Plan Integration for Ecological Resilience: Examining Factors Associated with Wetland Alteration

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Abstract: A community's resilience is strongly influenced by the growth management guidance provided by its *network of plans*. Wetland loss has been shown to amplify flood damage. This study explores the relationship between plan integration and wetland alteration, comparing findings from Fort Lauderdale, Florida, and League City, Texas. Combining spatial analytics, a Plan Integration for Resilience Scorecard™ evaluation, and correlational statistics, we find that wetland loss is significantly associated with plan integration and development patterns and is less acute in League City than Fort Lauderdale. Integrating wetland protection policies throughout a network of plans helps build resilience to flood hazards.

Keywords: Ecological resilience; Plan integration; Wetland loss; Hazard vulnerability; Land development

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Introduction

Seventeen percent of the land area and 52 percent of the population of the United States are found in coastal areas (NOAA, 2013). These areas regularly contend with flooding threats (especially from hurricanes and coastal storms) which are exacerbated by threats from sea-level rise. The amount of vulnerable urban area is increasing as development increases in flood-prone locations. Simultaneously, a lack of coordinated hazard mitigation planning can contribute to increased losses from both surge- and rainfall-related flood events (National Research Council, 2014). Resilience to flood disturbances also heavily depends on a healthy ecosystem and its related services (Yu et al., 2020; Burby, 1998). Changes in ecological conditions associated with land use development can directly impact ecosystems, including their ability to withstand natural hazards and sustain human activities on a larger scale (Brody et al., 2008; McPhearson et al., 2015). Such changes increase the vulnerability of communities. Urban planning plays a crucial role in directing land use development and, therefore, resilience (Godschalk, 2003). For these reasons, more attention in plans must be focused on protecting natural habitats and directing development away from hazardous areas.

Coastal wetlands provide hurricane protection by absorbing storm energy and buffering residential areas from storm landfall (Newman et al., 2019; NRC, 2014); they have also been shown to be effective at mitigating wave energy, decreasing the exposure of open water areas to wind, cutting off wind action on water, and controlling water motion (Costanza, 2008; NRC, 2012). Wetland loss, therefore, can amplify damage from floods over large areas. In areas experiencing high physical vulnerability, with portions of the built environment characterized by high flood risk, wetland preservation and the appropriate use and connection of green infrastructure has been shown to decrease stormwater runoff and increase floodwater sequestration (Karaye et al., 2019). Empirical research suggests that wetland loss may increase the frequency and magnitude of flood events (Brody et al., 2008); even a small amount of wetland loss in a watershed can have a long-term impact on flood damage (Xu et al., 2018)

City plans and policies help determine how effective urban growth can be in mitigating flooding and preventing wetland loss. The resilience of the built and natural environments is influenced by the development and growth management guidance provided by a community's *network of plans* (Berke et al., 2021; Albrechts & Mandelbaum, 2007). Examples of plans in the network may include a comprehensive plan, hazard mitigation plan, parks or open space plan, and transportation plan. This variety of plan documents guides development, even in hazard-prone areas, and the ways these multiple and independent plans interact can significantly impact communities and their vulnerability (Berke et al., 2015; 2018; Hopkins, 2001). A well-integrated network of plans that safeguards the natural environment and enhances ecological resilience can significantly aid in building resilient communities and reducing losses from flood events. For instance, Yu et al. (2020) found that a well-integrated municipal network of plans was aligned with flood safety goals and successfully pursued nature preservation in neighborhoods most vulnerable to flooding.

From a socioecological systems perspective, resilience depends on a community's capacity for absorption, self-organization, and adaptation (Folke et al., 2002). Flood vulnerability can therefore be reduced through enhancement of social capital and engagement in processes focused on flood risk. Unfortunately, marginalized neighborhoods tend to experience greater damage during flood events than do other communities (Berke et al., 2019; Yu et al., 2020; Peacock et al., 2014). Many of the root causes of inequality in flood damage are linked to environmental injustice, which exacerbates disparities in the capacity of the built environment to withstand hazard forces. This can be especially seen in the prevalence of green infrastructure (including wetlands), which research has shown can reduce the impacts of such forces (Hendricks et al., 2018; Brody et al., 2008).

