



# Spatial comparisons in wetland loss, mitigation, and flood hazards among watersheds in the lower St. Johns River basin, northeastern Florida, USA

Nisse Goldberg<sup>1</sup> · Russell L. Watkins<sup>2</sup>

Received: 7 August 2020 / Accepted: 22 June 2021 / Published online: 6 July 2021  
© The Author(s), under exclusive licence to Springer Nature B.V. 2021

## Abstract

Wetlands provide invaluable ecosystem services to moderate the effects of flooding. In the United States, Sect. 404 of the Clean Waters Act requires that mitigation of impacted wetlands from issued Environmental Resource Permits (ERPs) occur in the same watershed. This study investigated spatial patterns of impacted wetlands and compulsory mitigation (e.g., preservation and/or purchase of mitigation bank credits) in three watersheds of the lower St. Johns River basin, Florida, from ERPs submitted in 2006–2019. Each watershed was stratified by the Federal Emergency Management Administration's (FEMA) designated 100-year floodplain, 500-year floodplain, and outside the floodplain. Flood hazards (e.g., projected 2030 Sea Level Rise, seasonal nuisance high tides, and storm surge) were compared among the three floodplain categories with ERP data, age and value of residential structures, FEMA field assessment following Hurricane Irma in 2017, and a composite flood hazard score. Results indicated that wetland loss occurred primarily in the 100- and 500-year floodplains, and wetlands were at greatest risk from projected 2030 SLR and nuisance high tides. These ERPs planned to preserve upland and wetlands by purchasing credits from banks located in areas with low risk of flooding. Older houses were typically in areas with greater flood hazard exposure, with higher home values. This study demonstrated that a watershed evaluation of flood exposure should be considered for future development, regardless of floodplain category. Given the significant social and economic costs from flood damage, community planners should prioritize protection of wetlands and open spaces in areas most vulnerable to flood hazards.

**Keywords** Flood hazards · Floodplains · Mitigation · Wetlands

---

✉ Nisse Goldberg  
ngoldbe@ju.edu

<sup>1</sup> Department of Biology and Marine Science, Jacksonville University, Jacksonville, FL, USA

<sup>2</sup> Threshold Spatial Sciences, St. Augustine, FL, USA

## 1 Introduction

Wetlands contribute valuable ecosystem services to moderate surge and flooding associated with extreme storm events, seasonal high tides, and sea level rise. In particular, wetlands help to decelerate runoff, increase water infiltration and attenuate floodwaters (Highfield and Brody 2006; Goldberg and Reiss 2016). For example, Novitski (1985) calculated that 5% of lake and wetland areal coverage can reduce flood peaks by 40–60% and Johnston et al. (1990) reported an increase in floodwater speeds with a decrease of 10% in wetland cover.

Floodplain delineations provide homeowners, insurance companies, and communities guidance regarding the economic and human risk associated with development in the floodplain. The Federal Emergency Management Administration (FEMA) flood zones are areas defined by their potential for inundation from water cresting the banks of a waterway (FEMA 2020a). The 100-year floodplain is an area that has 1% annual chance of flooding as compared to the 500-year floodplain which has a 0.2% annual flood risk and is rated as a minimal flood hazard region. Areas with undetermined flood hazards are outside these two flood zones (FEMA 2020a). Highfield et al. (2013) argue that these designations do not accurately predict the likelihood for flooding because they do not highlight the predictive uncertainty with respect to local conditions, climate, and assumptions of the flood prediction models.

Section 404 of the Clean Waters Act requires an Environmental Resource Permit (ERP) for projects that impact wetlands typically from dredge and fill activities. The United States Army Corps of Engineers, the Florida Department of Environmental Protection, and regional water districts evaluate the ERP applications. Proposed compensatory mitigation plans may include upland or wetland preservation, or wetland creation, enhancement, or restoration (ACOE 2020). In addition, permittees may opt to purchase credits from a mitigation bank within the service area to offset impacts to freshwater and palustrine forested and herbaceous, estuarine, and saltwater wetlands and marshes. Mitigation banks are locations with restored, enhanced, established, or preserved wetlands and other natural resources located in riparian zones, streams, and upland habitats. Bank sponsors are private entities that must provide a mitigation plan before credits can be released and a commitment to maintaining the natural resources in perpetuity (ACOE 2020). In Florida, credits are released by the United States Army Corps of Engineers, and either the Florida Department of Environmental Protection or St. Johns River Water Management District as based on the bank's achievement of ecological performance-based standards. A mitigation bank credit's value is commensurate to the ecological function per wetland acre as result of meeting ecological performance objectives and can range from tens to hundreds of thousands of dollars per credit (ACOE 2020). For the most part, mitigation banks in northeastern Florida were formerly silviculture plantations or rangelands with restored wetland habitats and communities (ACOE 2020).

ERP compulsory mitigation plans are meant to protect wetland function in a watershed. Highfield and Brody (2006) recommend that local governments mitigate development with the conservation and protection of open spaces and wetlands. FEMA's National Flood Insurance Program (NFIP) provides homeowners an opportunity to reduce their flood insurance premiums by participating in the Community Rating System (CRS) to support floodplain management (NFIP CRS 2020). Nationwide participation in the CRS program in 1999–2009 contributed to a \$290,036 USD/2020 annual savings in property damage caused by floods, primarily with the preservation of open

space (Brody and Highfield 2013) rather than use of dams for flood protection (Brody et al. 2007).

With pressures to increase development for residential, commercial, and industrial uses, wetland loss can exacerbate flooding. In particular, wetland alteration was the third predictor for flood risk, following rainfall and adjacent damage (Highfield and Brody 2006). Damages from cumulative small floods and events in Florida reached \$1.10 USD/2020 billion from 1997 to 2002 (NCEI 2020) and \$11,350,339 USD/2020 from 2019 to 2020 (FEMA 2020b). In Florida, more than 40% of 118,999 wetland permits were issued in the 100-year floodplain and were correlated with flooding (Brody and Highfield 2005). Between 1997 and 2001, \$1,579 million USD/2020 in property damage occurred in coastal counties with an estimate of \$2,557,264 USD/2020 per flood (Brody et al. 2007). One wetland permit was estimated to increase the average cost of each flood in Florida by \$1,596 USD/2020, with an average \$908,581 USD/2020 of flood damage per county per year, and an average of \$49,063,397 USD/2020 per year for all of Florida (Brody et al. 2007).

