995; Nassauer et al., 2001). This balancing is key because projects are unlikely to garner support or receive the maintenance they depend on if they are not aesthetically pleasing, even if they enhance ecological value (Gobster et al., 2007).

The case for better understanding the ecology of urban areas and the human dimension of restoration, recreation, and environmental preferences is clear. However, assessing ecological value, public perception, and behavior in large, patchy, and densely populated areas may be impractical and expensive using surveys, observational studies, and other traditional approaches. The advent of social networking and data sharing platforms has facilitated data collection and sharing. Citizen science data, and the platforms that collect, store and manage these data, have allowed data collection on species distribution across large areas and in spaces otherwise inaccessible to scientists, like backyards (Andrianandrasana et al., 2005; Chandler et al., 2017).

Social media data, via the analysis of text, networks, and sentiment strength of posts (Thelwall, 2018), has proven a useful source of observational and passive public opinion data for social and natural scientist that make use of a ‘network of human sensors’ (Goodchild, 2007; Rogers, 2018). This is particularly true because the use of social media platforms have transformed beyond social networking, though the culture of each platform varies, to a means of sharing, contributing, and disseminating geospatially referenced information (Kaplan &

Haenlein, 2010). This is evidenced by the use of Twitter data to track fire, flood, and the impact of disruptive events (De Longueville et al., 2009; Fuchs et al., 2013; Murthy & Gross, 2017). Geotagged photos, though subject to less attention, have been used to examine point patterns and supplement authoritative disaster relief datasets (Gao et al., 2011; Goodchild, 2007; Panteras et al., 2015). Recognizing that taking a picture is linked to preference, opinions, and favored characteristics of the surrounding environment, researchers have used Flickr data as proxies for observed preferences (Bernetti et al., 2019), to characterize spatial and environmental patterns of recreation (Westcott & Andrew, 2015), and to derive the travel cost and water quality value of inland lakes (Keeler et al., 2015).

1.2 Focusing on Southern California

Southern California is facing many of the same challenges other cities face in the rehabilitation of their rivers, including concerns over green gentrification, spatial constraints in restoring hydrology or large swaths of habitat, technical gaps about the extent to which restoration is possible in urban environments, and a need to balance the desire for urban amenities, ecological rehabilitation, and economic drivers for waterfront redevelopment. A broad fluvial stream typology, the legacy of destructive flooding events, and climate projections predicting more frequent and extreme storm events in one of the most heavily urbanized regions in the nation further complicate stream rehabilitation and efforts for the lateral reconnection of habitats (Gumprecht, 2001; Ingram, 2013; Swain et al., 2018). Nevertheless, in Los Angeles, a movement ignited by advocacy organizations that thought far too much had been lost when the Los Angeles River was paved for flood control purposes created the momentum to build a green corridor along the Los Angeles River, which currently bisects various park-poor and pollutionburdened communities (Dahmann et al., 2010; Su et al., 2011; *The Lower Los Angeles River Revitalization Plan*, 2017).

Efforts to revitalize the Los Angeles River began with scattered restoration efforts and river centered performance pieces have since been buoyed by government protection, federal funding, and the incorporation of the River into local and regional plans (Dorfman, 2018). The 2010 declaration that the River was a navigable water, the creation of urban parks linked to the River, a 2012 law that enshrined that the River was held in the public trust for use by the people, and the completion of an U.S. Army Corp of Engineers (USACE) study focused on the restoration opportunities along a soft bottom reach further ignited the revitalization movement. The USACE-selected study alternative has paved the way for the removal of 11 miles of concrete, restored riverbed habitat, wetland restoration, and park creation along and within the River (USACE, 2013). Meanwhile, local to countywide efforts have considered River revitalization within their planning updates, with efforts focused on the creation of connected bike path, improving habitat, and augmenting recreational and open space (L.A. Metro, 2016; LADPW, 2021; *The Lower Los Angeles River Revitalization Plan*, 2017; Woods, 2000).

Climate change predictions for the region, which include extreme storm events and long periods of drought (Berg & Hall, 2015; Cayan, 2008; Swain et al., 2018), have simultaneously spurred efforts to prioritize local water resources, often via green infrastructure projects, and to look to the river's watershed to enhance local water resources (LADWP, 2015; *The Greater Los Angeles County Open Space for Habitat and Recreation Plan*, 2012; *The Lower Los Angeles River Revitalization Plan*, 2017). The emphasis on local water has also led some cities to focus their gaze on the unnaturally large volumes of wastewater that currently flow down the Los

Angeles River. Currently, upwards of 80% of dry weather flows are from wastewater effluents (Council for Watershed Health, 2018). Efforts to increase the use of recycled water through the diversion of existing flows have created critical questions about how best to manage flows to support increased water recycling, aquatic species, and existing recreational uses along a highly urbanized River.

Priorities focused on enhancing river system functions that support wildlife habitat and aquatic ecological health can be at odds with goals focused on enhancing recreation, water reuse, economic vitality, and community well-being in a heavily urbanized Mediterranean-climate watershed. As efforts in restoration, revitalization, water capture, recycling, and conservation progress for the Los Angeles River, it will be critical to coalesce ecological considerations with community values and uses of the River. Revitalization offers the opportunity to strengthen our understanding of the ecological principles that are applicable to urban systems and to employ socio-ecological concepts and frameworks for decision development. As planning and investment in urban rivers, like the Los Angeles River, continue critical questions remain related to uses and attitudes toward the River, measures of success, and the habitat characteristics around which species associate.

1.3 Organization of this Dissertation

The following topics will be the focus of my dissertation and will be presented in separate chapters:

1. Understanding Cultural Ecosystem Services Along A Heavily Urbanized River Using Social Media Data and Expert Interviews

The Los Angeles River dissects diverse communities throughout Los Angeles, including park-poor communities that have long used the River for recreation. Like many rivers in the region, the LA River is fed by effluent that is discharged from wastewater treatment plants and, during summer, effluent accounts for the majority of the River's flow. These flows sustain cultural ecosystem services (CES). However, a statewide effort to increase water recycling will reduce effluent volumes along the region's rivers and potentially impact CES that are dependent on flow. Current attitudes toward the River may also impact future project selection, design, and recreational opportunities, as communities engage with local government over questions of access, safety, and the design of a public amenity. My research focused on understanding CES along channelized portions of the River, surveying where they occur, and the relationship between CES, flow and other site characteristics. My research is unique in that most studies focused on CES and the site characteristics of where those uses occur have focused on natural landscapes, such as national parks and state recreation areas, and not on an urban river with typologies that range from completely channelized to soft-bottom and vegetated. I used both focus group and social media data to better understand CES, the relationships between CES occurrence and site attributes, and attitudes toward the River.

2. Understanding the relationship between species presence and site characteristics in Southern California Streams using citizen science.

The southern California region is a biodiversity hotspot that has, like other Mediterranean biomes, experienced rapid species decline. The rapid decline of endemic species is due, in part, to the region being home to two of the most densely populated metropolitan areas in the country (Moyle & Williams, 1990; Underwood et al., 2009). Los Angeles and neighboring cities have begun planning and implementing projects with the objective of revitalizing the Los Angeles River and adjacent communities through investment in riverine trails, green infrastructure, parks, greenways, and habitat restoration. I explored the relationships between environmental variables, land-use, population density, and bird species occurrence in streams across the southern California region. This research is important to revitalization efforts along the Los Angeles River and a growing number of communities that look to convert channelized or urban adjacent rivers to community assets that support ecological functions. Uncovering the relationship between species occurrence and site characteristics can help practitioners and managers target bird species, a taxonomic group that is a good ecological indicator (Furness et al., 1993), for restoration efforts. Additionally, by making use of citizen science observations and publicly available data sources to better understand the land use and environmental variables that are important to bird species occurrence, this study attempted to model a cost-effective approach to understanding the species habitat relationships that better inform management, design, and areas for future research in urban areas that lack comprehensive species observations.

3. Identifying the metrics that capture habitat value of multi-benefit green infrastructure projects using a Delphi approach.

Green infrastructure projects have been implemented across southern California to treat, capture, and infiltrate stormwater runoff in a drought prone region that is largely dependent on imported water (*The Lower Los Angeles River Revitalization Plan*, 2017; Water Quality, Supply, and Infrastructure Improvement Act, 2014). Park projects and greenways with stormwater management objectives are also slated for construction along the Los Angeles River corridor. Recognizing the potential to enhance habitat value and urban diversity within the urban core, practitioners have sought to better measure the habitat benefits of green infrastructure projects. Identifying a set of metrics that capture project performance, from a habitat perspective, will be key step in setting a foundation for future monitoring and research programs that are needed to help researchers decipher the value of green infrastructure projects and, ultimately, generate the design recommendations that enhance their habitat value.

My research focused on determining the habitat goals that green infrastructure can achieve and the associated suite of habitat metrics that are key to capturing and understanding the habitat value of green infrastructure projects. I employed an iterative survey approach, the Delphi method. The Delphi method is used to reach group consensus in the absence of empirical evidence by making use of expert insight. The Delphi method is well suited for this research question considering the considerable expertise of stream, restoration, and urban ecologist in the region and because key questions about the habitat value of small urban parcels remain unanswered in the academic literature.

In this document I will provide additional background for each of my research topic, review pertinent literature sources, describe study methodology, and present final analysis. I will then discuss overarching themes, next steps, and the implications of the completed work in the conclusion. Each of the research chapters below is presented in the order enumerated above.

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2 Understanding Cultural Ecosystem Services Along A Heavily Urbanized River Using Social Media Data and Expert Interviews

2.1 Introduction

The benefits ecosystems provide to society are known as ecosystem services (ES) and are categorized into provisioning, regulating, supporting, and cultural (MEA, 2005). Cultural ecosystem services (CES) are the non-material benefits that ecosystem provide to human populations such as spiritual, recreational, aesthetic, and educational values (MEA, 2005). Cities present a compelling case for understanding ecosystem services, however fragmented they may be, given the high density of beneficiaries compared to natural areas (Thorp et al., 2010) and the location of many cities near threatened ecosystems and along riverine corridors (Botkin & Beveridge, 1997). Those benefits include social cohesion, (Kuo et al., 1998), increased perception of quality of life and health (Maas et al., 2006; Stigsdotter et al., 2010), and opportunities for physical activity (Coombes et al., 2010), among others. Additionally, several studies have found that there is greater dependence on CES with greater economic development and since CES are non-substitutional, their loss is permanent (Guo, 2013; MEA, 2005; Rodríguez et al., 2006). Green spaces in cities may also provide a gateway for urbanites to engage with ES, to better understand the impact of environmental change, and to ultimately support restoration projects (Andersson et al., 2015; Richards et al., 2017). Many studies have examined the relationships between CES and site attributes and recognized the implications this research can have on development, planning, and land management (Bernetti et al., 2019a). My research is focused on understanding cultural ecosystem service occurrence along a heavily urbanized river that is in the midst of revitalization and the relationships between CES occurrence and site attributes, at the census tract level.

CES have received less attention than other ES because many of the benefits of CES are intangible and thus difficult to quantify (Guo et al., 2010; MEA, 2005; Rodríguez et al., 2006). Economic valuation of ecosystem services is a flourishing area of study because valuation approaches allow scientist to communicate ecosystem value to politicians and the general public, however these approaches often ignore social perspectives (Chan et al., 2012). Nevertheless, of the CES valuation literature, a large volume of CES literature has focused on the value of recreation and tourism using contingent valuation methods (CVM), particularly willingness to pay (WTP), near national parks, preserves, state recreation areas, and scenic rivers (Carlsen & Wood, 2004; Ken Cordell et al., 1990; Shrestha et al., 2007). The value of recreation in urban areas has been similarly evaluated (Dou et al., 2017; Jim & Chen, 2006; Majumdar et al., 2011; Tyrväinen & Väänänen, 1998) and studies have shown recreation is one of the most valued CES categories (Dou et al., 2017; Langemeyer et al., 2015). Valuation approaches have also been used to assess educational value, an understudied CES, generated from school field trips using the travel cost approach (Hutcheson et al., 2018). While contingent valuation approaches are imperfect and can vary widely, they have been valuable in quantifying preferences and guiding environmental decision making (Hudson & Ritchie, 2001; Lindsey & Knaap, 1999). Beyond the valuation of CES particular ecosystems provide, some studies have mapped the supply of CES using land cover data and indicators of CES (Thiele et al., 2020). Thiele et al., (2020) in an assessment of German rivers, used indicators related to vegetation, physical habitat, and density of archeological, natural, and cultural monuments and facilities to map CES supply (Thiele et al., 2020). Andrew (2015) used high resolution Google imagery and spatial environmental datasets to develop indicators of recreation for management of off-road vehicles. Plieninger (2013) used structured interviews and participatory mapping to capture CES and the bundling of services and disservices. Despite the difficulty in capturing the value and occurrence of CES, studies have made use of CVM surveys, interviews, participatory mapping, and geospatial analysis.

Social media data has allowed researchers to define, value, and better understand the provisioning of CES in a more cost-effective manner, without surveys, interviews, or focus groups. Social media research makes use of social media data by recognizing that humans serve as a network of sensors that share information about their environment. That potential network of human sensors is large; 90% of the global population lives near a mobile internet connection and 70% of the US population are active social media users (ITU, 2018; Kemp, 2019), and users are using social media applications for more than social networking but as a means of sharing, contributing, and disseminating geospatially referenced information (Kaplan & Haenlein, 2010). For example, given the wide distribution and volume of geotagged photos from tourists, Becken et al. (2017) suggested photographs could be used to monitor the Great Barrier Reef. Additionally, photo analysis has been used to reveal preferences about the environment (Bernetti et al., 2019b) and text from geotagged posts has helped researchers track political opinion (O’Connor et al., 2010) and natural disasters (De Longueville et al., 2009; Fuchs et al., 2013). Havinga et al. (2020), noting the definition of cultural ecosystem services is not yet operationalized, suggested that the Global Ecological Model definition of ecosystem services which describes “the use and availability of information” is fitting for assessing cultural services using social media data since ecosystems provide the information that people then retain, process, and report. Havinga et al. (2020) noted the typologies of CES that can be assessed using large public datasets, including activity, aesthetic, amenity, artistic, heritage, knowledge, naturalist, and religious and spiritual services (Figueroa-Alfaro & Tang, 2017; Millenium Ecosystem Assessment, 2005; Richards & Friess, 2015).

The ease of accessing FlickR's API and the multi-dimensional nature of posts, which can include text, photo, and geographic information, has meant that this data source is prevalent in the literature and can be used to better understand CES relationships with the environment, CES provisioning, and can discern many CES typologies. Richards and Friess (2015) characterized CES in different mangrove sites and their work supported the ease of discerning CES typologies from analysis of FlickR photo content. Bernetti et al. (2019b) used the density of FlickR photographs and a geostatistical model to understand the relationship between site characteristics and aesthetic value. FlickR posts, a proxy of site visitation, have been used to conduct more cost-effective valuation analysis using the travel-cost method (Keeler et al., 2015). Van Zanten (2016) used posts from FlickR, Instagram, and Panoramio to understand global recreational patterns and Bing et al. (2021) measured the supply and demand of CES in Shanghai using recreational indicators and FlickR post, respectively. The accessibility of social media data and of environmental datasets that serve as predictors of CES can increase the ease by which municipalities understand and manage natural areas and open spaces. This includes allocating more resources (e.g., rangers or guides, trash cans, maintenance crews) to heavily visited areas or establishing formal recreational areas at locations with high CES supply.

The frequent co-location of cities and rivers has created a convergence of challenges and opportunities for CES. Flood is a common element that has led to the channelization of urban rivers and the construction of dams and extensive storm drains systems. Widespread patterns of development and flood control have resulted in an urban river condition known for geomorphic simplification, reduced societal value of stream systems, and ecological simplification (Bernhardt et al., 2005; Walsh et al., 2005). The impacts of urbanization are so archetypical that the condition has been termed "urban stream syndrome" (Walsh et al., 2005), whereby impermeable land cover and highly effective storm drain systems quickly move large volumes of runoff, create a flashy hydrograph, allow for elevated nutrients and contaminant concentrations, reduce aquatic richness, and alter channel morphology. Nevertheless, these highly modified and managed systems may still provide CES. For example, well designed green infrastructure in urban settings have been shown provide amenity services (D'Arcy & Frost, 2001). Restored urban rivers have been found to provide greater recreational value than before restoration (Polizzi et al., 2015). However, the CES value of channelized rivers have been rarely measured since they have been assumed to be non-existent or low (D'Arcy & Frost, 2001). Among the few studies that have measured CES in urban areas have found high preference for scenes containing water, whether natural or urban (White et al., 2010).

The Los Angeles River, which is channelized along the majority of its length, faces many of the constraints associated with urban river rehabilitation: a heavily urbanized floodplain, a deficiency of greenspace, and highly altered flow conditions. Additionally, the River's flow, which is about 80% wastewater during the summer, may support certain CES. The River is undergoing major re-envisioning and revitalization efforts, which includes goals to support healthy, connected ecosystems, enhance access to the River, and provide equitable open space and trails (LADPW, 2021). Simultaneous efforts to maximize local water resources through water recycling will also impact the future of the River by altering the existing flow regime and the recreational uses that are supported by existing flows. This study will make use of FlickR photo and caption data, triangulated with group interview data, to answer the following research questions about the Los Angeles River:

- What is the intensity of CES use along the Los Angeles River?
- What are the sentiments towards the River?
- What is the relationships between CES and site attributes along a highly urbanized river?

The study is unique in its attention to a highly altered river system but borrows approaches from existing studies that have examined CES typologies, CES intensity, and CES relationships with the environment using social media data and geospatial analysis. Results support our understanding of CES in a highly urban setting and can guide ongoing revitalization priorities based on the relationship between CES and site attributes.

2.2 Methods

2.2.1 Background and Site Context

The study location is the Los Angeles River (the River) in Southern California. Like the majority of urban rivers in Southern California, the River is channelized and its flow for most of the year is largely made up of treated wastewater effluent. The River lies adjacent to heavily populated areas and a variety of land uses, including industrial, commercial, open space, and residential. The River channel is accessible via parks and the bike path and sometimes, more informally, via bridges and gaps in fencing. Access along the River varies from easily accessible, particularly in locales where the trails and parks run along the trapezoidal channel, to inaccessible where development, fencing, or a box channel configuration render channel access difficult or unsafe.

The analyses detailed below were completed at one of two scales: the census tract or reach scale. The census tract scale was used to make use of the wealth of population, ecological, and socioeconomic data available by census tract. The reach scale was a useful spatial unit of analysis because it captured the main typologies of the River (Figure 1; Figure 2; Table 1). It is also the basis by which water agencies make management decisions about the River and it allows for use of some data that would be too scant to analyze at a finer level. The dominant characteristics of each reach are described in Table 1.


Reach 1 Reach 2 Reach 3
Reach 4 Reach 5 Reach 6

Figure 1 Photograph of features that typify the unique conditions of each reach of the Los Angeles River. Photo source is the Los Angeles River flow study.

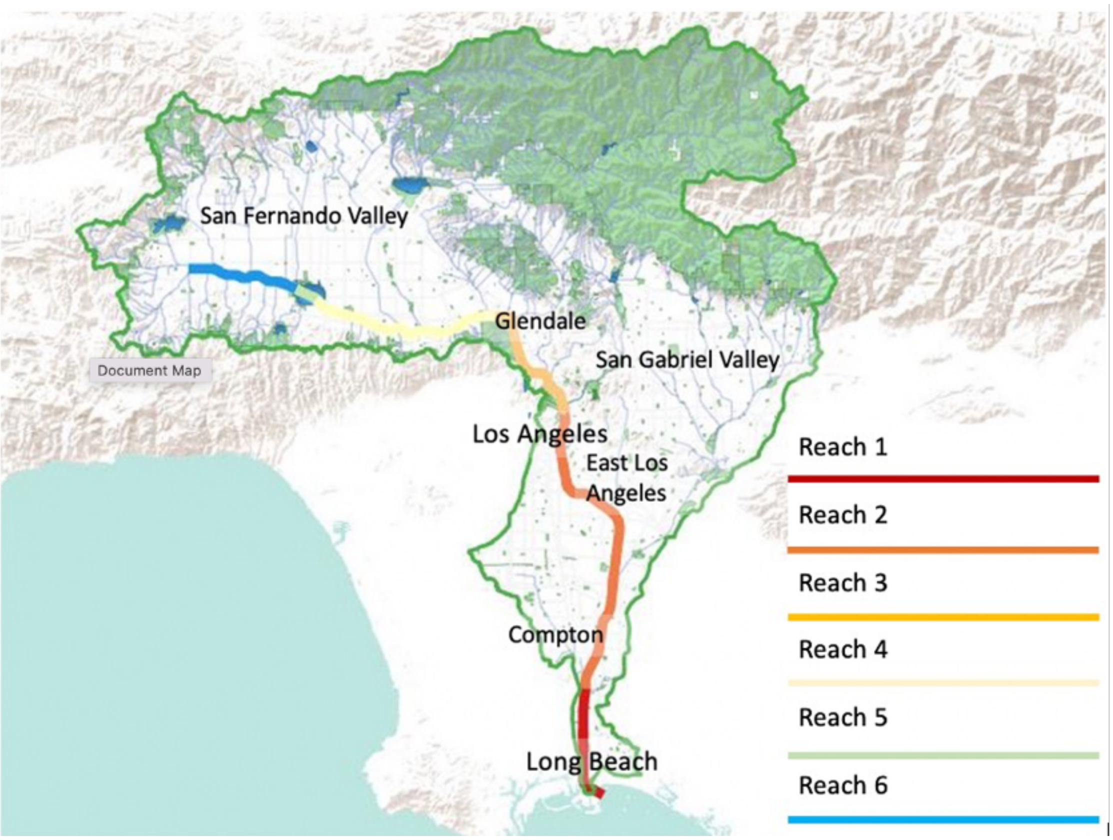


Figure 2 Reaches of the Los Angeles River

Table 1 Reach Descriptions

Reach	Description
Reach 1	Tidally influenced reach that has one soft bottom areas near the coast and rip rap along the channel edges. Above the tidally influences portions, the River is a hard bottomed, trapezoidal channel.
Reach 2	Entirely channelized and in the trapezoidal configuration. This reach abuts large areas of commercial and industrial land uses.

Reach 3	Encompasses one of the few continuous soft-bottom and vegetated portions of the river. Along this section, the River runs adjacent to a large, urban park and several smaller parks.
Reach 4	A mix of soft bottom and hard bottomed channel typologies, including both trapezoidal and box channel configurations. There are several parks and large open spaces that are adjacent to this reach.
Reach 5	Known as the Sepulveda Basin, this reach has a large park, trails, a Japanese Garden, and sports fields adjacent to the River. This is a large, open and vegetated area with a soft bottom.
Reach 6	Entirely hard bottomed and trapezoidal, the River channel runs adjacent to largely residential land uses.

2.2.2 Surveying Recreational Uses through Focus Group and Expert Interview

I used focus group responses to triangulate statistically supported findings about recreation and its relationship to the environment. The focus group was initially focused in on identifying agreed upon-indicators of recreation, such as water depth, and specific targets for each indicator (such as 3 feet of water in the summer) for each reach of the Los Angeles River. This is due to the potential importance of flow to sustaining certain recreational uses along the River and California's focus on recycling water, and thus reducing the effluent that feeds much of the River's current flow. However, since the focus group discussion and indicators (e.g., presence of wildlife or access) were more broadly related to CES and the conditions that sustain CES along the River, the study objectives shifted.

The benefit of group techniques is that the method makes use of facilitated discussion and participant interaction, providing more depth to participant opinion than surveys (Basch, 1987). A drawback to group methods is that group dynamics and dominant individuals can overtake discussion (Smithson, 2000). Deleterious aspects of group dynamics can be counterbalanced, as was done in this study, by ensuring that participants are diverse enough that no single perspective is dominant based solely on group representation, and to break up facilitated discussion with opportunities for individual and confidential response (Powell & Single, 1996). Following open-ended group interview questions, prompts to inventory the activities along the River, and facilitated discussion, social choice methodology, a voting-based method for combining individual opinion to reach a collective decision, helped elicit judgments that could be enumerated to obtain individual weighted scores to identify the most important indicators of recreational use and the extent of agreement among participants. The full set of indicators and targets are presented in the Detailed Focus Group Results in the Appendix A. Social choice methodology, closely akin to Multi-Criteria Decision Making, is preferred method for group decisions when information is limited, unreliable, or qualitative (Kelly, 2013; Srdjevic, 2007). The method has been applied to variety of environmental decision making issues including water management (Srdjevic, 2007), timber harvesting (Laukkanen et al., 2004), and forest management (Kant & Lee, 2004).

To begin, I compiled a list of potential participants from stakeholder lists and community engagement events for the Los Angeles River Revitalization (plans for the River have been drafted with formal feedback from stakeholders -largely NGOs, agencies, city leaders, and the larger community via community events). Participants were then filtered based on the criteria that participants hold a formal position with a non-profit or community-based organization, business, or government entity that has a focus, per mission statement, advocacy campaign, or project work, related to at least 2 of the following:

- Community engagement and education
- River access
- Active transit or recreation
- River revitalization or rehabilitation

A total of fifty-two individuals fit the participant criteria. For the purposes of this study, I considered selected individuals recreational experts. Recreational experts were sent a summary document about the Los Angeles River Flow Study and the objectives of the recreational focus group. Experts also received an Institutional Review Board (IRB) study consent form and were asked to fill-out a preliminary survey. Preliminary survey questions focused on the recreational activities their organizations led, the location where those activities took place, and provided an opportunity for other experts to be referred to the group. A total of eighteen people responded to the preliminary survey and ten expressed interest in participating in a focus group. Prior to the focus group, stakeholders received the participation criteria, a description of project goals and work products, a list of other survey participants, and the opportunity to refer colleagues and partners who met the participant criteria. Participants that were identified by other experts were invited to participate. I contacted participants that were unavailable for the focus group for a phone interview. Phone interviews ranged from 1-1.5 hours, depending on the participant's capacity and interests. In total fifteen recreational experts participated in the study who were familiar with walking, biking, fishing, boating, wildlife viewing, horseback riding, and park use along the Los Angeles River. Recreational experts were affiliated with non-profit organizations, a joint-powers authority, local city government, the County, or were small business owners that led recreation activities along the River.

During the group interview, I gave participants background information about each reach including channel morphology, access, and a map of each reach of the River. I asked participants to review a list of recreational uses for each reach of the Los Angeles River, compiled from previously published reports. Participants then updated recreational uses and identified the indicators and targets for each recreational use, guided by a series of open-ended questions. Notes or audio recordings were taken during the interviews. I recorded the focus group and processed and analyzed the recording according to the Krueger and Casey framework (Krueger & Casey, 2014), mainly noting frequency, intensity, and specificity of responses. I selected the Krueger and Casey framework because of the accessibility of the method to beginners and the many resources offering practical guidance on its use (Rabiee, 2004). However, some of the recommendations from Krueger and Casey (2014) regarding the homogeneity of the participants, in terms of ethnic, age-range, social class background, and recommendations that the group be unknown to each other could not be followed given the small number of recreational experts for the River. However, the lack of anonymity among study participants likely had no impact on study findings given the non-sensitive nature of the discussions. Additionally, recommendations from Krueger (1994) to continue holding focus groups until theoretical saturation were not followed because of the small number of recreational experts along the River and low participation rates.

2.2.3 Assessing CES Through Social Media

I made use of two social media platforms to better understand recreational occurrence patterns, FlickR and Instagram. I scraped FlickR posts uploaded between 2008 to 2018 using a Python interface by searching the Los Angeles River tag, and it's various iterations (e.g., LA River, L.A. River, Los Angeles River), as well tags of river adjacent parks. Downloaded data included photo captions, descriptions, date photographs were taken, date a photograph was uploaded, GPS coordinates, and usernames. Data outside of a 1-mile buffer from the Los Angeles River was removed and discarded. Recent restrictions to Instagram's API limited use of Instagram data and, as a result, data was collected manually for the Los Angeles River geotag and the Los Angeles River hashtags (and its various iterations) for the period of September to December 2019. Collected data included date uploaded, username, and photo caption. Instagram data was used in conjunction with FlickR data for text analysis.

The images from FlickR were categorized to capture the activity pictured, pictured location (trail, river channel, park, or bridge), and photo subject. Photo categories were iteratively derived and reviewed to ensure consistency in categorization across posts. After categorization they were cross checked with Havinga et al.'s (2020) typologies of CES. Those categories along with the associated CES included:

1) Small gatherings: Social Services – Photos of a small group of people
2) Community event: Social Services – Photos or captions that captured large, organized, community events (e.g., CicLAvia, trash clean ups, art festivals)

3) Educational: Knowledge Services – Captions that described a tour, outdoor classroom or activities where the River is contributing to understanding (e.g., community science, monitoring)
4) Art and photography: Aesthetic and Artistic Services – Photographs that pictured a wider view of the River landscape, depicted artistic activities (dancing or music videos) or captions that included camera models (e.g., Cannon, Nikon)
5) Wildlife viewing: Naturalist Services – Photographs of animals
6) Active Recreation: Activity Services – These categories included biking, walking, kayaking, swimming, horseback riding, fishing, skateboarding, and exercising. Photographs were categorized into one of these uses if the activity was pictured, including photographs of the recreational equipment (e.g., bike, kayak, fishing rod), or described in the photo caption.

A total of 1727 posts were reviewed and categorized but, ultimately, only 886 posts were used in data analysis due to missing geospatial data or because they were redundant posts by the same individual, on the same day, and in the same area. To identify any differences between FlickR and Instagram data, a dataset that was preferred but was unavailable, I compared the top 10 words across posts from both platforms and sentiment scores using 95% confidence intervals. Statistical analysis were not completed for FlickR text data since it was a census approach using all data from 2008-2018, not a subsample of the data.

I used the Tidytext package and the methodology detailed by Silge and Robinson (2016) to complete sentiment analysis, tri-gram graphing, and word counts in the R statistical computing software (R. Core Team, 2017). To prepare the data for analysis, I filtered common words, numbers, and location out of the analysis (e.g., “the”, “an”, “San Fernando Valley”) using existing and custom-built dictionaries. To prevent dividing counts between plural and singular words, I singularized words that had plural forms. I also corrected common spelling errors to not undercount commonly misspelled words .This involved creating summary tables and counts of all the words used in social media posts. I reviewed this table, identified misspelled words, and misspellings with counts greater than five were corrected using a substitution function. I categorized the top ten most popular words for each reach into art, recreation, parks, and urban environment categories and calculated percentage of words within each category. The “AFINN” dictionary was used to derive a sentiment score for texts and scores were averaged across posts (A. F. Nielsen, 2011). The AFINN dictionary scores words on a scale from -5 to 5, with positive scores associated with positive words and negative scores with negative words.

The dictionary compiled by Finn Arup Nielsen was used because the lexicon was built around the short informal nature of internet text and was tested on and expanded using twitter posts (Hansen et al., 2011; F. Å. Nielsen, 2011). AFINN identifies words, obscenities, and phrases commonly found on the internet (e.g., “LOL” or “WTF”)(F. Å. Nielsen, 2011). It is important to note the shortcomings associated with the use of emotion lexicons like AFINN. Lexicons, which in the case of AFINN, depend on matching text data of interest to a scored dictionary, cannot identify sarcasm and will not adjust sentiment scores based on qualifiers (e.g., “not good”). AFINN is also biased toward negative text (F. Å. Nielsen, 2011).

I used clustering analysis to understand the commonalities between reaches. I used a k-means cluster analysis of the social media data described above and the percent of emotive words. To better understand whether clustering patterns based on social media content may reflect differences in environmental conditions, I then did K-means clustering of all reaches based on percent canopy cover, percent imperviousness, percent roads, average park percent, and percent of the riparian area that is vegetated for river adjacent census tracts.

2.2.4 Maxent Modeling

To better understand the relationship between recreational occurrence and site characteristics, I used Maxent modeling and the FlickR data, filtered to remove posts by the same user, on the same day, in the same location. Maxent is a species distribution model that estimates probability densities of species in covariate space using presence-only observations. The model correlates species presence with the pattern in environmental variables where species occur (Elith et al., 2011; Phillips et al., 2006). The constraints of using citizen science or museum specimen for understanding species distributions and habitat relationships are the same as the constraints to using social media data, mainly, the lack of absence data and sampling bias in presence data. Maxent is mostly used for biological species modeling, but there have been other studies that use Maxent to understand cultural ecosystem services and their relationship to the environment (Arslan & Örücü, 2020; Richards & Friess, 2015; Yoshimura & Hiura, 2017). For example, Yoshimura and Hiura estimated the supply of CES using Maxent. They used FlickR photos and a viewshed analysis to map target sites and reveal visitor preference for landscapes in Hokkaido, Japan.

I selected ecological, socioeconomic, and physical characteristics of a site as predictors for the Maxent model and they are detailed in Table 2. Is it important to note that studies focused on CES have made use of a variety of scales and noted that extent and scale can significantly impact results (Anderson et al., 2009; Casalegno et al., 2013). Ecosystem services may be generated, perceived, and managed at different scales (Hein et al., 2006). In general, identifying the appropriate scale for study of CES is complex because there is no specific structure or function that have been shown to facilitate CES (Hale et al., 2019). In the present study, the census tract level allowed me to make use of existing publicly available environmental, land use, and demographic data. However, previous studies have found viewsheds may be important to CES and features that obstruct views, like dense forest, may result in loss of CES demand (Chen et al., 2018; Norton et al., 2012). Many points along the Los Angeles River, particularly near downtown Los Angeles, offer vistas of the downtown skyline and they are unaccounted for in the present study, with the exception of the photo categorization described above.