In this study, we examine the association between wetland loss and the level of plan integration. We also explore (and control for) contextual factors such as development intensity, physical vulnerability, and socioeconomic status to expand the analysis and detect the independent relationship of plan integration and wetland loss. Two cities in different stages of development are selected for analysis and comparison: Fort Lauderdale, FL, and League City, TX. Fort Lauderdale is almost fully built out, whereas League City contains large undeveloped (mostly peripheral) areas and is still rapidly growing. We investigate plan integration in both communities, and whether it has a stronger relationship with wetland loss in the built-out community or the rapidly developing one. We hypothesize that higher levels of plan integration are related to a network of plans that target "hotspots" of wetland loss, thereby helping deter decreases in wetlands. To achieve this, we apply several analytical tools, including spatial analytics, the Plan Integration for Resilience Scorecard (PIRS)™, and correlational statistics to examine how plan integration, development intensity change, physical vulnerability and socioeconomic status relate to the loss in wetland land cover.

Literature Review

Ecological Resilience and Wetland Loss

The concept of resilience has its origins in the field of ecology. Holling (1973) defined ecological resilience as an ecosystem's ability to adapt to change; in ecological systems, resilience is rooted in essential functional groups and the accumulation of resources for recovery. Pimm (1984) built on this definition to describe ecological resilience as the speed at which an ecosystem returns to its original state after a disturbance. More recently, scholars have begun to coalesce around a definition of resilience as an ecosystem's capacity to absorb perturbation (Holling et al., 1995; Lebel et al., 2006). Hazards and urban planning scholars have utilized the concept to describe and investigate the capacity of a city (or community) to withstand or absorb and then recover from a hazardous event (Mileti, 1999; Godschalk, 2003; Masterson et al., 2014), and have long recognized the importance of natural ecosystems in maintaining this capacity (Kim et al., 2022; Haase et al., 2014; Burby, 1998; Burby et al., 1999).

Several studies have used wetland loss as a measure for ecological resilience (Brody et al., 2012; 2015; Reja et al., 2017). Brody et al. (2012) suggest that wetlands function as a key ecological indicator of resilience in terms of flood mitigation, which is consistent with Cutter and colleagues' (2008) community ecological resilience indicators. Empirical observations and modeling indicate that wetland loss can increase the frequency and magnitude of flood events. In a study that controlled for socioeconomic and geophysical factors, Brody et al. (2008) discovered that wetland loss in 37 coastal counties in Texas significantly exacerbated the level of flood damage and added over $38,000 in average property damage per event to a city's budget. Watson et al. (2016) applied a simulation model to evaluate wetland protection, finding that growing wetland losses increased stream peak flow. Although non-total-loss forms of wetland alteration (e.g., degraded quality) may reduce functionality and the provision of ecosystem services (Millennium Ecosystem Assessment, 2005), wetland *loss* removes these benefits entirely by transforming the ecosystem, thereby dramatically reducing the resilience of communities confronting natural hazards (Brody et al., 2012, 2008). It is for this reason, and the recent availability of reliable and accurate data which tracks wetland loss (see Methods), that we focus on wetland loss in this study.

Factors Associated with Wetland Loss

Prior studies related to plan integration have suggested a link to environmental resilience (Yu et al., 2020), of which wetlands are an often-critical component. Examining that relationship with greater nuance and testing it in an empirical setting is the core aim of this research. By way of increasing the robustness of that investigation in this exploratory study, we include additional factors associated with wetland loss and relevant to land use, based on a review of the literature. Research suggests strong relationships between wetland loss and individual built environment and social factors, including development intensity (Brody et al., 2006; Mustafa et al., 2018); physical vulnerability (Godschalk, 2003; Brody et al., 2008); and community socioeconomic status (Anguelovski et al., 2016). Understanding these leading variables in combination and including them in the analysis will better illuminate the theoretical association of plan integration and wetland loss. Each factor and its suggested association with wetland loss is explained below.

First, plan integration is an important factor associated with wetland loss (Yu et al., 2020; Newman et al., 2017). As noted, the resilience of the built and natural environments is strongly influenced by a city's network of plans. Berke et al. (2015) originally designed a resilience scorecard to better analyze a community's networks of plans with respect to physical and social vulnerability, in response to calls for better integration of natural hazards planning. Yu et al. (2020) extended the prior research by applying the scorecard to environmental vulnerability, defined as the potential of an ecosystem to respond to stress and threats across time and space (Williams & Kapustka, 2000). The Plan Integration for Resilience Scorecard (PIRS)™ enables the evaluation of a community's network of plans to measure the degree of coordination in different geographic areas in a community (Berke et al., 2018; Yu et al., 2021). Researchers applied the resilience scorecard in six communities vulnerable to coastal flooding and sea level rise in the U.S (Berke et al., 2018; Yu et al., 2021), and later in two communities in the Netherlands (Malecha et al., 2018; Yu et al., 2020). They aimed to address the crucial issue of plan integration, and to demonstrate how planning can more effectively respond to the growing losses posed by hazard events, inform the public and decision makers, and highlight gaps and conflicts in planning and policy instruments (Berke et al., 2019; Malecha et al., 2021).