Vulnerability models predict flooding from high tides, sea level rise (SLR) and storm surge. Seasonally extreme high tides can increase the vulnerability to nuisance flooding, as has been recorded along the eastern coast of the United States from Key West, Florida, to Eastport, Maine (Ezer and Atkinson 2014). The range in the high tides has increased from 44 to 1096% since the 1990s (Ezer and Atkinson 2014). With climate change, sea level rise is predicted to increase 16–46 cm above mean sea level in Duval County, Florida by 2030 (ACOE 2019). The National Hurricane Center with the National Oceanic and Atmospheric Administration has generated vulnerability categories 1–5 that predict storm surge upriver based on a resolution of tens to thousands of kilometers (National Storm Surge Hazard Maps 2020).

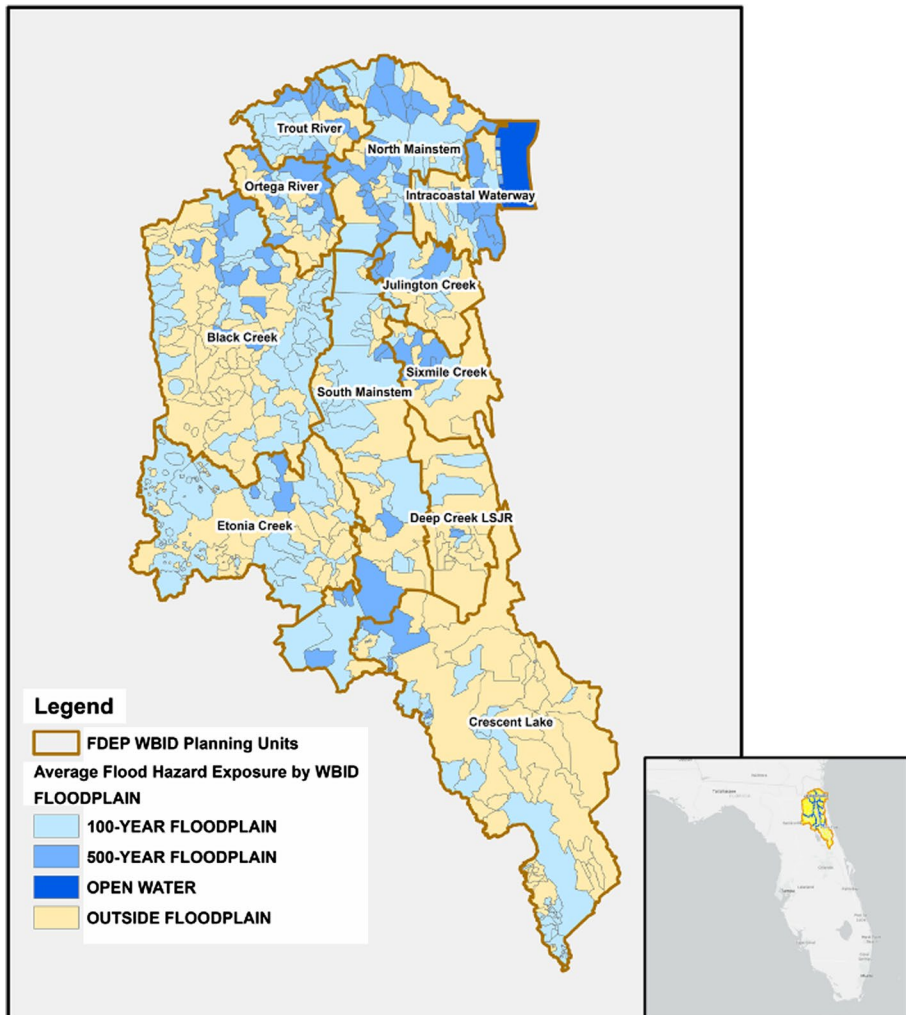
This study followed the recommendations by Highfield and Brody (2006) and Brody et al. (2007) to analyze wetland loss and mitigation across a watershed from 2006 to 2019. The lower St. Johns River basin (LSJRB), Florida, has experienced significant wetland loss due to land conversions with the recent increase in the pace of development (Goldberg and Reiss 2016). This region along the Atlantic coast has experienced substantial growth and development with county populations increasing by 11–39% in the LSJRB from 2010 to 2019 (US Census Bureau 2020). Wetlands make up approximately 25% of the 730,000 ha in the LSJRB and forested wetlands have decreased by 17% from 1973 to 2009 (SRR 2020). Between 2006 and 2013, 57% of the 1046 ha of impacted wetlands were located on parcels described as high-development and mid-development areas and ERP permittees typically opted to purchase mitigation credits instead of onsite wetland preservation, creation, enhancement, or restoration (Goldberg and Reiss 2016).

The objectives of this study were to compare flood risk among three watersheds in the LSJRB among the 100-year, 500-year, and outside the floodplain from 2006 to 2019. Since 2006, the LSJRB has experienced repetitive storm and flooding events that include Tropical Storm Fay in 2008; Tropical Storm Beryl and Debby and Hurricane Sandy in 2012; Hurricane Matthew in 2016; and Hurricane Irma in 2017 (National Hurricane Center and Central Pacific Hurricane Center 2020). Exposures to flood hazards were identified in each of the waterbodies (WBID) that made up a planning unit, using the satellite post-Hurricane Irma flood imagery from 2017 (AER 2018), NOAA 2017 intermediate 2030 SLR projection, high tide flooding (Sweet et al. 2018), and Storm Surge Hazard projections (categories 1–5, National Hurricane Center and Central Pacific Hurricane Center 2020). Each ERP was classified by the flood hazard associated with the permit's WBID. The proportion of cumulative wetland loss and compensatory mitigation measures relative to the LSJRB was compared among the three floodplain categories and seven flood hazards. To

address Highfield et al. (2018) observation that few parcel-level studies investigated storm-surge damage from Hurricane Irma, composite flood hazard exposure score, year built, and home just value of exposed residential buildings among floodplain and flood hazard were evaluated.

