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Green infrastructure in comprehensive plans in coastal Texas

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By guiding where, how, and when development occurs, comprehensive plans are an important vehicle to implement green infrastructure. To examine how green infrastructure is incorporated into local comprehensive plans, we evaluate 38 city and county plans in coastal Texas. Like many coastal regions, coastal Texas is experiencing rapid population growth, environmental degradation, and growing natural hazard threats. We found that local comprehensive plans in this region do not effectively incorporate green infrastructure. Few plans include goals related to green infrastructure or discuss the benefits of green infrastructure. The plans lack information critical for planning a green infrastructure network and rely on a narrow set of policies. Based on the prevalence of strategies to protect open space, green infrastructure is valued by communities even if they do not use the term "green infrastructure." Ultimately, the results suggest that there is a critical need to build planning capacity to advance green infrastructure implementation.

Keywords: green infrastructure; plan quality; coastal; comprehensive planning

Research highlights

- We evaluated how a green infrastructure plan is incorporated into local comprehensive plans in coastal Texas.
- We found local comprehensive plans do not effectively incorporate green infrastructure.
- While plans do not explicitly use "green infrastructure," strategies to protect open space are common.
- There is a critical need for capacity building to incorporate green infrastructure into comprehensive planning.

1. Introduction

Since 1992, urban area globally has doubled (IPBES 2019). This unprecedented urbanization has resulted in ecosystem loss, mass extinctions, exacerbation of climate change, and rising damage costs from weather-related disasters. By 2050, 68% of the world's population is projected to live in urban areas (United Nations 2019); the US has already surpassed this figure (Scyphers and Lerman 2014). As urban populations

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continue to grow, planners grapple with how to reconcile urban development with environmental protection.

Green Infrastructure (GI) is increasingly promoted to strategically balance urban development and protection of ecological systems (Lennon 2015; Lennon and Scott 2014). GI is defined as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations,” (Benedict and McMahon 2006, 5) ranging from improved public health to stormwater abatement. This network of green space includes large landscape features such as river corridors and site-scale design features such as bioswales; it also encompasses natural areas, working lands, and urban elements that mimic ecological processes. At these different scales and locations, GI highlights the essential services that green space and nature provides (Benedict and McMahon 2006; PCSD 1999).

GI occurs at varied spatial scales, ranging from landscape scale conservation efforts to site scale retention ponds and street trees. Across these scales, GI provides ecological functions—such as sheltering wildlife, improving water quality, replenishing aquifers, reducing air pollution, sequestering carbon, absorbing floodwaters, and moderating microclimates—while supporting societal functions such as physical activity and recreation, food production, economic productivity, cultural identity, and community cohesion (Rouse and Bunster-Ossa 2013). As such, GI has become a key strategy to advance sustainability and, now, resilience of cities globally (Lennon and Scott 2014; Meerow and Newell 2017; Rouse and Bunster-Ossa 2013).

While sustainability focuses on the balance of equity, economic, and environmental goals (Berke and Conroy 2000; Campbell 1996), urban resilience emphasizes the ability to maintain or return to desired functions in the face of disturbance and ability to adapt to change (Meerow, Newell, and Stults 2016). GI can help mitigate natural hazards and, in particular, flooding (Brody and Highfield 2013). As climate change increases the frequency and magnitude of natural hazards, GI has only become a more valuable tool. By investing in GI, communities can delay or even potentially negate the need for larger, expensive interventions (Abunnasr, Hamin, and Brabec 2015). Focusing on stormwater management, for example, GI can relieve pressure on aging or undersized sewer systems (Ahern 2013). GI is also thought to be more modular and flexible than buried pipes and pumps. In other words, GI fosters characteristics of urban resilience such as flexibility, modularity, redundancy, and diversity (Ahern 2013; Meerow and Newell 2017).

Recognizing that GI can advance sustainability and resilience goals, there have been numerous international efforts to promote GI. In 1999, the concept of GI was endorsed by The US President’s Council for Sustainable Development (PCSD). The PCSD promoted GI as an approach to “understand, leverage, and value the different ecological, social, and economic functions provided by natural systems in order to guide more efficient and sustainable land use and development patterns as well as protect ecosystems” (PCSD 1999, 64). To encourage the implementation of GI, congress amended the Clean Water Act in 2019 to direct the Environmental Protection Agency (EPA) to provide outreach, training, and technical assistance for local governments to utilize GI. In England, the 2012 National Planning Policy Framework requires that local plans consider GI to address the growing threat of climate change (Lafortezza *et al.* 2013). In 2013, the European Commission developed a new strategy to mainstream GI in spatial planning (Hansen and Pauleit 2014). As such, GI has been viewed as a framework for balancing conservation and development in planning (Benedict and McMahon 2006; Lennon 2015; Sandström 2002).

In the US, local land use (or comprehensive) plans play an important role in guiding where, how, and when development occurs. Local comprehensive plans are intended to provide a long-term vision of a community's development patterns and to translate that vision into proactive short-term actions (Berke *et al.* 2006; Brody 2003). With the legal authority to guide community development and the scope to address relevant systems, comprehensive plans are an important vehicle to implement GI (Brody 2008; Godschalk and Anderson 2012; Rouse and Bunster-Ossa 2013).

Conversely, GI can help address many of the planning issues communities struggle with (Rouse and Bunster-Ossa 2013). As the primary policy document of local governments, comprehensive plans typically address land use, transportation, housing, environment, and economic development (Godschalk and Anderson 2012). GI provides a tool to establish connections across these interrelated systems and identify mutually beneficial strategies (Rouse and Bunster-Ossa 2013). Ultimately, incorporating GI into urban planning offers an opportunity to effectively manage land and the ecosystem services it provides for the benefit of humans and the natural environment (Lennon and Scott 2014; Meerow and Newell 2017).