Raster files of each predictor were generated in R, using the SF (Pebesma, 2018), SP (Pebesma & Bivand, 2005), and Raster (Hijmans et al., 2021) packages, and QGIS (version 3.14.1-PI). Predictors that were heavily correlated with other predictors (r>0.75) were removed from the model and model performance iteratively tested. The ENMeval (Muscarella et al., 2014) package was used to run Maxent in R (version 4.0.3) and regularization parameter ranging from one to two were used. Model features (which include linear, quadratic, hinge, threshold, and product) and regularization parameters were refined based on Akaike's Information Criteria (AIC) (Warren & Seifert, 2011).

The area under the curve (AUC) is derived from the receiving operator curve (ROC) and is a measure of predictive accuracy based on how a model distinguishes between presence and background points. The ROC curve plots sensitivity, the correctly predicted positives, against commission error, the false positives. AUC-ROC values above 0.70 have been used as a threshold at which one can assume the model has good predictive accuracy. There has been criticism about the use of AUC for determining model performance due to the lack of sensitivity AUC has to poor model fit, the equal weight assigned to omission, or false negatives, and commission errors, or false positives, the lack of information ROC curves provide about the spatial distribution of modelling errors, and the false inflation of values by pseudoabsences outside the extent of where occurrences are found (Lobo et al., 2008). Raes and ter Steege (2007) detail the use of the null model for evaluating model performance by comparing a random distribution of AUC values against the modeled AUC to derive a probability value, similar to traditional hypothesis testing. In order to overcome some of the criticisms related to the sole use of AUC to evaluate model performance, I compared the test AUC to AUC values generated by chance from the same distribution as presence data using a null model. The random distribution of AUC values were compared to the test AUC in a manner similar to hypothesis testing (Raes & ter Steege, 2007). Null models were generated in R using the SDMPlay package (Charlene et al., 2020).

Table 2. Predictors used in Maxent modelling iterations. Predictors that were used in the final model are denoted in green. Predictors that were removed, either due to high covariance or due to low contributions to model performance, are in gray.

Data	Description	Source
Historic Bridges	Point data of historical bridges along each census tract.	Digitized from the laconservancy.org list and spatially joined to overlying census block groups. Tracts without access for a given access category were coded as zeroes.
River Access	Point data of river access (includes bridges, trails, transit stops, equestrian facilities, field facilities) was then spatially joined to census tract layer.	Point data was spatially joined to overlying census groups. Data was summed by census tract using BGRP ID. Blocks without access for a given access category were coded as zeroes. Data was downloaded as KMZ file from https://www.lariver.org/blog/explore-la-river
Riverside Park	Point data denoting presence of riverside parks	
Bridge Access	Point data denoting presence of bridges crossing the River	
Trail Access	Point data denoting presence of riverine trails	
Rec Zone Access	Point data denoting recreation zone access points to the LA river	
Public Transit	Point data of public transit access points within the River buffer	
Equestrian Access	Point data of equestrian access points along the LA River	
Field Facilities Access	Point data of field facility access points along the LA River	

Cobble Gravel %	Percent of channel bottom that consist of cobble sized gravel.	Los Angeles River Watershed Monitoring Program sites (www.watershedhealth.org/larwmp) were used to create Voroni polygons (which partition a plane into n points). Data was interpolated so that census tracts within a Voroni polygon boundary had the same value assigned for a given predictor variable. Some census tracts were then manually adjusted based on site condition (i.e. if a soft bottom portion of the River was grouped with polygons that largely included hard bottomed portions of the River).
CRAM Score	Metric for quantifying riparian habitat condition. Includes 4 sub-metrics: hydrology, biotic score, buffer score, and physical habitat condition.	
Biotic Score	Measure of habitat diversity based on vertical structure, plant community composition, and zonation	
Buffer Score	Attribute that assesses the connectivity of the landscape, riparian buffer width, and buffer condition	
Hydrology Score	Measure of the sites hydrology compared to natural condition based on water source, channel stability, and hydrological connectivity	
Physical habitat score	Measure of physical habitat diversity based on patch types count and the topographic complexity of the stream channel	
Algal IBI	Bioassessment metric that captures algal community composition and enumerates algae. Algal communities may show the net response of an algal community to water quality conditions at each site, particularly nutrients.	
ChlA	Chlorophyl A, a measure of the amount of algae present in a waterbody.	
Concrete Percent	Percent of channel bottom that consists of concrete	
SpecCond	Specific conductivity, a measure of salts or inorganic chemicals, present in a water body.	

Water %	Percent of water area within a census block	Los Angeles County Tree Canopy Data, TreePeople
Build %	Percent of built aread within a census block	
Road %	Percentage of roads within a census block	
Veg%	Percentage of census block covered by vegetation	Added total shrub, grass, and tree canopy area and divided by census block area to calculate vegetated percent.This data was constructed from high resolution LIDAR imagery. Used data from Los Angeles County Tree Canopy Map, TreePeople
Green Space %	Total green space within census block. Green space includes trees, forest, shrubs, grass, herbaceous, woody wetlands, and emergent wetlands.	EPA community metrics data for Los Angeles found at https://www.epa.gov/enviroatlas
Impervious %	Impervious area within a block group	
Walkability	National Walkability Index score for each census block	
Wetland %	Percent cover of woody and emergent wetland within a census block	
PctPopNotPark	The percent of a block group population that is not within an easy walking distance (500m) to a park	
School Count	Number of K-12 schools within a census block	
Non-white	Percent population other than White, non-Hispanic	
TotPop	Total Population [census block group]	
Impervious Riparian %	The percent of impervious cover within 15m of a water body.	

TrafProx	Average annual daily traffic within 500 meters	EJ screen data from epa.gov/ejscreen
LowIncm	Percent of the population in a census block where the household income is less than or equal to the federal poverty level	
POC%	The percent of people within a block group that do not list their ethnicity as white alone	
Park %	Percentage of park space within a census block	The LA County parks need assessment park inventory was used to calculate park area, overlayed with a census block layer, to calculate park percent by census block.
Median Flow Depth	Median flow for each reporting node	Data interpolated from Southern California Coastal Water Research Program Hydrologic Engineering Center River Analysis System modeling for the Los Angeles River.
Flow Velocity	Median flow velocity for each reporting node	
Wet Season Flow	Median flow from October to April	
Dry Season Flow	Median flow from May to September for each reporting node	

2.3 Results

2.3.1 Using FlickR and Group Interview to Understand and Identify Activities Along the River

I was able to categorize 13 different activities along the Los Angeles River using FlickR images and captions. The most popular uses were art and photography followed by walking (Table 3a). Activities that were adaptable to the River's many typologies were art and photography, biking, walking, and wildlife viewing. The reaches that hosted the greatest number of uses were reach 3, a largely semi-natural, soft-bottom reach, followed by reaches 2 and 5, which is entirely channelized and semi-natural soft-bottom, respectively.

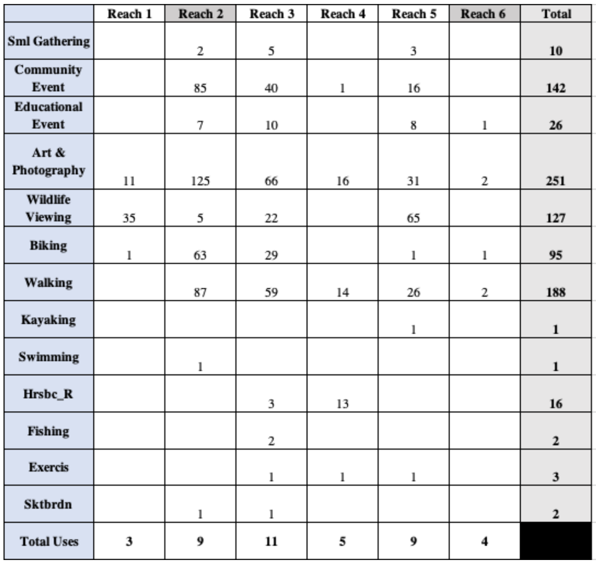
Interviews with recreational experts were also helpful in surveying recreational occurrence along each reach of the River and in understanding the intersection between recreation and site conditions, including the role of flow. Experts relayed that the main-stem of the Los Angeles River host a diversity of recreational uses (Table 3b) in both the naturalized soft-bottom and the hard bottom reaches. Experts identified 12 total uses along the Los Angeles River. While this research was originally focused on the flow required to sustain recreational activities along the Los Angeles River and the majority of experts did rank flow or depth as the most or second most important indicator for many activities, recreational experts also articulated the relevance of a diversity of indicators and themes, beyond flow (

Table 4; Table 5; Appendix A Detailed Focus Group Results). The themes that emerged from focus group discussions are summarized in

Table 4 and include frequent discussions about safety, access, water quality, and enforcement (e.g., swimming in the River is prohibited but not enforced) among others. Some of themes most widely expressed by experts were related to enforcement, aesthetics, and negative description of the River. Among the top themes, the importance of water quality and the importance of wildlife to the aesthetic appreciation of the River were expressed with intensity (i.e., the use of emotional language, superlatives, and hyperbole) by recreational experts.

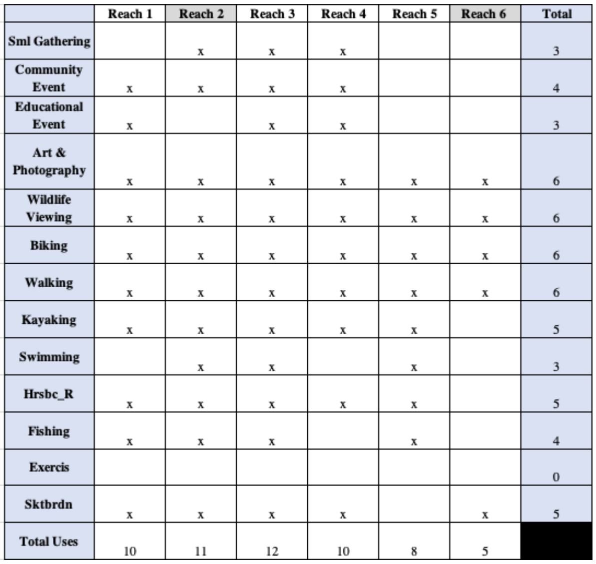
Table 3. a.) CES activities that occur along the Los Angeles River by reach based on FlickR posts. b.) CES activities based on focus group input. The reaches that are highlighted in gray are entirely channelized and include Reach 2 and 6. Reach 3 and 5 contain soft bottom portions. While Reach 1 and 4 are predominantly hard-bottom but contain some stretches of soft-bottom.

a.



	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Total
Sml Gathering		2	5		3		**10**
Community Event		85	40	1	16		**142**
Educational Event		7	10		8	1	**26**
Art & Photography	11	125	66	16	31	2	**251**
Wildlife Viewing	35	5	22		65		**127**
Biking	1	63	29		1	1	**95**
Walking		87	59	14	26	2	**188**
Kayaking					1		**1**
Swimming		1					**1**
Hrsbc_R			3	13			**16**
Fishing			2				**2**
Exercis			1	1	1		**3**
Sktbrdn		1	1				**2**
Total Uses	**3**	**9**	**11**	**5**	**9**	**4**	

b.



	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Total
Sml Gathering		x	x	x			3
Community Event	x	x	x	x			4
Educational Event	x		x	x			3
Art & Photography	x	x	x	x	x	x	6
Wildlife Viewing	x	x	x	x	x	x	6
Biking	x	x	x	x	x	x	6
Walking	x	x	x	x	x	x	6
Kayaking	x	x	x	x	x		5
Swimming		x	x		x		3
Hrsbc_R	x	x	x	x	x		5
Fishing	x	x	x		x		4
Exercis							0
Sktbrdn	x	x	x	x		x	5
Total Uses	10	11	12	10	8	5	

Table 4. Top ten recurring topics discussed by recreational experts during the group interview and individual interviews. The recurrence of each topic, the number of participants that brought up each topic, and the intensity (use of emotional language, hyperbole, or superlatives) were tallied from recordings and interview notes.

Theme	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Recurrence	# of Participants	Intensity	Activities
Public Safety		x	x				16	4	No	Biking, Kayaking, Wading
Difficulty in definiting flow targets	x	x	x		x		13	3	No	Biking, Aesthetic Uses, Kayaking, Birding, Fishing
Enforcement (allowed recreational activities)	x	x	x				10	6	No	Biking, Wading, Kayaking, Fishing
Water quality	x	x	x	x	x	x	10	4	Yes	All
Importance of wildlife	x	x	x				7	5	Yes	Aesthetics, Wildlife Viewing
River as a park space/lack of green space		x					7	4	No	Not Specified
Heterogeneity of the River			x				6	2	No	Kayaking
Designing the River to better host recreation		x	x				8	3	No	Kayaking and Aesthetic Uses
Importance of current flow levels to recreation			x				6	3	No	Kayaking, Birding
Negative descriptions of the River		x					6	5	Yes	None Specified

Table 5 Top two indicators for each activity that occurs along the Los Angeles River according to recreational experts. The black box signifies that the recreational activity does not occur in that River typology.

Activity	Soft-bottom Indicators	Hard-bottom Indicators
Wildlife Viewing	Habitat Complexity, %Water Area	Substrate, Water Depth
Path Activities	Water Depth, Flow Velocity	
Aesthetic	Depth, Flow Velocity	Wildlife, Flow Velocity
Community Events	Water Depth, Flow Velocity	
Wading	Water Depth, Flow Velocity	■
Boating	Water Depth, Access	
Fishing	Habitat Complexity, Temperature	Water Depth, Flow Velocity
Horseback Riding	Flow Velocity, Water Depth	

2.3.2 Agreement between Data Sources

Expert feedback and FlickR data varied in the recreational uses that were identified along the River. In general, FlickR underrepresented the extent of CES along the River compared to experts (Table 3). For example, according to FlickR data, fishing only occurs in reach 3. While recreational experts noted that fishing is dependable along the soft bottom sections of reach 1, 3, 4, and 5. Recreational experts also did a better job of capturing recreational use along certain reaches than were captured in FlickR posts, particularly along Reaches 1 and 4 and activities that are restricted (e.g., wading or kayaking in the channelized reaches). The apparent short comings for surveying specific recreational uses using FlickR data (e.g., kayaking, fishing, and wading) and poor model performance for a subset of individually modeled recreational activities (data not shown) supported the aggregation of all recreational uses together for Maxent modeling.

2.3.3 Social Media Text and Photo Analysis

I made use of captions and photo descriptions from two social media platforms, FlickR and Instagram, to better understand sentiment, social media culture of Los Angeles River visitors and the relationship between social media posts, recreation, and site conditions. Firstly, the most

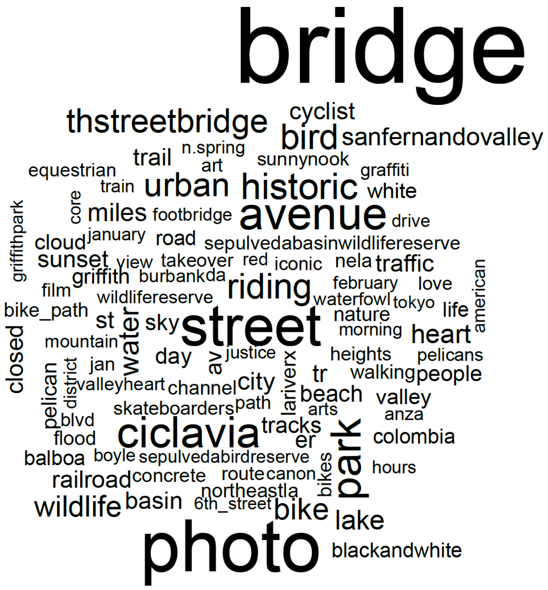


Figure 3 . Word cloud of the top 100 words found in captions and photo descriptions of the River on FlickR and Instagram.

common 100 words used in conjunction with the River were tallied together and are presented in the form of a word cloud (Figure 3). The most popular words reveal that posts of or near the River largely describe urban forms that surround the River and also capture the diversity of typologies along the River. On average posts relayed a near neutral or very weakly positive sentiment (Table 6). Scores range from -5 to +5 and a positive numerical score denotes positive sentiment and vice versa. Sentiment score and popular word use between platforms was compared and largely revealed the similarity in post content across platforms since 70% of the top 10 words were shared between platforms and sentiment scores did not differ significantly (Table 6).

Table 6 Top ten most frequently used words in Instagram posts and FlickR , including both captions and photo descriptions. The average sentiment score for each platform across all posts is based on the AFinn dictionary. A positive score indicates positive sentiment and vice versa.

Rank	FlickR	Instagram	Both
1	bridge	bridge	bridge
2	street	photo	photo
3	birds	street	street
4	ciclavia	avenue	avenue
5	park	ciclavia	ciclavia
6	historic	park	park
7	thstreetbridge	historic	historic
8	riding	bird	bird
9	bike	riding	riding

10	lake	urban	urban
Sentiment Score	0.70	1.00	0.90
95% CI	0.40-1.0	0.80-1.2	0.70-1.0

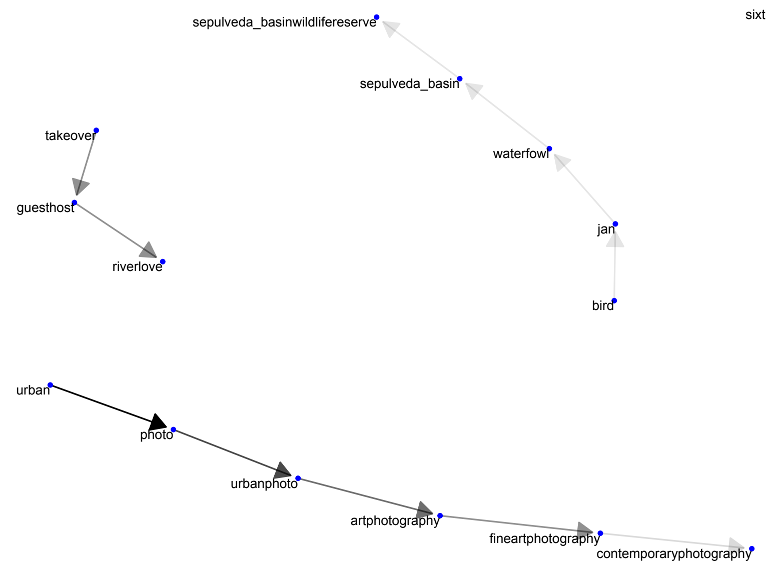


Figure 4. A Markov Chain model based visualization of the 20 most popular trigrams found in social media posts. The arrows depict the directionality of word use. Darker arrows depict a higher frequency of tri-gram use.

To get better context for post content and the relationships between text, a networks visualization was completed using Markov Chain model. Briefly, the Markov Chain Model predicts how a process moves from state to state. The model helps predict the word sequences that are the most likely to occur together based on probability distributions. Figure 4 shows the result of a network tri-gram visualization, using Markov Chain, of all social media text. The arrows indicate directionality of words, for example sixth tends to precede the word street based on the directionality of the arrow. The spatial arrangement of the word networks is random however, arrow darkness does denote the frequency of a particular network. For example, the bottom left of the graph shows a series of hashtags that commonly appear together in LA River posts and, among the most frequent, is “urban” and “photo”. Aside from the popular urban photography themes across posts is the theme related to urban runoff and flood, which also appears with high frequency. In general, the themes of social media posts, as captured by trigrams, capture the functions of the River, access points and vistas to the River, and uses of the River, mainly photography and wildlife viewing. It is important to note that data were not filtered by user so multiple posts by the same user may impact text analysis. For example, one popular Instagram account, LARiverX, invites multiple hosts to “takeover” the account. The commonly used text and hashtags associated with the account appeared as a popular trigram (Figure 4).

I used FlickR data to explore spatial patterns in social media posts from categorized photos. First, I categorized social media posts by the pictured location along the River and photo content. The most popular words for each reach of the river were categorized into six different topic areas including art, recreation, parks, urban environment (e.g., streets, bridges), and natural world (e.g., plants, wildlife, water) (Figure 5). The sentiment score for most reaches of the River, on average, were neutral Figure 5. The highest sentiment score was for Reach 3 of the River while the lowest sentiment score was found in Reach 4. The analysis revealed that the sentiment score do not show a clear pattern with the text content and categorization top posts (Figure 5). For example, sentiment scores do not correspond with high percentage of words about the natural world, parks or art.

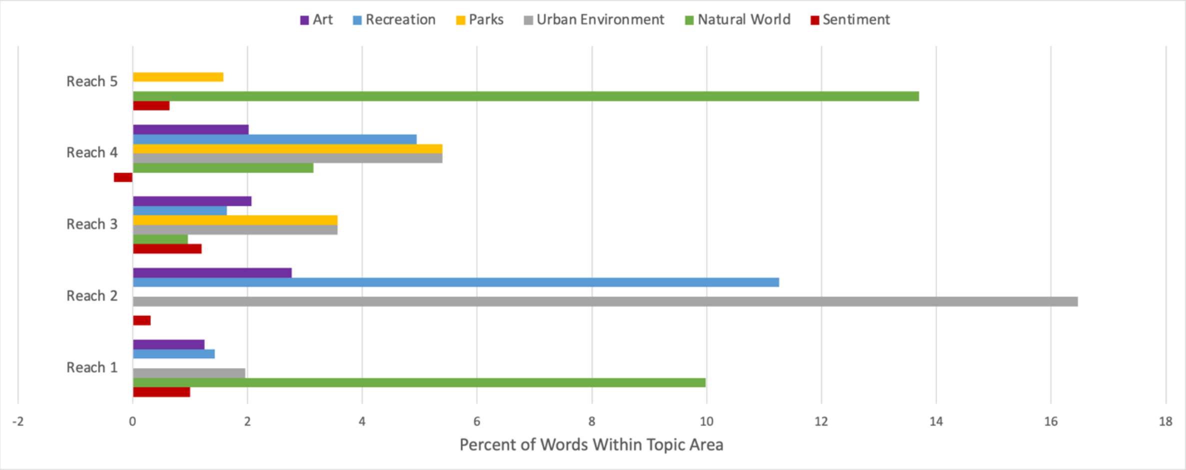


Figure 5 Graph depicting the categorization of the top 20 words found on FlickR for each reach of the River for the years 2008 to 2018.

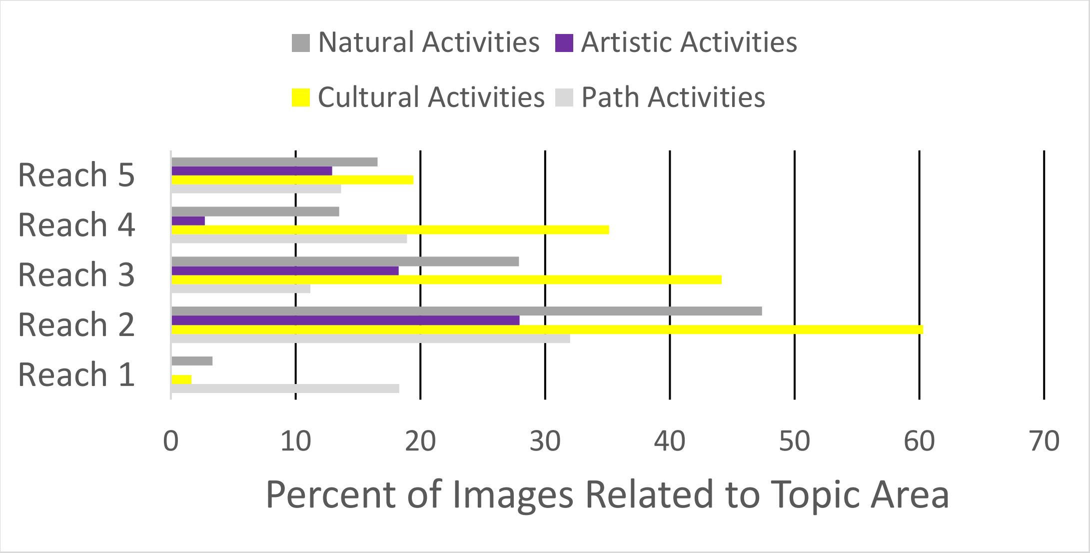


Figure 6 Graph depicting the categorization of all images posted about the Los Angeles River for the years 2008 to 2018.

The most popular text categories within each reach are mirrored in photo content. A high proportion of photos capturing natural activities in reach 1 and 5 mirror text patterns (Figure 5 & Figure 6). However, artistic activities are pictured in more than 10% of photos in all reaches, except reach 1, but are not proportionally represented in the most popular text.

Figure 7 shows photo locations of social media photos taken along the River. Park photos are markedly lower in reach 1 and reach 2 than all the other reaches. Photos taken from a bridge are lower in reach 1 and 5. While bike path photos are lower in reach 1, reach 2, and reach 5.

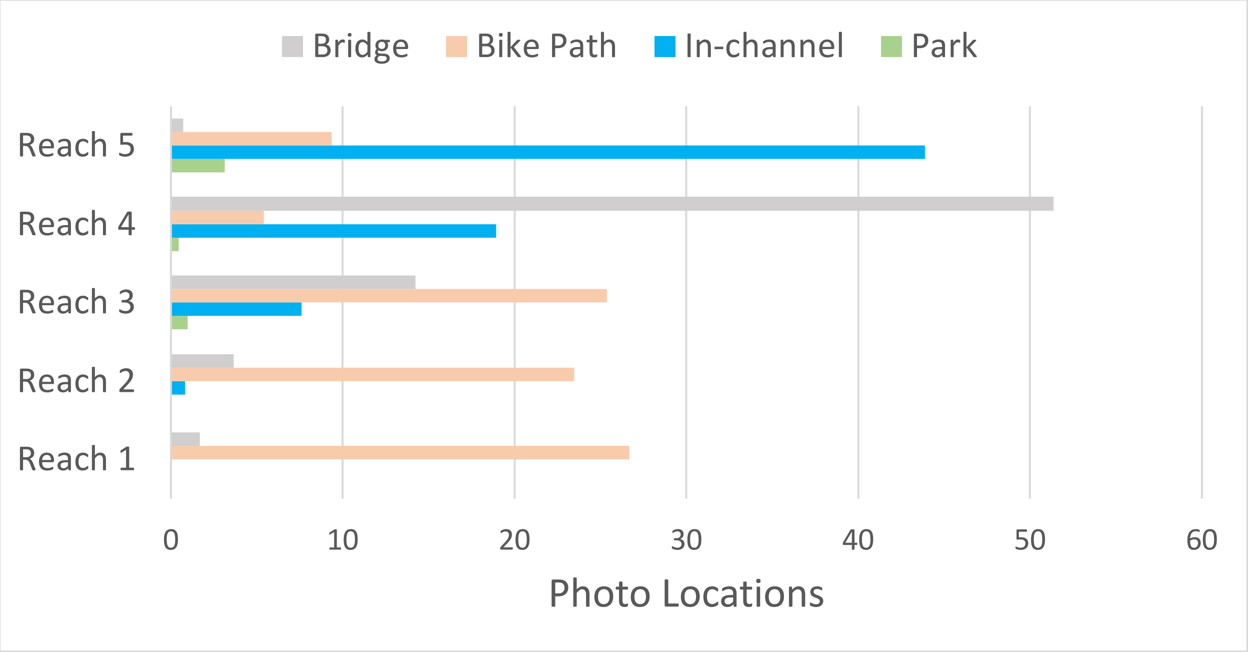


Figure 7 Categorized locations of posted photos within the River buffer for each reach of the River.

I conducted a K-means cluster analysis to better understand patterns in word usage, sentiment score, and photo content between reaches of the River. The cluster analysis showed that social media content for reach 2 of the River was unlike any of the other reaches while reaches 1 and 5, and 3 and 4 clustered closely (Figure 8). This clustering pattern was not necessarily in response to differences in environmental conditions, whereby reaches in close geographical proximity clustered together (Figure 9). Reach 5 was the most dissimilar to all reaches based on environmental conditions, yet clustered with reach 1 based on social media content. The environmental conditions at reach 2 were most similar to reach 1 and, again, social media content from these reaches of the River did not group together.

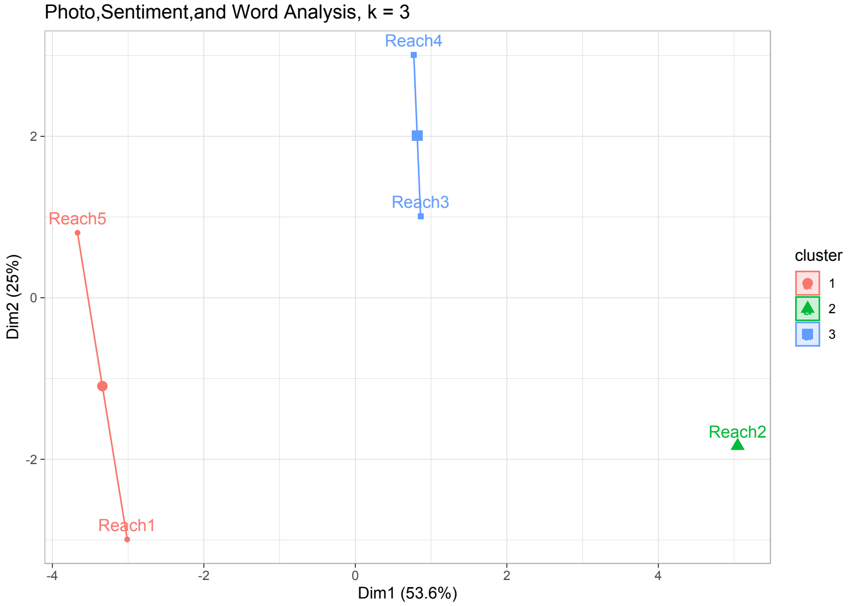


Figure 8 K-means Cluster analysis of each River reach based on social media content (data depicted in graphs 7-9).

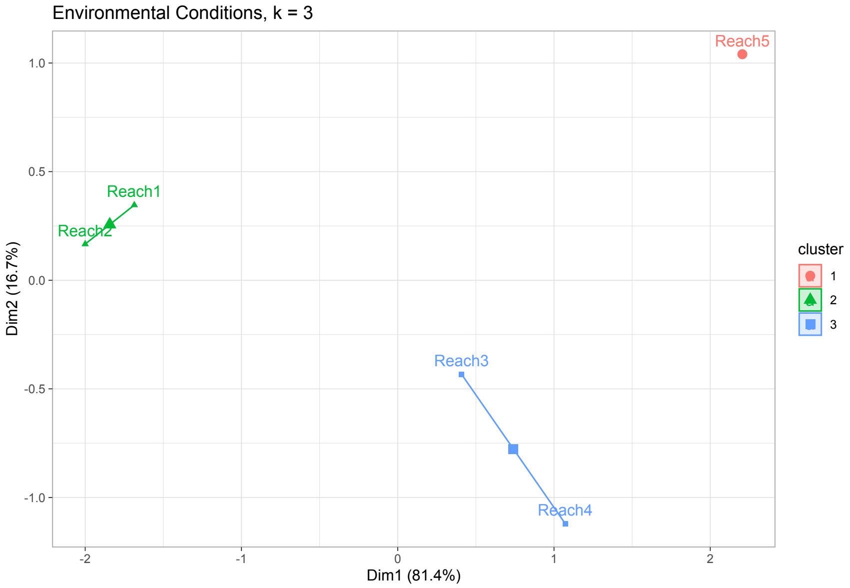
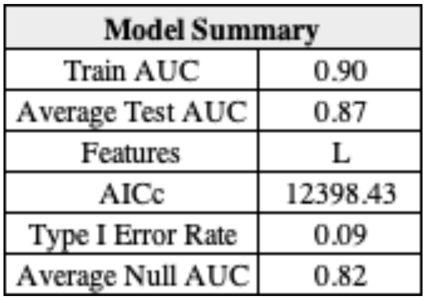


Figure 9 K-means cluster analysis of average environmental conditions for each reach of the River. Environmental conditions included average values for percent permeability, percent canopy, road percent, park percent, and percent vegetated riparian buffer.

2.3.4 Maxent Model

I used a Maxent model to better understand the predictors associated with recreational occurrence in the Los Angeles River. The Maxent model training AUC was 0.90 and the test AUC was 0.88 (Table 7). AUC is a value that measures the model's ability to correctly predict presences from absences, which in this instance are pseudo-absences (Hanley & McNeil, 1982). The data is split into training data, which supports model development, and testing data to support model validation. In this instance, the model performed strongly in

Table 7 Summary of Maxent model performance. Model presented below was selected from model sub-runs, which included all features (linear=L, quadratic, hinge, threshold, and product) and regularization values between 1 to 2.



Model Summary	
Train AUC	0.90
Average Test AUC	0.87
Features	L
AICc	12398.43
Type I Error Rate	0.09
Average Null AUC	0.82

discriminating presence from random data (Merow & Silander, 2014). When using SDM that are presence only AUC values of 0.8 can be interpreted as good model performance. However, since AUC values can be unreliable and inflated when one uses presence only data (Merow & Silander, 2014), a null model was used for statistical testing. The proposed model performed better than 91% of random models (p=0.09).