## 2 Methods

To compare spatial patterns in total wetland loss, mitigation area, mitigation bank credits, and residential structures, we focused on three watershed planning units North Mainstem, South Mainstem, and Black Creek in the LSJRB from 2006 to 2019 (Fig. 1). Forested



**Fig. 1** North Mainstem, South Mainstem, and Black Creek Planning Units, Florida, with WBIDS located in the 100-year, 500-year, and outside the floodplain

wetlands represented 60%, 71%, and 78% of wetlands in North Mainstem, South Mainstem, and Black Creek, respectively. In the North Mainstem, salt marshes represented 37% of wetlands. Each planning unit consists of a number of waterbodies (WBIDS, Table 1). These WBIDS were identified by their category of floodplain (e.g., 100-year, 500-year, or undesignated (hereafter referred to as outside) floodplain) and flood hazard exposure (Fig. 1). Seven flood hazard categories were compared: 2030 SLR, high tide, and storm hazard categories 1–5 (NHC 2020). In addition, patterns in geocoded ERP parcels with evidence of flooding from Hurricane Irma were compared among floodplain and flood hazard categories.

Publicly available geocoded shapefiles of the LSJRB, planning units, and ERP data were accessed from the Florida Geographic Data Library (FGDL 2020) and the St. Johns River Water Management District (SJRWMD 2020a). The ERP database provides the total impacted wetland acreage and wetland mitigation acreage (preservation, enhancement, restoration, and creation), and/or bank credits per issued permit. A flood hazard grid was created using hexagonal cells with an area of 1 km<sup>2</sup> for the study site. Hexagonal cells provide a more accurate representation of continuous and noncontinuous data across the landscape by minimizing discontinuities or changes in features in space. Flood hazard layers were spatially joined to the grid and relevant hazard attributes were attached to each cell (e.g., FEMA flood hazard zone, high tide flooding status, sea level rise status, and storm surge category). Storm surge categories were classified for clarity into high (categories 1–3) and low (categories 4 and 5) frequency categories. This was calculated by segmenting the distribution of storm categories to strike Florida based on a NOAA-maintained record of 120 storms between 1851 and 2019 (NOAA 2021).

Parcel-level flood hazard exposure was derived from the *Lower St. Johns River Wetland Analysis* app (<https://arcg.is/0SKnDm0>), a browser-based tool for analysis and display of wetlands and housing susceptible to flood-related hazards in the LSJRB. Housing characteristics of interest were extracted from the statewide parcel database (FGDL 2020). Just value and effective year built are of particular importance to this study. Just value is updated annually and defined as fair market value after an adjustment, and effective year built is defined as the year the primary structure was built and then adjusted for significant renovations or depreciation (Florida Department of Revenue 2020). Flood hazard exposure is determined using a simple spatial presence/absence formula comprised of FEMA100- and 500-year floodplains, sea level change projections (2030 and 2050 NOAA intermediate high), storm surge (grouped by high (categories 1–3) and low (categories 4 & 5) frequency), high tide flooding, and post-Irma flooded lands derived from satellite imagery. A

**Table 1** Area (km<sup>2</sup>) and # WBIDs in the LSJRB, Black Creek, North Mainstem, and South Mainstem Planning Units

	LSJRB (km <sup>2</sup> ), WBID (#)	Black Creek Area (km <sup>2</sup> ), WBID (#)	North Mainstem Area (km <sup>2</sup> ), WBID (#)	South Mainstem Area (km <sup>2</sup> ), WBID (#)
100-year	2599.8, <i>n</i> =202	485.9, <i>n</i> =39	238.7, <i>n</i> =18	594.0, <i>n</i> =25
500-year	887.6, <i>n</i> =90	108.6, <i>n</i> =10	204.9, <i>n</i> =26	121.8, <i>n</i> =8
Outside	3832.4, <i>n</i> =218	727.3, <i>n</i> =56	174.1, <i>n</i> =15	318.4, <i>n</i> =20
Total area	7319.8, <i>n</i> =510	1322.5, <i>n</i> =105	618.0, <i>n</i> =59	1034.6, <i>n</i> =56
Wetland area	1825.0	296.8	94.1	203.2

Flood Hazard Exposure Index (FHEI) was calculated using a simple geographic presence/absence analysis, i.e., a parcel or area located within a hazard zone was assigned a value of 1 for that hazard or a 0 if outside the given flood hazard zone. The overall score was calculated as a sum of values ranging from 0 (no exposure) to 8 (exposed to all hazards) and then an average estimate was calculated for cases where the analysis feature spanned multiple cells. The flood hazard exposure for each ERP was derived by averaging flood hazard exposure within the project's WBID location. The app contains 27 data layers and allows for the visualization and simple query of all spatial data used in this study.

A Kruskal–Wallis test was used to test for differences in the following ERP variables: total wetland loss, mitigation area, and mitigation bank credits per floodplain category. In addition, the median total exposure scores, year built, and home just value in 2020 USD were compared among flood hazard categories. A United States Inflation Calculator was used to convert dollar values to 2020 USD (US Inflation Calculator 2021). If there were significant differences ( $p < 0.05$ ) among floodplains, then Dunn pairwise comparisons were conducted among the flood hazard categories.