Second, land use development patterns and trends are highly related to flood vulnerability and wetland loss (Xu et al., 2018). Increased development concentrated within a flood zone typically results in increased damage and more people negatively affected. Relatedly, development density impacts flooding risk (Mustafa et al., 2018). Increases in density create more impervious surfaces, which then generate more runoff (Brody et al., 2006; Muñoz et al., 2018). Increased impervious surfaces from development in coastal areas leads to often-irreversible environmental damage, including loss of farmland, the destruction of natural and open spaces, and a loss of wetlands and other lands that naturally attenuate flooding and act as buffers (Brody et al., 2008; Muñoz et al., 2018). Current development patterns tend to ignore the ecosystem service benefits of otherwise functional lands, such as wetlands (McPhearson et al., 2015).

Different intensities of development affect wetland loss differently (Brody et al., 2006). Development intensity refers to the proportion of land area taken up by impervious surfaces (e.g. parking lots, driveways, roofs) as a result of development (see Table 1). Several studies focus on the environmental impacts and consequences of low-intensity development (Brody et al., 2006; Kahn, 2000). These studies found that even low-intensity development is strongly related to wetland loss, largely due to the employment of conventional development practices, which significantly alter the natural environment despite relatively low building or population densities.

This study tests the association between multiple intensities of development and wetland alteration in flood-prone areas.

Regardless of the level of intensity, policies to mitigate wetland loss are often articulated and implemented in a reactive, and thus less effective, manner. Burby and French (1981) articulated the “Land Use Management Paradox”— that communities tend to take strong hazard mitigation initiatives only after substantial floodplain development. However, once development has occurred in the floodplain, such land use management is effective neither in mitigating the flooding hazards nor in preventing more floodplain development. Similarly reactive policy responses are found in the realm of environmental policy (Brody, 2012; Haeuber, 1998) as “train wrecks” of ecological mismanagement often must occur before the enactment of major environmental programs.

Third, physical vulnerability, the expected degree of loss or damage resulting from the impact of a flood event on the built environment, is associated with wetland loss (Thiagarajan et al., 2018). Dimensions of physical vulnerability include buildings, structures, infrastructure, level of financial investment and structural integrity (Masterson et al., 2014). Physical vulnerability involves the interaction between geophysical forces and the built environment (Yu et al., 2021; Dong et al., 2021), and is often the result of human decisions to place property in hazardous locations. Studies suggest that more physically vulnerable areas, which receive more investment, are often the focus of policy attention aimed at further densification and greater pressure to transfer wetland areas to development (Godschalk, 2003; Brody et al., 2008).

Fourth, several scholars have suggested that people with higher incomes are more likely to value the protection of the natural environment (Dunlap et al., 2000). Moreover, Lubell et al. (2009) noted that communities with higher socioeconomic status tend to be more supportive of implementing environmental policies to protect wetlands. Resilience issues in affluent neighborhoods can be more easily addressed than lower socioeconomic ones due to increased resources (Anguelovski et al., 2016). Flocks et al. (2011) found that lower income communities had the lowest ecological resilience and the least amount of ecosystem services. Improved implementation of environmental policies ensures greater emphasis on wetland areas and encourages ecologically resilient communities.

Methods

This research evaluates the association between wetland loss and four likely related urban factors – plan integration, development intensity, physical vulnerability, and community socioeconomic status – by way of a comparative analysis of two case studies. We compare Fort Lauderdale, FL, with League City, TX, both of which are low-lying littoral cities in the southern United States exposed to coastal and fluvial flooding, containing large amounts of wetlands. Both are also faced with development pressures. The cities differ, however, in their development stages. Fort Lauderdale is almost fully built out, whereas League City contains large undeveloped areas and is still growing rapidly. Fort Lauderdale also contains over twice as much land as League City and has a much higher amount of its population residing within the 100-year floodplain. Table 1 indicates the land area exposed to the 100-year floodplain, as well as the population, average parcel value, and average per capita income in these exposed areas in Fort Lauderdale, FL and League City, TX. They also differ with respect to their economic and governance contexts: Fort Lauderdale is a cultural and economic hub of the northern Miami metro area, in a state with historically progressive land use planning (Burby, 1998), while League City is a growing bedroom community in metropolitan Houston, known for a much more laissez faire approach to planning and land use. Our primary aim in this exploratory analysis is to investigate the relationship between plan integration and wetland loss, and whether that relationship is stronger in the built-out community or the rapidly developing one. Several other potentially relevant factors are also investigated.