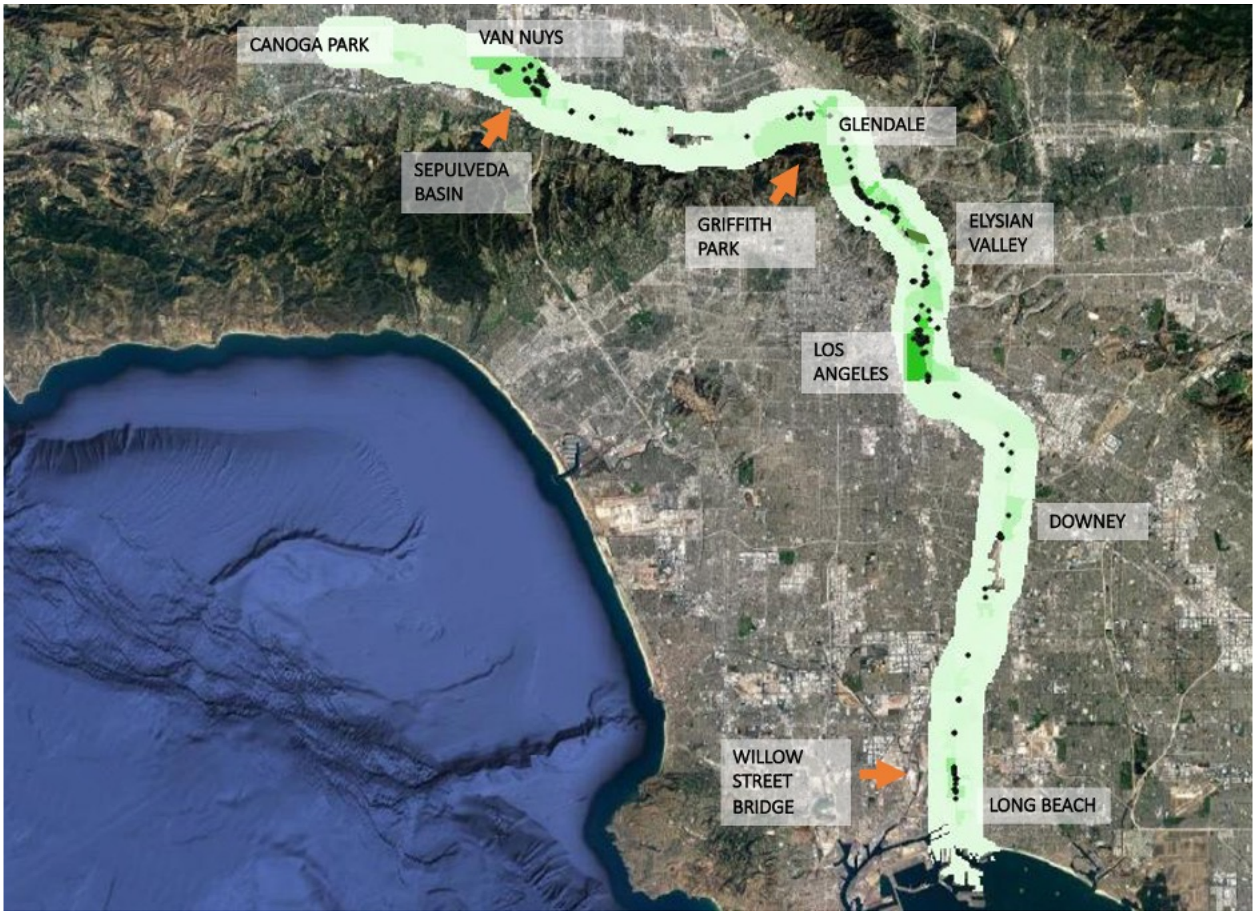


Figure 10 Relative occurrence map for the Los Angeles River whereby darker shades of green represent a higher probability of recreational occurrence. The highest predicted relative occurrence was predicted at the dark green census tract near Elysian park. Black dots are the locations of actual FlickR posts along the River.

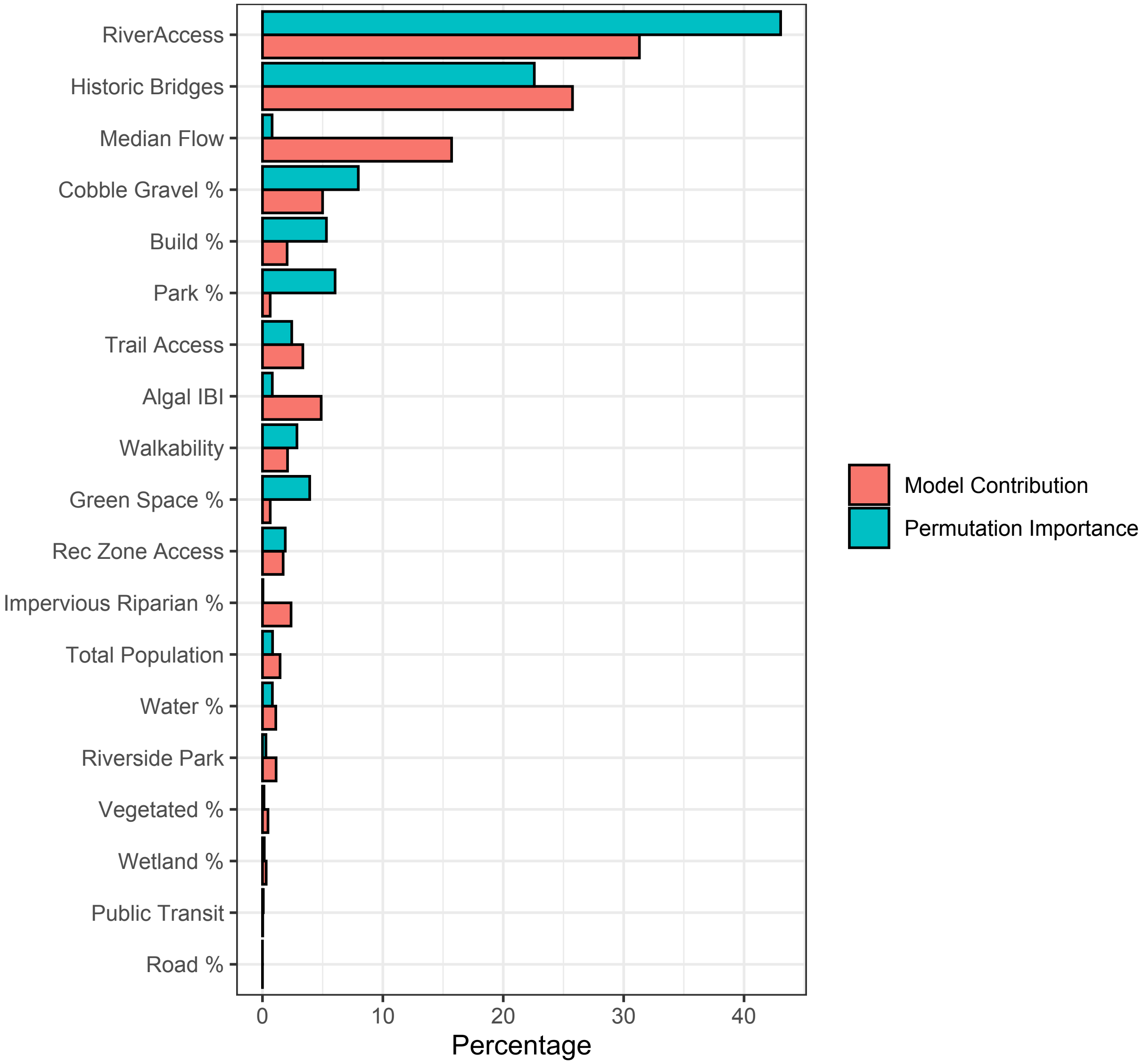


Figure 11 Graph of variables important to predicting recreational occurrence. Variables were also permutated and their impact on model performance, specifically the drop in AUC-ROC, are presented as percentages.

There were a high density of posts near a soft bottom areas near the Willow Street Bridge in Long Beach, along the Main and First to Seventh street bridges in Downtown Los Angeles, along the Greenway Trail in the Elysian Valley, near riverside parks and along the Greenway Trail in the Glendale Narrows, at an equestrian center near Griffith Park, and in the Sepulveda

Basin that can be interpreted as locales with high CES intensity (**Error! Reference source not found.**). Maxent predicted the highest occurrence of CES near Elysian park, followed by Downtown Los Angeles (**Error! Reference source not found.**). Figure 11 shows the environmental variables used to predict the likelihood of CES occurrence, specifically their contribution to model performance and permutation importance. The most important predictors of recreational occurrence include higher river access, the presence of historical bridges, and higher median flow. Together these 3 predictors have a cumulative contribution of nearly 73 percent to model performance. However, the Maxent model is sensitive to permutation of many of the predictor variables used in the model, particularly the top 2 predictors (Figure 11).

2.4 Discussion

2.4.1 Urban Rivers Supply Many CES

Despite the sometimes-stark differences in channel typologies along the Los Angeles River, ranging from completely channelized to soft bottom and vegetated, and the extensive urbanization that borders the River, it hosts a surprising diversity of CES. For example, all reaches of the River appear to convey aesthetic and artistic information to users, despite variability in site conditions. Using both expert interviews and FlickR data, I was able to assess CES along the River. I was able to identify the same CES typologies using both photo content analysis and expert interviews. They included: 1.) aesthetic services, the sensory configuration of beauty that ecosystems communicate, 2.) activity services, the contribution of ecosystems that inspire physical activity, 3.) artistic services, the creative information that ecosystems transmit to users that they interpret into art and for cultural benefit, 4.) heritage services, historical features that shape the cultural identity and sense of place, 5.) knowledge services, the information ecosystems transmit that support the development of knowledge, and 6.) naturalist services, information that ecosystems convey that create ecological meaning and lead to human enjoyment (Havinga et al., 2020; MEA, 2005; Richards & Friess, 2015).

FlickR and expert interviews captured the same CES typologies but there were many discrepancies in specific activities and where they occurred. Expert interviews better captured the distribution of specific activities along the river (e.g., fishing), particularly for activities that are restricted or engaged in by underserved and/or unhoused communities (e.g., wading in the river is restricted as well as kayaking along certain reaches). The poor surveying of certain uses also resulted in reaches 1 and 4 being poorly characterized in terms of the diversity of activities along those reaches. FlickR captured CES in a spatially explicit manner but is likely unreliable in fully accounting for the geographic distribution of each activity. FlickR posts showed that aesthetic and artistic services were the most popular CES categories, unsurprising given the data was gathered from a photo sharing platform, while previous observational surveys of recreation along the River, which admittedly were not focused on capturing the full suite of CES, found that biking was the most popular use of the River (LARWQCB, 2014). It is important note that some activities may not be well captured by social media data because they are difficult to post (e.g., kayaking) or are restricted (e.g., swimming) and are thus likely to be underrepresented as a result. Based on expert input and previous observational surveys (LARWQCB, 2014), underrepresented activities in FlickR include kayaking, biking, wading, horseback riding, skateboarding, wildlife viewing and fishing.

Based on FlickR data alone, reaches one and five had a greatest abundance of natural activities, like wildlife watching. Reach one is a completely channelized section of the River near industrial land uses while reach five is a large open space and a soft bottom section of the river channel. Birding, a popular word that emerged across Los Angeles River posts, likely explains the high percentage of occurrence of natural services along reaches that do not cluster together based on environmental conditions. Both the Sepulveda Basin and the Lower Los Angeles River (at Willow Street) are listed in the top 20 birding hotspots for Los Angeles (eBird, n.d.). This is because reach 1 has a maritime influence and consistent flows create novel urban habitats where shorebirds are attracted to the algae present on the concrete channels of the Lower Los Angeles River (Cooper, 2006). On the other hand, Reach 5 is a large, open space with large riparian buffers and a diversity of habitats.

Previous studies have used the number of users that posted photographs as measures of recreational intensity and assigned locales with frequent posts higher recreational value (Mancini et al., 2019). This is supported by multiple studies that have found visitation rates, as assessed via social media, rival traditional visitation surveys (Wood et al., 2013). Based on the density of posts alone, areas with the highest CES value include census tracts with both naturalized sections of the River and channelized sections that are adjacent to the urban core of Los Angeles. The high CES value of both highly urban sections of the River and naturalized portions, along with the unequal distribution of CES suggests that predictors of CES will depend on CES type, as found by other studies (Richards & Friess, 2015). Some popular CES may also be adaptable, since they occur in nearly all reaches of the River, such as aesthetic and artistic services or activity services, such as walking. Others may require certain physical habitat conditions or improved water quality, such as for fishing as found by Richards and Friess (2015). The aggregation of posts have made it difficult to specifically resolve those relationships and thus I am limited to broad generalizations about CES based on Maxent results. However, expert interviews do provide insight about the conditions that support specific activity services. These include complex habitat and low temperatures for fishing, water depth and access for boating, and habitat complexity and water area for wildlife viewing.

The geospatial model, Maxent, highlighted that environmental quality was not an important predictor of CES, broadly, and helped identify areas with high suitability for recreation. Maxent predicted the highest likelihood of occurrences along a soft bottom section of the River north of Downtown Los Angeles and moderate occurrences at the channelized section of the River at the heart of Los Angeles. Important predictors of recreational occurrence were increased river access, the presence of historical bridges, and increased levels of flow. There were no predictors related to the natural environment that explained more than 5% of recreational occurrence. These findings are similar to other studies that have found that riverine areas of high recreational value are not necessarily the most pristine and that built elements, like roads and recreational infrastructure, are more important than natural elements (Hale et al., 2019). In fact, visitors may have reduced preferences for some natural features that obscure views, like thick forests, and certain ecosystems, like wetlands and agricultural lands (Van Berkel et al., 2018). White et al. (2010), found that users value water, irrespective of the setting. Hale et al. (2019) similarly found that river reaches with more water had a higher density of CES. van Zanten (2016) found accessibility, population density, income, mountainous terrain, and proximity to water explained recreational patterns on a continental scale. In urban parks, Donahue et al. (2018) found access, neighboring population densities, nearby water features, and amenities to be associated with higher visitation rates and acknowledged the importance of built features. When analyzing the role of trees in urban park visitation, Shanahan (2015) found that park visitation was associated with park availability and only those that had a greater orientation towards nature would travel for more vegetated parks underscoring the importance of user groups, an unexamined element in this study. Richard and Freiss (2015) noted that infrastructure appreciation was a common photograph at a nature preserve, such as a boardwalk. While Van Berkel et al. (2018) noted high number of photo content that included built features and surmised that they enhance experiences with the landscape. Of course, these relationships will vary depending on the specific CES typologies that are being examined. However, unlike Richard and Friess (2015), historic bridges appear to be more than a means to better capture the River landscape, as the total amount of bridges within a census tract was not a significant predictor. To my knowledge, few studies have found the important role of heritage infrastructure in urban CES. Photos of bridges were common. particularly along reach 2 and the most common word used in social media text. The historic nature of some bridges appears to inspire their own aesthetic appreciation that, like other heritage features, create a sense of place or of cultural distinctiveness (MEA, 2005).

Text and photo analysis added a richness to my understanding of CES along the Los Angeles River and corroborated the conclusions from other analyses. I found that by analyzing both text and photographs from social media posts I was able to identify a variety of CES that photos alone would not capture, as noted by Hale et al. (2019). For example, knowledge services, some forms of recreation (e.g., walking), and artistic services would have been harder to enumerate if not for photo descriptions and tags, such as those describing camera models (e.g., Cannon 5d). Additionally, by tallying the location from which users photographed the River, I was able to capture access across different reaches of the River. I found that very little access to the River channel occurs along reach 4 and that bridges, bike paths, and parks are important avenues for river access along reach two, four, and five, respectively. Analysis of text frequency, in this instance through the use of a word cloud, helped in capturing what visitors to the River thought was significant enough to label, as suggested by Dunkel (2015). Those categories included urban infrastructure, recreational activities, and an annual cycling event. Additionally, I found, on average, neutral or modestly positive attitudes towards the River. Despite assertions that people share their emotional experiences on social media platforms and that post analysis may be a means to capture reticent stakeholders (Do, 2019; Drijfhout et al., 2016), the River in its current form does not appear to inspire strong written sentiment among FlickR users. As park projects and amenities are installed along the River as a result of ongoing revitalization and as new users are drawn to the River, text analysis may capture public reaction towards the changing landscape and result in a stronger sentiment signal.

The trigram analysis provided more context than word frequency alone could have and brought into focus themes and, potentially, River user communities within FlickR. Those themes included text focused on flow, travel photography, wildlife viewing, and urban photography. The most popular trigrams further supported some of the CES relationships I found using Maxent. If prominent themes among posts relate to flow and urban photography, the high aesthetic/artistic value provoked by different reaches of the River and the importance of flow for predicting CES occurrence is further supported. Additionally, the prevalence of the travel related trigram supports previous studies that have found that tourist are more likely to post to social media (Becken et al., 2017). If contributions by tourist communities are indeed sizeable this, as acknowledged by Becken et al., will introduce bias to data because posts will not reflect normal conditions or may potentially capture the preferences and values of tourist, which may not reflect those of the local community.

Expert interviews added nuance that social media data could not or that was lost due to the aggregation of all CES data for geospatial modeling. Expert interviews also helped triangulate findings derived from social media data. For example, experts confirmed the aesthetic and artistic value of the River's many typologies.They noted that there was aesthetic and artistic value communicated to visitors by the "large, imposing, concrete channel" but also aesthetic value in the presence of wildlife and the conditions that support the species that are present. Experts also noted that flow made the River more picturesque and that visitors were drawn to the River to observe its extreme flows in what they termed, "flow gawking." The aesthetic qualities of water, even in urban settings, have been supported by other studies (White et al., 2010) and flow was an important predictor of recreational occurrence. The allure of large, powerful flows has not been observed by other studies but as noted by previous studies, people tend to post to social media when experiences are novel or unexpected (Becken et al., 2017; Wood et al., 2013). The prevalence of the flood trigram, the importance of flow as a predictor of CES, and the confirmation of the allure of high flows from recreational experts means that using social media data to understand preferences for the River may misrepresent preferences of the communities living along the River and weigh the preferences of flow gawkers more heavily than other users. Nevertheless, my study supports that flow is important to FlickR user communities. However, given the aggregation of CES posts and the linear features of the final model (threshold features may have helped identify specific targets), I cannot propose flow recommendations that broadly support CES. Future studies of CES along the River may consider analyzing fair weather CES separately to understand CES relationships in the absence of extreme flows and, if possible, specific thresholds for fair weather flow.

Safety and access were common and frequent themes of discussion by experts, specifically the need for better signage, the importance of channel access and designs that ensure conditions are safe for visitors, and the need for better communication and information about the flow velocities in the channel. The concern for high flows are likely compounded by multiple reported drownings along the River (Pyle & Berger, 1992; Rocha, 2017). Other survey studies have found safety and access to be among a set of converging values related to recreation and green space across stakeholder groups (Gobster & Westphal, 2004).

There were some themes that emerged from discussions with experts but were unsupported by the geospatial model or other social media data. Experts stressed the importance of water quality for all recreational activities stressing that smell, excessive algal growth, and bio-accumulating contaminants should not cause nuisance or harm to people or wildlife. Water quality was a prominent theme, particularly when discussions focused on removing wastewater flows in the River which dilute some existing contaminants. Other studies have found that water quality is important to sustaining recreational uses because it underpins other ecosystem services (Doi et al., 2013; Hua & Chen, 2019; Sinclair et al., 2018). However, no such relationship emerged from my own geospatial analysis. I used bioindicators, specifically benthic macroinvertebrates and algal community-based metrics, specific conductivity, and chlorophyl concentrations as proxies of general water quality. The lack of significance in the current study is likely due to lack of significant variability in these constituents across a heavily urbanized River (unpublished analysis). Additionally, experts noted that many sections of the river are adjacent to populous areas and that the River becomes a de facto open space in communities that lack them. The importance of population density, whereby dense human populations translates to high demand of CES, has also been documented in previous studies (Doi et al., 2013; van Zanten, Van Berkel, et al., 2016), however neither population density nor percent green or park space was important to predicting recreational occurrence along the Los Angeles River.

Despite the large volumes of data that are easily scraped from social media platforms there are short-comings to the use of social media data that must be recognized, particularly if data is to inform management or planning efforts which are centered around equity. Different social media platforms have a different audience and culture than those of the general public. Previous studies have noted that FlickR users tend to be concentrated in urban areas, fitting for a study in an urban area but likely inappropriate for rural settings (Hecht & Stephens, 2014). Much work has identified the existence of a digital divide and the resulting demographic differences within social media platforms can create blind spots in big data whereby non-English speakers or underserved or disabled communities are not represented (Mah, 2017). Donahue et al. (2018) compared demographic characterizations of social media platforms to in person surveying of urban parks in Minneapolis and found that FlickR users tended to younger and more female than park visitors. However, other studies have characterized the average FlickR users to be 39 and male (Ignite, 2012; Quercia et al., 2018). This is not to ignore the potential bias of interview methods that make use of experts, like my own study, since the expertise may be validated based on participation within existing institutional structures, education, and job titles (Choi & Pak, 2004). In the present study, it is likely that social media and experts do not fully represent site preferences and attitudes towards the River, given the diversity of the Los Angeles region. For example, unhoused populations make use of the River, settling along shady locations under bridges and near adjacent parks and facilities (personal observation). The preferences of this community of River users and their relationship to the River are almost certainly not captured. Additionally, experts noted a large quantity of working class commuters that bike along the River during commuting hours and while these uses are captured from expert interviews, the preferences this group may have, perhaps for transit corridors, are likely underrepresented (Mashhadi et al., 2020). Fear and avoidance of parks by women and other marginalized communities has also been documented by other studies and the male bias in the FlickR dataset may further limit our understanding of how those preferences manifest themselves spatially (Madge, 1997). Additionally, aesthetic values and recreational preferences are not universal. Many studies have shown that landscape preferences vary depending on socio-cultural characteristics like education (van Zanten, Zasada, et al., 2016), demographics (Lyons, 1983; Stamps, 1999), environmental values (Kaltenborn & Bjerke, 2002), age (Stamps, 1999), familiarity, and living environment (Yu, 1995).

Understanding CES is important because of the revitalization now occurring along the River. Advocates for more ecological restoration of the River have emphasized the importance of natural elements in supporting CES. Based on FlickR data, naturalness, represented by pervious area in the riparian corridor, vegetation, and assessments of habitat quality, is not an important predictors of CES, in the aggregate. Instead, it’s the designed elements and flows that occur along the River that are important to CES occurrence. However, this is not to ignore the benefits that more naturalized sections of the River may provide (Fuller et al., 2007; Twohig-Bennett & Jones, 2018; Wood et al., 2013) or to ignore studies that have found moderate levels of CES to be associated with higher diversity of ecosystem services (Raudsepp-Hearne et al., 2010). Mapping CES demand (approximated by population density, for example) can also ensure that amenities, parks, and restoration sites align with areas with high demand of CES. The results of this study suggest planners should prioritize access, recognize the importance of heritage infrastructure, and include water features in their designs, particularly if flow along the River is to be diverted. Other studies have noted that ecosystem services appear to be bundled (Plieninger et al., 2013; Raudsepp-Hearne et al., 2010) so that tradeoffs between provisioning and regulating services, for example, may need to be managed. The revitalization offers an opportunity to understand the trade-offs between ecosystem services, the resulting bundles of CES, and how changes to the environment will shift the bundling of services. Revitalization also creates an opportunity to manage ecosystem services that have fallen below predefined thresholds, as suggested by Raudsepp-Hearn et al. (2010). As more projects are implemented along the River, social media data and expert feedback can be used to better understand changes in use, CES demand, and the response to newly implemented amenities and the rehabilitation of native ecosystems.

2.5 Appendix A

2.5.1 Focus Group Discussion Questions

The questions below were used to prompt discussion during the focus group. The responses to these questions were recorded, analyzed, and coded. Specific indicators and targets were noted on a white-board for all participants to review and respond.

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1. How do you or the communities you serve or engage currently use this reach of the River?
    - Does this use vary seasonally?
    - How often does this use occur?
2. What site characteristics or indicators do you think are important to sustaining this recreational activity?
3. What levels of flow or water depth targets do you need to sustain this recreational activity?
4. What other specific targets are important to sustaining this recreational activity?
5. What recreational activities do you think are most likely to occur along this reach of the River in the future?

2.5.2 Individual Response Worksheet

After a group discussion, the participants were asked to rank the indicators and targets the group identified on an individual worksheet. The worksheets are excerpted below.

Recreational Indicators

1. Based on your experience, please score the indicators highlighted during our group discussion. Score the indicators according to their importance toward sustaining __________ along the LA River?

Please rate each indicator starting from least important, score = 0, to most important.

Note: The score of the most important indicator is one minus the total number of indicators (n-1). For example, if the there were 5 total indicators discussed, the highest score would = 4.

Indicator	Score
	0
	1
	2
	3

	4
	5
	6
	7
	8

2. How confident are you about the indicators you selected as most important?
    a. Extremely
    b. Very
    c. Somewhat
    d. Not very
    e. Not at all
3. If you have additional comments or justifications that you would like to share, please note them here.

Recreational Targets

1. Based on your experience, please score the numerical targets for ___________. Score the targets according to its importance toward sustaining ______________ along the Los Angeles River?

Please rate each target starting from least important, score = 0, to most important.

Note: The score of the most important target is one minus the total number of indicators (n-1). For example, if the there were 5 total indicators discussed, the highest score would = 4.

Indicator	Score
	0
	1
	2
	3
	4
	5
	6

	7
	8
	9
	10

2. How confident are you about the criteria you selected as most important?
    a. Extremely
    b. Very
    c. Somewhat
    d. Not very
    e. Not at all
3. If you have additional comments or justifications that you would like to share, please note them here.

2.5.3 Detailed Focus Group Results

The results of the ranking exercise for each recreational use is detailed below. Since the sample size for the focus group and phone interviews were low and the results exhaustive, they are not included in the main body of the text.

Wildlife Viewing

Table 8. Indicators and targets for wildlife viewing uses in soft bottom and cement bottom reaches. Indicators with the highest ranking are highlighted. For most indicators, participants gave one or no specific target.

	Indicator	Average Rank	Stdev	Target	Kendall's W
Bird and Wildlife Viewing- Soft Bottom	Spring flows	2.00	1.15	Unknown, generally described as presence of spring flow	0.08
	% Algae cover	2.50	1.97	Unknown	
	Temperature	3.00	.	Unknown	
	Water Depth	3.57	0.98	Both shallow (2-6 inches) and deep (24-36 inches) areas	
	Flow Velocity	4.29	1.25	Unknown	
	% Water area	5.33	0.52	Water should cover 50% of channel	

	Habitat Complexity	6.57	0.53	Unknown- - Narratively described as diversity of flow habitats (pools, riffles, fast/slow water)	
Bird and Wildlife Viewing- Hard Bottom	% Algae Cover	2.00	0.82	Unknown	0.08
	Spring Flows	2.43	1.62	Unknown	
	Water Depth	2.90	1.18	Unknown	
	Substrate	3.14	0.90	Presence of sediment islands and 25-40% channel cover by rocky substrate.	

Wildlife viewing is a recreational use that occurs yearlong. When describing wildlife viewing, recreational experts were largely focused on bird life, particularly along the cement bottom portions of the River. Substrate and habitat complexity were the most important indicators to sustaining wildlife viewing along the River. The flow related indicators varied from soft bottom to hard bottom reaches, whereby depth was the most important along hard bottom areas, and the percent of the channel area that was composed of water was most important in the soft. The cement bottom indicators and targets are largely focused on reach 1, along sections of the River near the Willow Street Bridge that are bordered by riprap. Experts noted that along reach 2, spring flows and algae for foraging become more important to sustaining wildlife. For most indicators, participants gave one or no specific target. There was poor agreement in the rankings among recreational experts.

Path Activities

Table 9. Indicators and targets for path uses. The indicator with the highest ranking is highlighted. For most indicators, participants gave one or no specific target.

	Indicator	Average Rank	Stdev	Target	Kendall's W	Notes
Path Activities- All River Reaches	Volume	1.57	0.79	Below 150,000 CFS or flood capacity of channel	0.05	Participants noted that path activities are not associated with flow.
	Flow Velocity	1.86	0.69	8-9 MPH		
	Depth	2.57	0.79	Unknown		

Recreational experts largely agreed that path activities, those that take place on the levy including biking, walking, running, scooting, and dog-walking, were not affected by flow. Flows were only important during storm events when dangerously high flows could inundate the bike path. Many path uses also occur within the river channel, the indicators and targets for those activities are described in community uses. There was some disagreement in the rankings among recreational experts, but based on average ranking, depth was the most important indicator.

Aesthetic- Hard Bottom

Table 10. Indicators and targets for aesthetic uses. Indicators with the highest ranking are highlighted. For most indicators, participants gave one or no specific target.

	Indicator	Average Rank	Stdev	Target	Kendall's W
Aesthetic-Hard Bottom	Birding Indicators	4.20	1.60	Aesthetic value is associated with the presence of wildlife. See wildlife viewing indicators.	0.02
	Flow velocity	3.43	0.90	Flow that ensures that there are no vector control issues, specific target is unknown	
	Depth	3.14	0.83	1.5 inches of water in channel bottom	

				or low flow channel	
	Presence of Water	2.57	1.05	Presence	
	Exposed Bank	1.43	0.73	80-90% of bank exposed	
Aesthetic-Soft Bottom	Depth	3.67	1.03	Unknown	0.02
	Flow velocity	3.50	1.05	Unknown	
	Birding indicators	3.00	2.00	Aesthetic value is associated with the presence of wildlife and birds	
	Water Quality	2.00	0.89	Unknown	
	Exposed Bank	1.83	1.17	Unknown	

Aesthetic uses of the River occur year-round in both the soft bottom and cement bottom portions of the River and are tied to admiring the scale of the flood infrastructure, storm flows, and the presence of wildlife. Some aesthetic uses include photography and art. Recreational experts thought that flows were important to sustaining aesthetic uses along the River. The most important indicator in the soft bottom portions of the River is depth. The most important indicators in the hard bottom portions are the presence of wildlife and flow velocities. There was poor agreement among experts in the ranking of indicators.

Community Events

Table 11. Indicators and targets for community uses. Indicators with the highest ranking are highlighted. For most indicators, participants gave one or no specific target.

	Indicator	Mean	Stdev	Target	Kendall's W
Community Events and Unofficial Gatherings	Flow Velocity	1.17	0.41	Flow target unknown. Narratively described as flows that are low enough to be fully contained in the low flow channel	0.14
	Water Depth-Max	1.83	0.41	Depth target unknown. Narratively described as a depth of water that is low enough to be contained in the low flow channel	

Community events, like the South East Los Angeles (SELA) Arts Festival, and unofficial uses (like gatherings and in-channel exercise) occur within the River channel. Unofficial uses occur year-round, except during storm events, while official community events, like SELA Arts

Festival, only take place during the summer. Recreational experts thought that reduced flows are important to sustaining these recreational activities and that water depth and flow velocities need to be fully contained within the low flow channel.

Wading

Table 12. Indicators and targets for wading use. The indicator with the highest ranking is highlighted. For most indicators, participants gave one or no specific target.

	Indicator	Average Rank	Stdev	Target	Notes	Kendall W
Wading- Soft Bottom	Level Surface	2.83	1.94	Unknown	Slipping hazard noted with sloped or slick surfaces	0.01
	Access	3.00	1.87	Unknown	Gentle slope entering and exiting River is important	
	Water Quality	3.50	1.05	Unknown	Smell and algae listed as concerns	

	Substrate	3.67	1.97	Unknown	Dominance of sand and fine substrates to avoid slipping and rough surfaces	
	Flow Velocity	4.00	1.41	Unknown	Described as “gentle flows”	
	Depth	4.17	1.94	18 inches	Depth of water to reach the knee	

Wading occurs in the spring and summer along many reaches of the Los Angeles River. According to experts, wading is rare and dangerous along the hard bottom reaches. In the soft bottom portions of the River, depth and velocity are the most important indicators for sustaining this use. Recreational experts did not differentiate between wading and swimming, particularly because swimming is rare along the River. There was poor agreement among experts in the ranking of wading indicators.

Boating

Table 13. Indicators and targets for the kayaking/boating use. Indicators with the highest ranking are highlighted. For most indicators, participants only gave one target, and there was no disagreement within the group. However, in reach 5, one participant noted that 6 inches of water depth was conducive to good kayaking conditions. This depth is lower than the 18 inches required along the Glendale Narrows.

	Indicator	Average Rank	Standard Deviation	Target	Notes	Kendall's W
Boating- Hard Bottom	Flow Velocity	1.50	0.84	Unknown		0.06
	Water Quality	2.33	0.82	Unknown	Smell and algal blooms listed as principal concern	
	Access	2.67	1.21	Unknown	Sub-indicators related to safety of users in entering and exiting the River	
	Depth	3.50	0.84	6" poor, 18" good, 25" optimal	Depth required also depends on vessel and weight of the person. Targets are best estimates.	

	% Veg Cover	2.33	1.97	Unknown	15% poor, 30% good	0.07
	Substrate	3.33	2.42	Unknown	Sandy substrate ensure that users to not fall or slip. Currently the river has some sharp pieces of cement along the channel bottom. These sharp substrates can create dangerous conditions for users.	
Boating- Soft Bottom	Proximity to vegetation	3.60	1.82	Unknown	Boating near vegetation and a vegetative buffer important to recreational uses	

	Water Quality	3.83	1.33	Unknown	Algae and smell listed as main concerns	
	Flow Velocity	4.17	1.47	Unknown	According to experts, the range of flow velocities observed during the summer do not affect boating activities.	
	Access	4.83	1.17	Unknown	Sub-indicators related to safety of users in entering and exiting the River	
	Depth	6.40	1.95	6" poor, 18" good, 25" optimal	Given the complexity of the channel bottom, experts thought that the depth indicator should be	

	🟨	🟨			applied to the most elevated sections of the River. Depth required also depends on vessel and weight of the person. Targets are best estimates	

Boating along the River largely occurs during the summer months (from Memorial Day to the end of September). Depth is an important indicator for sustaining boating along the Los Angeles River in both soft bottom and cement bottom sections. One expert noted that the reaches currently lack the flow that would host optimal conditions for boating.

Though experts expressed uncertainty and difficulty in defining targets, particularly given the complexity and heterogeneity of the soft bottom portions of the River, there was strong agreement regarding the targets that were selected. Experts noted that there was only a single gauge that provided real time data for the River, the USGS gauge at the Sepulveda Basin, and that estimated flow targets were educated guesses based on the limited data that is available. One expert also noted that conditions were poor for kayaking at volumes that exceeded 2,000 CFS at the Sepulveda Basin.