### 3 Results

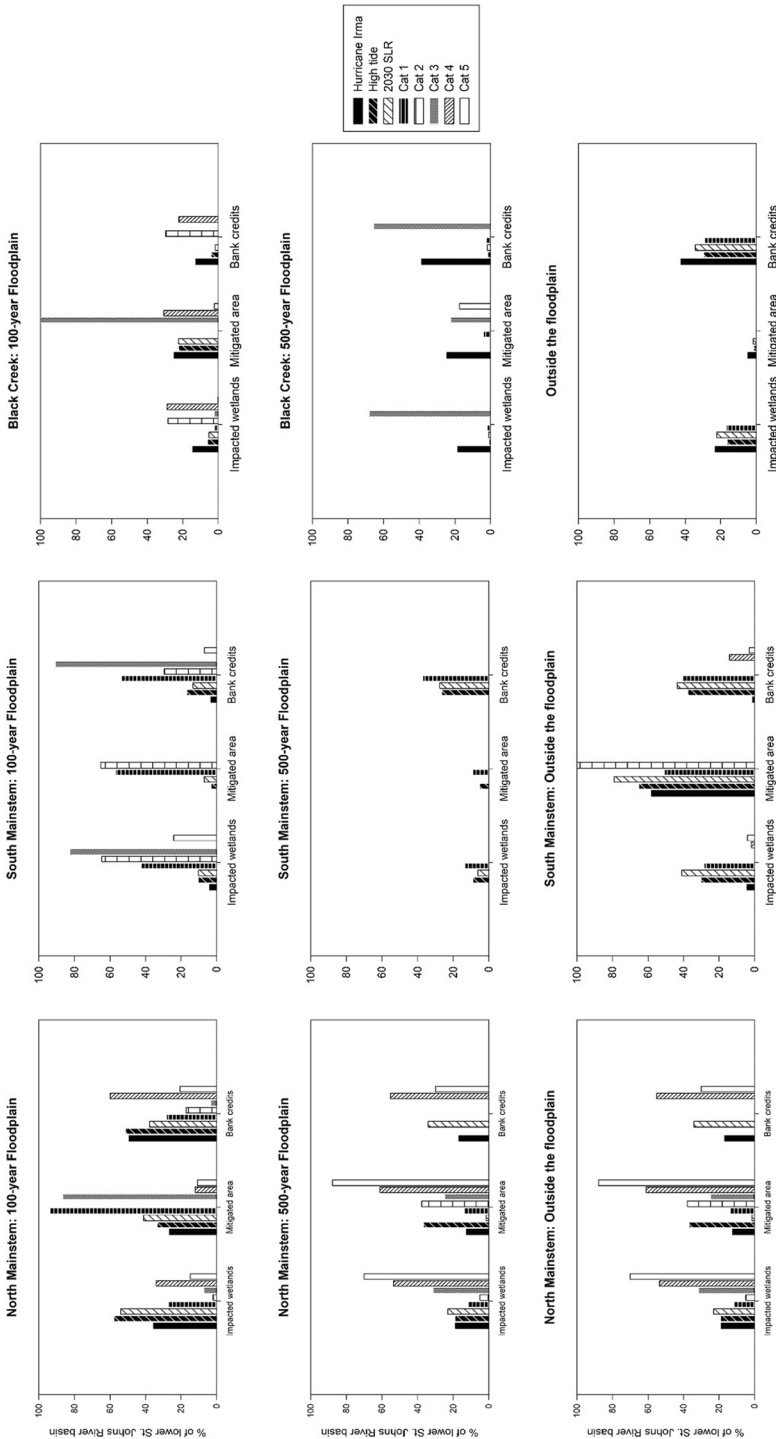
#### 3.1 Patterns in ERP impacted wetlands and compulsory mitigation

In the LSJRB from 2006 to 2019, 52.7% of impacted wetland area was located in the LSJRB 100-year floodplain (Table 2). These impacted wetlands represented 34.6% of the ERPs processed in the LSJRB. Of the 11 planning units in the LSJRB, Black Creek, North and South Mainstem represented 40.6% of the areal coverage (Table 1) and 43.2% of the impacted wetlands (Table 2) in the LSJRB. The percentages of impacted wetlands relative to the LSJRB were 12.5% in the North Mainstem, 31.0% in the South Mainstem, and 21.7% in Black Creek (Table 2).

The proportions of impacted wetland area differed among the three planning units, yet the potential for flooding was present irrespective of whether the ERP project was located inside or outside of the floodplain (Fig. 2). In the 100-year floodplain, total impacted wetland area was greatest in the North and South Mainstem with 13.4% and 51.5% of the 9.7 km<sup>2</sup> impacted wetlands in the LSJRB (Table 2). Most notably, 95.7% of the North Mainstem's 2.3 km<sup>2</sup> of impacted wetland area was located in the 100- and 500-year floodplain. In addition, 54% impacted wetland area in the LSJRB was identified in WBIDS with

**Table 2** Total mitigated impacted wetland area, total preserved, created, enhanced or restored area, and total number of bank credits for mitigation in the LSJRB, Black Creek, North Mainstem, and South Mainstem Planning Units. Total number of ERPs indicated in parentheses

Floodplain	LSJR km <sup>2</sup> /km <sup>2</sup> /# credits (# ERPs)	Black Creek km <sup>2</sup> /km <sup>2</sup> /# credits (# ERPs)	North Mainstem km <sup>2</sup> /km <sup>2</sup> /# credits (# ERPs)	South Mainstem km <sup>2</sup> /km <sup>2</sup> /# credits (# ERPs)
100-year	9.7/18.0/1351.8 (389)	1.2/6.5/105.0 (71)	1.3/2.6/243.7 (78)	5.0/3.8/740.7 (67)
500-year	3.7/16.4/287.9 (295)	0.6/4.3/158.9 (24)	0.8/2.5/53.6 (95)	0.2/0.4/30.4 (18)
Outside	5.1/19.9/230.6 (438)	2.1/4.0/572.4 (76)	0.1/0.7/4.8 (22)	0.4/3.1/40.1 (34)
Total	18.4 /54.3/1870.3 (1122)	4.0/14.8/836.4 (171)	2.3 /5.7/302.1 (195)	5.7/7.3/811.1 (119)



**Fig. 2** Percentage of impacted wetlands and mitigation in three planning units (North Mainstem, South Mainstem, and Black Creek) compared to the LSJRB that were located in waterbody units with observed flooding (Satellite flooded zones from Hurricane Irma: September 2017) or projected for flooding from 2030 SLR, high tide, and storm surge categories 1–5 in the 100-year floodplain, 500-year floodplain, and outside the floodplain

satellite-recorded flooding from Hurricane Irma and were located in the North Mainstem's 100- and 500-year floodplains (Fig. 1). North Mainstem had > 50% of impacted wetland area in the LSJRB's 100-year floodplain for high tide flooding and projected 2030 SLR, and > 50% of impacted wetland area in the LSJRB in the 500-year floodplain for storm surge categories 4 and 5. By comparison, the percentage of impacted wetland area in the LSJRB located in flooded WBIDS was 4.3% and 23.2% in the South Mainstem and Black Creek, respectively (Fig. 2). The South Mainstem had the greatest impacted wetland area relative to the LSJRB in the 100-year floodplain for categories 1–4 and outside the floodplain for the projected 2030 SLR. Black Creek showed a different pattern, with the greatest proportion located in the 500-year floodplain exposed to a storm surge category 3 (Fig. 2). Black Creek's impacted wetland area was greatest outside the 100- and 500-year floodplains, representing 41.1% of impacted wetland area in the LSJRB (Table 1).