Table 1. Contextual Conditions in Fort Lauderdale, FL and League City, TX (100-year floodplain), 2010.

The unit of analysis is the sub-jurisdictional district within the hazard zone (100-year floodplain) in Fort Lauderdale and League City (Figure 1). U.S. Census block groups are a convenient and widely utilized sub-jurisdictional spatial unit (Masterson et al., 2017) which form the basis for delineating districts in the study cities. Specialized planning districts (e.g. 'downtown') are often the focus of planning initiatives and policies, and are therefore included, along with the block groups, to form context-specific layers of mutually exclusive districts—111 districts in Fort Lauderdale and 21 districts in League City.

Hazard zones comprise the spatial extent of the community affected by a particular hazard—in this case, flooding. Despite occasional challenges (National Research Council, 2012), the FEMA-delineated 100-year floodplain remains a widely accepted and influential driver for local land use policy and is thus used as the hazard zone for this analysis. Districts within this hazard zone are examined for each of the study cities (Figure 1). As this study focuses specifically on wetland alteration within the defined hazard area, we apply FEMA Digital Flood Insurance Rate Maps. We test the *Pearson's r* to understand the relationships between wetland alteration and four key factors: the level of plan integration, development intensity, physical vulnerability, and community socio-economic status (Table 2).[1] Future studies should include additional variables, such as community planning capacity (Norton et al., 2018) and recent experience with flooding (Yu et al., 2021). Future studies should also build on these results to include more case studies and enhance the generalization of the methodological approach and results from this paper's initial exploratory findings.

Figure 1. Planning districts and hazard zone in Fort Lauderdale, FL, and League City, TX. The 100-year floodplain is shown in blue.

Wetland alteration is measured by proportion of area change in wetland cover from 2006 to 2016 within the 100-year floodplain in each district (Brody, Peacock & Gunn, 2012; Brody et al., 2015), calculated by summing 30m^2 pixels from Landsat Thematic Mapper remote sensing imagery. District-level plan integration scores are measured via an index derived from applying the PIRS™ method (Berke et al., 2015, 2018; explained in greater detail below). Development intensity is measured by proportion of area change in low-/medium-/high-intensity development land cover from 2006 to 2016 (Brody et al., 2012; 2015). Low-intensity development is defined as areas with impervious surfaces occupying 20-49% of the total area; these areas typically include single-family housing units. Medium-intensity development is defined as areas with impervious surfaces occupying 50-79% of the total area; these also typically include single-family housing units, but with smaller lots. Finally, high-intensity development is defined as areas with impervious surfaces occupying 80-100% of the total area; these typically include apartment complexes, as well as commercial and industrial areas (Homer et al., 2012; Anderson, 1976). Physical vulnerability is ascertained using improved parcel value as a proxy (Patterson & Doyle, 2009; Shi & Yu, 2014) and summing the values of all parcels within the hazard zone in each district (Yu et al., 2021). Socioeconomic status is measured via per capita income (Lubell et al., 2009; Grube et al., 2014).

Table 2. Factors Examined in This Study

The key variable of plan integration is ascertained by spatially evaluating the network of adopted plans in each community that were in place prior to 2016, following the PIRS™ method

(Yu et al., 2020; Malecha et al., 2019). We include primary land use plan documents that were adopted between 2006 and 2016. These plans were used by each city to guide development during the period that we evaluate wetland alteration (change in wetland cover from 2006 to 2016) and include six plans in Fort Lauderdale and four plans in League City (Table 3). To produce plan integration scores, each district in the hazard zone is assigned a score of '+1', '-1', or '0' for every applicable land use policy in each plan (see Yu et al., 2020 for a detailed explanation of this process). A score of '+1' indicates that the policy is expected to positively affect flood vulnerability, while '-1' indicates a negative effect. A score of '0' indicates that the land use policy does not affect flood vulnerability in the district. After scoring each applicable policy, the resultant scores are summed for each district in the hazard zone. District scores then summed for each plan and across the entire network of plans and divided by the number of districts to compute a mean policy score (Table 5). Findings from this approach indicate the level of plan integration, with higher scores indicating a stronger focus on mitigating flood vulnerability in the community's network of plans. The policy scoring process is performed independently by two trained researchers, with intercoder reliability calculated using both percent agreement for each policy (mean = 91.04%) and Krippendorff's Alpha (mean = 0.78) (Freelon, 2013).