While GI planning is on the rise, few studies have examined the extent to which GI is incorporated into local comprehensive plans (Brody 2008; Kim and Tran 2018; Lynch 2016). To fill this gap, we ask: To what extent do local comprehensive plans integrate GI? We apply plan evaluation techniques to analyze comprehensive plans of 38 counties and cities in coastal Texas. Through this process, we define what a strong GI plan looks like and develop measurable metrics to provide a model against which to test plans (Brody 2008). Analyzing the integration of GI into land use planning identifies opportunities to elevate plan quality and improve current planning practice (Berke and Godschalk 2009; Brody 2008). The goal of this study is to document current practice and opportunities for improvement, not to highlight best practices to be translated elsewhere.

The Texas coast has experienced rapid population growth. Between 1970 and 2010, the population more than doubled to 6.1 million residents (Texas Sea Grant 2017). By 2050, the population of the state's coastal region is expected to exceed 10 million (Bush 2019). Population growth has been accompanied by loss of habitat such as wetlands, coral reef, and seagrass beds (Texas Sea Grant 2017). Rapid population growth combined with weak planning and consequent loss of ecosystems is often highlighted as a driver of flood losses in Texas. Texas incurs the most deaths and insurance losses from flooding from any other state (Brody, Kang, and Bernhardt 2010). Unplanned growth not only puts more people and property in harm's way, but also degrades the natural ecosystems that can ameliorate flooding. As such, GI planning is an important tool for communities along the Texas coast. The 2019 Texas Coastal Resiliency Master Plan promotes GI to address flooding, storm surge and erosion as well as loss of habitat, negative impacts on wildlife and fisheries, and degradation of water quality and quantity (Bush 2019). The issues of coastal Texas – rapid population growth, degradation of environmental resources, and growing threats of natural hazards - reflect challenges of coastal regions globally. Examining local plans in coastal Texas can help identify common limitations and challenges in planning for green infrastructure.

In the following section, we briefly review the literature on planning for green infrastructure, highlighting planning best practices that inform our evaluation. Next, we describe the study area of coastal Texas and our methods. We then present our findings. First, we describe the quantitative results across the entire sample. Then, to provide a deeper understanding of the state of green infrastructure planning in coastal Texas, we explore three plans in greater detail. Finally, we discuss the implications of our findings and provide recommendations to improve green infrastructure planning.

1.1. Green infrastructure in planning

The term "Green Infrastructure" was first coined by the Florida Greenways Commission's report in 1994 to discuss the importance of connecting conservation areas into an interconnected network (Florida Greenways Commission 1994). While the term "green infrastructure" is relatively new, the concept of preserving open space for the benefits it provides has a long history in planning. Frederick Law Olmsted's park designs and Ebenezer Howard's "Garden City" are early examples of planning to preserve natural benefits (Rouse and Bunster-Ossa 2013; Colding 2011). In his 1969 book "*Design with Nature*", Ian McHarg (1992) argued the benefits of nature can be balanced with development through careful design and planning (BenDor *et al.* 2017; Steiner *et al.* 2019). These concepts are also evident in plans. In an analysis of land use plans for Melbourne and Stockholm from the last 90 years, Wilkinson *et al.* (2013) found that every plan recognized the benefits of natural areas. More recent plans make stronger connections between environmental assets and quality of life (Wilkinson *et al.* 2013) demonstrating the alignment of land use planning and GI (Colding 2011).

The American Planning Association (APA) includes GI as a best practice for comprehensive planning (Godschalk and Rouse 2015) and has also published a report on integrating GI into planning (Rouse and Bunster-Ossa 2013). McDonald *et al.* (2005) similarly established "best practices" for GI planning. These "best practices" encourage planners to (1) establish goals to protect ecological functions and processes; (2) compile information such as protection status to identify gaps, establish priorities, and map a future green infrastructure network; and (3) use a broad range of strategies available to protect and develop green infrastructure (Brody 2008; McDonald *et al.* 2005; Rouse and Bunster-Ossa 2013). In addition to these direction setting elements, guidance on incorporating GI into planning recognizes the importance of public participation, coordination, and implementation details for effective planning (Brody 2008; Godschalk and Rouse 2015; McDonald *et al.* 2005; Rouse and Bunster-Ossa 2013). A participatory planning process is critical to provide necessary input to ensure that needs are met and to garner public support for GI efforts (Brody 2008; McDonald *et al.* 2005). It is particularly important to engage populations that may experience negative consequences of GI, such as increased property values and displacement, and to proactively address these issues in planning GI. To ensure plans translate into action, plans should include specific implementation tools and funding sources (McDonald *et al.* 2005). These concepts align with the principles of plan quality commonly used in plan evaluation studies (Berke and Godschalk 2009; Brody 2008; Lyles and Stevens 2014).

In addition to these planning "best practices," the literature on GI planning emphasizes that GI design and policies should be based on ecological concepts (Dramstad, Olson, and Forman 1996; Perlman and Milder 2005). The relevant ecological concepts will differ based on the scale and type of GI. In this paper, we focus on land use planning and basic landscape ecology principles that can guide conservation of open space.

Specifically, conservation should prioritize large, connected patches and seek to minimize edges of open space (Dramstad, Olson, and Forman 1996; Haddad *et al.* 2015). Preserving or creating multiple patches of green space is also important to protect the diversity of ecosystems in area (Dramstad, Olson, and Forman 1996). As the quantification of ecosystem services becomes more common, there has also been a push for GI to protect areas of high ecological value (i.e. providing more services) or areas that provide multiple services (Kim *et al.* 2018). Consequently, it is important to assess the extent to which GI planning incorporates ecological concepts in addition to the common plan quality principles.