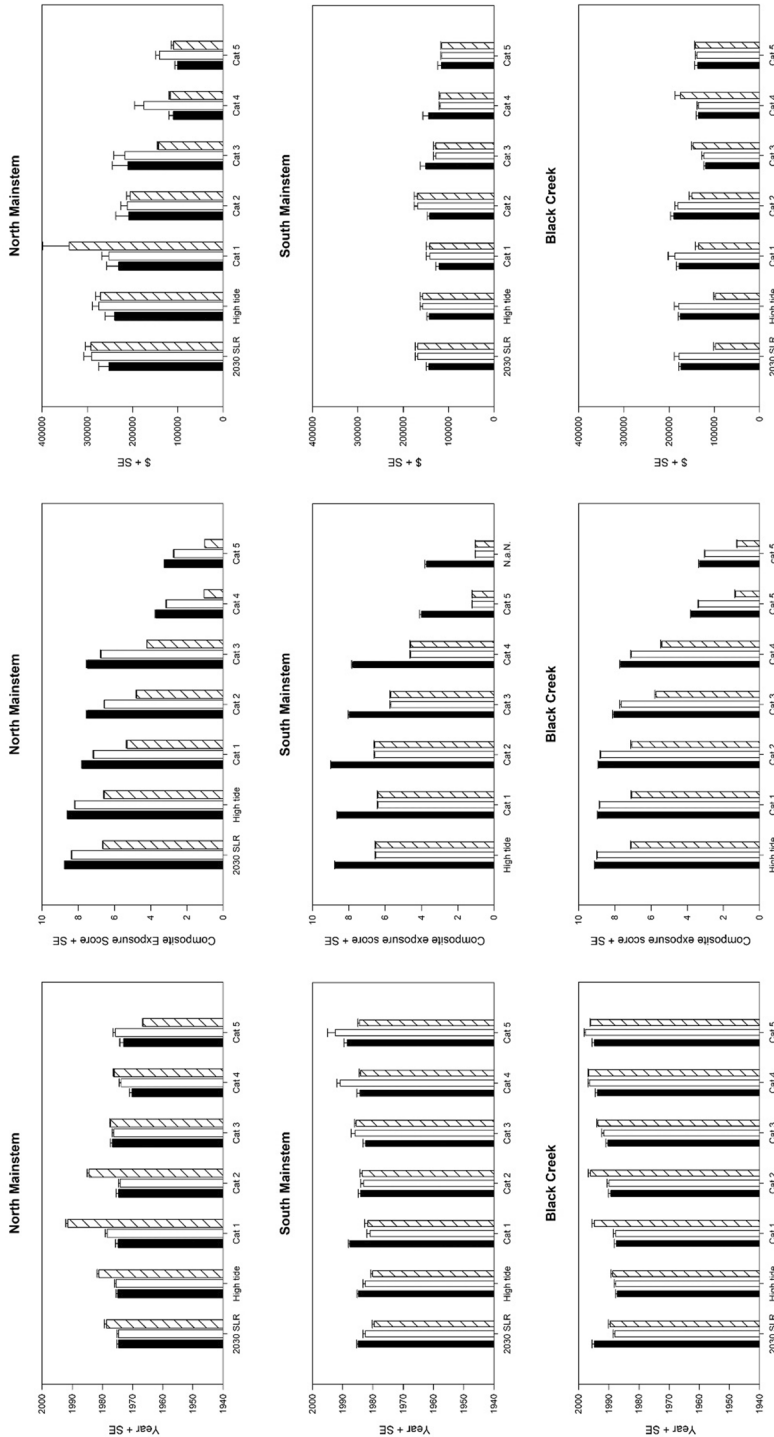
From 2006 to 2019, the proportion of mitigated area in the LSJRB was greatest in the 100-year floodplain for the three planning units as compared to outside the floodplain (Table 2, Fig. 2). Over 98% of the mitigated area was identified as upland or wetland preservation rather than wetland creation, restoration, or enhancement. In the 100-year floodplain, > 50% of the mitigation area in the LSJRB was located in the North Mainstem's 100-year floodplain with storm surge categories 1 and 3, in the South Mainstem with storm surge categories 1 and 2, and in Black Creek with storm surge category 3. In the 500-year floodplain, only the North Mainstem had > 50% of the mitigation area in the LSJRB with storm surge categories 4 and 5. Outside the floodplain, South Mainstem had > 50% mitigation area in the LSJRB with flood hazard categories of high tide flooding, 2030 projected SLR, and storm surge category 1.

ERP projects that had plans to purchase mitigation bank credits had similar patterns as mitigation area with respect to floodplain and flood hazard. In particular, 72% of the mitigation bank credits purchased in the LSJRB were from ERPs located in the 100-year floodplain (Table 2). More than half of the purchased credits in the LSJRB were from North Mainstem ERPs located in areas predicted to be exposed to high tide flooding and category 1 storm surge (Fig. 2). In the South Mainstem's 100-year floodplain, ERPs were located in areas with storm surge categories 1 and 3. In the North Mainstem's 500-year floodplain, 50% of bank credits the LSJRB were from ERPs located in storm surge category 4 and in Black Creek, storm surge category 3. Outside the 100- and 500-year floodplain, < 50% of bank credits were located in areas with flood hazard (Fig. 2).