Experts noted that boating is best in the afternoon, when releases from Publically Owned Treatment Works (POTW) provide enough water for kayaking and worse in the mornings when

POTW releases are reduced. Since the Sepulveda Basin is relatively flat compared to the Glendale Narrows, one expert thought that 6 inches of water along this reach would be sufficient to support kayaking. Not all experts agreed.

Fishing

Table 14. Indicators and targets for fishing uses. The indicators with the highest ranking are highlighted. For most indicators, experts had difficulty in defining targets for the species currently found along the channelized portions of the River and thought biologists could better estimate flow targets. The targets listed are for trout, which, according to fishing experts, would suit a larger assemblage of fish species.

	Indicator	Average Rank	Stdev	Target	Notes
Fishing- Hard	Volume	1.86	1.07	20 CFS (trout)	
	Water Quality	2	0.93	Unknown, DO and nutrients identified as important to sustaining fish populations	
	Flow Velocity	2	-	Max of 6 ft/s for trout, 2-3 ft/s for people to comfortably wade	Suggested by fishing expert after the group interview. Ranked

					most important.
	Depth	2.29	1.18	Minimum of 12 inches, 36 is maximum depth that anglers can comfortably wade	
Fishing Soft	Spring Flow	2	1.15	Unknown	
	Algae Cover	2.5	1.97	Unknown	
	Depth	3.57	0.98	Minimum of 12 inches, 36 is maximum depth that anglers can comfortably wade	
	Water Area	3.67	2.64	Unknown	
	Contaminant Level	3.67	0.82	Unknown-concern is bio-	

				accumulating contaminants that cause harm to wildlife and people	
	Water Quality	4.17	3.31	Unknown, nutrients and DO is concern	
	Flow Velocity	4.29	1.25	2-3 ft/s is safest for anglers	
	%Vegetative Cover	5.33	0.52	Unknown	
	Temperature	6.14	1.95	60-65° F for trout	
	Habitat Complexity	6.57	0.53	Unknown- narratively described as varying depths, velocities, riffles, pools, runs, fast/slow water	

Fishing occurs year round, except during storm events, but is more common during the recreational season that spans from Memorial Day to late September. Fishing is limited to the soft bottom portions of the Los Angeles River. According to fishing experts, fish are occasionally seen along the cement channel, but the lack of channel complexity that helps create flow refugia would make it unlikely that these areas are able to sustain fish populations and regular fishing activities. Popular locations for fishing are the Sepulveda Dam and the soft bottom portions of the River that occur from Forest Lawn (reach 4) to the Arroyo Seco (reach 3), and the soft bottom areas near Willow Street.

There were several non-flow related indicators that were important to fishing uses including habitat complexity and vegetative cover. The important flow related indicators were temperature and velocity in the soft bottom portions and depth in the cement bottom areas. Fishing experts were not present at the group interview, so the indicators varied considerably between the group interview and individual interviews. As a result, Kendall's coefficient of concordance could not be calculated. One of the fishing experts added resting pool depth, slope, and active channel width to the list of indicators along the soft-bottom areas. This expert ranked volume and depth as the most important indicators in the soft bottom sections, and ranked volume and velocity as the most important indicators along the hard bottom sections. Fishing experts noted that reduced flows would not negatively affect fishing activities but that a depth of at least 12 inches is necessary to sustain fishing activities.

Generally, experts had difficulty in identifying flow targets for this use and suggested that biologist define appropriate flow targets. The fish specific targets that are described in Table 14 are for trout and not the species that are commonly found along the main-stem of the Los Angeles River.

Horseback Riding

Table 15. Indicators and targets for horseback riding. The indicator with the highest ranking is highlighted. For most indicators, experts had difficulty in defining targets. Unlike other uses, horseback riding experts (n=2) perfectly agreed on the indicators and the ranking of those indicators.

Indicator	Average Ranking	Stdev	Target	Notes
Flow Velocity	3	0	Unknown	
Depth	2	0	Unknown	
Volume	1	0	34,700 CFS along reach 3, unknown in other reaches	Reach 3 of the river has reduced flood capacity. This target is for horseback riding that occurs adjacent to the River. The volume target is unknown for all other locations.

Horseback riding along the River occurs year round except during storm events. In reach 2, the equestrian trail is on the toe of the slope of the River channel, opposite of the River. Horseback riders have no contact with the River along this reach unless they are accessing underpasses as crossings.

Originally, horseback riding was grouped with path uses because experts thought that horseback riding was largely unaffected by flows unless they were on the bike path during a large storm. However, horseback riding occurs both in-channel and adjacent to the channel along reach 3, near Griffith Park. Since some horseback riders will ride in-channel in reach 3, the targets for velocity, depth, and volume would be lower along this reach of the River.

The most important flow indicator for sustaining horseback riding activities was flow velocity. Experts could not identify a velocity target, neither along trails or in-channel. Though the experts that were interviewed for this use were most familiar with a single reach, experts were in perfect agreement regarding the rankings across reaches.

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3 Understanding the relationship between species presence and site characteristics in Southern California Streams using citizen science.

3.1 Introduction

Riparian areas are the narrow mesic corridors along streams, rivers, and lakes where hydrophytic species, in a patchwork of upland and unvegetated areas, experience moist soil conditions due to flooding or shallow groundwater. In the Mediterranean climate of the southwest United States, riparian areas provide food, shelter, nesting and breeding grounds, and a movement corridor for about 80 percent of all wildlife due to the availability of water and the dense, complex habitat structure that is often otherwise missing in dry upland areas (Krueper, 1995). Today, many of these corridors are biologically impoverished due to habitat loss, invasive species, overexploitation, pollution, and climate change (Allan & Flecker, 1993). The urban areas that lie adjacent to many streams and rivers host cosmopolitan species that exploit or adapt to external inputs and the simplified physical environments and food webs common across cities resulting in biological homogenization (McKinney, 2006; Olden & Poff, 2003; Rebele, 1994). However, cities can host heightened levels of biodiversity. Studies have found that gardens, depending on the taxa of interest, size, and garden features, contribute to urban biodiversity (Schwartz et al., 2002). Declining biodiversity threatens the loss of valued societal services and products (Cardinale et al., 2012) due to the role organisms play in the formation of ecosystems (Jones et al., 1996), the maintenance of biogeochemical cycles (Beare et al., 1995; Braeckman et al., 2014; Silver et al., 1996), and ecosystem productivity (Isbell et al., 2015; Tilman & Downing, 1994; van der Heijden et al., 1998). As cities in the region focus on building sustainable cities, revitalizing waterfronts, and designing and managing cities and their rivers to increase ecosystem services, ecologist need to better understand biodiversity and the opportunities for restoration along urbanized rivers. This study will focus on better understanding species habitat relationships for target avian species found along urban rivers so as to inform urban habitat restoration and conservation.

Rehabilitating and restoring riparian areas, particularly those centered among urban land uses, will be an immense challenge, in part because of recurring anthropogenic disturbance, fundamental shifts in function and composition (Hobbs et al., 2009) of urban ecosystems, and previous restoration efforts that poorly inform future work (Grayson et al., 1999). However, restoration is a critical strategy for the repair and sustainable management of our lands, particularly in areas where land is so altered that conservation is no longer a feasible option (Hobbs & Harris, 2001). However, restoration is still in many ways a nascent science and analysis of past restoration efforts have identified that there are no agreed upon criteria, a lack of long term data, and overtly starry eyed assessments of restoration success that are largely anchored in public opinion (Bernhardt et al., 2007; Palmer et al., 2005; Woolsey et al., 2007). Hobbs and Norton (1996) describe a favored restoration framework by which managers identify causes of degradation, determine realistic remedies, goals, and metrics, monitor project success, and develop processes for implementing goals into planning and land management. Systematic approaches, like those advocated by Hobbs and Norton, are still relatively rare. This is especially true because realistic goal setting can be a difficult exercise (Ehrenfeld, 2000), particularly in the absence of guidance for restoration prioritization or of the environmental variables that govern species distributions so as to inform remediation and goal setting.

Species distribution models (SDMs) make use of computer algorithms, along with species observations and a gridded landscape of environmental predictors, to predict species occurrence in geographic space and identify predictors important to habitat suitability. They can be important tool for restoration by identifying restoration hotspots and the variables that govern species distributions (Asadalla et al., 2021), and can thus inform goal development, management, and planning. SDMs are particularly helpful when selection of the environmental variables is based on capturing disturbances, resources, and the regulating factors that control ecophysiology (Guisan & Thuiller, 2005). SDMs have been used to understand the ecological requirements of species (Hirzel et al., 2002), barriers to dispersal (Guisan & Hofer, 2003), select target species for more climate resilient restoration projects (Gelviz-Gelvez et al., 2015), model habitat overlap for invasive Tamarisk and the native Southwestern Willow Flycatcher (York et al., 2011), identify sites for recovery and restoration (ElsäBer et al., 2013), and aid conservation planning and reserve design (Araújo et al., 2002; Howard et al., 1998). Traditionally, distribution models made use of presence/absence and abundance data and were reliant on regression and discriminant analysis (Elith & Leathwick, 2009). More recently, the lack of comprehensive multi-species biological survey data and extensive species presence records has led to the popularization and refinement of methods that make use of presence-only data, such as Maxent. Maxent is a type of SDM that estimates probability densities of species in covariate space using presence-only data by correlating species presence with the pattern in environmental variables where species occur (Elith et al., 2011; Phillips et al., 2006a). Presence only species distribution models have proven useful for making use of radiotelemetry, citizen science, and decades of presence-only data from museum and herbarium collections. However, as with most models, there are many critiques of standard use and model assumptions.

Criticism of Maxent, in particular of the typical use of Maxent by the user community, and the use of citizen science data are plentiful. Bias in the data has been the principal concern among researchers, particularly in instances where a small number of species observations makes it difficult to identify signal from random noise due to model overfitting (R. P. Anderson & Gonzalez, 2011). There are key assumptions for the use of presence only models that are not always met in the published literature, which include random sampling or sampling that captures the range of covariates in the study area, in the least having made corrections for variation in sampling intensity (Yackulic et al., 2013). Another criticism is the packaged and automated nature of software packages that do not allow for model validation and assessment of model performance, particularly since the use of standard modeling parameters can significantly effect model performance (Elith & Leathwick, 2009; Phillips et al., 2009). Additionally, the standard model validation in Maxent, as provided by the guided user interface, usually occurs through splitting the data into test and training groups and assessing performance using a performance metric, such as area under the curve from receiver operating curves (AUC-ROC or AUC). This model validation approach can result in overly generous assessment of model performance for presence only or biased data (Olden et al., 2002).

However, the presence-only statistical conundrum appears to be less vexing as published work has strengthened arguments for the use of Maxent, since presence-only data also creates the imprints that reveal habitat suitability (Elith et al., 2011; Jiménez-Valverde et al., 2019) and investigations of model performance reveal that Maxent models can perform comparably to presence/absence distribution models (Elith et al., 2006). There has also been some focus on approaches for correcting spatial bias of data used for Maxent. The use of Thiessen polygons, for example, can also help visualize spatial bias, aid in correcting estimations about the likelihood of occurrence, as well as help focus future sampling efforts (Schulman et al., 2007). The target group background method is also a promising approach for reducing sampling bias but is not foolproof and can overcompensate and lead to false positives in under-sampled locales (Barber et al., 2022). Despite citizen science data reducing model vigor due to sampling bias and user classification error (Dickinson et al., 2010), correcting for these errors, using accurate data, and using ecologically appropriate predictor variables can produce reliable distribution models (Elith et al., 2011; Wang et al., 2018). The use of the Akaike Information Criterion (AIC) has also been discussed as an approach for refining model features and regularization parameters, since AIC penalizes models that overfit data, a likelier scenario in instances of biased data (Phillips et al., 2009; Warren & Seifert, 2011).

In Southern California, efforts to rehabilitate highly urbanized rivers are underway and provide an opportunity to better understand the biodiversity value and the opportunities for improving the ecology of urban Rivers. For example, many reaches of the Los Angeles River are currently subject to extensive hydro-modification, high temperatures, altered habitat, and nutrient inputs. The Los Angeles River also tends to host invasive aquatic species that are tolerant to the suite of stressors found in urban environments (The Nature Conservancy, 2016). However, considerable species diversity remains in soft-bottom portions of the River (The Nature Conservancy, 2016) and in the upper watershed, particularly within the large, open spaces within the Angeles National Forest. The urbanized rivers to the south, which face similar constraints, are also being re-imagined as amenities, habitat, and open space (City of San Diego, 2013). The ongoing efforts focused on the rehabilitation of urban streams can be supported by better understanding the select native species that flourish along urban streams of the South Coast region and the environmental variables associated with habitat suitability. I will explore avian species habitat relationships at the catchment scale using Maxent. I will make use of publicly available data sources, in particular data freely available from eBird to answer: 1.) What is the relationship between bird species occurrence and habitat characteristics in California's South Coast streams; 2.) How can these relationships help guide restoration and management efforts in heavily urbanized streams; and 3.) What is the utility of Maxent and citizen science data to planners and project practitioners seeking to better inform actions focused on ecological rehabilitation?

3.2 Methods

I will examine the relationship between species presence and environmental variables at the catchment scale using Maxent species distribution models. The study area includes streams of coastal Southern California watersheds from Ventura to San Diego Counties. The area encompasses major metropolitan areas which have a diversity of stream typologies ranging from completely channelized areas, soft bottom, and completely natural streams, many at higher elevations further from population centers or in protected areas.

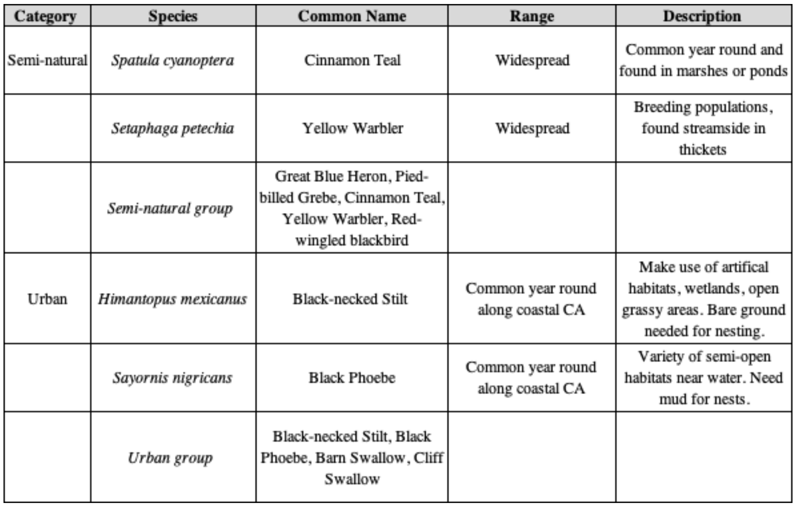
3.2.1 Biodiversity Data

Several million species observations records, many collected from applications that facilitate data collection by citizen scientist, are freely available online and have facilitated conservation and biodiversity research (Chandler et al., 2017.; Cooper et al., 2007; Shirey et al., 2019). A user friendly observation network and web application launched by the Cornell Lab of Ornithology and the National Audubon Society, eBird allows community members, ranging from the amateur to the sophisticated birder, to contribute observations using standardized protocols (Sullivan et al., 2009). I solely used eBird data since users provide metadata about sampling strategy and data that can estimate effort so as to enhance data quality (Johnston et al., 2020). The basic eBird dataset was downloaded in January 2021 for the entire state of California via ebird.org/data/download for the period between 2009 to 2018 time. Observations were clipped in R using a polygon of Southern California coastal watersheds, resulting in a data set of more than 105 million bird species observations. I further limited observations to those that had taken place in streams and river corridors by removing observations that occurred outside of a 250m buffer of known water bodies, which included stream/river, artificial path, and canal ditches, according to the National Hydrography Dataset.

Citizen science data present challenges for statistical analysis because observations can be clustered, non-random, and novice collectors can misidentify species (Dickinson et al., 2010). As a result, I implemented quality control measures for the use of eBird data and care in selecting appropriate species. I selected a subset of bird species for Maxent modeling by consulting three expert ornithologist for suggestions of species commonly observed in heavily urbanized and semi-natural streams/rivers and refined final species list based on overlapping recommendations, removing any species for consideration that had less than 1000 observations across the study area. Small sample sizes and under sampling of the landscape can effect model performance, despite Maxent outperforming many models in this respect (Wisz et al., 2008; Yackulic et al., 2013). Furthermore, to enhance data quality and reduce instances of erroneous species occurrences, I selected bird species for Maxent modeling that would not be easily confused for conspecifics by novice birders based on expert knowledge. The species selected for semi-natural streams included the cinnamon teal (*Spatula cyanoptera)* and yellow warbler

(*Setophaga petechia*) and, in heavily urbanized streams, the black phoebe (*Sayornis nigricans*) and black-necked stilt (*Himantopus mexicanus*). Additionally, groups of highly urban and semi-natural species were also modeled together to broadly understand species habitat relationships across the two stream typologies. The highly urban species list included the barn swallow (*Hirundo rustica*) , black phoebe (*Sayornis nigricans*), black-necked stilt (*Himantopus mexicanus*), and cliff swallow (Petrochelidon pyrrhonota). The semi-natural species list included the cinnamon teal (*Spatula cyanoptera)*, great blue heron (*Ardea herodias*), pied-billed grebe (*Podilymbus podiceps*), red-winged blackbird (*Agelaius phoeniceus*), and yellow warbler (*Setophaga petechia*). Species are briefly described in Table 16. Since some urban or suburban species may be common and, as a result, underreported, I removed incidental observations and incomplete checklist from analysis, a recommended step for enhancing model performance that allows species absence to be better inferred (Johnston et al., 2020). Since each species had a more than generous sample size (1000+) and because spatial autocorrelation can inflate measures of model accuracy (Veloz, 2009), I attempted to reduce spatial autocorrelation by removing repeat observations, which may have also represented multiple individuals of the same species at a location. Specifically, records by multiple users of the same species on the same day within the same area were deleted.

Table 16 Brief description of species and general habitat requirements for selected species.



Category	Species	Common Name	Range	Description
Semi-natural	*Spatula cyanoptera*	Cinnamon Teal	Widespread	Common year round and found in marshes or ponds
	Setaphaga petechia	Yellow Warbler	Widespread	Breeding populations, found streamside in thickets
	Semi-natural group	Great Blue Heron, Pied-billed Grebe, Cinnamon Teal, Yellow Warbler, Red-wingled blackbird		
Urban	*Himantopus mexicanus*	Black-necked Stilt	Common year round along coastal CA	Make use of artifical habitats, wetlands, open grassy areas. Bare ground needed for nesting.
	Sayornis nigricans	Black Phoebe	Common year round along coastal CA	Variety of semi-open habitats near water. Need mud for nests.
	Urban group	Black-necked Stilt, Black Phoebe, Barn Swallow, Cliff Swallow		

3.2.2 Maxent Species Distribution Modeling

To better understand the relationship and environmental conditions at a catchment scale, I used Maxent. Maxent is a species distribution model that estimates probability densities of species in covariate space using presence-only observations. The model correlates species presence with patterns in environmental variables where species occur (Elith et al., 2011; Phillips et al., 2006a). The environmental predictor for the Maxent model included only freely available environmental datasets that could be summarized to the HUC-14 sub-watershed scale (Table 17). As much as possible the selected predictors attempted to capture factors that limit species distributions, disturbances, and resources per Guisan and Zimmermann (2000). Predictors and data sources are described in Table 17. Raster files of each predictor were clipped to the study extent and the resolution and scale standardized using both R (version 4.0.3) and QGIS (version 3.14.1-PI). Predictors that were highly correlated with other predictors (R>0.75) were removed from the models with a preference for removing predictors that were highly correlated with several variables (e.g., population density was high correlated with population density in the riparian zone, road density, and runoff). Model performance was iteratively tested following removal of each predictor, specifically variable contributions and AUC values.

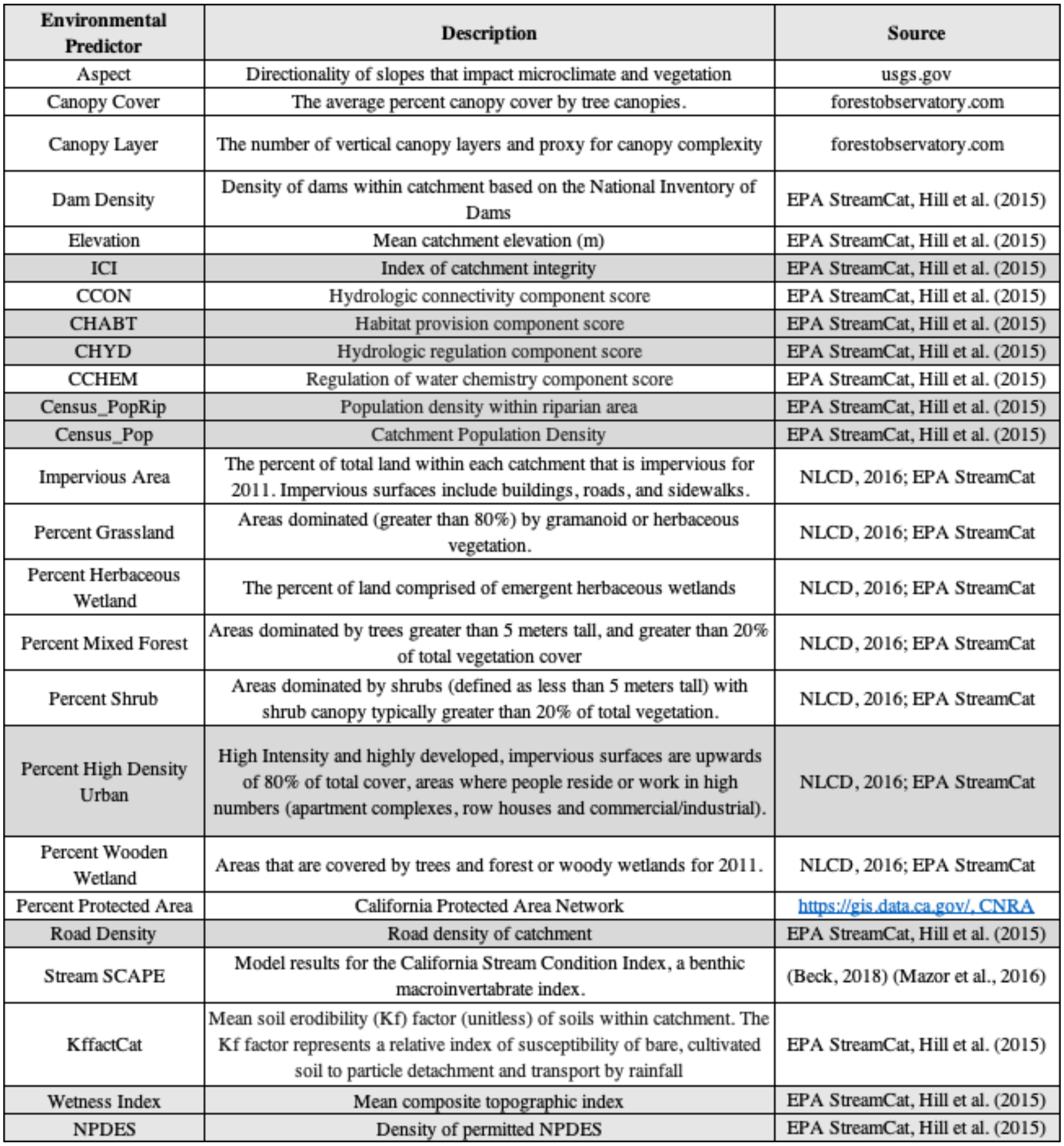
The ENMeval (Muscarella et al., 2014) package was used to run and optimize each Maxent model run in R (version 4.0.3). Occurrence data was split into 30% test and 70% training data, as is standard practice. All models were run with training data with a regularization parameter ranging from one to three, a k-fold cross validation of 5, and using all model feature types (linear, quadratic, product, hinge). In k-fold partitioning the data is divided into bins, in this instance 5, of equal size and models are built iteratively using (k-1) bins and evaluated using a withheld bin (Fielding & Bell, 1997). AUC values were averaged across validation data. The feature types and regularization value were selected using Akaike's Information Criterion (Warren & Seifert, 2011). Regularization controls model complexity and other authors have experimented with random partitions in regularization values ranging from 0.25 to 10 and found model-overfitting rapidly decreases as regularization values approach one, the default value, and that higher values can sometimes further reduce overfitting (R. P. Anderson & Gonzalez, 2011; Phillips & Dudík, 2008; Warren & Seifert, 2011) . Background data is used in SDMs to better characterize the full range of environmental predictors and to provide some measure of model predictive performance, when compared to known species occurrences. I used both a target background and pseudo-background approach since eBird, like much citizen science data, is presence-only data. As in Phillips et al. (2006b) I generated 1000 pseudoabsences randomly across the study extent. Since the background can impact modelling predictive performance and to better account of sampling bias, which if unaccounted for results in models that reflect survey effort, I re-ran all models using 1000 randomly selected data points from a targeted background, or eBird data that captures the same sampling bias as the occurrence data (Phillips et al., 2009).

Other efforts have found that spatial filtering of observation, in this instance observations were reduced to one per catchment, can improve model performance (Kramer-Schadt et al., 2013; Phillips et al., 2009). In this is instance, filtering resulted in negligible changes in AUC and larger differences between test and training AUC values (Table 18). However, occurrences were uniformly reduced to one occurrence per catchment across all catchments instead of in heavily sampled ones. Additionally, filtering data by effort (Johnston et al., 2020) by removing records that covered an area of more than 5km similarly did not improve model performance, as assessed by differences between training and test model runs (Table 18).

Several strategies were used to evaluate model performance and the importance of predictors to relative habitat suitability. The importance of predictors was estimated using the standard Maxent analysis features in which increases in regularized gain are added to the corresponding predictor to estimate percent contribution. While percent permutation importance values result from the percent drop of a model's training AUC when a predictor is randomly permutated (Phillips & Dudík, 2008). The AUC-ROC curve is used in many presence-absence species distribution models as a measure of model performance, specifically the probability that a model correctly classifies random occurrences and absences. Phillips et al. (2006b) re-defined the AUC, for presence only models, as the probability of the correct classification of species presence and random data. AUC values are usually interpreted so that a value of 0.5 indicates the model performs no better than random, 0.5-0.7 indicate poor performance, 0.7-0.9 reasonable performance, and values greater than 0.9 indicate high performance. However, this standard model validation approach for presence-only data can result in overly generous assessment of model performance that results in inflated AUC values (Olden et al., 2002). Raes and ter Steege (2007) detail the use of the null model for evaluating model performance in which a random distribution of AUC values are used to derive a probability value, similar to traditional hypothesis testing. I generated null models in R using the SDMPlay (Charlene et al., 2020) package and compared each model's AUC value to a distribution of AUC values generated by chance using a null model (Raes & ter Steege, 2007). Nulls models sample randomly from the study extent and in instances where data collection is biased, the randomly drawn data will capture environmental conditions not represented in the SDM and will thus be more likely to significantly differ from random. As a result, to correct for bias, null models randomly drew data from areas that had already been sampled as recommended by Raes and ter Steege (2007).

Additionally, I made us the continuous Boyce Index, which roughly evaluates how much a model differs from random. The Boyce Index calculations partition habitat suitability values into bins and calculates the predicted frequency of suitability values within evaluation data based on model predictions and the expected frequencies based on a random distribution (P/E) (Hirzel et al., 2006). The Boyce index is the correlation between the predicted to expected ratios and habitat suitability values. Boyce index values range from -1 to 1, whereby values close to zero denote that a model is not different from chance, negative values denote an incorrect model, and positive values denote a strongly performing model with predictions that align with the presence distribution. I used the "moving window" approach for binning data and a bin width of 0.1 as suggested by Hirzet et al. 2006. I calculated the continuous Boyce Index in R using the enmSdm package (Smith, 2022). The habitat suitability predictions for withheld test data was used for Boyce Index calculation.

Table 17 Predictors used in Maxent models. Predictors that are grayed were highly correlated with others variables and were removed .



Environmental Predictor	Description	Source
Aspect	Directionality of slopes that impact microclimate and vegetation	usgs.gov
Canopy Cover	The average percent canopy cover by tree canopies.	forestobservatory.com
Canopy Layer	The number of vertical canopy layers and proxy for canopy complexity	forestobservatory.com
Dam Density	Density of dams within catchment based on the National Inventory of Dams	EPA StreamCat, Hill et al. (2015)
Elevation	Mean catchment elevation (m)	EPA StreamCat, Hill et al. (2015)
ICI	Index of catchment integrity	EPA StreamCat, Hill et al. (2015)
CCON	Hydrologic connectivity component score	EPA StreamCat, Hill et al. (2015)
CHABT	Habitat provision component score	EPA StreamCat, Hill et al. (2015)
CHYD	Hydrologic regulation component score	EPA StreamCat, Hill et al. (2015)
CCHEM	Regulation of water chemistry component score	EPA StreamCat, Hill et al. (2015)
Census_PopRip	Population density within riparian area	EPA StreamCat, Hill et al. (2015)
Census_Pop	Catchment Population Density	EPA StreamCat, Hill et al. (2015)
Impervious Area	The percent of total land within each catchment that is impervious for 2011. Impervious surfaces include buildings, roads, and sidewalks.	NLCD, 2016; EPA StreamCat
Percent Grassland	Areas dominated (greater than 80%) by gramanoid or herbaceous vegetation.	NLCD, 2016; EPA StreamCat
Percent Herbaceous Wetland	The percent of land comprised of emergent herbaceous wetlands	NLCD, 2016; EPA StreamCat
Percent Mixed Forest	Areas dominated by trees greater than 5 meters tall, and greater than 20% of total vegetation cover	NLCD, 2016; EPA StreamCat
Percent Shrub	Areas dominated by shrubs (defined as less than 5 meters tall) with shrub canopy typically greater than 20% of total vegetation.	NLCD, 2016; EPA StreamCat
Percent High Density Urban	High Intensity and highly developed, impervious surfaces are upwards of 80% of total cover, areas where people reside or work in high numbers (apartment complexes, row houses and commercial/industrial).	NLCD, 2016; EPA StreamCat
Percent Wooden Wetland	Areas that are covered by trees and forest or woody wetlands for 2011.	NLCD, 2016; EPA StreamCat
Percent Protected Area	California Protected Area Network	https://gis.data.ca.gov/, CNRA
Road Density	Road density of catchment	EPA StreamCat, Hill et al. (2015)
Stream SCAPE	Model results for the California Stream Condition Index, a benthic macroinvertabrate index.	(Beck, 2018) (Mazor et al., 2016)
KffactCat	Mean soil erodibility (Kf) factor (unitless) of soils within catchment. The Kf factor represents a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall	EPA StreamCat, Hill et al. (2015)
Wetness Index	Mean composite topographic index	EPA StreamCat, Hill et al. (2015)
NPDES	Density of permitted NPDES	EPA StreamCat, Hill et al. (2015)

Table 18 Summary of exploratory Maxent model runs using occurrence data that had filtered out low effort observations and reduced observations through spatial filtering. Note, null models were only run for models with AUC values > 0.7.

	Filter Out Low Effort Data, Random Background					**Spatial Filtering-One Sample per Catchment Data, Random Background**				
Model	**n**	**AUC Training**	**AUC Test**	**p**	**Top predictores**	**n**	**AUC Training**	**AUC Test**	**p**	**Top predictores**
Black Necked Stilt	1631	0.73	0.70	>0.20	Water Index, Percent Shrub, Elevation, Percent Mixed Forest	182	0.80	0.68	>0.2	Percent shrub, percent protected area, percent mixed forest, runoff
Urban Species	14445	0.57	0.53		Impervious, Percent Protected area, canopy cover	1567	0.60	0.76	>0.2	Elevation, Percent herbaceous wetland, canopy cover
Cinnamon Teal	1168	0.67	0.70		Percent protected area, Streamscape, and percent mixed forest	171	0.61	0.62		Percent protected area
Yellow Warbler	1166	0.59	0.56		Canopy cover, sttreamscape, percent wooded wetland	1567	0.60	0.72		Percent herbaceous wetland, impervious, runoff, canopy cover

3.3 Results

Four species were selected for species distribution modeling: black-necked stilt, black phoebe, cinnamon teal, and yellow warbler as well as combinations of urban and semi-natural species. The majority of observations, across all species, are at low and intermediate elevations, with few occurring above 2380 feet and observations appeared to be biased spatially around coastal population centers (Figure 12). black phoebe and yellow warbler observations appear to be particularly widespread across the Southern California study region. black phoebe observations were the most numerous of all sampled species.