Lynch (2016) analyzed nine GI plans based on ecological principles such as connectivity, preserving areas of greater ecological quality, and supporting a diversity of landscapes. Comparing the plan analysis to landscape change, Lynch (2016) concludes that counties with more GI policies retain greater quantity, quality, and connectivity of green space overtime.

In Europe, the *Green infrastructure: Enhancing biodiversity and ecosystem services for territorial development* (GRETA) project analyzed 12 case studies to assess planning for and implementation of GI (Carrao *et al.* 2018). They found that, in general, the case studies have integrated GI into spatial and urban planning, although GI and related concepts are not always explicitly discussed (Carrao *et al.* 2018). In the US, Kim and Tran (2018) evaluated 60 comprehensive plans on five GI principles established by the EPA's Water Quality Scorecard: (1) promote natural resources and open space; (2) promote efficient, compact development patterns and infill; (3) evaluate the design aspect of the development; (4) efficiency of parking; and (5) GI stormwater management. They conclude that GI is not fully incorporated into plans, with particularly weak baseline information and strategies (Kim and Tran 2018). Still, there are relatively few empirical studies of GI planning in practice (Hansen and Pauleit 2014), particularly in coastal regions.

In this paper, we use plan evaluation techniques to assess the degree to which local comprehensive plans in coastal Texas incorporate the "best practices" for GI planning. By identifying specific strengths and weaknesses of plans, this study provides an opportunity to review land use planning and improve future plans integration of GI (Berke and Godschalk 2009).

1.2. Study area

The Texas coast is one of the fastest growing coastal regions in the US (Texas Sea Grant 2017). This rapid growth has put people and property in risky locations and erodes ecological services. The Texas coast is one of the most vulnerable coastal regions in the nation, subject to hurricanes, tropical storms, and floods (Peacock and Husein 2011). Since 2005, four hurricanes – Rita (2005), Dolly (2008), Ike (2008), and Harvey (2017) – have made landfall in Texas. Hurricane Harvey, the second costliest hurricane in the US, caused more than $125 billion of damage. In addition to hurricane and tropical storm exposure, coastal flooding is projected to cost the state more than $5 billion in the next five years (Texas Division of Emergency Management 2018).

Vulnerability of the Texas coast is expected to increase due to climate change and rapid development. Development not only puts people in harm's way but also erodes the protective services of the environment. For example, in a study of Texas coastal counties, Brody *et al.* (2008) found that loss of wetlands significantly increased flood damage between 1997 and 2000. Conversely, open space reduces property damage from floods. Local parks, playing fields and other green space can act as a storm buffer to surrounding properties (Highfield and Brody 2013).

To address severe flooding issues and other environmental impacts of development, the 2019 Texas Coastal Resiliency Master Plan promotes GI (Bush 2019). The plan highlights the many benefits of healthy ecosystems. For example, coastal wetlands are estimated to provide $21,600 per acre in water filtration, nutrient control, carbon sequestration, habitat, recreation, biodiversity, and storm protection (Bush 2019).

The Texas Coastal Resiliency Master Plan encourages local governments to create comprehensive plans and protect natural systems that provide critical services. In Texas, municipalities are empowered to create and adopt a comprehensive plan, but they are not required to do so (Karaye *et al.* 2019). Under the Texas Local Government Code, municipalities are granted the power to define the content of a comprehensive plan. Comprehensive plans may have the power to guide development and zoning regulations, but it is not mandated that zoning regulations be consistent with comprehensive plans.

Like the coastal region of Texas, many coastal regions globally face challenges of rapid population growth and development, degradation of natural resources, and increasing threat of hazards (Silva *et al.* 2017). Consequently, GI may play a particularly important role in coastal regions (Ruckelshaus *et al.* 2016). Examining how GI is integrated into comprehensive planning can help identify common limitations and challenges in planning for GI in dynamic coastal regions. The findings of this study are particularly relevant for other coastal regions with weak planning requirements and regimes, providing empirical evidence for a region where both planning and planning for GI is optional.

2. Methods

To assess how comprehensive plans integrate GI, we used plan evaluation to analyze comprehensive plans from 38 cities and counties in coastal Texas as shown in Figure 1. These 38 plans represented all comprehensive plans available at the time of this study from coastal cities and counties in Texas with over 10,000 residents.

Plan evaluation applies content analysis to identify specific strengths and weaknesses of plans (Lyles and Stevens 2014). Using this method, researchers develop a set of criteria and then systematically evaluate plans to determine whether they fulfill the specified criteria. Assessing the presence/absence of criteria allows the conversion of text to a quantitative measurement of plan quality, which eases comparisons between plans and statistical analyses (Lyles and Stevens 2014). The goal is to conduct analyses and draw inferences from plans that are both replicable and valid (Stevens, Lyles, and Berke 2014).

Researchers have used plan evaluation to analyze plans from multiple domains, including hazard mitigation (Berke, Lyles, and Smith 2014), sustainability (Berke and Conroy 2000), and climate change adaptation planning (Woodruff and Stults 2016). Plan evaluation has also been applied to measure focus of plans on a specific topic, such as sustainability in hazard recovery planning (Song *et al.* 2017) and climate change adaptation in resilience plans (Woodruff *et al.* 2018).