### 3.2 Patterns in residential parcels

House mean effective year built differed among the three planning units and differed significantly among flood hazard categories (Fig. 3). In the North Mainstem Planning Unit, mean effective year built was from the 1970s irrespective of floodplain category and differed significantly among the flood hazard categories per floodplain ( $H=29.08, 86.63, \text{ and } 544.23; p<0.001, 100\text{-}, 500\text{-year floodplain, and outside, respectively}$ ). However, mean effective year built for houses in the North Mainstem houses was, on average, after 1980 outside the floodplain for those exposed to high tide flooding, storm surge categories 1 and 2. By comparison, houses in the South Mainstem Planning Unit had mean effective year built in the 1980s, on average, and differed significantly among flood hazard categories per floodplain ( $H=49.89, 35.64, \text{ and } 135.50, p<0.0001, 100\text{- and } 500\text{-year floodplain, and outside, respectively}$ ). In the 500-year floodplain, mean effective year built for houses located in the storm surge categories 4 and 5 was not significantly different ( $p=0.638$ ) and





**Fig. 3** Mean (+SE) home effective year built (left column), composite exposure score (middle column), and home just value in 2020 USD (right column) from three planning units (North Mainstem, South Mainstem, and Black Creek) in the LSJRB that were located in waterbody units with projected flooding from 2030 SLR, high tide, and storm surge categories 1–5 in the 100-year floodplain (black), 500-year floodplain (white), and outside the floodplain (hatched)

was up to ten years newer than those located in WBIDs with 2030 SLR, high tide flooding, and storm surge categories 1–3. Of the three planning units, Black Creek had the youngest effective mean year built as compared to the North and South Mainstem and differed among the flood hazard categories per floodplain ( $H=79.87, 287.45, 11.74, p<0.0001$ , 100-year floodplain, 500-year floodplain, and outside, respectively). Similar to the South Mainstem, houses in the 500-year floodplain had younger ages in WBIDs with storm surge categories 4 and 5 than in the 2030 SLR ( $p<0.0001$ ), high tide flooding ( $p<0.001$ ), and storm surge categories 1–3 ( $p<0.001$ ). Outside the floodplain, Black Creek homes in WBIDs with storm surge categories 1, 2, and 4 were from the 1980s and 1990s, and not significantly different ( $p>0.05$ , Fig. 3).

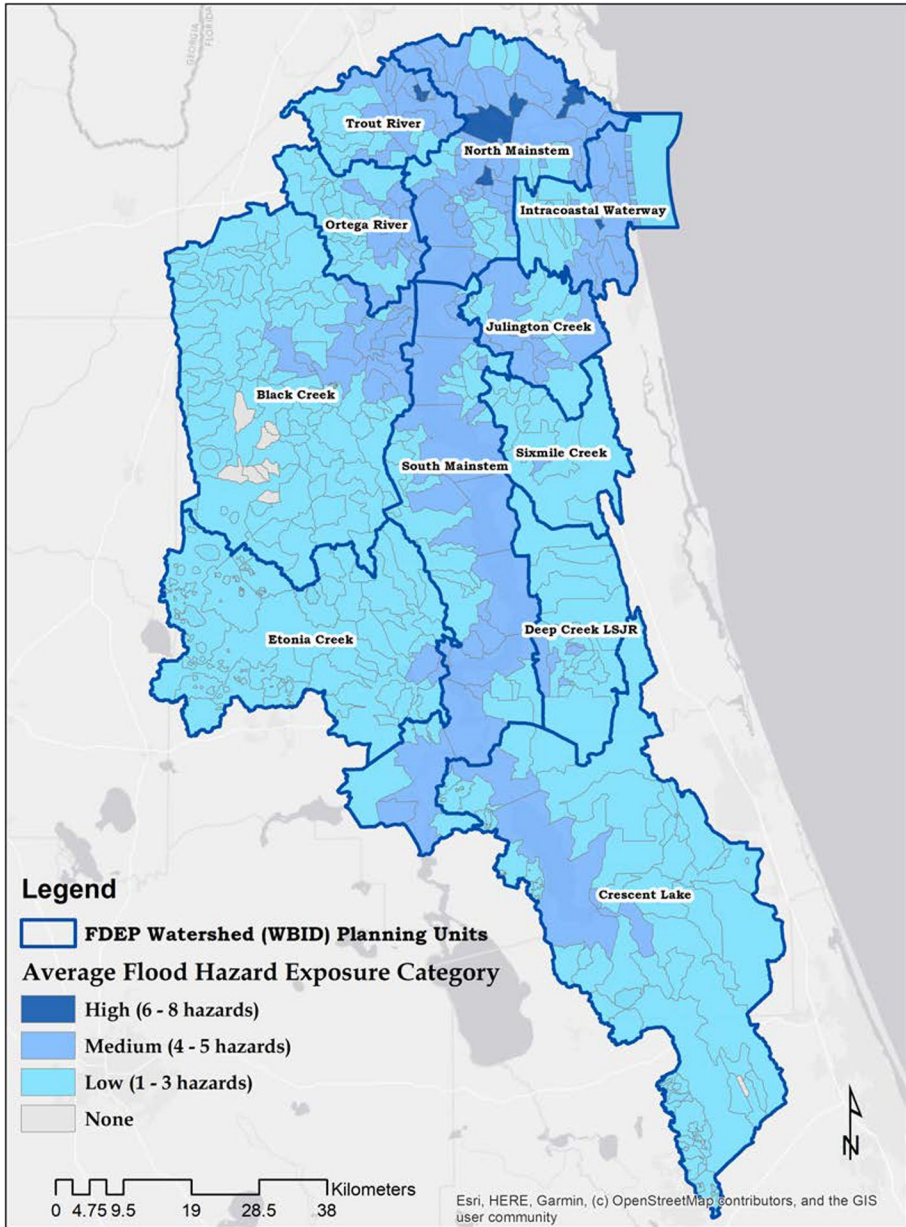
Planning units differed among composite exposure scores per floodplain category (North Mainstem  $H=3134.13, 6731.36, 8799.16$ ; South Mainstem  $H=2019.93, 1030.67, 9899.73$ ; Black Creek  $H=1914.84, 3409.17, 6667.03, P<0.001$ , 100-, 500-year floodplain, and outside, respectively. Figures 3 and 4). As expected, mean composite exposure scores were greater for houses in WBIDs with 2030 SLR, high tide flooding, and storm surge categories 1–3, irrespective of planning unit. Houses located in WBIDs with storm surge categories 4 and 5 had the lowest exposure scores, irrespective of planning unit ( $p<0.05$ , Figs. 3 and 4).

Mean home just values were greater by more than \$50,000 USD/2020 in the North Mainstem as compared to South Mainstem and Black Creek (Fig. 3). Each planning unit differed significantly among flood hazard exposure per floodplain category (North Mainstem  $H=537.03, 6731.36, 1684.10$ ; South Mainstem  $H=69.67, 31.66, 64.56$ ; Black Creek  $H=139.45, 171.48, 524.27, P<0.001$ , 100-year floodplain, 500-year floodplain, and outside, respectively). The North Mainstem had greater values in the 2030 SLR, high tide flooding, and storm surge category 1 than in the remaining flood hazard categories, irrespective of floodplain ( $p<0.03$ ). In the 100- and 500-year floodplains, Black Creek mean just values were greatest in WBIDs with SLR 2030, high tide flooding, and storm surge categories 1 and 2 ( $p<0.02$ ). Outside the floodplain, category 3 surge had the greatest just values ( $p<0.005$ ). No patterns among exposure categories were evident among the three floodplain categories in the South Creek planning unit (Fig. 2).