Table 3. Networks of Plans in Fort Lauderdale and League City

Findings

Wetland Alteration

A significant proportion of the naturally occurring wetland areas occupy the floodplains of both Fort Lauderdale and League City as of 2016 (Table 4). In Fort Lauderdale, wetlands currently cover 670.08 acres (6.2% of the 100-year floodplain land area), including both palustrine wetland (512.4 acres) and estuarine wetland (157.68 acres). In League City, wetlands include 492.83 acres (9.51% of the 100-year floodplain land area), including 347.83 acres of palustrine wetland and 145 acres of estuarine wetland.

Table 4. Wetland Alteration in Fort Lauderdale, FL, and League City, TX, from 2006 to 2016 (in the 100-year floodplain)

Wetland loss was greater in Fort Lauderdale (Appendix Figure A.1) than League City (Appendix Figure A.2) between 2006 and 2016. In Fort Lauderdale, the total wetland area in 2006 was 885.35 acres, but 215.27 acres (24.31%) of wetlands were lost between 2006 and 2016. In League City, the total wetland area in 2006 was 553.99 acres, with 61.16 acres (11.04%) of wetlands lost over 10 years.

Whether the cities' networks of plans are aligned toward protecting wetlands remains unknown. The remainder of this study is devoted to (1) examining plan integration performance in Fort Lauderdale and League City, identifying what policy themes and frameworks are built into the networks of plans to reduce hazard vulnerability and protect wetlands, and (2) testing the associations of plan integration, development intensity, physical vulnerability, and socioeconomic status with wetland loss between 2006 and 2016.

Plan Integration

Overall mean policy scores indicate that the network of plans generally supports vulnerability reduction in the 111 districts within the 100-year floodplain in Fort Lauderdale, FL, as well as the 21 districts in League City, TX—in large part through the protection of wetlands and environmentally significant areas. Overall mean policy scores for districts from the six plans in Fort Lauderdale (13.86) and four plans in League City (29.10) between 2006 and 2016 are relatively positive (Table 5), and the plans include many policies aimed at environmental protection. Compared to Fort Lauderdale, plan integration and vulnerability reduction appears stronger in League City, suggesting a difference in flood mitigation and wetland protection priorities between the two communities. These broad trends can be better understood through a closer inspection of the individual plan scores.

Table 5. Mean Policy Scores for Plans in League City and Fort Lauderdale (100-year floodplain)

Fort Lauderdale's network of six plans, adopted between 2006 and 2016, is relatively well-integrated and generally reduces vulnerability to hazards. The mean policy score for the 2008 Fort Lauderdale Comprehensive Plan is 5.53, while the mean policy score for the Enhanced Local Mitigation Strategy is 6.23. The coastal management element in the Comprehensive Plan explicitly uses wetland preservation and other resource protection policies that support wetland protection like development prohibitions and buffer requirements to satisfy the requirements of Chapter 163, Florida Statutes that "local coastal governments plan for…[and] restrict development where development would damage or destroy coastal resources and protect human life and limit public expenditures in areas that are subject to destruction by natural disaster" (Fort Lauderdale 2008, p. 4-1). However, mean plan scores are negative for the other four plans in the network, including the 2007 Davie Blvd. Corridor Master Plan (-1.00), the 2007 Downtown Master Plan (-1.00), the 2008 Downtown New River Master Plan (-2.00), and the 2010-2015 Consolidated Plan (-0.08). The variability in direction and strength of scores suggests differences across the study plans in terms of emphasis and prioritization of the policy frameworks supporting hazard vulnerability reduction, including through natural means. Throughout the four negative scoring plans, more attention is paid to (re)development in the downtown and corridors, and little or none is given to environmental protection.

Several notable policy themes work together in reducing existing vulnerability, protecting wetlands, and preventing future vulnerability due to new development or redevelopment. First, we find development regulations explicitly focused on protecting coastal areas and hazard-prone locations. Policies found in multiple chapters of the city's comprehensive plan encourage protection and conservation of existing wetlands, especially in hazardous areas. Second, land acquisition policies and guidelines for land use in hazard-prone areas are often targeted at reducing vulnerability for new developments and redevelopment projects, especially by avoiding low-lying and wetland areas (Masterson et al., 2017). Fort Lauderdale's comprehensive plan contains policies suggesting that the undeveloped land in the Coastal High Hazard Area, which includes estuaries, lagoons, and coastal mangroves, should be considered for acquisition as recreation and open space and restoration to its natural state. Moreover, the specific and cumulative impacts of development or redevelopment should be "limited upon wetlands, water quality, water quantity, wildlife habitat, living marine resources and the beach dune system" (City of Fort Lauderdale, 2008). Finally, many policies are aimed at directing capital expenditures related to coastal, sensitive, and hazard-prone areas—many of which contain wetlands.