In this research, we assessed the extent to which comprehensive plans incorporate green infrastructure across the following six well-established plan quality principles:

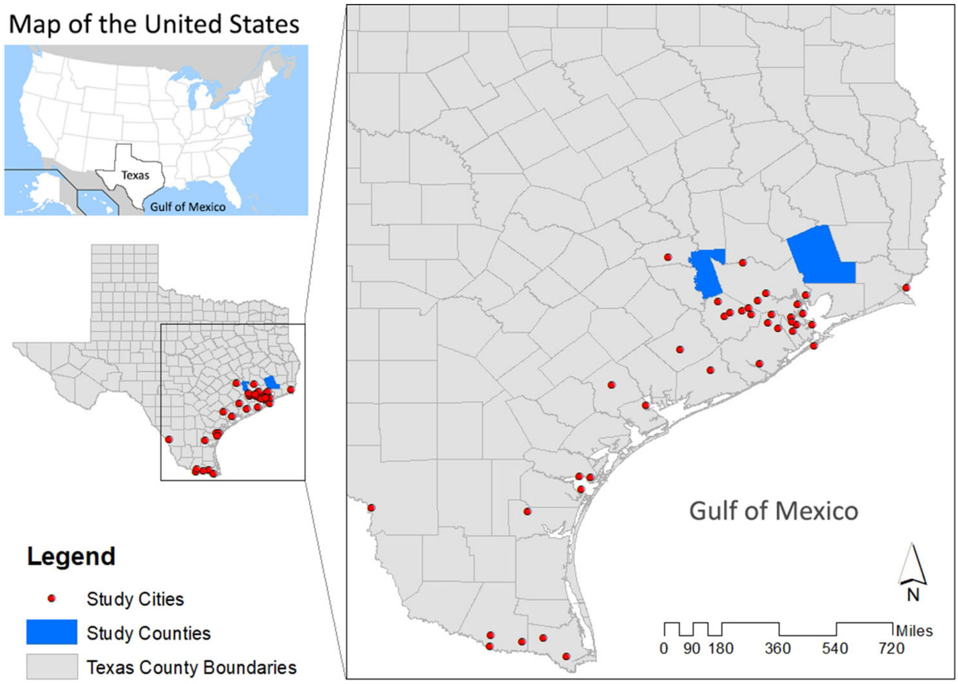

Figure 1. Sample of plans included in the analysis.

(1) *Goals* that provide a vision for the community's future; (2) *Fact Base* that identifies community issues and provides empirical foundation for action; (3) *Strategies* to achieve the goals established in the plan; (4) *Public Participation* in the planning process; (5) *Coordination* across organizations and plans; and (6) *Implementation and Monitoring* that articulate how the plan will lead to action (Lyles and Stevens 2014). Table 1 defines these plan quality principles and provides example criteria.

Across these six plan quality principles, we included 80 criteria (see Appendix A). The criteria were based on earlier plan evaluation studies (Lynch 2016; Steelman and Hess 2009; Woodruff and Stults 2016) and a previous survey of key informants in the study area on the hazard mitigation policies and strategies adopted by jurisdictions (Peacock and Husein 2011). Of the 80 criteria, 40 are explicitly about GI. The remaining 40 are general planning best practices (Table 1). All the planning principles and metrics included in this analysis are important elements of a strong GI plan. For example, coordination with other stakeholders such as business and private land owners has been shown to significantly improve GI planning and outcomes (Brody 2008), but a planning process can have strong coordination without addressing GI. The criteria explicitly about GI were intended to capture the plans' focus on GI as well as the use of ecological principles in guiding GI. To measure focus, we had criteria such as including a GI goal, defining green infrastructure, justifying the use of GI, and proposing GI strategies. For these codes, plans were required to explicitly use the term "green infrastructure." We were also interested in whether plans incorporate relevant ecological principles such as connectivity into their discussion of GI and strategies.

Determining the presence/absence of criteria allows the conversion of text to a quantitative measurement. For example, one of the criteria in the *fact base* principle was defining GI. If the plan does define GI, it received a score of 1; otherwise it

Table 1. Plan principles used in analysis. Principles are divided into General Planning Criteria and GI specific Criteria.

Principle	Definition	General Planning Criteria		GI Specific Criteria		Total Criteria
			Examples		Examples	
Goals	Vision and desired conditions for the future	4	Vision statement, objectives	3	Green infrastructure goals	7
Public Participation	Recognition of how public was involved in the planning process	8	Plan preparation involvement, participation techniques	0		8
Coordination	Recognition of interdependent actions of multiple organizations	11	Engagement of businesses, regional plan coordination	1	Coordination specifically on green infrastructure	12
Fact Base	Empirical foundation that identifies issues and ensures that strategies are well informed	4	Prioritizes community issues, data sources	10	Define green infrastructure, identifies benefits of green infrastructure, discusses ecological concepts	14
Strategies	Guide to decision making and actions to achieve plan goals	2	Strategies are tied to goals, strategies address all issues identified	24	Acquisition of land, ecosystem restoration/enhancement, prioritize connectivity	26
Implementation and Monitoring	Guidance to translate plan strategies into action and track progress	11	Timetable for implementation, funding, reporting requirements	2	Mainstreaming of green infrastructure, barriers to implementing green infrastructure	13

received a score of 0. We then calculated scores for each principle based on the percentage of the principle criteria the plan includes. We also calculated aggregate plan quality by averaging principle scores. These scores ease comparisons between plans and help identify trends across plans.

The criteria were pre-tested on comprehensive plans from Texas outside the coastal zone. Pre-testing helped us refine the criteria and coding instructions so that they captured the concepts intended. In addition, pre-testing allowed us to train coders and ensure that intercoder agreement fell within an appropriate range (0.80 or higher; Berke and Godschalk 2009).

All plans were independently read and coded by two trained coders in line with recommendations from the plan evaluation literature (Stevens, Lyles, and Berke 2014). To ensure reliability, we calculated intercoder agreement using percent agreement and Krippendorffs alpha for each plan and criteria (see Appendix A). Disagreements between coders were discussed and reconciled by referring to the qualitative content of the plan.

To further explore how GI is incorporated into land use planning in coastal Texas, we examine three plans in greater detail. Specifically, we qualitatively discuss how the comprehensive plans for League City, Galveston, and Brownsville fulfill plan quality principles. These three plans include the most GI specific criteria in the sample. Reviewing these plans highlights how GI is integrated into comprehensive planning and opportunities for improvement.