## 4 Discussion

Similar to the findings by Highfield et al. (2013) in the Houston, TX area, the 100-year floodplain was not a consistent predictor of exposure to flooding in the LSJRB. Based on satellite data and projected inundation models for high tide flooding, sea level rise and storm surge hazards, flood exposure was not necessarily greater for ERP areas and houses located in the 100-year floodplain. Costanza et al. (2008) estimated that \$45,213 USD/2020 in storm damage increases per hectare loss of wetlands. Of concern, the purchase of mitigation bank credits was the more typical mitigation option for those ERPs located in WBIDs predicted to be exposed to high tide flooding and 2030 SLR and yet these mitigation banks were located in areas with low vulnerability scores. By comparison, ERPs that listed preservation of existing wetlands were located in storm surge categories 1 and 3 and would provide inland communities some measure of flood hazard protection.

The quality of ecosystem services provided by wetlands near population centers is dependent on their spatial distribution across a drainage basin (Mitsch and Gosselink 2000). The North Mainstem which includes the urban core, Jacksonville Port Authority,



**Fig. 4** North Mainstem, South Mainstem, and Black Creek Planning Units, Florida, with WBIDS identified by high (6–8 hazards), medium (4–5 hazards), low (1–3 hazards), and no composite exposure score

and several tributaries affected by nutrient loading is located closest to the St. Johns River mouth and was most impacted by predicted flood hazards despite having the smallest total and impacted wetland areas relative to the South Mainstem and Black Creek. On Galveston Island, \$5000 USD/2020 in property damage from Hurricane Ike has been estimated to be

saved by retaining wetlands within 152.4 m of the shore (Highfield et al. 2018). Mitsch and Gosselink (2000) argue that that 3–7% of wetlands across the landscape would ensure ecosystem services. In the North Mainstem planning unit, salt marshes represented 37% of the wetland area, but the incremental wetland loss with each ERP issued fragments the connectivity among wetlands and compromises flood-protection services (Kim and Park 2016).

Cumulative effects of wetland loss across a watershed may have contributed to reported damages from Hurricane Irma. In 2017, Hurricane Irma was responsible for > 80% of the flood damages reported to FEMA in 2006–2019, with damages of \$67,709,817 ( $n=895$  claims), \$13,600,334.1 ( $n=327$  claims, and \$19,951,658.45 ( $n=293$  claims) in the North Mainstem, South Mainstem, and Black Creek, respectively (USD/2020, FEMA NFIP 2020). FEMA flood damage claims were greatest in the North Mainstem, affecting houses with just values of \$50,000 USD/2020 higher than in the South Mainstem and Black Creek. With proximity to the river mouth and the concomitant likelihood for flood risk with sea level rise, high tide, and storm surge, Torio and Chmura (2013) urge urban planners to utilize a coastal squeeze index to identify high-quality tidal marshes for protection and restoration. Yet, permittees of ERPs located in WBIDS with 2030 SLR and high tide flooding opted for mitigation credits. Mitigation banks servicing this planning district are typically inland from the river and have palustrine wetlands rather than salt marsh. The North Mainstem may be subjected to coastal squeeze and yet only one mitigation bank in this watershed has salt marshes (SJRWMD 2020b). For those ERPs located in WBIDs vulnerable to flooding, Kousky et al. (2018) advocate the use of cost–benefit tools (e.g., the Hazus Flood Model) for selecting parcels to purchase for green infrastructure flood mitigation.

Although located in a region further upriver from the river mouth with widespread palustrine wetland areas, the South Mainstem had the greatest wetland loss among the three planning units investigated. In the 100-year floodplain, issued ERPs that planned for wetland preservation may help ensure flood protection across the watershed. Vázquez-González et al. (2019) noted that soil water retention per hectare varies with the type of wetland, with freshwater marshes having similar economic value as mangroves (\$238,241 USD/ha/2020, \$241,750, respectively). Flooded grasslands, although valued less (\$185,084 USD/ha/2020) can provide significant flood protection due to greater coverage (Vázquez-González et al. 2019).

The greatest area of wetland loss due to development in the Black Creek planning unit was located primarily outside the floodplain and a greater proportion of ERPs located in WBIDs exposed to flood hazards from Hurricane Irma, 2030 SLR, high tide flooding, and category 1 storm surge flood hazards. Patterns in the relative proportion of average home exposure scores, effective year built, and home just values were similar outside the floodplain in Black Creek and the 500-year floodplain in the North Mainstem for these four flood hazard categories, suggesting a comparable exposure to flooding. Unlike the North Mainstem, ERP permittees were more likely to mitigate for wetland loss using bank credits rather than preservation and yet mitigation banks are located in areas with low exposure scores.

Hydrological functions of wetlands across the floodplains are likely to be impaired due to fragmentation and filling of isolated wetlands, conversion of wetland area to impermeable cover, and exporting wetland services from the ERP parcel to where the mitigation bank is located (Brody et al. 2007). The North Mainstem in the LSJRB cannot afford more wetland loss and the increasing number of large-scale development projects in the South Mainstem and Black Creek will likely contribute to flood damage. Mitigation of two roadway projects that represented 25% of impacted wetland area in this study relied primarily on the purchase of mitigation bank credits, which may afford limited flood protection in

the WBIDS where the ERP parcels are located. Another two roadway projects representing 70.2% of impacted wetland area in the South Mainstem included the purchase of credits from three mitigation banks that are located in WBIDs with little risk of flood hazard. Given the number of ERPs issued in the LSJRB and loss in wetland area, planning for conservation easements and open space across the watershed and clustering of development projects could safeguard wetland ecosystem services (Kim and Park 2016).