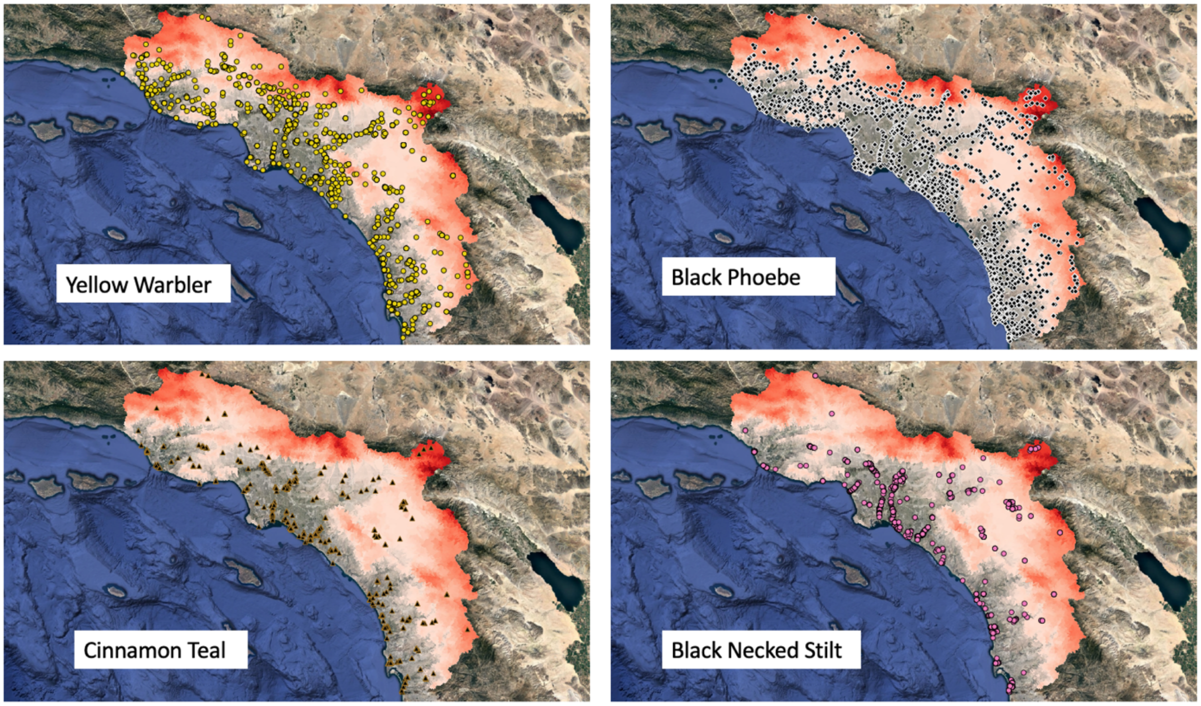


Figure 12 All observations of black-necked stilt, black phoebe, cinnamon teal, and yellow warbler within 250 meters of a stream or river in coastal watersheds of Southern California

Despite the large sample sizes for each species and predictors that capture broad stressors, albeit not all stressors to stream habitats, Maxent models for selected species did not significantly differ from random based on a comparisons to a null model (

Table 19). Models that made use of a random background tended to have inflated AUC values and generally more complex model features (

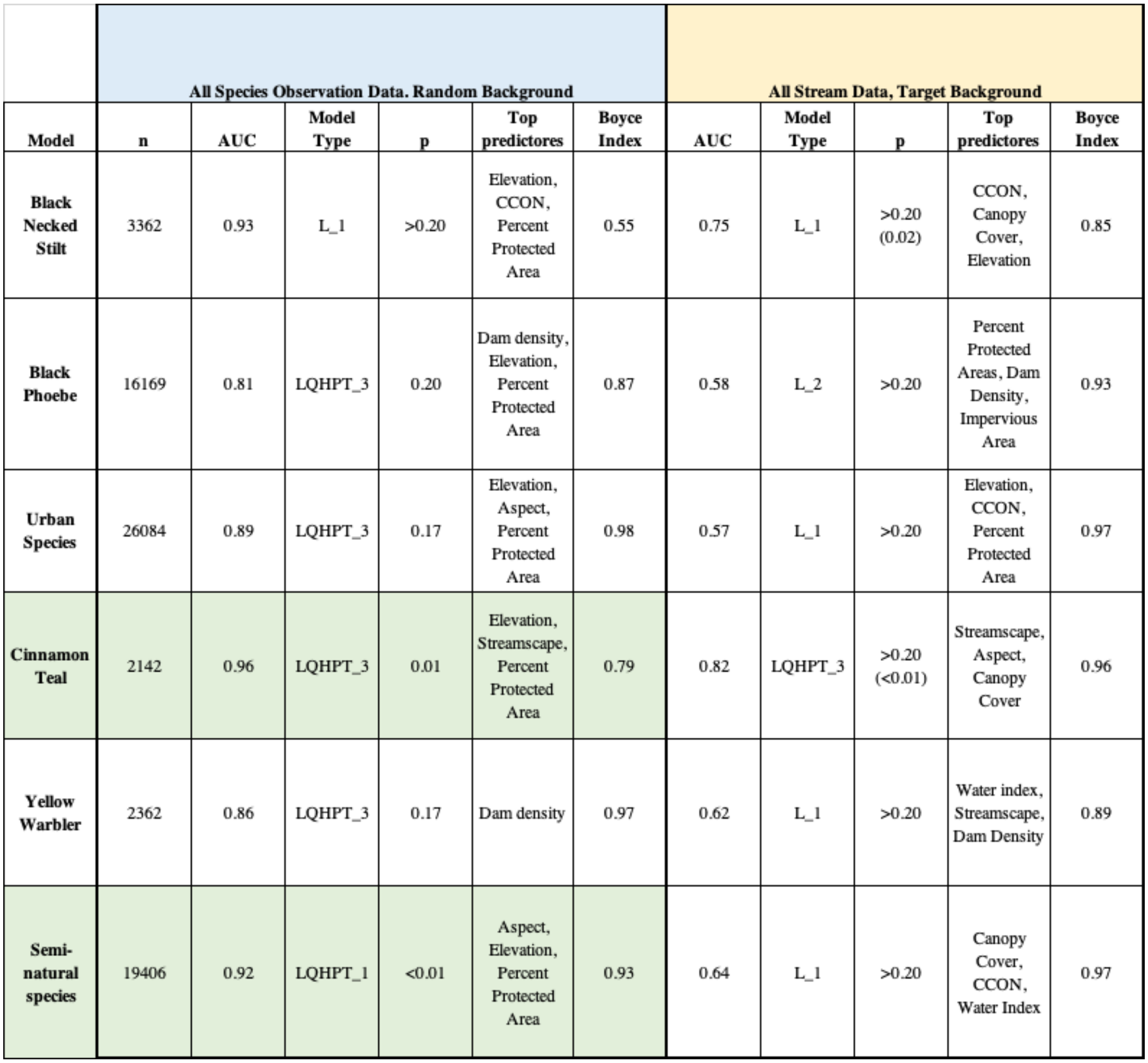
Table 19). Meanwhile, models that accounted for bias, through a target background approach, had lower AUC values and not one significantly differed from random compared to the AUC distributions of targeted null models. Additionally, there were stark differences in significance for null models depending on whether random samples were taken from sampled locations (I will refer to these as targeted null models) or the entire study area, revealing the bias in occurrence data and the appropriateness of a target null model for deciphering model significance as discussed by Raes and ter Steege (2007). The only models that were significant using a targeted null were those for cinnamon teal and grouped semi-natural species that made use of a random background (

Table 19).

Predictors across models shifted, sometimes considerably, based on whether the model was run with a random or target background. Interestingly, the dominance of elevation as a top predictor in models that made use of a random background, half the models had elevation as the most important predictor, shifted as models better accounted for sampling bias (

Table 19). The top 3 predictors for models that used a random versus target background varied considerably for semi-natural species. While for urban species, predictor order shifted and new predictors, such as canopy cover, impervious area, and hydrological connectivity (CCON) were introduced as important predictors for black-necked stilt, black phoebe, and urban group of species, respectively.

Table 19 Summary of model performance for each species and species groups using a random background or target background for model runs. Significant models are highlighted in green. All models were evaluated using the Continuous Boyce Index and using a null model. The null models were targeted and drew random samples from the sampled area. Null models that used the entire study extent have p values in parenthesis. The listed top predictors are the three predictors that contributed the most to model performance based on model gain. In the random background yellow warbler model, dam density had a model contribution of 80% and was thus the only listed predictor. Model type denotes the model features (L= linear, Q= quadratic, H = hinge, P = product, T = threshold) and regularization values (1 to 3) that were selected based on AIC.



	All Species Observation Data. Random Background						All Stream Data, Target Background				
Model	**n**	**AUC**	**Model Type**	**p**	**Top predictores**	**Boyce Index**	**AUC**	**Model Type**	**p**	**Top predictores**	**Boyce Index**
Black Necked Stilt	3362	0.93	L_1	>0.20	Elevation, CCON, Percent Protected Area	0.55	0.75	L_1	>0.20 (0.02)	CCON, Canopy Cover, Elevation	0.85
Black Phoebe	16169	0.81	LQHPT_3	0.20	Dam density, Elevation, Percent Protected Area	0.87	0.58	L_2	>0.20	Percent Protected Areas, Dam Density, Impervious Area	0.93
Urban Species	26084	0.89	LQHPT_3	0.17	Elevation, Aspect, Percent Protected Area	0.98	0.57	L_1	>0.20	Elevation, CCON, Percent Protected Area	0.97
Cinnamon Teal	2142	0.96	LQHPT_3	0.01	Elevation, Streamscape, Percent Protected Area	0.79	0.82	LQHPT_3	>0.20 (<0.01)	Streamscape, Aspect, Canopy Cover	0.96
Yellow Warbler	2362	0.86	LQHPT_3	0.17	Dam density	0.97	0.62	L_1	>0.20	Water index, Streamscape, Dam Density	0.89
Semi-natural species	19406	0.92	LQHPT_1	<0.01	Aspect, Elevation, Percent Protected Area	0.93	0.64	L_1	>0.20	Canopy Cover, CCON, Water Index	0.97

The Boyce Index was not useful in deciphering model performance despite the index also making use of a null model approach that compares modeled predictions to random or background points. Except for the black-necked stilt random background model (

Table 19), values were high across all models. Boyce index values range from -1 to 1 with negative values denoting an incorrect model, 0 a model that does not differ from random, and 1 indicating a model that can predict species distributions of the dataset accurately. The Boyce Index requires predicted habitat suitability values for test data, occurrence data that was not used in model training, and for background points. Despite the background, and the associated habitat suitability values, shifting from a random to a targeted background, Boyce Index values remained consistently high. Additionally, Boyce Index values did not appear to correspond to the results of the null model in any way. For example, the significant random background model for cinnamon teal had the second to lowest Boyce Index value (

Table 19). While the Boyce Index values by themselves are uninformative, the predicted/expected ratio plots do provide information about how model performance varies by species across habitat suitability values (Figure 13). P/E curves show the black-necked stilt, black phoebe, and yellow warbler models had considerable variability in performance across habitat suitability values. The yellow warbler and black phoebe model, in particular, were unable to discern appropriately low habitat suitability values for background data. Models that perform strongly produce a monotonically increasing P/E curve. Some models, like those for cinnamon teal and the urban species group, were able to predict low suitability values with a high resolution for random data but showed more variability in predicting habitat suitability values for species presences, albeit most are above 1. The linearity of the urban species model over the entire habitat suitability range, except the highest values, demonstrates that this model predicts suitability with a finer resolution.

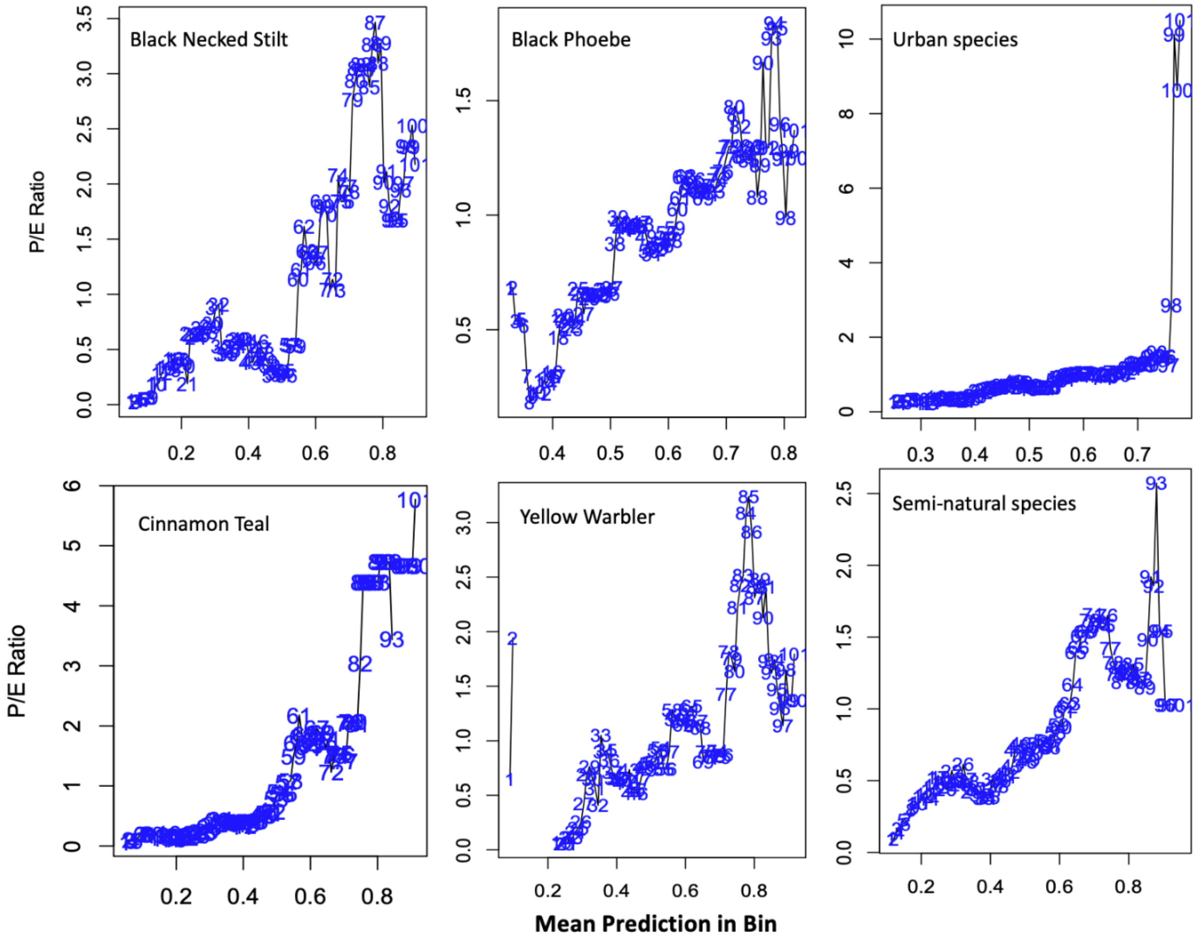


Figure 13 Predicted/expected curves from the continuous Boyce Index for each species and species group modeled in Maxent using a target background. Numbers are the bins numbered from lowest to highest based on mean habitat suitability prediction in that bin. Occurrence data should have P/E ratios larger than 1 and well performing models should produce a monotonic, increasing curve.

3.4 Discussion

Maxent has shown promise for predicting species distribution and habitat suitability in instances where resources for more structured data collection are few (Rhoden et al., 2017; Sharma et al., 2018; West et al., 2016). There has, in particular, been excitement for making use of presence only data, such us herbarium, citizen science, or museum records, that is otherwise unusable with traditional statistical approaches (Graham et al., 2004; Phillips et al., 2006b). However, Maxent has assumptions for its use that are often unmet by these type of data (Yackulic et al., 2013) but there are published strategies for meeting assumptions that do not require additional data collection (Phillips et al., 2009; Raes & ter Steege, 2007). In this study, I explored the potential to use Maxent and citizen science data to better inform ongoing urban river rehabilitation as governments in the region continue to invest in revitalizing and restoring their riverine waterfronts (City of San Diego, 2013; LADPW, 2021). I also wanted to explore whether Maxent was a practical tool in urban river revitalization for resource limited planners or practitioners. Recognizing that many rivers in the region are limited in the extent to which they can be restored, due to, among other reasons, a heavily populated floodplain, I selected species that were, in the least, urban tolerant and employed several strategies for improving model performance through tuning (Radosavljevic & Anderson, 2014), filtering (Johnston et al., 2020), and bias correction (Phillips et al., 2009). Since many traditional approaches for model evaluation were invalid for presence only models, such as AUC and the true skills statistic (Lobo et al., 2008), and without the benefit of structured field data or complementary data to support model interpretation and validation (Holder et al., 2020; West et al., 2016), I made use of techniques that compared model results to random data to gauge model significance and performance (Hirzel et al., 2006; Raes & ter Steege, 2007).

Using eBird data and environmental data at the catchment scale, I was not able to determine with certainty the predictors that are important to habitat suitability for selected species. I used both a random ("pseudoabsences") and a targeted background approach and found that Maxent models that make use of a random background are considerably different from models that corrected for bias using a target background. This is evident by drops in AUC values and statistical significance once bias is corrected using the target background approach. Background data is important to characterizing the full range of environmental predictors and will inflate a model's predictive performance, particularly when the background differs from occurrence locales (Phillips et al., 2009). Therefore, the significance of the cinnamon teal and semi-natural models are likely an artifact of uncorrected bias in occurrence data and may suggest that environmental covariates captured from a random background are different than those captured by occurrence data. The recurring importance of elevation in uncorrected models and the limited number of samples at higher elevations suggest that models that used a random background are likely reflecting sampling and not species distributions (Phillips et al., 2009).

The evaluation approaches employed for Maxent model runs confused interpretation despite both approaches making use of null model approach in model evaluation. Boyce index values were unhelpful since they were nearly uniformly high across all models (they are based on Pearson's rank correlation and relationships are roughly linear). However, the P/E ratio curves were useful for understanding model performance over the range of habitat suitability values, insight that no single evaluation metric can provide. The variability in the prediction of presences by Maxent at high suitability values, as shown by all P/E ratio curves, may indicate that appropriate environmental predictors for many species are missing. Additionally, the noisy fluctuations in model predictions may indicate a need for a more structure dataset (Hirzel et al., 2006). The cause and remedy to the mismatch between these evaluation methods is unknown.

Model evaluation, or a model's ability to make predictions using independent data, is still a thorny subject in the Maxent literature (Araújo & Guisan, 2006). Null models have been the subject of plenty of criticism, peaking in the 1970s, because it can be difficult to parameterize a model that definitively captures a null hypothesis and because null models that are too constrained can increase false negatives, or type II errors (see review by Gotelli and Ulrich (2012). Null models can also be affected by spatial autocorrelation, matrix size and heterogeneity, sample sizes, and can be more likely to produce Type I or Type II errors if null distributions are non-normal (Gotelli & Ulrich, 2012; Veech, 2012). Raes and ter Steege's (2007) asserted that a targeted null model can correct for collector bias. However, in the present study, there are considerable inconsistencies in model performance depending on the approach used for bias correction, whether a targeted background or a target null model. However, the criticisms about the biologically uninformative nature of null models ring particularly true in the present study as the lack of congruence between these evaluation approaches and specific model weaknesses cannot be further explored given that outputs strictly speak to deviation of a Maxent model from random (D. R. Anderson et al., 2000).

Araújo and Guisan make the case for three model evaluation strategies: descriptive, whereby the strength of relationships is measured, understanding, hypothesis about relationships are tested, and prediction, whereby hypothesized relationships are projected onto independent situations. In this instance, I sought to understand species habitat relationships and tested the strength of these relationships by testing how well the model could predict habitat suitability for a withheld set of data. However, this approach, though commonly used, has been called into question since the withheld "test" data are not truly independent, particularly if data is spatially autocorrelated (Araújo et al., 2005). Araújo and Guisan (2006) suggests model evaluation occur using data from a different region or time and this recommendation could have been implemented by withholding certain watersheds for model evaluation. Nevertheless, the mismatch between model evaluation metrics highlights the challenging nature of model evaluation amidst pointed and active discussion about assumptions and techniques.

Maxent and the selected predictors were not effective in determining the broad scaled environmental relationships for species that are common in urban areas. The constraints of identifying species for Maxent modeling in highly urban environments led to the selection of generalists species, making the identification of a set of environmental predictors difficult. For example, Evangelista (2008) applied SDM to generalist and specialist invasive plant species and found models for the generalist species to perform worse, attributed to generalist habitat preferences not being easily captured by environmental predictors. However, other studies have successfully identified predictors for generalist invasive species (West et al., 2016), albeit at finer resolutions. In a study examining whether certain species traits make species more amenable to being modeled, McPherson et al. (2004) found traits like range size, habitats visited, trophic level, and endemism to have a small but negative impact on model performance. Urban species may also make use of the urban matrix in a way that is poorly accounted for in the selected model or their distributions may be governed by a heterogeneous predictor that is too coarsened at the catchment scale to provide predictive power (discussed below in further detail). SDM modeling with more fine-grained predictors may also be required to better understand what resources may be more plentiful in degraded streams for these generalist species or the inclusion of species interactions that favor their occurrence.

Studies of bird species in urban areas have documented a set of recurring findings that not only point to the importance of the urban matrix but also of the environmental predictors that may better capture the niche of these urban, generalist species. Patch size, urbanization, and vertical heterogeneity of patches have been found to be important in explaining patterns in urban bird species richness (Saunders et al., 1991; Suarez-Rubio & Thomlinson, 2009; Watson et al., 2005). In the present study, some of those predictors, or in the least closely related predictors, were included in models for urban stream species. Those closely related predictors included canopy layer, impervious area, and percent protected area, respectively. These predictors were among top predictors, specifically impervious area percent protected area, of habitat suitability for all species except the yellow warbler. Lacking among predictors of urban species habitat suitability were measures of connectivity and disturbance, important predictor in urban biodiversity studies, but for which data was not readily available with the exception of fire area within each catchment (Beninde et al., 2015; Faeth et al., 2011; Kang et al., 2015). Additionally, as other studies have noted, urban biodiversity and the vulnerability of a bird species to urbanization and the resulting fragmentation will depend on whether species can make use of matrix habitat (Ganzhorn & Eisenbeiß, 2001). The matrix, particularly the structure, disturbance, and composition, is important to species vulnerability, area sensitivity, and dispersal (Watson et al., 2005). Measures of matrix quality were not explicitly included as predictors.

The difficulty with selecting appropriate environmental predictors, aside from the ease of data availability and quality, for species distribution models is determining the scale at which organisms interact and respond to their environment. In published Maxent models the use of the 1km grain size is ubiquitous, particularly with many studies focusing on the impact of climate change to species distributions and the roughly grained climatic data available through BIOCLIM (www.worldclim.org) being limited to the 1 km scale (Manzoor et al., 2018). However, recent research has critiqued the standard use of courser scales since habitat features are lost and coarse grain size can affect model transferability and accuracy (Manzoor et al., 2018; Roach et al., 2017). It is important to note that this relationships is also not a rule, upscaling of grain size does not necessarily worsen model performance, and will also depend on species, sample size, the intrinsic error associated with observation data, and the importance of model transferability (Guisan et al., 2007; Manzoor et al., 2018). Gottschalk (2011) used different grain sizes, ranging from 1m to 1000 m grain size, to understand how grain size impacts model performance for bird species in Germany and found that explained variation decreased with courser grained data for both specialist and generalist bird species; he ultimately suggested that the observation technique grain match those of the predictors. Other studies of bird distributions have found that predictors are hierarchical, different predictors will be important at different scales, with vegetative cover and species interactions emerging as important in determining species distributions at finer resolutions (Luoto et al., 2007; Menke et al., 2009). Gottschalk et al. (2011) found that a 2-3 meter resolution explained the most variability in SDMs. These small scaled habitat features may be more fully within the realm of control of project practitioners when seeking to enhance biodiversity along urban rivers and streams. However, land cover and vegetation data at these resolutions are not readily publicly available and would require high resolution imagery and land use classification based on spectral signatures or textural analysis as in Gottschalk et al. (2011). Additionally, it is also important to note the limitations of citizen science data at finer scales. A subset of eBird observations, such as traveling counts, do not have standardized locations (e.g., coordinates are not necessarily from the middle of a transect as is recommended) and may not reflect the immediate habitat conditions of a species observation (Sullivan et al., 2009).

I made use of freely available environmental data found via EPA's StreamCat database. These datasets have been important in ecological research because they characterize the environmental conditions of stream segments across entire regions; they have also been previously employed in Maxent fish species distribution studies (Holder et al., 2020; McGarvey et al., 2021). In the present study, I selected catchments as the grain size because the study was focused on bird species utilizing river/stream corridors and because upstream conditions will impact local conditions (Hunsaker & Levine, 1995). Furthermore, Pickett et al. (1997) suggested that the watershed scale can be useful in urban ecological studies because catchments integrate human impacts on water quality and hydrology, connection aquatic and terrestrial systems, and integrate impact of human activities on catchment functioning. However, for SDM, multiple studies have found that a finer resolution will more accurately represent the environment in which a species was found and that habitat variables, in particular, lose explanatory power at course resolutions (Gottschalk et al., 2011; Luoto et al., 2007; Menke et al., 2009).

3.4.1 Can Maxent be Applied to Urban Areas?

It is useful to examine the assumptions of SDM to understand the complexities that SDMs cannot or have not accommodated and whether these assumptions apply to urban areas. One of the simplifications that many SDM have made, particularly because most raster data is only able to capture a moment in time, is assuming that species are in pseudo-equilibrium with their environment (Guisan & Thuiller, 2005). Disequilibrium may result from disturbance, particularly the intensity, timing, duration, of disturbance events and the succession that follows (Connel and Slatyer, 1977) because disturbance is a force structuring ecological communities (Intermediate Disturbance Hypothesis -Connell's, 1978; Huston, 1979; 1994). Disturbance can alter stream geomorphology, opens up space or resources that a different set of species can utilize, shifting species richness, composition, and life histories (Nilsson and Svedmark, 2002; Townsend et al., 1997a). Ecosystems in equilibrium, as is the theory, exhibit no long term change in structure or function because of disturbance. However debates about whether ecosystems are ever in equilibrium is decades long (Kéfi et al., 2019; May, 1972; Pennekamp et al., 2018; Pimm, 1984). Urban ecosystems would largely be considered in disequilibrium given higher levels and more frequent disturbances and the continuous need for maintenance for stability of habitats (Rebele, 1994).

Several studies have made the case for including people in urban ecological studies. Several researchers have documented the ecological and societal response to disturbance in urban areas and the manner in which these responses interact, reinforcing the dynamic nature of urban ecosystems and the need to include humans in all models of urban systems (Carreiro & Zipperer, 2011; McPhearson & Tidball, 2013). Rodriguez-Pastor et al. (2012), for example, found that the distributions of invasive monk parakeets was linked to high tree densities and populations over the age of 65, which were likely feeding the parakeets. Alberti and Marzluff (2004) proposed that the resilience of urban ecosystems is linked to patterns of human activities. This is particularly important given research linking economics and cultural background to biodiversity at the neighborhood scale (Kinzig et al., 2005). These approaches are well ingrained within socioecological frameworks (S. T. Pickett et al., 1997) but the how of incorporating people into SDMs is still unexplored and limited by data availability. While much socioeconomic and demographic data is readily available there is the unaddressed difficulty in reconciling scales of study since humans play an outsized role in ecosystems and institutional boundaries can very much differ from the ecological gradients in which they are nested.

Another limitation is that many SDMs assume a niche to be Grinellian, species occur where the environment is suitable, or a realized Hutchinson niche, whereby species are excluded by interspecies dynamics. However, species distributions are also controlled by source/sink dynamics and species dispersal that sustain bird densities in locations that may have poor habitat quality, such as highly urbanized areas (Marzluff, 2008). The model presented herein assumed a

Grinellian niche and I did not include predictors that would capture interspecies dynamics that may limit species distributions due to competition or predation. Aside from percent protected areas and measures of imperviousness, no other predictors associated with ease of dispersal, connectivity, or that would capture source sink dynamics were included in understanding species habitat relationships and the lack of predictors that capture important dynamics in urban areas may further limit model transferability (Randin et al., 2006).

3.4.2 Maxent Use: Lessons Learned

Maxent is an attractive approach for urban ecologist and practitioners to better understand a species niche and predict species distributions. It is among a few approaches that does not require absence data, others include Ecological Niche Factor Analysis (Hirzel et al., 2002) and the Genetic Algorithm for Rule-Set Prediction (GARP) (Stockwell, 1999), and thus can make use of data that may be unusable with other methods (Guisan & Thuiller, 2005). However, the utility of the approach can be limited by the iterative nature of modeling in which the predictors, their availability at the appropriate scale, and model validation and evaluation will need to be trialed in finding the best performing model for a given context. In this study, I implemented many recommendations for the use of Maxent that were not always fruitful in enhancing model performance. The use of 4 different modeling strategies, each supported by the literature, led to a shuffling of top predictors, varying model performance, and model evaluation approaches that confused model interpretation and, ultimately, did not result in recommendations for enhancing biodiversity along urban streams. Some common recommendations to include multiple analysis techniques to aid comparison, targeting a few locales to collect presence/absence data to truth model performance, and limiting data to structured datasets collected by experts or trained volunteers (Boyce et al., 2002; Phillips et al., 2009; Préau et al., 2018; Raes & ter Steege, 2007) further limit the more broadscale use of this model by practitioners. I will review some of the common recommendations of Maxent, caveats, and disagreements that have emerged about common practices.

Firstly, the use of citizen science data in SDM introduces challenges in assessing and correcting bias but model performance can be improved through filtering, the selection of appropriate species, and a target background approach. Accuracy rates for species identification by citizen scientist can range between 70-95% and accuracy can wane considerably in instances where rare species identifications are used (Swanson et al., 2016). Filtering by time spent or distance traveled, to account for effort, can increase probabilities of detection, may be critical for longitudinal efforts, and can account for differences between methodologies (Link & Sauer, 1999; Sullivan et al., 2009). In models that suffer from sample selection bias, spatial filtering can reduce occurrences in oversampled locations (Phillips et al., 2009; Veloz, 2009). Spatial filtering of observation can improve model performance but, if sample sizes are greatly reduced, can reduce statistical power and model rigor (Kramer-Schadt et al., 2013; Phillips et al., 2009). However, since there is too much heterogeneity in model performance depending on the species and species traits there are thus no universal recommendations for optimizing model performance using filtering (Steen et al., 2019).

Another common bias of citizen science data is spatial bias of data collection toward areas with better accessibility and near population centers (Zhang, 2020).This pattern in my own data appeared to be confirmed by a high density of observations near urban centers, such as Los Angeles and San Diego. The clustering of observations can mean that the dataset used in model training does not fully capture variations in predictor variables across the study extent limiting model transferability (Menke et al., 2009). However, there are statistical approaches to ameliorate error and bias in citizen science data. (see Bird et al. 2014 for a review of approaches). A commonly used strategy is the target group background method, the use of a random sample from the same sampling distribution as a target species, so that species presence and background are biased in the same way (Phillips & Dudík, 2008). Additionally, some citizen science platforms, like eBird, have systems in place to ensure better quality data including data quality filters, encouragement to report common birds, additional metadata requirements for unusual reports, and the submission of proxy absence data through the submission of complete checklist (Sullivan et al., 2009).

Bias is generally a topic of much discussion for SDM since bias can lead to overfitting and noise that impact transferability or falsely inflate model performance (Radosavljevic & Anderson, 2014). Model parameterization, specifically the selection of model features and regularization values can reduce overfitting and improve model performance (D. R. Anderson et al., 2000). A common method for reducing model complexity, and thus overfitting, and to select an appropriate model among alternatives is to select a model using the principle of parsimony, making using AIC or the Bayesian information Criteria (BIC) in model selection (Boyce et al., 2002). However, it is important to note recommendations to eliminate certain features, such as quadratic, hinge, and threshold, for very small sample sizes (Merow et al., 2013). If model transferability is not a priority and instead the objective is to understand predictor relationship and minimize false positives, model overfitting will not be a critical consideration in model selection (Araújo & Guisan, 2006).

A common model validation and model selection approach is the use of discriminant analysis, a measure of whether a model assigns higher habitat suitability to presence location compared to random locations. Model validation splits data into a training and test datasets using several methods (e.g., K-fold partitioning or jackknife) by which model performance is based on the ability to predict habitat suitability of occurrence data that the model has not previously “seen”. Methods that randomly split the data can create large variabilities in test statistics (Raes & ter Steege, 2007). Several studies have favored the use of k-fold partitioning in model validation (Boyce et al., 2002; Phillips & Dudík, 2008). However, many have more broadly questioned the approach because the withheld data is drawn from the same biased and potentially spatially auto-correlated sampling distributions that would inflate a model’s discriminatory accuracy (Warren et al., 2020). Additionally, the complex model algorithms may produce intermediate habitat suitability values that are indistinguishable across models, thus making model selection based on discriminant strength unwise. This phenomenon is worsened by a large number of collinear predictors (Warren et al., 2020). Warren et al. (2020) further notes that model selection based on discriminant analysis is a widely adopted best practice that at best has negligible effects and at worst is detrimental to selecting the most functionally accurate model.

Traditionally, many SDM evaluate model performance based on AUC (Hanley & McNeil, 1982). AUC is a measure of how well a model can discriminate between species presences and absences and thus whether a model can discern habitat from the background (Hanley and McNeil, 1982). Phillips et al. (2006b) re-defined the AUC, for presence only models, as the probability of the correct classification of species presence and random data. Generally, researchers have noted that metrics related to a confusion matrix, such as AUC and Kappa, are inappropriate for presence/available species distribution models since the distribution of used sites and available sites are not exclusive, being drawn from the same distribution of sites, and thus cannot be categorized (Boyce et al., 2002; Lobo et al., 2008). Pseudoabsences, which are commonly generated with presence-only data, require a downward adjustment of the AUC value based on the proportion of the geographic area covered by a species, a value which is rarely known (Merow and Silander, 2014). However, some recent studies that have made use of presence-only data have recognized that AUC is inflated by sampling density but have nevertheless advocated for the metric because of its widespread use and consistent results, whether presence-only or ground-truth data (Konowalik & Nosol, 2021).