League City's Parks and Open Space Master Plan (2006), Local Mitigation Plan (2010), Comprehensive Plan (2013), and 5-year Strategic Plan (2012) support a common policy framework aimed at open space protection, including wetlands in low-lying areas and along Clear Lake/Creek, and hazard mitigation, with a mean plan score of 4.48 for the Parks Plan, 4.43 for the Local Mitigation Plan, 19.67 for the Comprehensive Plan, and 0.52 for the 5-year Strategic Plan across the 21 districts within the 100-year floodplain (Table 5). The Parks Plan and Local Mitigation Plan include the adopted future land use map, used by the city to guide future development and redevelopment. Areas designated for parks and low-density development generally coincide with flood hazard zones – riparian areas and wetlands, in most cases – and are supported by policies within each plan. A core attribute of the four plans is to protect people and structures using smart development and environmental management practices aimed at supporting flood mitigation and protection of natural means of flood attenuation.

There are several themes in the policies drawn from League City's plans that focus on limiting development in existing floodplain areas and protecting wetlands. First is the suggested designation of public expenditures for expansion of open spaces in undeveloped floodplains. The Parks and Open Space Master Plan specifies that city funds for land acquisition be used to target undeveloped preservation areas (e.g., marshes, wetlands) that offer flood mitigation benefits as well as recreational and other open space benefits, such as wildlife habitats and water conservation. Policies in the Local Mitigation Plan explicitly support public investment in parks and open spaces, including existing wetland areas, in the floodplain. Second, land use regulations often require reduction in vulnerability for new development in undeveloped floodplain areas, which includes avoiding development in hazardous and sensitive places. The implementation elements of both plans indicate that the city revise ordinances to carry out the intentions of the comprehensive plans. Finally, the plans suggest public facilities for parks that will reduce the impacts of flooding. The parks plan proposes investment in a string of flood detention lakes, connected by trails, to be located along a regional drainage corridor with parks integrated in areas adjacent to the lakes and marshes.

Associations between Wetland Alteration and Plan Integration, Development Intensity Change, Physical Vulnerability, and Income

Findings in the previous section reveal discrepancies in how plans are focused on ecological resilience in Fort Lauderdale and League City, most conspicuously in how they target vulnerability reduction and, especially, wetland protection. In Figure 2, wetland alteration between 2006 and 2016 is correlated with four different factors (plan integration scores for plans adopted between 2006 and 2016; development area change between 2006 and 2016; physical vulnerability; and per capita income). Correlation results are shown for Fort Lauderdale and League City, at the district scale, within the 100-year floodplain.

Figure 2. Correlations between wetland alteration and plan integration score, change in low-/medium-/high-intensity development, physical vulnerability and per capita income.

The results indicate *a significant inverse relationship* between *wetland alteration* and *plan integration scores* in both Fort Lauderdale (-0.26) and League City (-0.54), with the negative correlation about twice as strong in the latter. Districts that experienced greater wetland loss have higher plan integration scores. That is, areas of the community with the greatest wetland loss are the focus of more environmentally friendly policy attention. This finding may reflect the adoption of policies across the communities' networks of plans to stem the trend of wetland loss and strengthen resilience, particularly in areas that have already experienced environmental degradation. This appears to be an example of the Land Use Management Paradox, articulated by Burby and French (1981), wherein vigorous floodplain land use management programs are adopted and implemented only after the start of development within and proximate to the hazard area, thereby limiting program effectiveness. It may also be true that districts with greater wetland loss are the focus of more development pressure and planning attention, and are thus the focus of more *total* policies, including those meant to strengthen environmental protection.

Variation exists, however, between the two cities. Fort Lauderdale is a nearly fully built-out city, and its level of plan integration has a somewhat weaker association with wetland loss than is the case in League City, a rapidly developing community. Appendix Figure A.2 shows that most of the wetland area in League City is along the creek, proximate to intense development. That area has high potential to be further densified and also experiences high development pressure. A well-coordinated policy framework to reduce existing vulnerability and protect wetlands for the city as a whole may therefore have been put in place to focus policy attention on wetland loss "hotspots" in League City (Appendix Figure A.2). This suggests that the network of plans targets areas of higher wetland loss, particularly in League City. Plans may be reacting to such trends in wetland loss and explicitly setting priorities to better conserve wetlands.