3. Results

The average plan principle and aggregate plan quality scores are presented in Figure 2. As shown in the figure, average aggregate plan quality is 0.36, which indicates local comprehensive plans in coastal Texas do not effectively incorporate GI. Across the principles, coordination (0.29) and strategies (0.33) are the weakest as shown in Figure 2. While fact base (0.38), implementation and monitoring (0.41), goals (0.45), and public participation (0.50) are stronger, there is still considerable room for improvement.

Generally, plans have a clear vision, goals, and specific objectives. However, few plans have sustainability, resilience, or GI goals. Of the 38 plans included in this analysis, 11 have a sustainability and 2 have a resilience vision or goal. Similarly, GI is not a central goal of most plans, only 8 plans ($M = 0.21$) have a GI vision or goal.

Weak scores on the fact base principle further demonstrate the limited integration of GI into comprehensive plans. Only 3 plans ($M = 0.08$) actually define GI. Plans consistently identify population change ($M = 0.87$, 33 plans), land use change ($M = 0.63$, 24 plans), flooding ($M = 0.61$, 23 plans), and water supply ($M = 0.53$, 20 plans) as key issues. However, environmental issues such as climate change ($M = 0.03$, 1 plan), ecosystem fragmentation ($M = 0.03$, 1 plan), and air quality (0.13, 5 plans) are rarely identified as important issues to the community.

Plans further lack information critical for planning a GI network. While most plans map existing GI ($M = 0.55$, 21 plans) and future land use ($M = 0.66$, 25 plans), information to identify gaps and needs is missing. Environmentally sensitive areas, defined as areas that are risky for development, such as floodplains and steep slopes, as well as areas of high environmental importance, such as endangered species habitat, are discussed in less than half the plans ($M = 0.45$, 17 plans). Ownership, which is critical

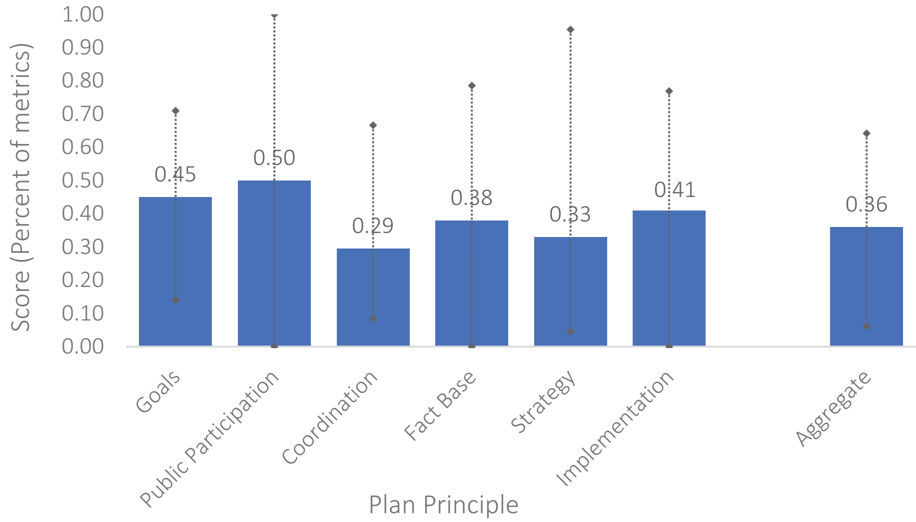

Figure 2. Plan quality score by plan principle.

for determining the appropriate GI strategies, is not discussed in any plans ($M = 0.00$). Ecological concepts to guide GI are not commonly discussed. Connectivity is discussed in two plans, but patch size and edge effects are not discussed in any plans.

Plans in our sample rarely provide a justification for GI or discuss its benefits. Only 10 plans ($M = 0.26$) identify a specific benefit of GI. In those plans, attenuation of stormwater runoff ($M = 0.15$, 6 plans) and recreation ($M = 0.15$, 6 plans) are most commonly discussed. The benefit of air quality and public health are not mentioned in any plans.

There is a relatively small set of strategies used across plans. The most common strategies are: natural resource protection ($M = 0.66$, 25 plans), open space ($M = 0.66$, 25 plans), drainage improvements and flood control ($M = 0.63$, 24 plans), and development regulations and land use management ($M = 0.53$, 20 plans). Few plans incorporate other strategies that can be used to protect GI such as development offsets ($M = 0.03$, 1 plan), limiting shoreline development ($M = 0.08$, 3 plans), and federal incentive tools ($M = 0.08$, 3 plans).

In addition, we were interested in whether plans utilize ecological concepts - connectivity, contiguity, ecological value, diversity, and multiple benefits - to prioritize the protection of open space. We found that 16 plans prioritize protection of open space based on at least one ecological concept. Connectivity is the most commonly referenced for prioritizing protection of open space ($M = 0.37$, 14 plans). Other principles – ecological value ($M = 0.08$, 3 plans), diversity ($M = 0.00$), and so on - are rarely used.