Since many long-term and voluminous data sets, like citizen science data, do not have absence data, there have been two approaches for model evaluation: generating pseudoabsences and evaluating a model using traditional techniques (Zaniewski et al., 2002) and methods that aim to understand how predictions differ from random (Hirzel et al., 2002). There are several indices that compare how model predictions differ from random. These include some threshold based approaches, whereby a threshold is usually defined arbitrarily, such as the absolute validation index (AVI), a proportion of occurrence points that are above a given habitat suitability value, and contrast validation index (CVI), the AVI of a selected model minus the AVI of a random model (Hirzel & Arlettaz, 2003). Raes and Steege (2007) also detail the use of null model to assess model significance by comparing AUC values derived from presence-only models to a distribution of AUC values from models generated using random data, in a manner similar to hypothesis testing. Since biased presence-only dataset will often significantly differ from an unbiased null model, Raes and Steege recommend bias correction by drawing null models from the biased distributions captured in presence-only data. However, as others have pointed out, statistical significance compared to random is not a measure of how well a model performs in predicting distributions and thresholds of significance based on $p<0.05$ are arbitrary (Yoccoz, 1991).

Hirzel et al. (2002) proposed an evaluation measure that is threshold independent, the continuous Boyce Index. The continuous Boyce Index is the predicted versus expected frequencies of presences in selected versus random null models correlated against the mean habitat suitability value of binned groups. The Boyce Index is insensitive to species prevalence and provides additional information about model quality, including deviation from random and measures of robustness. In the present study, these two model evaluation metrics were markedly different for each model and there can be dizzying amount of model evaluation metrics. Konowalik and Nosol (2021), for example, found that a subset of model evaluation metrics were correlated, by varying degrees, to each other. Some metrics were poorly correlated with ground-truthed data. Konowalik and Nosol (2021) ultimately recommended that several non-correlated metrics be used in model selection in addition to expert judgement and comparisons to known species distributions.

3.4.3 Recommendations

Species distribution models and citizen science data can and have informed restoration efforts. However, after considerable investment in finding data, formatting and scaling data for use in Maxent, parameterizing the model, reducing the bias of occurrence data, and model evaluation approaches, I was not able to identify the predictors important to habitat suitability for urban and semi-natural avian species. This may have been due to the coarsened scale of predictors, missing predictors (such as those that account for connectivity or urban matrix quality), the use of generalist species, or Maxent model assumptions that are more poorly met in urban areas. Future efforts to make use of citizen science and Maxent in urban areas should consider the use of fine scaled predictors to determine whether the challenges described above can be remedied by a finer scale analysis. However, these challenges suggest that the resource limited practitioner may be better served by review of the ecological literature and discussions with fellow experts to inform project design. Sometimes, however, presence-only SDMs and citizen science data are useful to seasoned practitioners because the scale of citizen science sampling cannot be replicated. In these instances, practitioners should consider targeted sampling that capture covariates that are under-sampled by citizen science efforts and the use of finer scaled predictors that may better predict habitat suitability for generalists species (McPherson et al., 2004; Yackulic et al., 2013). Additionally, as restoration projects are implemented along the River there is the opportunity to collect better quality data that informs future restoration efforts, a proposed framework is discussed in the following chapter.

3.5 References

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4 Better Capturing the Biodiversity Benefits of Green Infrastructure: Using a Delphi Process and Expert Insight to Identify Habitat Metrics for Green Infrastructure in Urban Areas

4.1 Introduction

Today, the majority of people live in cities and that number is expected to grow by 2.5 billion by 2050 (UN, 2014). Increased urbanization will undoubtedly have impacts on local ecosystems through the increased growth of impervious area, natural resource demand, land development, and habitat loss (Booth et al., 2004). Chief among the impacts of urbanization is the loss of biodiversity, the variety of life on earth, which is already rapidly declining throughout the planet (Millenium Ecosystem Assessment, 2005; Singh, 2002). Urban areas, however, can have a role in enhancing biodiversity through the use of gardens, green networks, abandoned lots, etc., and can enhance ecosystem services, such as provisioning (Sandifer et al., 2015) and supporting services (Bolund & Hunhammar, 1999; Goddard et al., 2010; Mathey & Rink, 2010). Intra-city meta-analysis have highlighted key strategies for supporting urban biodiversity, such as increasing the area of habitat patches, corridor networks, and heterogeneous vegetation structures (Beninde et al., 2015). One strategy less rigorously documented in the academic literature is the widespread implementation of green infrastructure (National Academies of Sciences, 2017).

Green infrastructure is a low impact development strategy that can reduce the flow of stormwater to stream networks, enhance the infiltration of stormwater into groundwater, and treat and capture stormwater using physical and biological processes. These strategies can range in size and the extent of naturalness, ranging from permeable pavement and dry wells to rain gardens, detention ponds, and bioswales (US EPA, 2015). The strategies encompassed within green infrastructure overlap considerably with the recently coined term, nature based solutions (NBS). However, opposed to the stormwater focus of green infrastructure (Grabowski et al., 2022), NBS is a transdisciplinary concept that emphasizes solutions that are nature based and can solve vexing urban environmental problems, like climate change (Escobedo et al., 2019; Raymond et al., 2017). In this study, we define green infrastructure similarly to the EPA, “the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapo-transpirate stormwater and reduce flows to sewer systems or to surface waters." This study specifically focuses on vegetated, stormwater management strategies that range in scale but can be embedded within urban land uses.

There are a few studies that have documented the ecological benefits of green infrastructure While some studies have questioned the performance and reliability of green infrastructure systems (Bernhardt et al., 2005; Tetra tech, n.d.), watersheds with a greater number of green infrastructure projects have a less flashy hydrograph, reduced peak runoff, and a reduction in the export of nitrate and total nitrogen (Pennino et al., 2016). Detention and retention ponds have been particularly well studied. Retention and detention ponds can mitigate common stressors to aquatic ecosystems by reducing the variability of flows and allowing salts, sediments, and contaminants to settle out, lessening the impact of stormwater to nearby streams (Wu et al., 1996). As a result, some practitioners view green infrastructure as the remedy to save the stream (Walsh et al., 2005), while also mitigating urban heat, water resource limitations, and flooding (Gill et al., 2007; Ignatieva & Manaaki Whenua, 2008; Palta et al., 2017).

While design criteria of green infrastructure projects have largely focused on hydrology and pollutant removal and not on habitat, wildlife have been shown to use green infrastructure and other urban features as habitat (Palta et al., 2017; Scher & Thièry, 2005). Stormwater ponds in urban and suburban areas with a low density of natural wetlands have been documented breeding sites for amphibian species (Brand & Snodgrass, 2010). However, some of these aquatic habitats may be of poor quality because they expose species to sub-lethal toxicity due to the presence of oils, grease, metals, and PAH in stormwater (Bishop et al., 2000; Simon et al., 2009). As a result, biodiversity can be limited to generalist and stress tolerant species, reflective of marginal habitats (Bishop et al., 2000). Habitat condition can, however, depend on setting. For example, under conditions of low impervious cover (<20%) and high forest cover (>40%), detention ponds can have species diversity comparable to natural ponds (Simon et al., 2009). While the breadth of studies are still limited and largely focused on stormwater ponds, where aquatic toxicity may be of particular concern, green infrastructure projects can serve as experiments in designing, monitoring, and hosting multiple benefits in urban areas, much like existing urban forests and gardens (Borysiak et al., 2017). Their ease of integration in the urban landscape, in easements, roadways, alleys, parks, and neighborhoods, would potentially allow for the connection of larger habitat areas across multiple scales that create a network by which species can move, migrate, and become more resilient to climate change (Green, 2010). The role green infrastructure can play toward increasing habitat and urban biodiversity merits further research, particularly given the value of small habitat patches (Wintle et al., 2019) and rapidly declining global diversity. After all, as noted by Rodrigues et al. (2004), reserves are too few, too isolated, and too degraded to depend on large open areas by themselves to sustain biodiversity.

Ecological theory supports managing and designing green infrastructure projects for biodiversity because such designs would not only increase habitat value but, also, reduce management needs and enhance ecosystem functioning. The biodiversity-ecosystem functioning theory, for example, surmises that more biodiverse systems create greater opportunities for the niche specializations that allow species to better capture resources (van der Heijden et al., 1998). Though the subject of an ongoing decades-long debate (Goodman, 1975; McCann, 2000; Murdoch, 1975), the complexity-stability theory states that biodiversity helps create more stable systems that are resilient to disturbance and invasion, further incentivizing designing green infrastructure systems that host complex species assemblages. Ecological theory provides ample incentive for designing green infrastructure systems that enhance biodiversity due to reduced maintenance needs, increased stability, and improved regulating services that maximize contaminant removal and, potentially, other ecosystem functions important to communities (Levin & Mehring, 2015).

While many municipalities have integrated green infrastructure into sustainability efforts and projects are increasingly located within the urban footprint, the relative novelty of green infrastructure projects has meant that there is no clear consensus on the habitat goals green infrastructure can achieve nor the associated metrics, particularly for non-water resource focused benefits, by which to measure habitat benefits. Metrics, defined herein as a measure of system performance, can, through agreed upon measures of a system's attributes of interest, create the foundation for monitoring programs that assess project success. The success of certain habitat goals and the metrics of interest will, undoubtedly, be project specific and depend on local context. However, by first standardizing a global set of goals and metrics, we can better inform project practitioners about key design and management strategies (Baggett et al., 2015; SER, 2004). The field of restoration ecology has provided many examples of metric frameworks, metric selection processes, and documented the purpose and value of standard metrics. For example, metrics related to river restoration and benthic macroinvertebrate communities have been used to understand recovery in restored sites (Leps et al., 2016) and stressor heterogeneity metrics for filtering candidate sites for restoration (Neeson et al., 2016). Indicator and metric frameworks have been used to facilitate communication about natural resources, characterize ecosystems, measure restoration success, and assess trends and status of natural resources (James et al., 2020; Luckenbach, 2011; NOAA, 2021; UNEP/CBD/COP, 2011). Metrics can support developing knowledge of a system, determining appropriate management action, and understanding the effect of actions on project and system performance (Convertino et al., 2013; McKay et al., 2012).

Many ecological goals can be monitored using a multitude of metrics. Standardizing metrics can support comparison between projects and accommodate the constraints managers may face in completing those measurements, (e.g. cost and difficulty). Others have described a few approaches for metric selection, these include the use of best professional judgment and historical precedence (Convertino et al., 2013; McKay et al., 2012). Each approach for metric selection has its associated strengths and weaknesses. Metrics based on best professional judgment, for example, are inexpensive but may bias metric selection based on included stakeholders. While historical comparisons allow for comparability between previous projects but may overlook better suited metrics for those that are familiar. Furthermore, methods that guide group decision making on the selection of goals, indicators, or metrics have their own associated strength and weaknesses, can lead to biased outcomes, and can range in the degree of structure for eliciting responses and reaching consensus (Bourrée et al., 2008; Humphrey-Murto et al., 2017). For example, multi-dimension criteria analysis, a highly structured consensus method, has been used in ecology to select appropriate metrics for monitoring restoration, using explicit utility criteria, and for selecting urban tree species based on aesthetics and maintenance criteria, among others (Convertino et al., 2013; Ghafari et al., 2020). The Delphi approach consists of a series of structured, anonymous, and iterative surveys and is a useful method for reaching group consensus in the absence of empirical evidence by making use of expert insight (Mukherjee et al., 2015). The approach has been employed in ecology to identify connectivity indicators (Eycott et al., 2011), water resource decisions focused on identifying water levels for fisheries (J. G. Taylor & Ryder, 2003), and has supported conservation decisions (Murphy et al., 1998).

In this study I will elicit the professional judgement of experts to develop and refine a set of goals and objectives for green infrastructure projects in urban areas using the Delphi approach. I will then identify plausible metrics for each objective based on expert suggestions and review of the academic literature.

4.2 Methods

Habitat goals and objectives for green infrastructure projects were identified using a Delphi approach. The Delphi is an iterative survey approach with successive rounds of feedback for participants after each round. Its iterative nature, which includes at least one round of feedback, ensures that there is more credibility than other consensus methods (Eycott et al., 2011; Mukherjee et al., 2015). However, it is important to recognize the associated weaknesses of the

Delphi technique, which has been criticized for the lack of accountability associated with anonymous response (Powell, 2003). Another criticism of the Delphi is that reporting between each round of surveys pushes participants to consensus under a mistaken view that the majority is correct (Sinead et al., 2011). However, other non-anonymous group methods have their own inherent weaknesses due to the social dynamics of groups, including “group think”, “egocentrism”, “halo effect”, and “dominance”, that can impact the prioritization of ideas (Mukherjee et al., 2015). The weaknesses associated with the approach were counterbalanced by selecting experts and practitioners with relevant experience and by comparing responses to academic literature, when available.

A list of potential participants was developed based on personal knowledge and a literature review of published literature from the region. Participants were vetted by ensuring they met at least two of the following criteria:

- Have implemented, or consulted on the implementation of, a green infrastructure projects in the Southwestern region;
- Have implemented, or consulted on, habitat restoration projects in the Southwestern region;
- Have expertise in urban ecology, riparian ecosystems, freshwater and wildlife biology, or conservation;
- Have made design and plant palette recommendations for restoration or green infrastructure projects;

- Have designed, made recommendation, or engaged in applied research to enhance ecosystem services in restoration, green infrastructure, or, generally, urban greening projects.

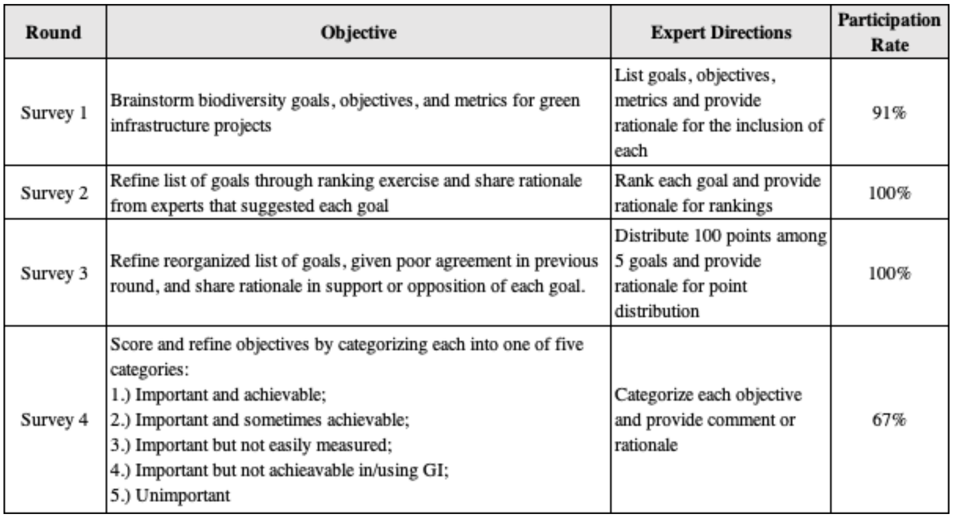
Those selected for participation were asked to recommend colleagues for participation, who were subjected to the same selection criteria. Since varied perspectives, personalities, and backgrounds have been associated with stronger outcomes (Murphy et al., 1998), participants were balanced to include experts from universities, government agencies, non-profit organizations, and project practitioners. Two to three experts were then selected from each field that was represented in the initial list of participants and invited to participate, so as to, as much as possible, balance representation within the fields represented. Represented fields included urban ecology, conservation biology, aquatic ecology, general biology, landscape architecture, and planning. A total of 15 experts were selected for project participation. Of the 15 experts invited to participate, 12 of the experts agreed to participate.

All potential participants were sent information about the study objectives, process, and context for the research. Previous work has suggested that the amount of knowledge on a topic, perceptions about the accuracy required, and willingness to participate influence survey non-response (Beatty & Herrmann, 2002). Efforts to reduce non-response have focused on cognitive, motivational, and design considerations. Since non-response or drop-out can introduce considerable error and add additional complexity to data analysis (Fowler, 2009), a short description of the Delphi's goals, the value of respondent feedback, the selection of knowledgeable respondents, and narrative ensuring the anonymity of survey responses were included with introductory materials.

The Delphi was planned as 3-4 round iterative survey. The objective of each survey round is summarized in Table 20. After an initial brainstorming survey, whereby experts were queried about broad goals applicable to green infrastructure, nested objectives, and applicable metrics, goals and objectives were queried separately to make the survey more manageable. Goals were queried for two survey rounds using a ranking and then a scoring method. A scoring method, whereby experts could assign points to each goal, was used on the second round because experts had noted that some goals were deemed of equal importance. Two survey rounds focused of refining the list of goals because there was considerable editing and reorganization of goals between survey rounds and additional rationale. In an attempt to reduce expert fatigue, given there were more than 23 objectives to review, and to stay within 3-4 survey rounds, the final survey requested that experts categorize objectives into one of five categories. These categories were developed based on themes in responses from previous survey iterations. They included disagreement with a given recommendation because it was not feasible, not easily measured, or unachievable using/in green infrastructure. Specifically, the 5 categories that were used to categorize a list of 23 objectives were: important and achievable, important but only achievable in certain conditions, important and unachievable using green infrastructure, important but cannot be practically measured, and unimportant. Since expert participation dropped considerably on the fourth survey and introductory documents described 3-4 survey rounds, the study was concluded on the fourth survey round. Given fatigue from expert participants, I selected metrics for each objective based on cost, feasibility for practitioners, expert recommendations, and scientific support for a given metric, making use, as much as possible, of data and reporting from existing and funded programs.

Before each successive survey, participants were provided a summary of survey responses from the previous round. Survey summaries also highlighted items with considerable disagreement and answered lingering expert questions (e.g. better defining green infrastructure). As the facilitator for the Delphi approach, I also summarized rationale in favor and in opposition to each goal or objective to facilitate ranking or scoring. I played the role of a critical evaluator, noting instances where expert critiques were missing or unbalanced and provided counter-arguments when they were missing. The summaries that were shared with experts also included measures of central tendency. These measured included the extent of agreement between participants, captured using Kendall's W (Schucany & Frawley, 1973) and variability in scores/ranks. A commonly used metric for within-subject stability across survey rounds, calculated using the Kappa statistic (Viera & Garrett, 2005), could not be calculated for the second and third surveys because goals varied between rounds due to re-wording and reorganization (i.e. goals like enhance water quality became an objective within the increase biotic integrity goal) and because scoring method changed between rounds.

Table 20. Objectives of each survey round, requested response from experts, and response rate for each survey round. Green infrastructure is abbreviated as GI.



Round	Objective	Expert Directions	Participation Rate
Survey 1	Brainstorm biodiversity goals, objectives, and metrics for green infrastructure projects	List goals, objectives, metrics and provide rationale for the inclusion of each	91%
Survey 2	Refine list of goals through ranking exercise and share rationale from experts that suggested each goal	Rank each goal and provide rationale for rankings	100%
Survey 3	Refine reorganized list of goals, given poor agreement in previous round, and share rationale in support or opposition of each goal.	Distribute 100 points among 5 goals and provide rationale for point distribution	100%
Survey 4	Score and refine objectives by categorizing each into one of five categories: 1.) Important and achievable; 2.) Important and sometimes achievable; 3.) Important but not easily measured; 4.) Important but not achieavable in/using GI; 5.) Unimportant	Categorize each objective and provide comment or rationale	67%

Ranks and scores for each survey were analyzed along with the themes in rationale. In the first survey, to better quantify alignment in priorities among experts and because there were often disagreements about what qualified as an objective versus a goal, I tallied the common themes across all question types (e.g. the improving habitat quality theme may have been mentioned within rationale or explicitly listed as a goal or objective) (Ryan & Bernard, n.d.). Common ecological themes were tallied based on the repetition of words or phrases in submitted responses. In order to not inflate counts from experts that were more preoccupied with a particular theme or had a lengthier response, repetition of the same theme within a single expert's responses were not counted. Themes in rationale for the third survey were similarly tallied.

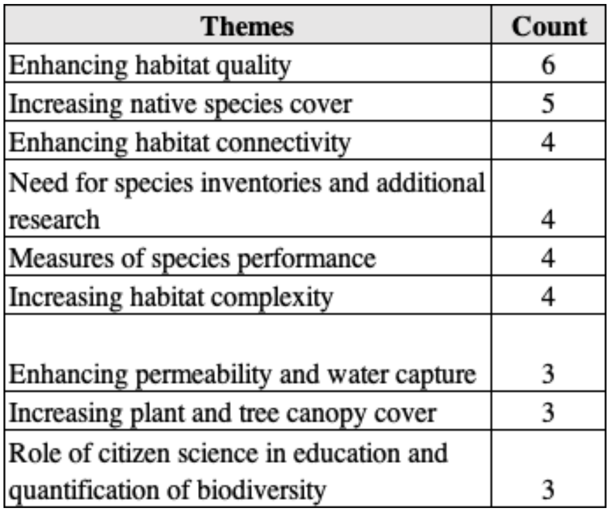
For surveys that involved ranking or scoring, I used hierarchical cluster dendrograms to identify clusters, whether goals, objectives, or experts, that were closely grouped or distant based on Ward's linkage. Ward's linkage minimizes the distance in sum of squares between clusters (Milligan & Cooper, 1988). I also used a one-way ANOVA to identify goals or objectives that received significantly lower scores from experts and boxplots to visualize the average and spread of scores or ranks. Both strategies were used to understand groupings and to support the removal of a goal or objective.

In the final categorization survey, categories were converted to numerical values so that "important and achievable" received the highest point value of 5, "important and sometimes achievable" a 4, "important but not easily measured" a 3, "important but not easily achievable" a 2, and "unimportant" a score of 1. These converted numerical values were used in determining the Kendall's W value of concordance. Based on the categories associated with each numerical value, average assigned scores above 4.6 were considered objectives that were important and well supported by experts, scores between 4.1-4.5 were important and considered moderately supported, scores between 3.6-4.0 were considered plausible for some projects but not widely supported, and any objective with a score less than 3.6 was considered poorly supported and proposed for removal.

4.3 Results

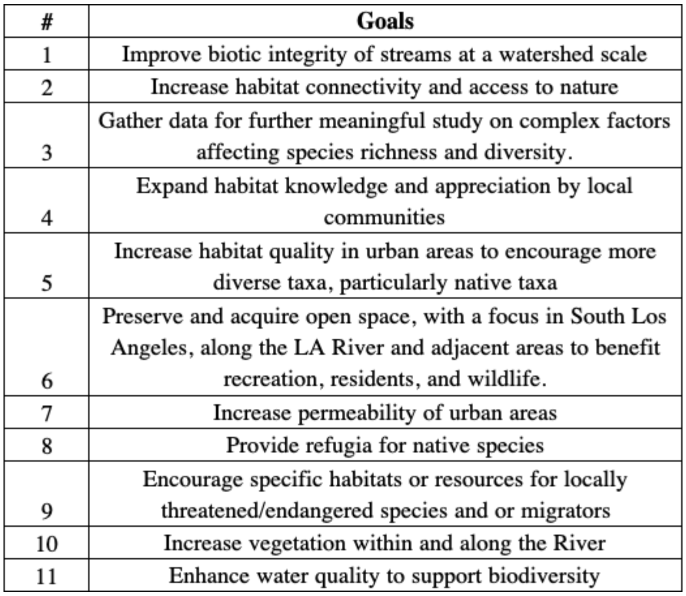
The Delphi approach is an iterative survey approach that, in this research, facilitated building consensus over the goals and objectives that apply to green infrastructure projects over several rounds. The first survey asked experts, "what goals and objectives should we have for habitat/biodiversity when developing green infrastructure projects?" The most popular of themes that emerged from the first brainstorming survey focused on habitat quality and increasing native plant species cover (Table 21). Experts suggested a total of 11 goals (Table 22), each with 2 to 9 associated objectives. Experts responses ranged from goals and objectives that strictly focused on the physical conditions that supported species, practical concerns about the feasibility of hosting biodiversity in urban spaces or measuring it, the practical and socioecological aspects of biodiversity, and the role of citizen scientists in supporting data collection. These themes continued to emerge and be a prominent point of discussion in subsequent survey rounds

Table 21 Most common themes across expert responses, based on counts of keywords and phrases, following the brainstorm survey.



Themes	Count
Enhancing habitat quality	6
Increasing native species cover	5
Enhancing habitat connectivity	4
Need for species inventories and additional research	4
Measures of species performance	4
Increasing habitat complexity	4
Enhancing permeability and water capture	3
Increasing plant and tree canopy cover	3
Role of citizen science in education and quantification of biodiversity	3

Table 22. Habitat goals identified by experts during brainstorming survey and ranked in the second survey round.



#	Goals
1	Improve biotic integrity of streams at a watershed scale
2	Increase habitat connectivity and access to nature
3	Gather data for further meaningful study on complex factors affecting species richness and diversity.
4	Expand habitat knowledge and appreciation by local communities
5	Increase habitat quality in urban areas to encourage more diverse taxa, particularly native taxa
6	Preserve and acquire open space, with a focus in South Los Angeles, along the LA River and adjacent areas to benefit recreation, residents, and wildlife.
7	Increase permeability of urban areas
8	Provide refugia for native species
9	Encourage specific habitats or resources for locally threatened/endangered species and or migrators
10	Increase vegetation within and along the River
11	Enhance water quality to support biodiversity

The second surveys focused on refining the lists of goals through a ranking exercise (a rank of one denotes that the goal was the most important). Goals with the highest average rank were “improving habitat quality” and “preserving and acquiring open space” (Figure 14). The goals that were deemed less important based on rank, in decreasing order, were “enhancing habitat knowledge”, “enhancing water quality”, and “data gathering”. Using an ANOVA, I determined that there were no significant differences between goal ranks, with the exception of habitat quality, which was highly ranked, and data gathering ($p=0.05$). Overall, expert rankings did not differ significantly from random and there was poor agreement (a Kendall's W of 1 denotes perfect agreement and 0 denotes no agreement) between experts (Kendall's $W = 0.14$, $p = 0.19$). Using a hierarchical cluster analysis (Figure 15), I found that there was no single goal that was very dissimilar, based on Ward's distance. Instead there were two distinct groupings of which open space and data gathering were distinct from creating refugia, improving habitat quality, and creating habitat for threatened and endangered species. Since the goal of gathering more data was ranked significantly more poorly than the habitat quality goal and because experts pointed out that data gathering was an underlying objective driving all goals, it was removed.

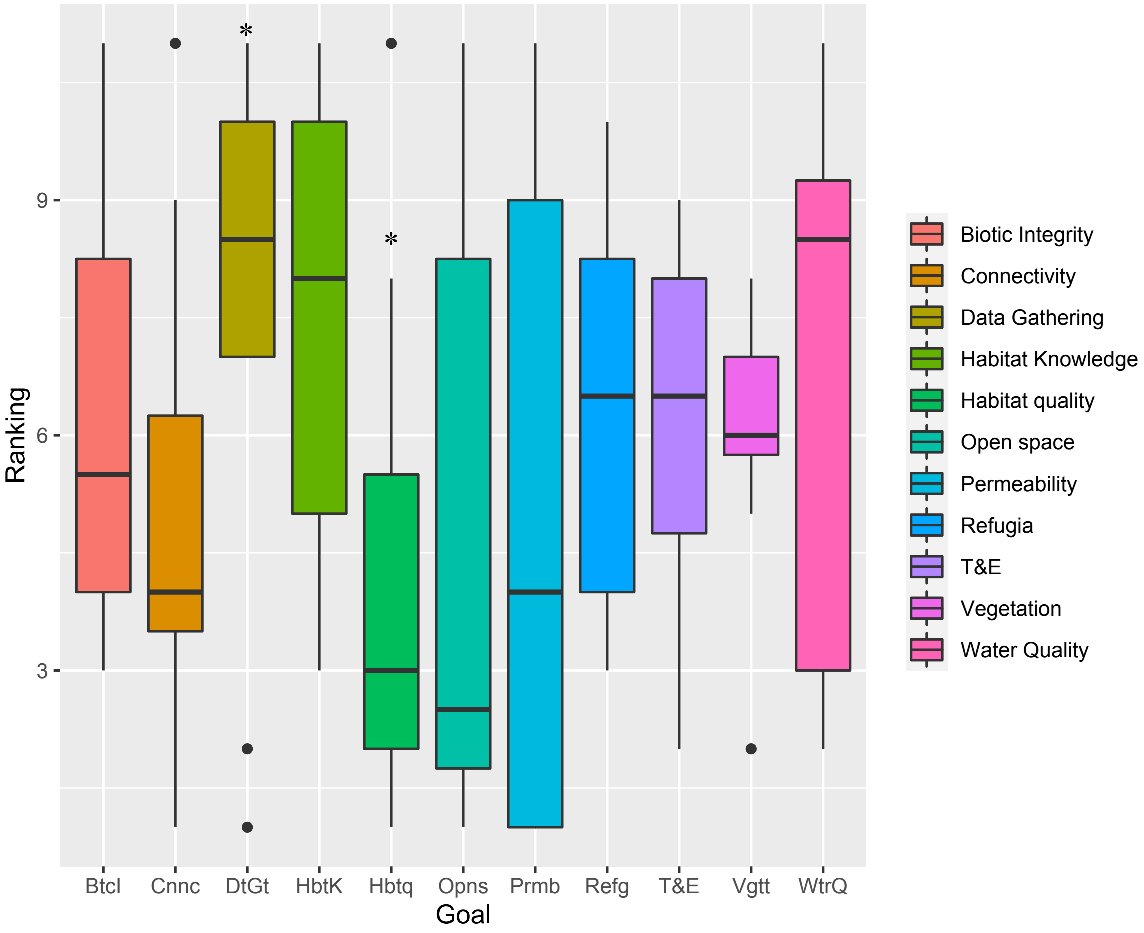


Figure 14 Box plot of survey two rankings for each goal. Note that goals with a lower numerical value are more important than goals with a higher numerical value (i.e. a goal ranked as 1 was deemed the most important). Stars denote significant differences in expert rankings. Goals were shortened for readability and are fully described in Table 22.

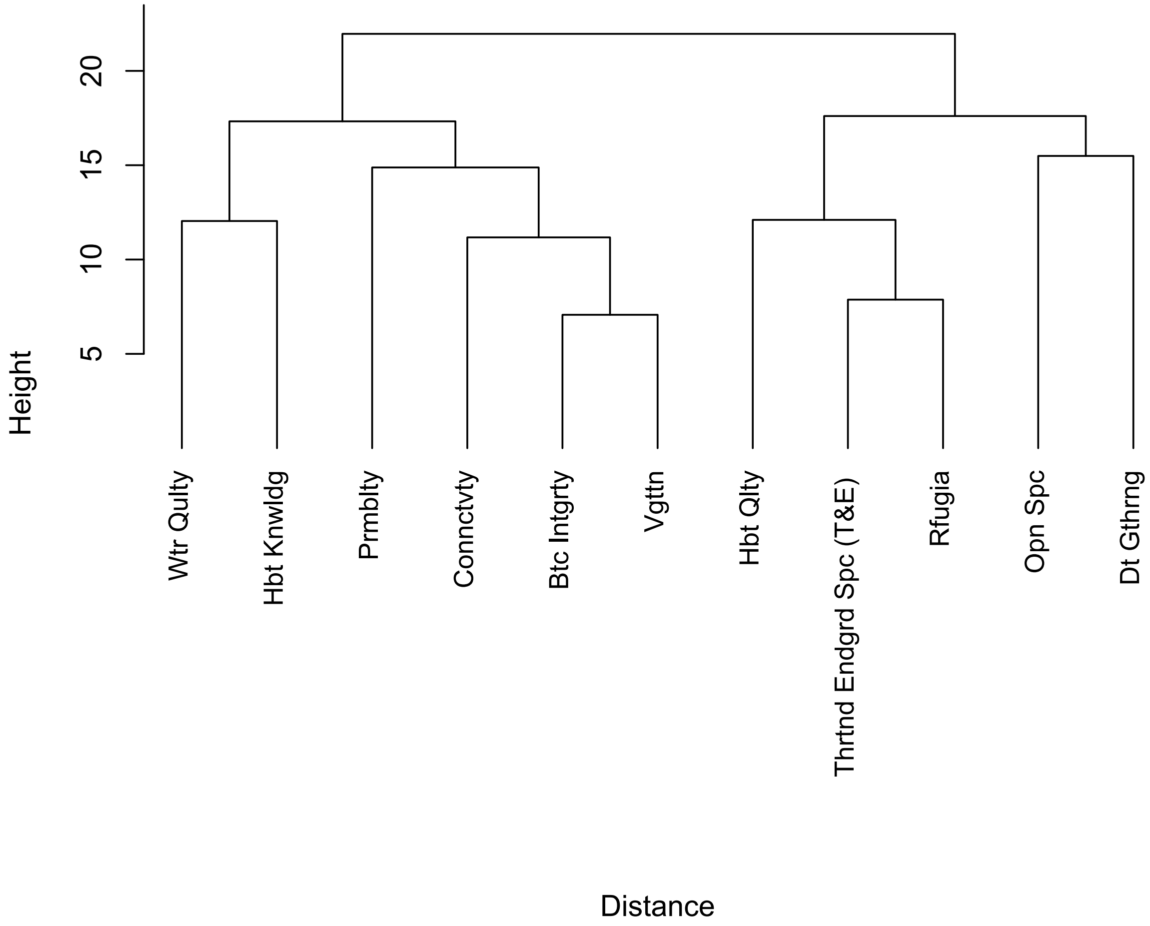
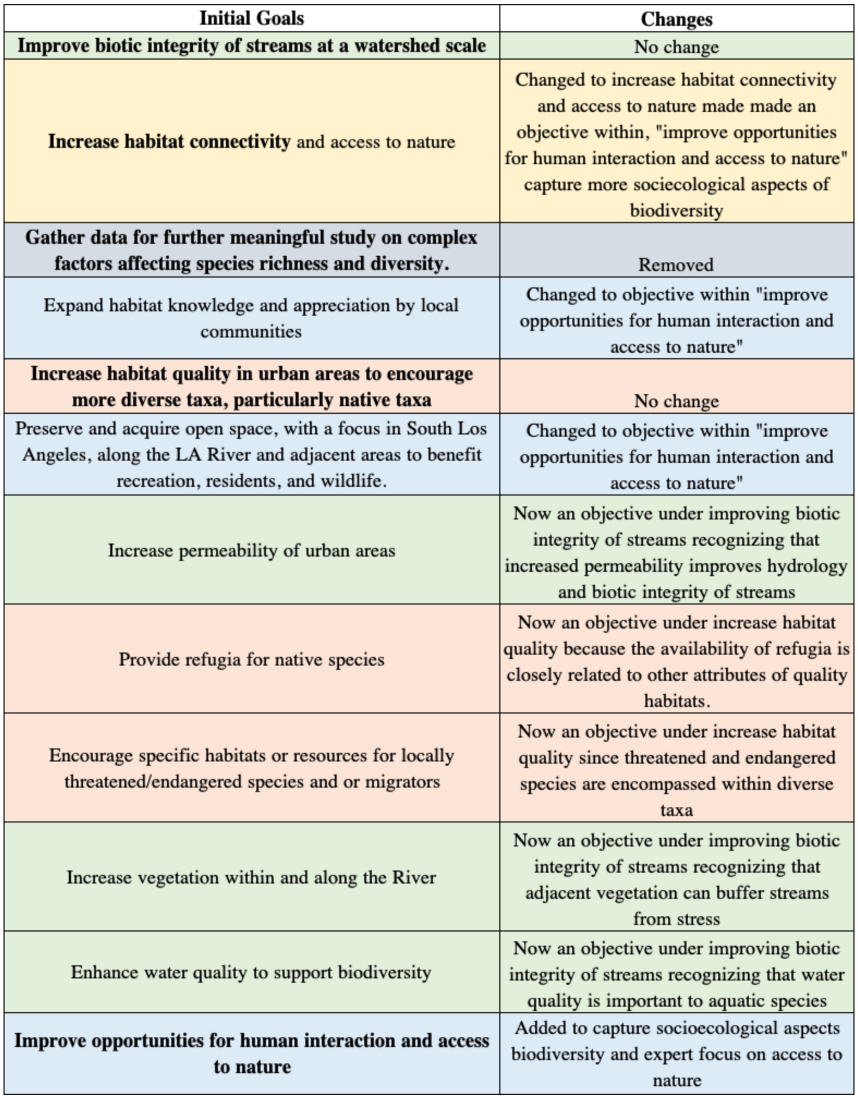


Figure 15 Dendrogram of the hierarchical cluster analysis using Ward's method, based on reducing within group sum of squares, for goals ranked in the second survey.