Correlation results between *wetland alteration* and change in *low-intensity development* are positive for Fort Lauderdale (0.31) and negative for League City (-0.57) (Figure 2). Both results are significant at the 99% confidence level. In Fort Lauderdale, an increase in low-intensity development is associated with less wetland loss. This suggests that wetland areas are not generally transformed into low-intensity development; rather, areas of low-intensity development may be densified into medium- or high-density development areas. In sum, in Fort Lauderdale, losses in low-intensity development exist alongside small losses in wetland area between 2006 and 2016, suggesting a general rise in development intensity rather than deliberate targeting of wetlands (Figure 2). As the comprehensive plan suggests, "…the City is nearly built-out, [so] new development is unlikely to impact threatened and endangered species in the coastal area. Coastal vegetation is not likely to be impacted by development because there are very few vacant development sites and redevelopment sites are already disturbed" (Comprehensive Plan, 2008, Coastal Management Element, Page 4-8). Positive correlations are also found between *wetland alteration* and change in *medium-intensity* (0.28) and *high-intensity development* (0.27) in Fort Lauderdale, but with less magnitude. This may indicate that developed lands of all intensities in Fort Lauderdale's 100-year floodplain are either being further intensified *or* returned to managed open space between 2006 and 2016, consistent with the preservation-minded network of plans described above.

In contrast, in League City, wetland area loss within the 100-year floodplain of a district is significantly correlated with an increase in low-intensity development (-0.57). Significance is not shown with respect to medium-intensity and high-intensity development, however. This suggests a transfer of wetland areas into low-intensity development between 2006 and 2016 in the 100-year floodplain, a trend indicating that League City's network of plans may be attempting to arrest via preservation-focused policies aimed at still-undeveloped areas.

Correlation results for physical vulnerability are relatively weak and not significant for both Fort Lauderdale (-0.03) and League City (0.12). Not much can therefore be concluded about the association between wetland loss and physical vulnerability, at least based on these two case examples. It is possible, and perhaps likely, that development pressure is acting as a moderating variable, leading to both wetland loss and higher physical vulnerability due to increased land development and the resulting increased value. Districts with relatively high physical vulnerability are typically high-value areas that have been the focus of significant investment and of policies aimed at further intensification or redevelopment. However, again, the Land Use Management Paradox may also be at work, leading to greater attention on preserving the remaining vestiges of wetlands in places that have already experienced significant development. This insignificant finding may therefore be the result of these mechanisms canceling each out.

For per capita income, correlation results are weakly negative for Fort Lauderdale (-0.03) and moderately negative for League City (-0.25), though neither is significant. This suggests that wetland loss may be greater in wealthier areas between 2006 and 2016 for both cities. Wealthier districts are typically desirable locations where development pressures are likely to be greater. Thus, districts with high per capita income generally have greater potential for development, including wetland areas.

Conclusions and Implications

This study sought to evaluate plan integration and its association with wetland loss in two coastal cities, and whether there are differences in this association between built-out cities (Fort Lauderdale) and rapidly developing ones (League City). We examined how wetland cover within hazard areas changed in Fort Lauderdale and League City and how four key factors related to that change. Findings indicate that a higher level of integration within the networks of plans are associated with areas of greater wetland loss in both cities, indicating that policy groundwork is being laid for higher future flood-resilience and more robust ecosystems. The cities may be reacting to trends in wetland loss and explicitly setting priorities in their plans to better conserve wetlands, meaning future wetland loss may be deterred in areas with higher plan integration. Several prominent themes of policies are integrated into the community networks of plans of both Fort Lauderdale and League City that protect the functionality of wetland areas and reduce hazard vulnerability. Fort Lauderdale’s plans focus on protecting the remaining wetlands by preserving them through acquisition and ensuring that redevelopment avoids the most hazardous areas, especially wetlands. League City’s approach to use public investment to expand parks and open spaces in undeveloped floodplains, as well as to guide new development away from flood-prone and environmentally sensitive places.

Despite these similarities, the greater magnitude of the inverse correlation in League City may indicate that the faster growing, non-built-out community has more flexibility to institute policy changes that manage growth and more effectively guide development. In contrast, built-out cities – especially if they are landlocked or fixed, like Fort Lauderdale – may be forced to limit their wetland preservation interventions to make room for new development. The rate of change in wetland land cover loss within the 100-year floodplain was faster in Fort Lauderdale (-24.31%) than in League City (-11.04%) from 2006 to 2016.