On average, the plans in our sample include 41% of the implementation and monitoring criteria. About half the plans do not include elements that are important in translating plans into action, such as prioritization of strategies ($M = 0.37$, 14 plans), timeline for implementation ($M = 0.39$, 15 plans), funding sources ($M = 0.32$, 12 plans), and requirements for reporting progress ($M = 0.50$, 19 plans). The scores on the criteria regarding green infrastructure are particularly low. Only two plans discuss how

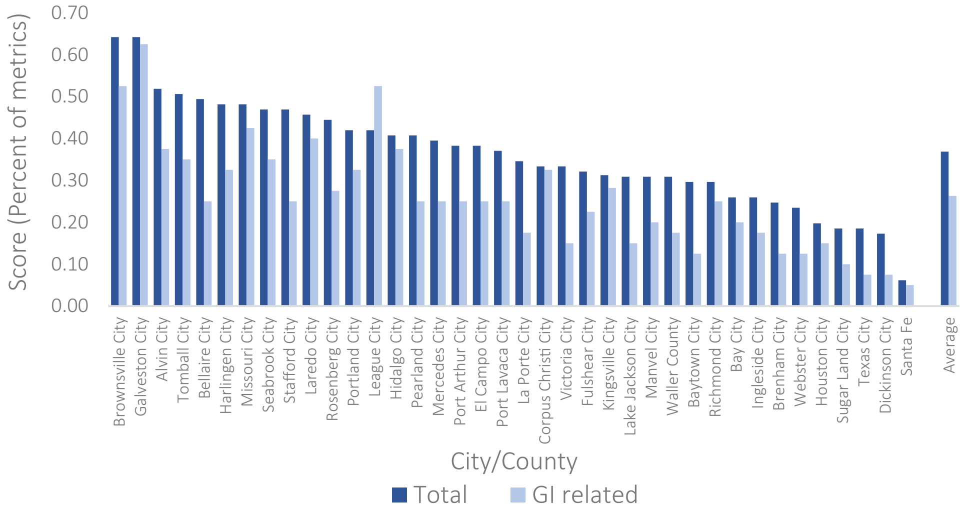

Figure 3. Plan quality score by city/county.

green infrastructure strategies in the comprehensive plan will be mainstreamed or integrated into other planning initiatives such as capital improvement plans, or park plans ($M = 0.05$).

The public participation principle score is the highest among all six principles ($M = 0.50$), but there is still room for improvement. Most plans outline the planning process ($M = 0.76$), how the public was engaged in the process ($M = 0.87$), and how citizen input was incorporated into the plan ($M = 0.84$). Plans less commonly report who was involved in preparing the plan ($M = 0.37$). In particular, plans do not articulate whether stakeholders involved in the process are representative of the community ($M = 0.13$) nor how they engaged disadvantaged populations ($M = 0.08$).

Across the plans in our sample, the coordination principle score ($M = 0.29$) is low, indicating that partners such as local universities, federal and state agencies, businesses, neighboring jurisdictions, and nonprofits are not commonly engaged in the planning process. While plans frequently discuss coordination with other local planning efforts ($M = 0.61$, 23 plans), coordination with regional planning efforts is less common ($M = 0.24$, 9 plans). The literature recommends that local green infrastructure planning be coordinated with regional efforts (Brody 2008; McDonald *et al.* 2005), however, only two plans discuss how green infrastructure measures are coordinated with regional efforts ($M = 0.05$).

3.1. Scores by cities or counties

There is large variation in plan quality across cities and counties, as shown in Figure 3. The cities of Galveston and Brownsville had the highest scoring plans, with 64% of the possible codes. The lowest scoring plan, with only 6% of the possible points, was the City of Santa Fe.

Separating metrics that are explicitly about GI, further illustrates which cities are incorporating GI into their land use plans. As shown in Figure 3, some communities have strong plans, they simply do not incorporate GI. In the City of Bellaire, for instance, the plan includes 78% of the general planning metrics, indicating a relatively

Table 2. Summary of case study scores across plan quality principles. Examples of criteria included in the plan demonstrate variation in plan focus and approach.

	League City		Galveston		Brownsville	
Principle	GI Related Planning Policies	Total Score	GI Related Planning Policies	Total Score	GI Related Planning Policies	Total Score
Goals	Goals: "Preserve and showcase the community's amenities and natural assets including Clear Creek, native habitats areas, open spaces/rural areas, and the Historic District." (54)	0.14	Goals: "Preserve and protect the sensitive natural resources of Galveston Island, the Galveston Bay Estuary, and the Gulf of Mexico." (93)	0.71	Vision Statement: "Brownsville builds on its unique historic heritage and culture, […] and abundant natural resources to create a livable, prosperous, engaged, connected, and sustainable community"(30)	0.57
Public Participation	Participation techniques: "A visual preference survey, was conducted at the beginning of the planning process" (4)	0.50	Public participation maintenance: "Encourage ongoing citizen input into changes in the needs of the community through questionnaires … " (195)	0.63	Engage disadvantaged populations: "Ongoing outreach efforts included mailing bilingual flyers to households, schools and churches" (50)	1.00
Coordination	Local Plan Coordination: "The Comprehensive Plan […] builds upon the actions recommended in the other plans" (4)	0.08	Planning Committee: *"The Steering Committee consisted of over 30 members who ensured that the Comp Plan was crafted to reflect the vision, values, aspirations, and priorities of the citizens of Galveston."* (2)	0.50	Planning Committee: "As a critical component of the Planning Process, a Task Force was established as an advisory and recommendation body, and to represent a broad cross-section of the City of Brownsville." (30)	0.42

(*Continued*)

Table 2. (*Continued*).

	League City		Galveston		Brownsville	
Principle	GI Related Planning Policies	Total Score	GI Related Planning Policies	Total Score	GI Related Planning Policies	Total Score
Fact Base	Defines GI; Connects GI with stormwater: "Natural systems including wetlands, native habitat areas and waterways are often referred to as 'green infrastructure'. These natural systems are very important in managing stormwater and water quality" (94)	0.79	Ecosystem Services: "The Island's […] wetlands provide a number of natural functions vital to the health of the Galveston Bay Estuary. These functions include flood control, filtering pollutants from the Bay, and providing vital habitat for many species." (101)	0.36	Maps Sensitive areas: *Maps Floodplains and Resacas* (53)	0.50
Strategies	Connectivity: "Open spaces should be connected within a development as well as with open spaces on adjacent sites. Linkages between open spaces and with other destinations should be considered a critical component of good site design." (56)	0.64	Connectivity; Multiple benefits: "the City should encourage open space to be aggregated, interconnected, and offer multiple benefits, including ecosystem function and view corridors" (109)	0.95	Green Infrastructure: "Develop and construct green detention/retention ponds that provide multiple benefits including flood control, recreation, environmental protection and esthetics." (444)	0.73
Implementation and Monitoring	Mainstreaming: Parks Master Plan is vehicle to implement GI (74)	0.15	Timetable for implementation; Identifies responsible parties (198)	0.62	Prioritizes strategies; Identifies responsible parties (440)	0.69

strong plan – one with clear goals, an inclusive and coordinated planning process, and implementation guidance. However, it only includes 25% of the GI metrics (resulting in a total score of 49%).