Table 23. Summary of changes to goals following input from experts in the second survey round.



Initial Goals	Changes
Improve biotic integrity of streams at a watershed scale	No change
Increase habitat connectivity and access to nature	Changed to increase habitat connectivity and access to nature made made an objective within, "improve opportunities for human interaction and access to nature" capture more sociecological aspects of biodiversity
Gather data for further meaningful study on complex factors affecting species richness and diversity.	Removed
Expand habitat knowledge and appreciation by local communities	Changed to objective within "improve opportunities for human interaction and access to nature"
Increase habitat quality in urban areas to encourage more diverse taxa, particularly native taxa	No change
Preserve and acquire open space, with a focus in South Los Angeles, along the LA River and adjacent areas to benefit recreation, residents, and wildlife.	Changed to objective within "improve opportunities for human interaction and access to nature"
Increase permeability of urban areas	Now an objective under improving biotic integrity of streams recognizing that increased permeability improves hydrology and biotic integrity of streams
Provide refugia for native species	Now an objective under increase habitat quality because the availability of refugia is closely related to other attributes of quality habitats.
Encourage specific habitats or resources for locally threatened/endangered species and or migrators	Now an objective under increase habitat quality since threatened and endangered species are encompassed within diverse taxa
Increase vegetation within and along the River	Now an objective under improving biotic integrity of streams recognizing that adjacent vegetation can buffer streams from stress
Enhance water quality to support biodiversity	Now an objective under improving biotic integrity of streams recognizing that water quality is important to aquatic species
Improve opportunities for human interaction and access to nature	Added to capture socioecological aspects biodiversity and expert focus on access to nature

The third survey was used to further refine and finalize a list of goals that had undergone considerable reorganizing based on expert input from the previous survey round (Table 23). Despite experts having to read the rationale of other experts immediately prior to point assignment, agreement among experts on scoring did not significantly differ from random and Kendall’s W values were similar to those from the previous survey round (Kendall’s W = 0.16, p

= 0.19). An additional round of surveying and the opportunity to share additional rationale for remaining goals did not improve agreement among experts. Hierarchical cluster analysis identified habitat quality as the goal with scores that were the most dissimilar to other scored goals, this goal had the highest average score at the end of the survey round but also a large range in assigned scores (Figure 16; Figure 17). Human connection, another goal with a large range in expert scores, had a nearly significantly lower score than habitat quality (p=0.09; Figure 17). Given that there was not strong support for removing any additional goals, querying of goals concluded after the third survey. The final set of biodiversity goals are broadly focused on the physical features or attributes that better host biodiversity, capture the humans elements of biodiversity, and the integrated aspect of ecosystems health that sustain functional biotic communities. The goals were largely unchanged between survey rounds, as only the goal of collecting additional data was dropped, but instead the most substantial changes resulted from the reorganization of goals.

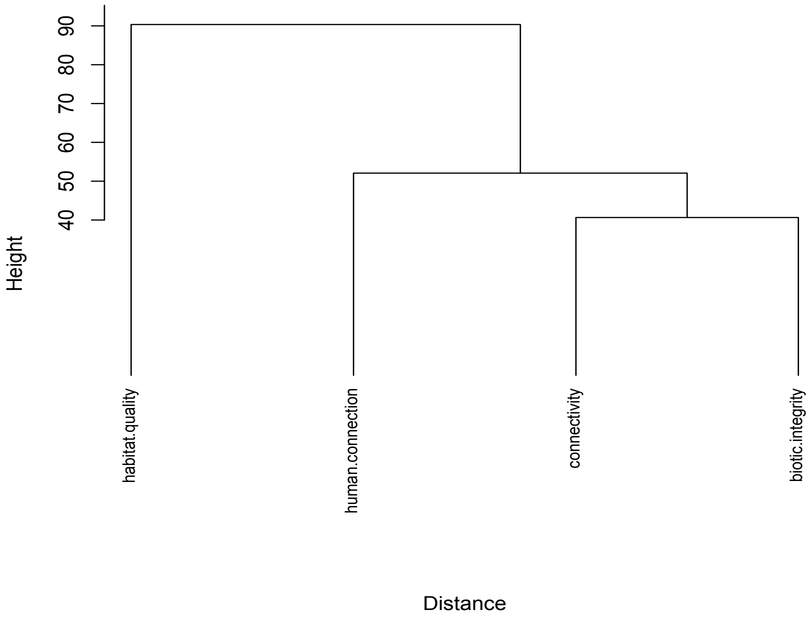


Figure 17 Hierarchical cluster analysis dendogram of the goals surveyed during the third survey round. Clustering method is based on Ward's distance.

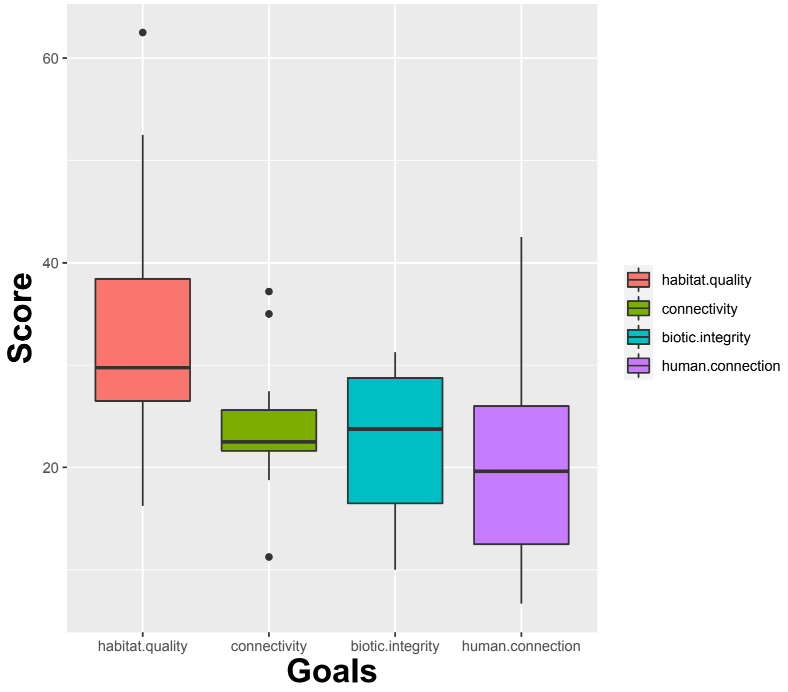


Figure 16 Box plot of expert scores for green infrastructure goal from survey 3. Higher scores denote a higher importance.

To better understand similarities and dissimilarities between experts that might reveal whether a subset of experts were driving a lack of agreement, I did hierarchical clustering for participants (Figure 18). Participants were categorized by expertise including aquatic ecology (AE), urban ecology (UE), conservation biology (CB), specialized biology (SB, used for experts that specialized in specific species), landscape architecture (LA), and planner (P). The HCA showed that experts with similar expertise did not necessarily score goals similarly. Additionally, several experts had scores that were similar to each other but distinct from those of other participants (P2, SB1, and CB2). This clustering suggests that differences in scoring during the goal setting exercise are not necessarily grounded in expertise and that no single expert, but instead a small and diverse subset, are responsible for the lack of concordance in the final round of goal surveying. Rationale that experts offered, albeit submitting a rationale was not required in the third survey and was often terse (e.g. “timeliness and feasibility”), for scoring provides some insight for the lack of concordance and is summarized in (Table 24). The stated reasons for goal ranks could be largely categorized into feasibility of measurement (e.g. whether connectivity can be measured at the project scale), relevance, and likelihood of success, which was the most frequently cited reason for a low score.

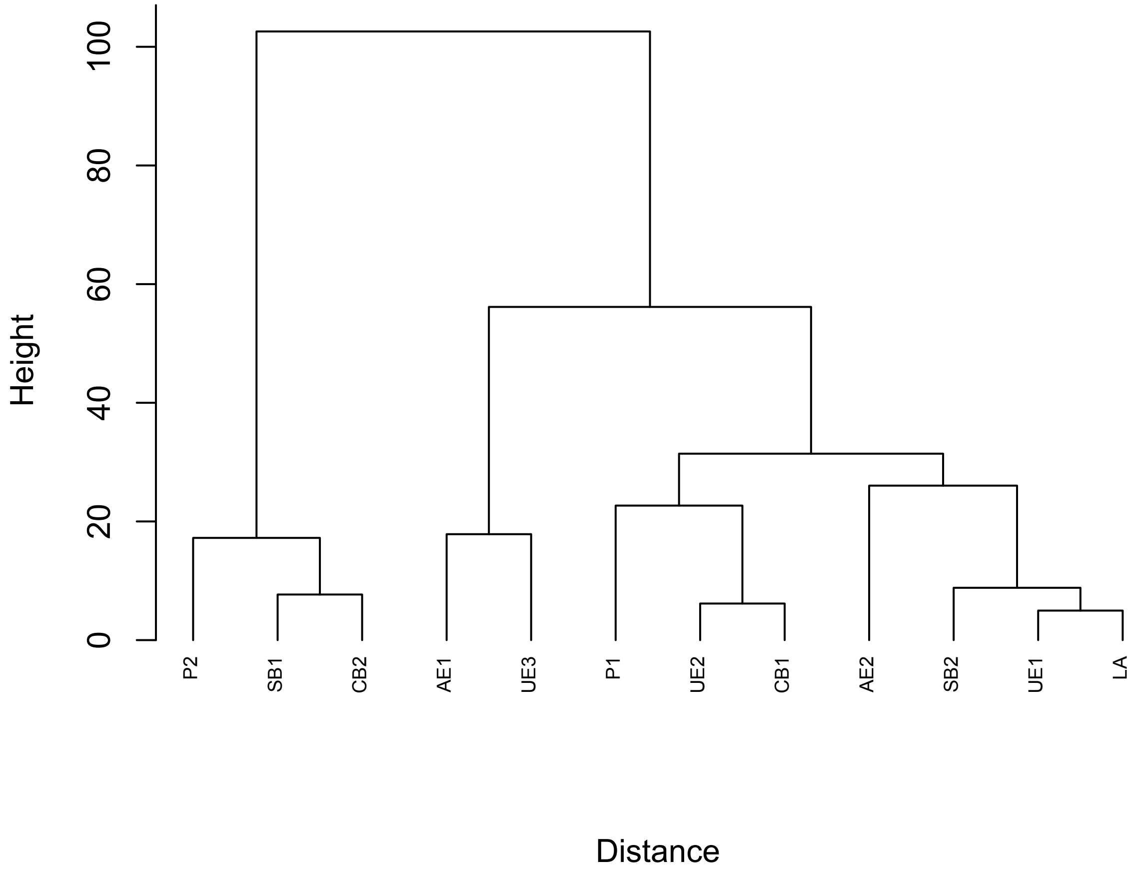
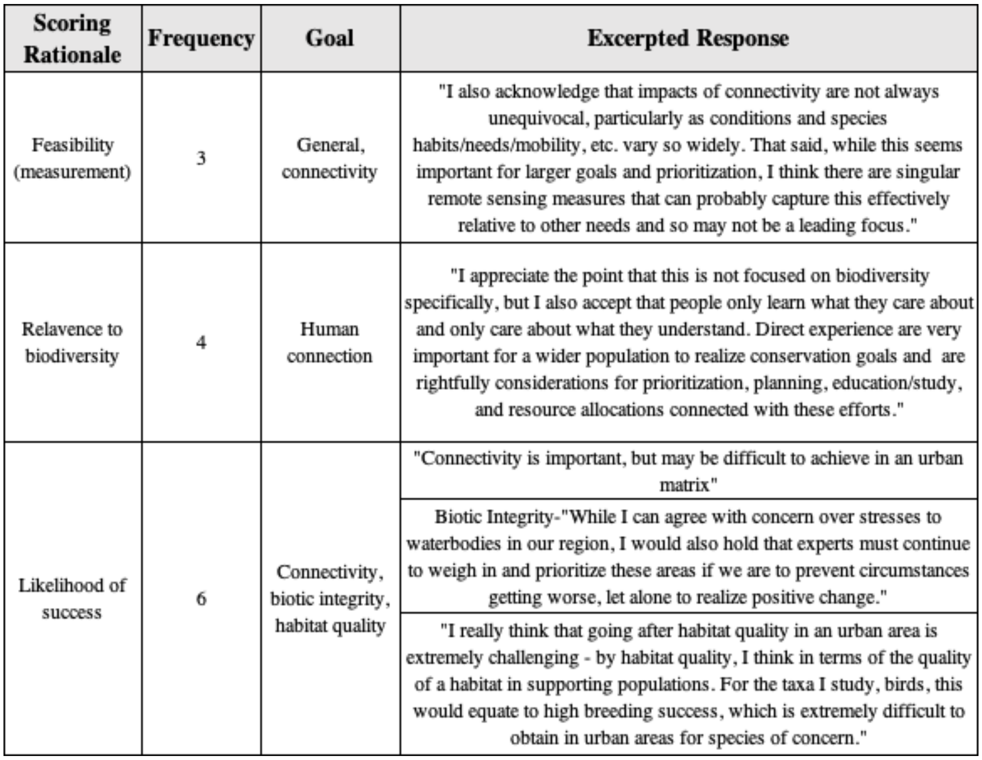


Figure 18 Dendrogram of hierarchical clustering of expert scores following third survey. Experts are identified by their expertise and they include planner (P), specialist biologist (SB), conservation biologist (SB), aquatic ecologist (AE), urban ecologist (UE), planner (P), and landscape architect (LA). Clusters are based on Ward's distance.

Table 24 Category of rationale for goal ranking provided by experts, frequency by which this rationale appeared in expert responses, along with an excerpted rationale from the third survey.



Scoring Rationale	Frequency	Goal	Excerpted Response
Feasibility (measurement)	3	General, connectivity	"I also acknowledge that impacts of connectivity are not always unequivocal, particularly as conditions and species habits/needs/mobility, etc. vary so widely. That said, while this seems important for larger goals and prioritization, I think there are singular remote sensing measures that can probably capture this effectively relative to other needs and so may not be a leading focus."
Relavence to biodiversity	4	Human connection	"I appreciate the point that this is not focused on biodiversity specifically, but I also accept that people only learn what they care about and only care about what they understand. Direct experience are very important for a wider population to realize conservation goals and are rightfully considerations for prioritization, planning, education/study, and resource allocations connected with these efforts."
Likelihood of success	6	Connectivity, biotic integrity, habitat quality	"Connectivity is important, but may be difficult to achieve in an urban matrix"
			Biotic Integrity-"While I can agree with concern over stresses to waterbodies in our region, I would also hold that experts must continue to weigh in and prioritize these areas if we are to prevent circumstances getting worse, let alone to realize positive change."
			"I really think that going after habitat quality in an urban area is extremely challenging - by habitat quality, I think in terms of the quality of a habitat in supporting populations. For the taxa I study, birds, this would equate to high breeding success, which is extremely difficult to obtain in urban areas for species of concern."

Finally, in the concluding survey I asked experts to categorize each objective that had been submitted during the initial brainstorm survey into one of five categories, objectives and categories are described in Table 25. The participation from experts in the final survey was 33% lower than in previous surveys but the final survey was also the longest survey with a total of 46 questions, 23 of which required a response. Of the objectives that were submitted by experts, the most strongly supported included increasing the permeability of urban areas and tree canopy cover followed by training and educating workers in maintenance, and expanding educational knowledge of biodiversity. Connectivity objectives were combined after one expert noted the need for simplicity and overlap. Generally, agreement among a diverse set of experts across all survey rounds had poor agreement despite survey and summary documents highlighting rationale each expert made for or against the inclusion of specific goals or objectives. The categorization of objectives was no exception. Despite categories that already captured themes in expert objections to previously surveyed goals, that is feasibility, likelihood of success, and relevance, the categorization of objectives across all experts did not significantly differ from random and agreement between experts was very low (Kendall's W = 0.10, p = 0.42). Except for a single expert ranking one objective as unimportant, all experts agreed that all surveyed objectives are important. However, categorization that does not differ from random suggest that experts disagree about feasibility, likelihood of success, and the relevance of several objectives.

Table 25 Categorization of green infrastructure objectives. Categories were converted to numerical values (important and achievable =5 and unimportant = 1). The average score was used as the basis for categorizing the importance of objectives and that breakdown is as follows: objectives with scores ≥ 4.6 are important and well supported; $4.5 \geq x \geq 4.1$ are moderately important and supported; $4.0 \geq x \geq 3.6$ are plausible for some projects but not widely supported; scores <3.6 are proposed for removal.

Goals	Objectives	Important and achievable	Important and sometimes achieavable	Important but not practically measured	Important but not achievable with GI	Unimportant	Average	SD
Improve biotic integrity of streams	Increase permeability of urban areas so as to increase infiltration and reduce runoff	75%	13%	13%	0%	0%	4.6	0.7
	Increase vegetation within and along local streams	50%	38%	13%	0%	0%	4.4	0.7
	Enhance water quality	63%	13%	25%	0%	0%	4.4	0.9
	Improve physical condition of streams	38%	25%	38%	0%	0%	4.0	0.9
	Provide suitable habitat for cold water species	38%	50%	13%	0%	0%	4.3	0.7
Improve habitat quality	Increase native plant cover	63%	25%	0%	0%	13%	4.3	1.4
	Enhance habitat complexity	38%	25%	25%	13%	0%	3.9	1.1
	Increase plant species diversity	63%	25%	13%	0%	0%	4.5	0.8
	Increase tree canopy cover	75%	25%	0%	0%	0%	4.8	0.5
	Support ecosystem functions	50%	0%	50%	0%	0%	4.0	1.1
	Increase area of high quality, native habitat	50%	13%	13%	25%	0%	3.9	1.4
	Provide refugia for native species	50%	25%	25%	0%	0%	4.3	0.9
	Support regional meta-populations to maintain genetic diversity	13%	13%	75%	0%	0%	3.4	0.7
	Ensure habitat is sustainable through inter-annual climate cycles	25%	25%	38%	13%	0%	3.6	1.1
	Minimize opportunities for invasive species to propagate	25%	13%	0%	50%	0%	3.1	1.4
	Create habitats for threatened and endangered species	38%	25%	13%	25%	0%	3.8	1.3
	Train and educate workers in maintenance	63%	38%	0%	0%	0%	4.6	0.5
	Asses and support reproduction and establishment of native or desired species in green infrastructure areas	38%	25%	38%	0%	0%	4.0	0.9
Increase habitat connectivity	Increase connectivity and permeability between areas of high quality habitat using green infrastructure as stepping stones	38%	25%	38%	0%	0%	4.0	0.9
	Create connectivity between green infrastructure projects	38%	63%	0%	0%	0%	4.4	0.5
Enhance access, cultural benefits of and connection to green space	Expand educational knowledge	63%	38%	0%	0%	0%	4.6	0.5
	Improve access to nature by restoring empty lots, preserving and acquiring open soace	38%	50%	0%	13%	0%	4.1	1.0
	Support locan citizen science and research	63%	13%	25%	0%	0%	4.4	0.9

4.4 Discussion

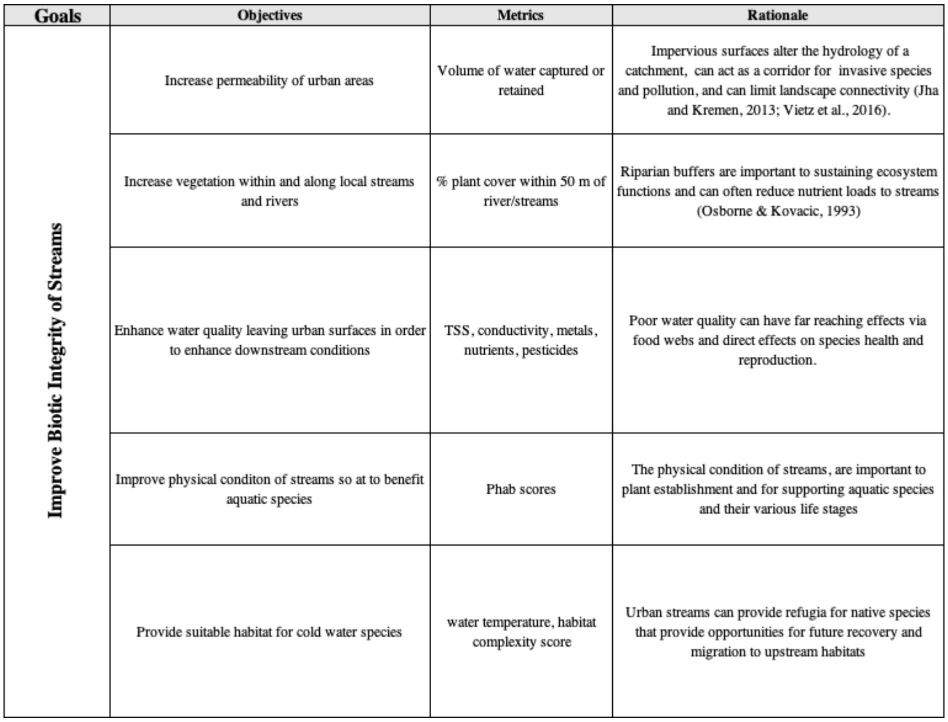
4.4.1 The Delphi Process for Identifying Goals and Objectives for Green Infrastructure

The Delphi approach supported expert identification of a set of biodiversity focused goals and objectives for green infrastructure that largely align with academic literature and previous frameworks for understanding biodiversity change. The outcomes are a first step toward better measuring the habitat value of projects that are being implemented across the region to mitigate ongoing drought. However, the outcomes are imperfect given the desire to include the diverse perspectives of experts that may be limited in the breadth of ecological expertise or in familiarity with the practical challenges of incorporating biodiversity into design goals as well as city and agency practices. This diversity of expertise did not make the goals and objectives any less rigorous, all are supported by academic literature, but instead, may have prolonged initial Delphi survey rounds as experts established a common vocabulary or made the case for more applied aspects of biodiversity. The diversity of experts however brought thoughtful discussions about cost, expertise, equity, and feasibility to the forefront of the goal and objective selection process, instead of being an afterthought. This is a unique aspect of this framework, the goals are sensitive to the resources that practitioners have available and suggested tools are resources were highlighted in rationale. In fact, the feasibility of measurements, to a lesser extent, and the probability of success were major concerns for experts in ranking and scoring. However, participation of unpaid experts did take a toll on the process, as many invited experts noted they needed compensation to participate and there was considerable drop-off on the final round of the survey. While the Delphi process is supposed to facilitate group consensus, there was no consensus, as measured by Kendall’s W, in any of the four survey rounds. The reason is unknown, in that there was no single expert or expertise driving non-consensus and may have been a byproduct of the terse rationale many of the unpaid experts provided. Based on the final categorization exercise, there seemed to be fundamental disagreements about feasibility and the probabilities of success and not necessarily about the importance of a particular objective to the goal of enhancing biodiversity. This may be based on a technical versus applied backgrounds of experts, lived success with green infrastructure projects, and familiarity with existing resources and partnerships that may facilitate measurement. Additionally, nuanced discussions about whether certain goals or objectives were achievable within certain landscape versus others (e.g. connectivity in highly urban areas, increased native vegetation along rivers and streams in land restricted locales that are highly altered) may have created entrenched disagreement as to whether a particular goal or objective could be "globally" achieved and was thus worth keeping.

4.4.2 A Review of the Outcome from the Delphi: Goals and Objectives for Green Infrastructure

The list of goals, objectives, and suggested metrics are presented below in Table 26. I will review the selected goals, a sub-set of objectives, and provide context for selection based on expert rationale and supporting literature.

Table 26 Biodiversity framework for green infrastructure projects organized by broad goals, specific objectives, and potential metrics.



Goals	Objectives	Metrics	Rationale
Improve Biotic Integrity of Streams	Increase permeability of urban areas	Volume of water captured or retained	Impervious surfaces alter the hydrology of a catchment, can act as a corridor for invasive species and pollution, and can limit landscape connectivity (Jha and Kremen, 2013; Vietz et al., 2016).
	Increase vegetation within and along local streams and rivers	% plant cover within 50 m of river/streams	Riparian buffers are important to sustaining ecosystem functions and can often reduce nutrient loads to streams (Osborne & Kovacic, 1993)
	Enhance water quality leaving urban surfaces in order to enhance downstream conditions	TSS, conductivity, metals, nutrients, pesticides	Poor water quality can have far reaching effects via food webs and direct effects on species health and reproduction.
	Improve physical conditon of streams so at to benefit aquatic species	Phab scores	The physical condition of streams, are important to plant establishment and for supporting aquatic species and their various life stages
	Provide suitable habitat for cold water species	water temperature, habitat complexity score	Urban streams can provide refugia for native species that provide opportunities for future recovery and migration to upstream habitats

Improve habitat quality	Improve quality of habitat for native taxa through native plant selection	Native plant cover	Native animal species are likely to use the resources of native plants. Native species are also extremely important for educating the general public about their benefits and provide a sense of place.
	Enhance habitat complexity and provide variable vegetative structure	Vegetative layer count	Habitat complexity has been identified as an important driver of biodiversity in many urban ecology studies. Habitat complexity is necessary for diverse flora and fauna.
	Plant diverse species, particularly climate adapted plants, to increase species and functional diversity	Growth form richness (trees, shrubs, sedges, rushes, grasses, herbs).	High diversity of traits leads to more effective use of available niches and resources, indicating improved ecosystem functioning(Hooper et al., 2005; Rao, 1982). High diversity of species also increases ecosystem resilience (Naeem et al., 1994; Tilman 1994; Tilman, 1996).
	Increase tree canopy cover to benefit urban wildlife and people	%increase in tree canopy	Increasing tree canopies has been shown to reduce local area temperatures. This will benefit people and wildlife and protect vulnerable communities from urban heat.
	Support ecosystem functions, particularly those that sequester or degrade contaminants and support healthy trophic structures	Tea bag index	A wide range of beneficial uses in the river and in downstream areas will benefit by reduced nutrient and contaminant levels often associated with healthy natural habitats
	Increase area of high quality, native habitat	Project area with 80% native species cover.	Larger patch sizes provide more benefits to the flora and fauna that reside within them. Smaller patches are subject to "edge effects".
	Provide refugia for native species	Habitat complexity checklist	Juveniles often require places to hide from predators during migrations and/or to grow prior to migration to their adult habitats. Sufficient refuge areas will support this function.
	Support regional metapopulations to maintain genetic diversity	Presence of native species that co-occur in adjacent watersheds	Many native S CA species exist as metapopulations in adjacent watersheds. Cross-breeding with nearby populations helps maintain genetic diversity and resiliency in the population
	Ensure habitat is sustainable through interannual climate cycles	Plant diversity	Resilience in ecosystems is related to species heterogeneity and habitat complexity (Estevo et al., 2017). Native species have specific tolerances for physical conditions that allow them to persist across naturally variable conditions
	Minimize opportunities for invasive species to propogate	% invasive plant cover	Invasive species often outcompete native species. Reducing suitable habitat for invasives will promote persistence of native species.
	Encourage specific habitats or resources for migrators and locally threatened or endangered species	Presence of habitat features important to T and E species	For many T&E species habitat loss is the main driver of species loss. Basic habitat across taxa is comprised of required resources - food, resting, and places to reproduce.
	Train and educate workers in maintenance	Hours of training	Many of the objectives related to habitat complexity will be challenged by existing maintenance practices and aesthetic preferences. Need training and education about the value of "messy" landscapes as refugia and food sources.
	Asses and support reproduction and establish of native or desired species in green infrastructure areas	Count of species (christae/juveniles) establishment at green infrastructure areas, native plant cover	Recruitment is a sign of healthy resilient communities that can sustain themselves over time. It also indicates that suitable processes are in place to support multiple life stages.

Goals	Objectives	Metrics	Rationale
Increase habitat connectivity	Increase connectivity and permeability between areas of high habitat quality using green infrastructure as stepping stones	Presence of habitat with connectivity potential	Large and connected areas of high habitat quality are important for supporting species. Connectivity allows species to move away from unfavorable conditions, connect isolated habitats, increase gene flow, and buffer populations from extinction (Bilton et al., 2001; Epps et al., 2005; Mech and Hallett, 2001; Taylor et al., 1993).
	Endeavor to create connectivity between green infrastructure projects (by their proximity to each other) to allow resilience for species living there, population growth, and greater likelihood of population establishment	% species shared between projects,	Connectivity between green infrastructure projects (by their proximity to each other) is essential for healthy and genetically diverse populations.
Enhance access, cultural benefits of and connection to biodiversity	Expand educational access and appreciation of native habitats to local communities	Number of visitation by local communities, presence of signage	Exposure to local biodiversity can reconnect communities to the local ecology and enhance stewardship and support for the conservation actions that sustain local and regional biodiversity (Cilliers, 2010; Coldwell and Evans, 2017).
	Improve access to nature by restoring empty lots, preserving and acquiring open space, and vegetating municipally owned facilities/parcels.	# people within 1/2 mile radius of a project	The LA region is notoriously underserved by parks and natural open spaces. Natural habitats enhance these opportunities and promote more awareness and stewardship
	Support local citizen science and research	Number of science projects by local community groups and schools	Local communities and youth understand and support habitat protection and management only through interaction and knowledge, which will be increased by promoting citizen and youth science projects/investigations.

4.4.2.1 Biotic Integrity of Streams

Improving the condition of streams, from the peri urban to highly urban, is one of the motivating goal for green infrastructure projects (Walsh et al., 2005; Yang & Li, 2013). As experts noted when discussing feasibility of this goal, measurement associated with biotic integrity benefit from water quality monitoring requirements for state funded green infrastructure projects, a comprehensive regional stream monitoring program that has established methods and already collects many of the identified metrics, and from the ongoing development of a regional monitoring network for BMPs (CNRA, 2019; SCCWRP, n.d., 2021). Numerous studies support the objectives captured within this goal although the success may, to some extent, be dependent on the context and scale. Objectives that were widely supported and poorly supported within this goal are reviewed below along with the rationale in expert scoring or categorization.

The goal of increasing permeability was one of the few objectives categorized, on average, as important and achievable. It is well known that urban rivers have highly altered hydrographs, due to impermeable surfaces, that impact riverine ecology (Vietz et al., 2016). Studies have shown that carefully designed and integrated green infrastructure that increase infiltration can reduce stream flows, particularly in small catchments (Burns et al., 2012; Cockerill et al., 2017; Mika et al., 2017; Vietz et al., 2014). However, as many experts noted, the most urbanized of watersheds will be challenged with fully ameliorating hydromodification without substantive changes, particularly due to limited floodplain space and reduced sediment supplies that exacerbate erosion downstream of dams and basins (Tillinghast et al., 2012; Vietz et al., 2014, 2016). Success will depend on the surrounding landscape, existing site conditions (e.g. geomorphology), and the combined impact of green infrastructure projects across a catchment. However, as Booth (2005) asserted, incremental improvements can have some impact and there is a need to not renunciate the possibility that urban streams will someday benefit from long-term, catchment wide action. One expert similarly noted, "while I can agree with concern over [the numerous and seemingly intractable] stresses to waterbodies in our region, I would also hold that experts must continue to weigh in and prioritize these areas if we are to prevent circumstances from getting worse, let alone to realize positive change." Wide agreement with this rationale, which was provided prior to the final survey, may have motivated wide-ranging support for this objective. However, some experts still expressed concerns over the feasibility and technical nature of measurements that capture permeability and reduced flows. As a result, the annual runoff captured or diverted, for example, was selected as a suggested metric. This measurement is commonly estimated in initial project design. However, while known for the majority of projects, this information is not yet widely reported or publicly available via existing databases.