Differences between the two case study communities also extend to the other factors. Wetland loss is shown to be positively associated with high-, medium-, and low-intensity development patterns in Fort Lauderdale (all significant at $p < 0.01$), while the opposite is true for League City (significant for low-intensity development only). For Fort Lauderdale, this suggests major development changes in areas of the city that lost wetlands during this time, but more often in the form of redevelopment and intensification. In contrast, in League City, more wetland area is apparently lost to low-intensity development between 2006 and 2016 in League City, perhaps due to different development preferences and less restrictive land use regulation. In both cases, however, positive plan integration scores and a variety of policies aimed at preserving the remaining wetlands and natural areas suggest that the communities are attempting to reduce further losses and strengthen ecological resilience.

District-level correlations for physical vulnerability and per capita income were relatively low and not significant for either study community. While this may indicate that neither factor is associated with wetland loss, it may also be the case that mediating or moderating variables beyond this analysis may be having an effect. As referenced above, development pressure should be included as a potential moderator, while the community's planning capacity (Norton et al.,

2018) and recent experience with flooding (Yu et al., 2021) might be attributes that mediate between built environment and socioeconomic factors and wetland loss. Follow up studies should test this assumption by expanding the suite of variables that are considered in this analysis.

Wetlands play a significant role in ecosystem services, regardless of whether a city is growing or fully built-out. Communities are increasingly adopting wetland preservation policies because naturally occurring wetlands provide various essential ecosystem services to communities, and their loss is shown to amplify property damage from floods over a larger area, especially in coastal regions. Undervaluing these important natural ecosystems could compromise public safety. Urban resilience functions and services provided by wetlands include buffering storm surge and attenuating flooding, improving water quality by filtering pollutants and sediment and quantity by storing floodwater and assisting with groundwater recharge, and sustaining or increasing biodiversity by providing rich habitat and resources (Millennium Ecosystem Assessment, 2005). These benefits, in turn, positively affect the local economy and quality of life by contributing to a safer, healthier environment (Haase et al., 2014).

For these reasons, policies and management strategies that protect wetlands, preserve natural ecosystems, and exceed NFIP requirements should be integrated throughout a community's networks of plans. Effective planning that helps protect naturally occurring wetlands can help build resilient communities and reduce losses from hazard events. Efforts like those found in the plans of Fort Lauderdale, FL, and League City, TX, and detailed in this article, should become standard practice, especially in coastal communities. Ideally, they would be recommended by planning staff and adopted by communities as early as possible, avoiding the

Land Use Management Paradox that is all too common in the U.S. and that likely occurred in Fort Lauderdale and League City. They must also be vigorously enforced.

The process of integrating wetland protection into a local network of plans not only helps reduce the impact on wetlands, along with the associated ecosystem services, but also enables a community to set priorities to conserve critical wetland “hotspots”. By doing so, the planners and city councils of Fort Lauderdale and (especially) League City have enabled their communities to take better advantage of the wide-ranging benefits of their wetland in the years to come. Lessons from these case studies should inform researchers, instructors, practicing planners, and planning students alike and proactively integrate.

Future research should build upon this initial evaluation by incorporating additional planning and community variables – including those that might moderate or mediate the factors included in this study – to more holistically investigate the association between plan integration and wetland losses, and whether causal links can be established regarding key influential factors. Such variables might include development pressure, community planning capacity (Norton et al., 2018), recent experience with flooding (Yu et al., 2021), local regulatory context and political will (Finn et al., 2019), or the power and actions of local nonprofits (Hopkins & Knaap, 2018). Future studies could also repeat the analysis in additional locations, thereby testing the generalizability of the methods and these initial findings. Alternative data sources, including different definitions of hazard zones, could also be explored to ascertain whether the identified relationships hold. Finally, reaching beyond statistical analysis and using mixed methods, especially surveys and qualitative interviews, and incorporating community input and collaboration as part of the research design would add depth and nuance to give a more complete picture of the drivers that lead to effective integration of networks of plans and enhanced wetland protection.

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Endnotes

State-mandated planning is a potentially extraneous factor not controlled by the research design and statistical measurements employed in this study. In particular, during the 2006-2016 study period Florida had state mandated local planning in place since the 1970s, but Texas did not. Since this difference is not accounted for, the analysis could produce spurious results. The presence of a state mandate could create a climate in Florida that is more supportive of planning to support wetland protection than existed in Texas, so that the associations attribute to the Florida mandate could in fact be linked to the mandate rather than the plans that are studied. Nevertheless, the other factor linked to change in low-intensity development creates pressure for supporting wetland protection, which adequately addresses this threat to validity.