All but one plan includes more general planning metrics than GI metrics. The notable exception is League City, which has 53% of the GI metrics but only 30% of the general planning metrics. This indicates a strong emphasis on GI but an overall weak plan, comparatively speaking. League City, Galveston, and Brownsville include the most GI metrics. To demonstrate how GI can be integrated into land use planning, we examine these three plans in greater detail.

3.2. Case studies

League City, a suburb of Houston, is growing rapidly. The population is projected to increase from 83,000 in 2013 to 228,000 in 2040 (League City 2013). Current land use patterns are dominated by low-to-moderate density residential neighborhoods, commercial strip corridors, and retail centers. The city is located in a low-lying coastal region facing significant flooding and hurricane hazards (Berke *et al.* 2019). The city has suffered repetitive flood losses. About 5,184 acres (15.4% of the city's total land area) is in the 100-year floodplain with only 482 acres of floodplain lands designated as permanent open space (public parkland and conservation areas; Yu 2019). The plan focuses on population growth and land use change, but the plan also identifies flooding and the lack of open space as important issues for the city.

GI concepts and strategies are woven throughout the plan. As shown in Table 2, the plan defines GI as "natural systems including wetlands, native habitat areas and waterways" (League City 2013, 94). However, the plan focuses on a relatively narrow range of benefits, specifically stormwater management, flood mitigation, and recreation. The League City plan demonstrates the power of GI to connect different community issues and find synergistic strategies. The plan connects GI to hazard mitigation and park and recreation goals. The plan highlights GI multiple benefits *"… supporting stormwater functions while also providing recreation opportunities for residents and visitors"* (League City 2013, 67).

The plan establishes goals to "Protect and enhance natural areas, particularly along the waterfront, as a means of managing the impacts of coastal storms and flooding" (League City 2013, 82) and "Keep future development out of known hazard areas" (League City 2013, 82). To achieve these goals, the plan identifies a wide range of strategies including zoning, acquisition, transfer development rights and education. Unlike most plans, League City's plan recognizes the importance of connectivity of open space (Table 2, Strategies). League City's plan also emphasizes these protected areas can serve as parks and recreational areas, advancing park goals. Aligning goals offers an opportunity to implement GI through the Park Master Plan (Table 2, Implementation and Monitoring). Green infrastructure programs are also included in the plan's infrastructure chapter.

While Galveston's Comprehensive Plan, "Progress Galveston", similarly recognizes the benefits natural ecosystems provide, the plan does not explicitly mention "green infrastructure". As a barrier island, Galveston is home to multiple ecological systems that provide critical services. The plan discusses the multiple benefits healthy ecosystems provide:

> "A healthy system of marsh and wetland areas can serve as a buffer from wave action, help protect against coastal erosion forces, absorb stormwater runoff, and provide flood control by holding water and releasing it slowly to the bay. Healthy wetland and marsh systems also improve water quality—as runoff is stored in wetlands, suspended solids settle out and pollutants are filtered and trapped in bottom sediments, resulting in enhanced quality as runoff reaches near shore waters. Wetlands and marshes also provide vital habitat for many species of plants, fish, birds, and wildlife and are an important source of nutrients and organic matter, which becomes food for organisms throughout the estuary." (City of Galveston 2011, 100)

The plan further recognizes that healthy ecosystems are the foundation for the city's tourism, fishery and other industries.

The Natural Resource element of Galveston's plan specifically sets the goal of "Preserve and protect the sensitive natural resources of Galveston bay estuary & the Gulf of Mexico" (City of Galveston 2011, 93). To realize this goal, the plan outlines seven objectives including "Protect the integrity and function of the beaches, dunes and bay wetlands" and "Preserve and protect sensitive natural resources by creating an open space network" (City of Galveston 2011, 93). To achieve the natural resource goals and objectives, the plan includes strategies ranging from outreach programs to land use tools. The plan includes 21 of the 26 policy types we include in our evaluation, resulting in a high score on the strategy principle (Table 2, Strategies). Furthermore, the plan discusses how preservation efforts should consider ecological principles such as connectivity and multiple benefits (Table 2, Strategies). Galveston's plan clearly identifies the value of GI, establishes strong goals, and uses a breadth of strategies. However, the plan lacks information that can be critical to preserving and enhancing GI such as maps of land use and environmentally sensitive areas.

Brownsville is located on the bank of the Rio Grande River and the Mexican border. In 2009, when Brownsville adopted its comprehensive plan, the population was estimated to be 172,806 and projected to grow to 365,000 by 2035. This projected growth puts significant development pressure on the city's environmental systems. The plan seeks to concentrate future development in the city core and protect the undeveloped, outlying areas. The plan recognizes that the city's creeks and resacas (former channels of the Rio Grande River that are now marsh, ponds, or dry river beds that transport flood water) provide multiple services including managing stormwater, wildlife habitat, and community identity (City of Brownsville 2009). However, similar to Galveston's comprehensive plan, the Brownsville plan never uses the term "green infrastructure". The plan maps environmental assets and sensitive areas alongside future land use. As with League City and Galveston, the Brownsville plan utilizes a wide variety of strategies to preserve and enhance GI.