The only objective experts scored as achievable under certain conditions was improving the physical conditions of streams. This was a curious result given more wide ranging support for the "providing suitable habitat for cold water species" objective, which would in some instances require the same design or management interventions. The support for providing suitable habitat for cold water species is not surprising given that stressors that degrade biotic integrity similarly impact cold water species habitat, these include hydromodification, particularly sedimentation, habitat degradation, and dams and other obstacles to movement (Kocher et al., 2008). Interestingly, several physical habitat attributes also enhance and create habitat for cold water species, such as the presence of plunge pools, riffle-pool sequences, course wooded debris, boulders, overhangs, root wads, backwater pools, overhanging and nearby vegetation, tree canopy, and, in more managed settings, deflectors, weirs, and cover structures (Kocher et al., 2008; Whiteway et al., 2010). Another expert noted the inter-related nature of this objectives with increasing vegetation, "This has direct overlap with the more simple objective to increase vegetation. Increasing vegetation would necessarily include many of the elements in this objective, and would be simpler to evaluate. That said, on a site-scale, designing for specific elements and having a reference for experts and lay people to implement would be a great tool that could also be improved over time." Given the diversity of fields that participated, it is not surprising that non-aquatic ecologist either did not recognize these objectives as being closely related or recognized that this objective could be more simply captured by other metrics and objectives. Additionally, a definition of physical condition, or the specific physical attributes was not explicit. The need to conclude the Delphi in four rounds meant that experts were not able to share and question the rationale of other experts or establish a shared definition for terms. While the need to keep each survey concise and short to maximize participation meant that I elected for rationale to be optional and thus the insight about how widespread this reasoning is unknown.

4.4.2.2 Habitat Quality

Improving habitat quality was a consistently a top ranked goal and the thirteen associated objectives capture the broad needs of species. While this goal was popular, there was doubt among experts about whether creating high quality habitat within urban areas was plausible, particularly for specific species. Objectives that would require large scale, coordinated and integrated action to ensure success (e.g. eradication of invasive species, supporting regional metapopulations) or customized approaches depending on landscape context and nearby species (e.g. creating habitats for threatened and endangered species) were generally less well supported. I will review the highly supported objective, of training and educating workers in maintenance, and the objective proposed for removal, minimizing opportunities for invasive species to propagate, to provide context for expert decisions.

Maintenance practices, and the aesthetic preferences that drive them, impact biodiversity. As one expert noted, “[The habitat value of projects can depend on maintenance practices such as:] not mowing down grasses (medium or taller) or forbs in the dry season to create hiding and resting spaces, leaving seed heads for wildlife to forage, keeping dead limbs/trees around for critters to burrow into (i.e., cavity nesters) or use as perches." Gobster (1995) and others have noted that public park users have a distaste of features such as downed wood, dead material, and scattered clear cuts, and generally favor features which reduce habitat complexity, biodiversity, and increase habitat edge. Recognizing that maintenance practices, and the underlying aesthetic values that drive maintenance can impact habitat value, a subset of experts more familiar with the practical aspects of project implementation and management steadfastly discussed the need for training of city and agency staff in maintaining the habitat value of a project. This practical objective is not, to the author’s knowledge, part of existing frameworks for biodiversity. The need to balance the unkept nature of high value habitats and the aesthetic preferences for verdant spaces and clean lines is something landscape architects are attuned to. Landscape architects have found techniques to provide “cues to care” by co-designing less appreciated ecologically beneficial features with features that are more widely valued, such as open water (Gobster, 1995; Nassauer et al., 2001). As others have argued, this balancing is key because projects are unlikely to garner support or receive the maintenance projects depend on if they are not aesthetically pleasing, even if they enhance ecological value (Gobster et al., 2007). On the practicality of implementing training programs and measuring their efficacy another expert noted, “this is a critical need but how would you measure it? This does feel like another goal that would require more discrete actionable objectives to achieve, such as a standardized set of practices that are tested/measured in populations through an established and consistent training and certification program.” A certification programs for maintenance staff, particularly agency and city staff, to the authors knowledge, have not yet been conceived but there are many existing templates to scale up that can, with enough support, enhance the habitat value of publicly managed parks, green infrastructure projects, and easements (Theodore Payne Foundation, n.d.).

Invasive species are drivers of ecological change and the second leading cause of species loss (Wilcove et al., 1998). Invasive species can alter physical habitat structure and entirely shift an ecosystem's species composition, insofar as making it difficult for native species to re-establish, through their impact on fire regime (Simberloff, 1998), water chemistry, hydrology, shading, predation, biogeochemistry and competition (D'Antonio and Vitousek, 1992; Richardson et al., 2007; Simberloff, 1998; Tickner et al., n.d.). Thus the negative impacts of invasive species are well established. This objective, however, was the most poorly scored objective because half the experts believed it was important but unachievable. As experts noted, human activities (such as trade and agricultural) as well as the attenuation of natural disturbance, such as the loss of scouring flows (Scott et al., 1997), can allow for invasive species to establish, thrive, and spread. Thus the complete eradication of some invasive species may not be successful until ecosystem processes that have been impaired are restored and invasive dispersal ceases (Holmes et al., 2005). Experts noted, "I think it is nearly impossible to stop invasive plants, like *Arundo donax*, from spreading without a big investment and constant management. There may be other objectives that are more discretely achievable/measurable (e.g. protect soil; support native cover; improve permeability; prioritize large, contiguous spaces in project planning; support a cat neutering program)." However, there is an interconnectedness to objectives. For example the sustainability of urban habitat (Gordon, 1998; Heneghan et al., 2009) or increased plant species diversity may prove difficult without invasive control (Hejda et al., 2009). Thus control or eradication of invasive species is tied to other biodiversity objectives and can thus explain why invasive management is a goal of many biodiversity efforts (City of LA, 2020; EEA, 2007; UNEP/CBD/COP, 2011). However, in this effort experts have identified that the objective, as written, is not feasible in green infrastructure. Perhaps, as suggested, future iterations of this objective should instead focus on the removal of a subset of invasive species or on site or practices that promote soil health, for example. Previous authors have established frameworks for managing invasive species in urban areas so as to consider the negative effects of the species and ecosystem services provided by the species in management decisions (Gaertner et al., 2016). In California, the Invasive Species Council has developed prioritized weed lists (https://www.cal-ipc.org/plants/inventory/) that can guide practitioners in invasive management. As experts noted, success of this objective, will prove difficult without a better understanding of the effect of invasive species, tools for prioritization, widespread management and amelioration of the processes and conditions that allow invasive species to spread and thrive.

4.4.2.3 Connectivity

Connectivity of the landscape is a touchstone of many conservation efforts. The role of habitat corridors in fragmented landscapes have received much attention as a means to encourage the movement of species from unfavorable conditions, connect isolated habitats, increase gene flow, and thus buffer populations from extinction (Bilton et al., 2001; Epps et al., 2005; Mech & Hallett, 2001; P. D. Taylor et al., 1993). Their importance is particularly resonant to urban practitioners given findings that corridors do not need to provide high quality habitat to encourage movement (Haddad & Tewksbury, 2005). However, researchers have asserted the need for nuance, since the need for corridors may be species dependent, species movement does not necessarily depend on the presence of suitable vegetation, and because corridors can also allow for the movement of pests (Mann & Plummer, 1995; Resasco et al., 2014). Connectivity studies that have been completed in urban areas have found that gaps in vegetation reduce permeability and corridors are effective in supporting species movement when patch distances are short (Beninde et al., 2015; Tremblay & St. Clair, 2011; Vergnes et al., 2012).

The challenges of enhancing connectivity and the inherent difficulties in quantifying connectivity at the scale of green infrastructure, was a theme in every survey round. The majority of comments and rationale were about connectivity and the inherent challenge of incorporating such a goal. One experts noted, "achieving connectivity within the urban landscape is a planning goal rather than a performance goal and success may prove difficult depending on the surrounding landscape." Another noted, "Individual projects should not be penalized if they are located in dense, urban cores and thus unable to easily promote connectivity." Apart from discussion focused on the feasibility of promoting connectivity, particularly for small scale projects, and in the most densified of landscapes, experts also noted the difficulty of measuring connectivity. Some measurements of connectivity, particularly functional connectivity, may indeed be an impractical and technical task, requiring extensive data collection, remote sensing data to assess common physical connectivity metrics, and/or geospatial modeling (LaPoint et al., 2015; Mann & Plummer, 1995; Michels et al., 2001). Facilitating ecological traps was another concern the experts raised about green infrastructure projects and, in two occasions, a reason for ranking the goal poorly. Dispersal can certainly have cost, particularly with the use of valuable energy compromises reproductive success and when suitable habitat and stepping stones to habitat are absent (Roff, 1977). There are many examples of ecological traps and sinks in urban areas but a less refined understanding of how to avoid designing them or the mechanisms by which they occur, though there is evidence that they are more likely in highly urban and fragmented landscapes (Bates et al., 2014; Bonnington et al., 2015; Lepczyk et al., 2017;

Robertson & Hutto, 2006). Since studies of functional connectivity in the urban environment are few, so are the recommendations to inform management and planning strategies (LaPoint et al., 2015). Without management strategies, it follows that the majority of experts expressed concerns about the feasibility of enhancing habitat connectivity and permeability using green infrastructure projects. Nevertheless, support for connectivity was consistent, even after expert critiques related to feasibility.

Given the constraints of monitoring green infrastructure, I selected connectivity metrics that would instead capture the physical connectivity potential of a project based on habitat quality. This approach is an oversimplification since habitat quality will vary by species and will need to be tailored to the local area (in the most urbanized areas highly mobile, native generalist or species that deliver important ecosystem services may be the most appropriate target species). If more monitoring resources are made available for understanding connectivity in urban areas, for example, academic partners could lead data collection for resource intensive methods, such as genetic distance, practitioners could ensure species appropriate habitat types for the area are installed to enhance permeability within the urban matrix, and citizen scientists collect or confirm the species presence data than can inform fine scaled modeling (Beninde et al., 2016; Cooper et al., 2007; Fournier et al., 2017; LaPoint et al., 2015).

4.4.2.4 Enhance access, cultural benefits of and connection to biodiversity

There was consistent uncertainty among the experts about the inclusion of people focused goals and objectives in a biodiversity framework, as evidenced by low scores for people focused goals across survey rounds. However, other frameworks and researchers have acknowledged that efforts to understand and improve biodiversity of urban areas cannot ignore people since institutional, socioeconomic, and cultural factors influence valuation, preference and success of conservation projects (CNT, 2010; Grimm et al., 2008; Kinzig et al., 2005; Turpie, 2003; Tzoulas et al., 2007; UNEP/CBD/COP, 2011; van Heezik et al., 2013). This is particularly important because biodiversity has wide-ranging benefits to humans, albeit some are weakly supported, including pathogen control, and the enhancement of immune, psychological, and physiological aspects of health (Brown & Grant, 2005; Costanza & Limburg, n.d.; Lovell et al., 2014; Millenium Ecosystem Assessment, 2005; Wall et al., 2015).

After initial debate about the inclusion of a people focused biodiversity goal, the objectives related to education, access, and citizen science were overall well supported. As experts recognized and noted in their rationale, exposure to local biodiversity can reconnect communities to the local ecology and enhance support for the conservation actions. One expert noted, "I appreciate the point that this is not focused on biodiversity specifically but people only learn what they care about and only care about what they understand. Introduction and direct experience are very important for a wider population to realize conservation goals and I think are rightful considerations for prioritization, planning, education/study, and resource allocations connected with these efforts." Concerns with access to habitats and biodiversity were frequent and consistent themes of discussion, ultimately embedded within objectives, and their necessity supported by both experts and published studies (Hope et al., 2003).

Citizen science as a means to collect more cost-effective data and to engage communities about habitat was a theme of discussion across surveys, as well as the concern about data quality and sustainability of the volunteer efforts. As others have noted, there are not enough resources nor professionals to monitor important dimensions of biodiversity at needed resolutions and citizen scientists can greatly help (Chandler et al., 2017). Additionally, citizen science has a long history of supporting conservation efforts (Kobori, 2016). However, as experts noted, despite the breadth of programs and locations captured by citizen science, data is not a perfect (Chandler et al., 2017). There is, however, statistical and data processing guidance as to overcoming such challenges (Bird et al., 2014; Link & Sauer, 1999). Chandler et al. (2017) noted the characteristics of the most prolific citizen and community based monitoring programs, mainly these are programs that serve hobbyist and expert amateurs, programs linked to well-funded institutions, and programs with expert verification. However, as experts noted, the regional entities that can support and create the monitoring infrastructure necessary to support monitoring green infrastructure projects, including facilitating partnership, trainings, resources, and data processing and sharing, are largely non-existent. However, the resources and training of some regional entities with closely aligned missions may be leveraged (Natural History Museum, n.d.). Given the benefits of biodiversity, the individual decisions that support or further degrade biodiversity, and the role yards, gardens, and parks can play (Goddard et al., 2010), the inclusion of goals focused on people and objectives related to education, access, and the elevation of citizen science may support biodiversity efforts as much as goals more narrowly focused on the environmental and physical factors that enhance biodiversity.

4.4.3 Comparison to Other Biodiversity Efforts

Global and regional scale efforts to better understand biodiversity and how it is changing can guide metric development and provide a model for the infrastructure necessary to support wide scale monitoring. One such effort is the United Nation’s global treaty on the Convention on Biological Diversity (CBD). The CBD is one of the most comprehensive biodiversity frameworks and a global commitment to reduce biodiversity decline (UNEP/CBD/COP, 2011). However, an emphasis on the considerable data gaps have resulted in efforts mum to the role urban areas can have in sustaining biodiversity. The challenges of more comprehensive data collection that the CBD has encountered are relevant for many efforts and include the lack of comparability between methods, the infrastructure to support data storage, workflow development and data sharing. To facilitate data collection as part of the CBD, Biodiversity Observation Networks, have focused on capacity building to ensure the sustainability of projects, for example assessment phases that include making use of existing infrastructure and monitoring, engagement, and the development of toolkits (Navarro et al., 2017; Proença et al., 2017).

Locally, California's statewide and local efforts have acknowledged the role of urban areas in benefitting both people and species. Governor Newsom (Executive Order N-82-20, 2020) initiated California's 30 by 30 effort to preserve 30% of California lands and coastal waters by 2030. The initiative includes efforts to inventory biodiversity efforts, highlight opportunities for action, and expand indicators and tools to monitor, track, and protect biodiversity. The 30 by 30 initiative explicitly recognizes the role urban areas and multi-benefit approaches, like green infrastructure, have in enhancing biodiversity. More locally, the City of Los Angeles' Biodiversity Index and frameworks, initiated by a biodiversity motion passed by the city council (CF#15-0499), supports tracking multiple aspects of biodiversity to ensure no net loss of biodiversity and, through management and stewardship practices, improvement of biodiversity. Local efforts are in nascent stages, though the City of Los Angeles Biodiversity Index has already gathered, analyzed, and reported on biodiversity indicators.

These biodiversity frameworks and efforts, ranging from local to global, can provide an important point for metric or indicator comparison. Global efforts like the CBD, for example, have also led to the development of indicators generalizable across ecosystems (Turak et al., 2017). These indicators are known as the essential biodiversity variables (EBVs), a minimum set of state variables that capture the multiple dimensions and biodiversity and inform public, managers, and scientist on biodiversity change. They are categorized into genetic composition, species populations, species traits, community composition, ecosystem structure, and ecosystem function (Pereira et al., 2013). The comprehensive nature of EBVs provide a point of comparison to understand axis of biodiversity that are lacking and the unique constraints green infrastructure practitioners may face in quantifying biodiversity benefits. I found that, generally, the experts surveyed in this study broadly captured most EBVs but have some of the same weaknesses identified by assessments of national reports to the CBD, specifically a lack or scarcity of EBVs accounting for genetic composition and species traits (Bubb et al., 2011).

Inclusion and even discussions of a subset of essential variables within this effort were few.

Genetic diversity was explicitly mentioned in the rationale for enhancing connectivity and was captured in the objective for supporting metapopulations, an objective that was dropped due to low scores and expert rationale that noted the challenges with this scale of study. Discussions of species traits were limited to the rationale for other goals (e.g. habitat complexity) but there is no objective to capture this essential variable. This pattern is likely due to the practicality of these measurements. Most citizen science programs do not measure these dimensions of biodiversity (Chandler et al., 2017), some variables require technical expertise, and there is a cost prohibitive nature of some measures, particularly since non-water resource monitoring is largely unfunded (*Urban Orchard: Measuring the Multi-Benefits of Green Infrastructure*, 2019). However, the rapid evolution of eDNA approaches in aquatic environments, may in the least, soon provide a more cost-effective solution for inclusion of genetic diversity in biodiversity frameworks (Harrison et al., 2019).

Measures of community composition were also lacking from the metrics framework so as to capture the stabilizing effect of common species. This type of monitoring is feasible given the small parcel sizes of most urban green infrastructure projects and important given that loss of common species resulting in the diminution of ecosystem functioning (Gaston & Fuller, 2008). Meanwhile, the green infrastructure biodiversity framework explicitly capture some threats to biodiversity, such as pollution, habitat loss, climate change and invasion, but did not have goals that would explicitly mitigate impacts of habitat change, overexploitation, and climate change. This was likely limited due to the project specific focus and acknowledgement that many urban landscapes, and the biodiversity therein, have already been exposed and irreversibly shaped by these biodiversity threats.

The metric categories also capture many themes emphasized by other frameworks for sustainability, biodiversity, or human health and well-being including hydrological regulation, improvement of water quality, and enhancement of natural functioning of rivers. Frameworks with overlapping themes are summarized in Table 27. Briefly, the benefits of green infrastructure broadly align with several sustainable development goals including: “ensuring availability and sustainable management of water and sanitation”, “protect and restore water related ecosystems…”, “build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”, and “make cities and human settlements inclusive, safe, resilient and sustainable (United Nations, 2015).” While experts expressed pause in integrating human objectives into a green infrastructure biodiversity framework, objectives that focus on people have also been integrated into other biodiversity frameworks. The City of Los Angeles’ Biodiversity Index, for example, has index themes that emphasize access, education, governance and community action (City of LA, 2020). The overlap in themes between these different and distinct frameworks is encouraging in that it emphasizes the truly multi-benefit nature of green infrastructure projects and alignment of expert priorities with more well-resourced efforts The objectives that are not aligned with pre-existing efforts, such training workers in maintenance and many of the biotic integrity objectives, but whose importance is otherwise supported by the majority of experts and the academic literature speak to the unique nature of green infrastructure, regional priorities, and the unique connection of green infrastructure to many aspects of stream ecology.

Table 27 Efforts with themes or objectives that overlap with the green infrastructure biodiversity framework. The bullet points are color coordinated so that each goal, indicator, or theme of other efforts and it’s reference correspond.

Objective	Overlap	Source
Increase permeability of urban areas	• Hydrological regulation • Soil Improvements-increased permeability	•(Pakzad and Osmond, 2016). • (Ely and Pitman, 2014)
Enhance water quality leaving urban surfaces in order to enhance downstream conditions	• Hydrological regulation and water cycle modification • Aichi Target 8: Excess nutrients brought to levels that are not detrimental to ecosystem function and biodiversity • Treat water through nature based solutions that provide habitat.	•(Pakzad and Osmond, 2016) •(UNEP/CBD/COP, 2011). • Natural and Working Lands Climate Smart Strategy
Provide suitable habitat for cold water species	• Restore rivers and floodplains to facilitate natural function	• Natural and Working Lands Climate Smart Strategy
Improve quality of habitat for native taxa through native plant selection	• Assesses habitat quality of urban landscapes	• (LASAN, 2020)
Increase tree canopy cover to benefit urban wildlife and people	• Climate and microclimatic regulation through evapotranspiration, shading, and wind modification to human health • Increase and maintain urban tree canopy	• (Pazkad and Osmand, 2016). • Natural and Working Lands Climate Smart Strategy
Support ecosystem functions, particularly those that sequester or degrade contaminants and support healthy trophic structures	• Waste decomposition and nutrient cycling	• (Pazkad and Osmand, 2016) adapted from Ely and Pitman, 2014.
Minimize opportunities for invasive species to propogate	• Aichi Target 9: By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment. • Goal 1.3b Assess presence and spread of invasive species and 3.2c Assess management activities to inventory, control, and manage invasive species. • Target 15.8 to introduce measures and prevent introduction and significantly reduce the impact of alien species on land and water ecosystems and control or eradicate priority species.	• (UNEP/CBD/COP, 2011) • (LASAN, 2020) • SDG
Increase connectivity and permeability between areas of high habitat quality using green infrastructure as stepping stones	• Aichi Target 5: "The rate of habitat loss, including forests, is at least halved, and where feasible brought close to zero, and degradation and fragmentation is significantly reduced." and sub-indicaators related to habitat connectivity (UNEP/CBD/COP, 2011). • Goal 1.1d and 1.1e Assess connectivity of natural and urban landscapes	• (UNEP/CBD/COP, 2011) • (LASAN, 2020)
Endeavor to create connectivity between green infrastructure projects (by their proximity to each other) to allow resilience for species living there, population growth, and greater likelihood of population establishment		
Expand educational access and appreciation of native habitats to local communities	• Provision of outdoor sites for education and research • Aichi Target 1: "People are aware of the value of biodiversity and the steps they can take to conserve and use it sustainably. • Goal 2.2a Assesses exposure of students to biodiversity topics by looking at school curriculum, off campus visits, and campus garden areas. • Public education as a benefit of green infrastructure and best management practices	• (Pazkad and Osmand, 2016) • (UNEP/CBD/COP, 2011) • (LASAN, 2020) • (CNT, 2010)
Improve access to nature by restoring empty lots, preserving and acquiring open space, and vegetating municipally owned facilities/parcels.	• Integrate climate solutions in community infrastructure investments and aquire land acquisition.	• Natural and Working Lands Climate Smart Strategy
Support local citizen science and research	• Goal 2.3a has an indicator for community scientist's engagement on iNaturalist annually.	• (LASAN, 2020)

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5 Conclusion

There are many challenges to enhancing the health of our urban streams and the ecosystem services they provide. For one, the information to improve revitalization planning is often lacking because resources are limited, timelines short, and previous revitalization projects have not implemented systematic approaches for measuring and reporting benefits, costs, and whether implemented projects fulfill revitalization goals in a way that can garner lessons learned and improve future efforts and designs. My dissertation was motivated by revitalization efforts along the Los Angeles and other Southern Californian rivers and attempted to address some of those constraints, specifically the need to understand species and human relationships with the environment so as to better inform goal setting as well as the need to better understand urban biodiversity and capture project success toward habitat goals. The general lack of data to inform goal setting makes the use of publicly available or publicly collected data appealing. In my research, I developed a framework for quantifying the habitat benefits of river adjacent green infrastructure projects that incorporates many essential biodiversity variables (Proença et al., 2017). However, this framework lacks consensus among experts after multiple rounds and reveals the difficulty in identifying goals that apply to all contexts, are feasible to measure, and which all projects can meet. I also made use of data collected by community members (through FlickR) and citizen scientists (through eBird) to better understand species and human relationships with the environment, each with varying degrees of success. The use of FlickR data was useful in identifying CES types along the river, understanding CES intensity, and revealed that CES along the River is best predicted by increased access, the presence of historic bridges, and high levels of flow. The eBird data and catchment scale predictors did not help in identifying species environmental relationships. However, this work helped highlight unsettled aspects of model evaluation, inherent difficulties in applying SDMs in urban areas, and the challenges associated with the use of unstructured and bias data.

The challenge with studying rivers is how dynamic river systems can be, given their connection to terrestrial ecosystems and the variability in the scale and intensity of disturbance. Incorporating the preferences and activities of people that visit and live near the River and of the decision making institutions that control the River further adds to the complexity in studying river systems. Globally population density and income predict recreational patterns (van Zanten et al., 2016). This type of data is largely summarized at the census tract scale and was incorporated in my CES model. However, people can impact species distributions in a way that would be poorly accounted for if analysis purely focused on the physical features like buildings, roads, or tree canopy. Failing to include people in biodiversity research, including species distributions models, would thus miss opportunities for improved species management and understanding. Research has already linked economics and cultural background to biodiversity at the neighborhood scale (Kinzig et al., 2005). For example, Rodriguez-Pastor et al. (2012) found that the distributions of invasive monk parakeets were linked to populations over the age of 65, which were likely feeding the parakeets. My species distribution model made use of the census tract scale, for the CES model, and the catchment scale, for eBird. However, it is important to recognize that the finer scales, sometimes as fine as a few meters (Gottschalk et al., 2011), that have been suggested for species distribution models would make it difficult to include people in urban ecological research and may further make the case for a hierarchy of scales (Gottschalk et al., 2011; Menke et al., 2009), which can include a neighborhood scale.

Furthermore, the institutions that have led the development of revitalization plans along the Los Angeles River add to that dynamism since they will create new environments for people and wildlife species. These plans generally relay a set of goals or visions with project design template for those opportunity areas (LADPW, 2021; Santa Monica Mountains Conservancy, 2021; *The Lower Los Angeles River Revitalization Plan*, 2017). The language is somewhat consistent across plans and call attention to equity in access and park space, clean water, healthy ecosystems, and, in some plans, safety. The goals and strategies described by recently completed Los Angeles River plans, once implemented, will effectively create or expand habitat, connections communities have to nature or the River (like trails and bridges), and make the River a multi-benefit "flood control channel" (LADPW, 2021). Project elements along the River's right-of-way include multi-use paths, stormwater infrastructure, increased tree canopy cover, wildlife habitat, and parks and gardens (LADPW, 2021; Santa Monica Mountains Conservancy, 2021). The projects consistent with these goals will likely host more people and, potentially, more species along the River given the focus on healthy ecosystems. The River should be a living laboratory, one of the goals of the Los Angeles River Masterplan, but one that also documents and learns from failures. As projects are completed, a living laboratory approach will help us understand the evolving nature of CES, species distributions, and how they both respond to the creation of novel environments. Until project implementation ramps up, there are lessons learned from my own work that would be useful for project practitioners.

The findings of the CES work described above, which revealed that historic bridges, flow, and access are important predictors of CES suitability, are in many ways encouraging to planners. Planning efforts have acknowledged the impossibility, under current storm flow scenarios, of naturalizing many sections of the River. Maintaining flood protection is the main goal of River revitalization (LADPW, 2021). Since the River is hemmed in along much of its course by adjacent development, there is no room for the river to expand during storm events. The lack of space for the channel to migrate means that naturalizing some sections of the River is likely precluded due to increased flooding risks. Some of these sections already have high CES intensity, even though they consist largely of imposing concrete structures that cannot be naturalized due to flood risks. Supporting CES in cities is a worthwhile goal for planners since the benefits of CES would be allocated to a high density of beneficiaries compared to natural areas (Thorp et al., 2010) and benefits may include social cohesion, (Kuo et al., 1998), increased perception of quality of life and health (Maas et al., 2006; Stigsdotter et al., 2010) that together may increase the visibility and appreciation of investments in communities that have experience considerable underinvestment. Based on my research findings, I recommend planners and designers enhance River access, highlight the River’s historic bridges, or, potentially, create heritage features along the River that create a unique sense of place. Flow is also an important predictor of CES, but clearly more important to some activities than others based on expert input. The large storm flows that draw people to the River will be unchanged by flow management scenarios that intend to recycle wastewater effluent. Aside from suggested expert targets for specific, in-channel activities, my CES study, which aggregated CES types, cannot inform flow management scenarios. However, many studies have documented the importance of water to CES suitability, irrespective of setting (Hale et al., 2019; van Zanten et al., 2016; White et al., 2010). As a result, designers and planners should recognize flows are important to sustaining

CES and design features should highlight the sounds and esthetics of flow, even if reduced from the flows of today.

In my research, I was guided by the assumption that species distribution models and citizen science data could inform habitat goals for revitalization efforts. However, after considerable investment in finding data, formatting and scaling data for use in Maxent, parameterizing the model, reducing the bias of occurrence data, and a deep dive into model evaluation approaches, I was not able to identify predictors that were important to species occurrence for urban and semi-natural avian species. This suggest that the resource-limited practitioner may be better served by review of the ecological literature and discussions with fellow experts. It is important to note that previous studies have successfully used Maxent to guide restoration (ElsäBer et al., 2013; Gelviz-Gelvez et al., 2015; Guisan & Hofer, 2003). However, many aspects of urban environments may be ill-suited for Maxent. This includes the use of generalist species, which are most likely to make use of urban environments but tend to be poorly modeled by Maxent (Evangelista et al., 2008). Model assumptions of a Grinnelian niche, in which species occur where environments are suitable, may be ill-suited for areas with source/sinks dynamics, as has been found in urban areas (Marzluff, 2008; Waits et al., 2008). When species distribution models would greatly benefit a project, practitioners should consider targeted sampling that capture covariates that are under-sampled by citizen science efforts and the use of finer scaled predictors that may better predict habitat suitability for generalists species (McPherson et al., 2004; Yackulic et al., 2013). A next step for research exploring whether Maxent and citizen science data could inform urban river revitalization would be to attempt to understand species and habitat relationships at a finer scale, to rule out whether catchment scale predictors coarsened the habitat features important to urban species. This approach would likely require the use of mixed approaches, Maxent, expert insight, or other presence only methods, to compared modeled predictions.

Citizen science data is an avenue by which to collect data of a coverage and resolution that would otherwise be cost prohibitive for scientists. Global biodiversity efforts like the Convention for Biological Diversity have really focused on how to facilitate and support the collection of biodiversity data by citizen scientists. These efforts have focused on increasing data quality by standardizing methods and supporting the capacity building that strengthens data collection efforts (Navarro et al., 2017; Proença et al., 2017). Green infrastructure experts made the case for citizen scientists to collect data that is currently unfunded (state monitoring dollars are largely oriented toward capturing water quality and quantity). My own research has revealed the power of community collected data in understanding CES intensity, identifying CES types, but also the difficulties of using such data, particularly correcting for bias and ensuring that sampling fully captures environmental covariates. In my own work, biased eBird data inflated AUC values and model significance. However, a targeted null model has been proposed as a strategy to account and correct for bias but did not sufficiently correct for bias based on comparisons to the target background model results (Raes & ter Steege, 2007). Background data is important for characterizing the full range of environmental predictors and will inflate a model's predictive performance, particularly when the background differs from occurrence locales (Phillips et al., 2009). Citizen science data will be most useful if it is guided to ensure collected data is comparable, of good quality, and at locales that capture covariates that have not yet been well sampled. The identification of the target species that are amenable to monitoring, because of ease of identification, and to ensure that species that are common are not ignored due to bias for rare species is an effort that is worthwhile and that platforms like eBird are already working to address (Sullivan et al., 2009). The educational opportunities that citizen science presents are promising but also unlikely to be fully realized on their own without purposeful engagement and mentorship (Krasny & Tidball, 2017). Given the challenges of using citizen science data, methods that make use of this data will likely require a mixed approach that facilitate comparison to ground-truthed data. For example, the use of multiple models whose results can be compared, data that triangulates model findings, such as was done for CES with recreational experts, so as to check model results against expert input or data that was collected using a structured approach.

The habitat metrics framework that was developed by biodiversity experts is a useful and foundational product for better capturing the habitat benefits of river-adjacent green infrastructure. While there was no consensus as to included goals and objectives, it is clear that successive rounds of surveying would not have resulted in expert consensus, given that feedback and each additional round never moved the group of experts any closer to agreement. The sources of these disagreements, which were related to feasibility and likelihood of success, can likely only be remedied with real data and experience, since habitat benefits have not yet been widely measured in green infrastructure projects. Since many ecological goals can be monitored using a multitude of metrics, refining of metrics is the next worthwhile step since expert fatigue did not allow for metrics, and the feasibility of their implementation, to be queried using a Delphi method. Standardizing metrics can support comparison between projects and accommodate the constraints managers may face in completing those measurements. The living laboratory approach, described by the Los Angeles River Master Plan (LADPW, 2021), will require monitoring to understand the contribution river-adjacent green infrastructure will have on ecosystem goals. This monitoring will better inform future projects, support the quantification of revitalization benefits, and can be facilitated by the metrics framework developed by biodiversity experts.

Climate change is and will change the ecology, flow, and resulting use of Southern California's streams and rivers (Buckley & Foushee, 2012; Filipe et al., 2013; Qin et al., 2021). It is critical to understand how weather extremes will shape human and species use of the landscape so as to inform adaptation efforts. The lack of temperature data at appropriate resolutions prevented its inclusion into both Maxent modeling efforts. However, many studies have highlighted the impact of temperature on human activity, in particular shifts in timing of visits and distribution, (Buckley & Foushee, 2012; Qin et al., 2021) and on species distributions as many species move northward in response to higher temperatures (Loarie et al., 2008). Studies have highlighted climate change refugia as a species adaptation strategy to climate change and the potential for nature based solutions, like green infrastructure, to serve to modulate climate impacts in cities (Hobbie & Grimm, 2020; Morelli et al., 2016). While vegetation and tree canopy are known to moderate temperature and were included in both Maxent models, neither predictor was important contributor to Maxent model performance. However, using existing FlickR data, there is the opportunity to explicitly analyze diurnal patterns in summer posts by separating midday posts, FlickR posts are time stamped, and analyze resulting shifts in predictors of CES occurrence. This approach is, of course, imperfect but a potential proxy for use of the River in warming conditions since temperature data is only available at the 1km scale and weather stations are too distributed to make use of existing data sources. As seasonal temperatures continue to reach new extremes, it is important to understand how use and species distributions may be shaped by a changing climate so as to inform the design or placement of refugia, for both people and wildlife.

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