4. Discussion and conclusion

GI promises to help address many of the planning challenges that communities confront today. By simultaneously providing benefits for the environment and humans, incorporating GI into planning can strategically guide growth and environmental protection. But is GI actually integrated into local comprehensive planning?

Our analysis of 38 comprehensive plans of cities and counties suggests that GI is not well incorporated into comprehensive planning. Because our study is limited to one region of the United States – the Texas coast – our ability to generalize is limited.

But our results are consistent with previous evaluations of GI planning in different regions of the United States and contexts (Brody 2008; Lynch 2016; Kim and Tran 2018). Future research could replicate this study in other areas, particularly coastal regions, to provide a more complete view of GI planning. As with previous studies, we find that plans lack information to guide GI programs and utilize a narrow set of strategies.

Where GI is incorporated into plans, there is a focus on stormwater runoff. GI planning is frequently critiqued for focusing narrowly on stormwater abatement (Meerow and Newell 2017). The narrow interpretation of GI is largely a result of the US Environmental Protection Agency's emphasis on stormwater runoff. While flooding and managing stormwater is an important issue for communities along the Texas coast, the narrow focus on stormwater represents a missed opportunity. Coastal ecosystems provide a multitude of benefits including attenuating storm surge, improving water quality, providing recreation, and supporting biodiversity. Recognizing the multiple benefits that GI provides can build a stronger case for conservation and protection in the face of rapid population growth. In addition, the multi-functional GI can link interrelated issues and build broader coalitions for action.

It is important to recognize that while communities may not explicitly use the term "green infrastructure," strategies to protect open space and natural resources are common. Currently, there are a number of underutilized tools that communities could leverage to better protect GI such as federal incentives. In addition, using ecological principles to prioritize open space protection would provide a more strategic approach to conservation. Research evaluating the benefits of coastal ecosystems – such as wave attenuation of wetlands - has demonstrated that location is extremely important (Ruckelshaus *et al.* 2016; Saleh and Weinstein 2016). Consequently, there is a need for these benefits to be more explicitly recognized in the planning process to optimize the benefits GI provides. Future research should further explore the link between planning practices, landscape change, and the resulting services (i.e. stormwater management and flooding).

While public participation is the highest scoring principle in our study, there is a need to improve engagement of disadvantaged populations and ensure stakeholders are representative of the community. Brownsville is one of the few plans that explicitly discusses reaching out to under-represented populations by providing materials in multiple languages (Table 2, Public Participation). GI can provide multiple social benefits, but there is unequal access to these resources (Jesdale, Morello-Frosch, and Cushing 2013; Apparicio *et al.* 2012). Consequently, GI planning needs to engage populations that will be affected by these decisions. This may be particularly important in developing regions and countries. Engaging local communities, particularly those relying on natural resources for their livelihoods, can be critical to the success of protection and restoration efforts in developing regions (Silva *et al.* 2017).

Based on the prevalence of strategies to protect open space and natural resources, GI is valued by communities even if they do not use the term "green infrastructure". The term "green infrastructure" also has competing definitions, which may lead to confusion among practitioners. Whether GI is defined broadly as a network of green space or narrowly as mimicking natural systems to better manage stormwater, GI includes multiple elements ranging from working farms to rain gardens. The numerous components of GI may make it difficult for local governments and planners to operationalize GI planning (Matthews, Lo, and Byrne 2015). Moreover, comprehensive plans vary in structure and content across communities. As a result, there is no single method to integrate GI into comprehensive planning. While GI is most commonly discussed in environmental elements of comprehensive plans, it cuts across elements including infrastructure, health, and recreation. As the primary policy document for local governments, comprehensive plans should incorporate GI principles to protect open space and guide future development (Brody 2008). However, communities may also utilize other types of plans to advance GI such as open space or parks plans (Carrao *et al.* 2018).

To improve GI planning in coastal communities, there is a critical need for capacity building. This entails, but is not limited to, (1) articulating a shared definition of GI planning and the landscape components it includes; (2) educating the public on the benefits of GI; (3) building collaboration vertically to regional systems and horizontally to neighboring jurisdictions; and (4) providing guidance on under-used implementation tools and strategies. The European Commission *Green Surge* project provides one roadmap for building capacity for GI planning. *Green Surge* surveyed planning practice to identify best practices for advancing GI, then piloted these practices in participating cities to make this new knowledge accessible and usable (Olafsson and Pauleit 2018). In our study area, tools such as the Texas Coastal Atlas, an online interactive portal that compiles information and data, could help better inform GI planning. Greater attention needs to be given to producing locally relevant examples and tools for planning, such as model language. Providing these resources and tools are particularly important where there are no requirements for GI planning.

Results from this study also raise concerns about the state of local comprehensive planning generally along the Texas coast. We found comprehensive plans are relatively uncommon in the region. As the primary policy document for local governments, local comprehensive plans should map future land use and environmentally sensitive areas. But, in our analysis, we found that many plans lacked these key elements. In addition, multiple plans fail to address critical issues such as population and land use change, not to mention climate change and environmental quality. Based on these findings there is a need to not only build capacity for GI planning in coastal Texas, but planning more broadly. Assessments of GI planning in other contexts, have reflected that in addition to providing GI tools there is a need to provide high-level guidance on zoning and land use management (Carrao *et al.* 2018). Strong planning can guide and control development in coastal regions, where protection of natural habitat and protection for natural hazards are high priorities.

GI is an important tool to balance development pressure and conservation in coastal areas. While this study cannot be generalized to all coastal regions, our findings highlight the limited use of GI in planning. Our results suggest that without planning or GI planning requirements, local governments may not have the commitment or capacity to incorporate GI into their planning processes. Given the promise that GI holds for planning, there is a need to build capacity and address the challenges local governments face in pursuing GI.

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Supplemental data

Supplemental data for this article can be accessed here.

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