Brody et al. (2010) reinforce the importance of protection of natural areas to reduce the impacts of predicted flood events. Mean composite exposure scores were >6 for houses located in WBIDS with 2030 SLR and high tide flood hazards, irrespective of floodplain. Of the three planning units studied, the North Mainstem's 100- and 500-year floodplains had the greatest overall exposure to flood hazards and would benefit from commitment toward green infrastructure projects. In the South Mainstem and Black Creek, efforts toward conservation of existing floodplain wetlands would be effective in supporting flood protection services. Given the likelihood of flooding irrespective of floodplain category, urban planners and communities must prioritize preservation of wetlands and open spaces in the face of predicted SLR, high tides, and storm surge with hurricanes and tropical storms. As noted by Vázquez-González et al. (2019) and Brody and Highfield (2013), the variability in a storm's flood discharge rate and residence time of groundwater and surface runoff underscores the importance of wetlands and other open spaces, particularly in low-lying regions such as the LSJRB. Mitigation bank locations are critical, and the WMDs should take a holistic spatial approach to evaluating permits and acceptable mitigation solutions.

**Acknowledgements** We wish to thank J. Heine and anonymous reviewers for their comments which improved the manuscript.

**Authors' contribution** Both authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Nisse Goldberg and Russell Watkins. The first draft of the manuscript was written by Nisse Goldberg and Russell Watkins commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

**Funding** None.

**Declaration**

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

- Atmospheric and Environmental Research, Inc. (AER) (2018) maxFlood experimental product. Lexington, MA
- Brody SD, Highfield WE (2005) Does planning work? Testing the implementation of local environment planning in Florida. *J Am Pl as* 71:159–176
- Brody SD, Highfield WE (2013) Open space protection and flood mitigation: a national study. *Land Use Pol* 32:89–95
- Brody SD, Kang JE, Bernhardt S (2010) Identifying factors influencing flood mitigation at the local level in Texas and Florida: the role of organizational capacity. *Nat Hazards* 52:167–184
- Brody SD, Zahran S, Maghelal P, Grover H, Highfield WE (2007) The rising costs of floods: examining the impact of planning and development decisions on property damage in Florida. *J Am Pl Assoc* 73:330–345
- Costanza R, Pérez-Maqueo O, Martínez ML, Sutton P, Anderson SJ, Mulder K (2008) The value of coastal wetlands for hurricane protection. *AMBIO: J Hum Environ* 37:241–248

- Ezer T, Atkinson LP (2014) Accelerated flooding along the US East Coast: on the impact of sea-level rise, tides, storms, the Gulf Stream, and the North Atlantic Oscillations. *Earth's Future* 2:362–382
- Federal Emergency Management National Flood Insurance Program (FEMA NFIP) (2020) FIMA NFIP Redacted claims data set. <https://www.fema.gov/media-library/assets/documents/180374>. Accessed 20 July 2020
- Federal Emergency Management Administration (FEMA) (2020a) Flood zones. <https://www.fema.gov/flood-zones>. Accessed 20 July 2020
- Federal Emergency Management Administration (FEMA) (2020b) Policy & claim statistics for flood insurance. <https://www.fema.gov/policy-claim-statistics-flood-insurance>. Accessed 20 July 2020
- Florida Department of Revenue, 2020 (2020) User's Guide Department Property Tax File, Tallahassee, FL, 47pp.
- Florida Geographic Data Library Metadata Explorer (FGDL) (2020) <http://www.fgdl.org/metadataexplorer/>. Accessed 20 July 2020
- Goldberg N, Reiss KC (2016) Accounting for wetland loss: wetland mitigation trends in northeast Florida 2006–2013. *Wetlands* 36:373–384
- Highfield WE, Brody SD (2006) Price of permits: measuring the economic impacts of wetland development on flood damages in Florida. *Nat Hazard Rev* 7:123–130
- Highfield WE, Brody SD, Shepard C (2018) The effects of estuarine wetlands on flood losses associated with storm surge. *Ocean Coast Manag* 157:50–55
- Highfield WE, Norman SA, Brody SD (2013) Examining the 100-year floodplain as a metric of risk, loss, and household adjustment. *Risk Anal Inter J* 33:186–191
- Johnston CA, Detenbeck NE, Niemi GJ (1990) The cumulative effect of wetlands on stream water quality and quantity. A landscape approach. *Biogeochemistry* 10:105–141
- Kim HW, Park Y (2016) Urban green infrastructure and local flooding: the impact of landscape patterns on peak runoff in four Texas MSAs. *Appl Geog* 77:72–81
- Kousky C, Olmstead SM, Walls MA, Macaulay M (2018) Financing flood losses: a discussion of the national flood insurance program. *Risk Manag Insur Rev* 21:11–32
- Mitsch WJ, Gosselink JG (2000) The value of wetlands: importance of scale and landscape setting. *Ecol Econ* 35:25–33
- National Centers for Environmental Information (NCEI) (2020) Storm events database. <https://www.ncdc.noaa.gov/stormevents/>. Accessed 20 July 2020
- National Flood Insurance Program Community Rating System (NFIP CRS) (2020) <https://www.fema.gov/national-flood-insurance-program-community-rating-system>. Accessed 20 July 2020
- National Hurricane Center (NHC) (2020) US Gulf and East Coast Category 5 Storm Surge Inundation (SLOSH Maximum of MEOWs). <https://www.arcgis.com/home/item.html?id=cb277cb0d18b4c08951cc0b5a102f463>. Accessed 20 July 2020
- National Hurricane Center and Central Pacific Hurricane Center (2020) Atlantic hurricane season. <https://www.nhc.noaa.gov/data/tcr/index.php?season=2017&basin=atl>. Accessed 20 July 2020
- National Storm Surge Hazard Maps (2020) <https://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=d9ed7904d8ec441a9c4dd7b277935fad&entry=1>. Accessed 20 July 2020
- NOAA Atlantic Oceanographic and Meteorological Laboratory (NOAA) (2021) <https://www.aoml.noaa.gov/hrd-faq/#landfalls-by-state>. Accessed 12 April 2021
- Novitski R P (1985) The effects of lakes and wetlands on flood flows and base flows in selected northern and eastern states. *Proc. Conf. on Wetlands of the Chesapeake, Easton, Maryland*: Environmental Law Institute, pp 143–154
- St. Johns River Report (SRR) (2020) State of the River Report for the lower St. Johns River Basin. <https://sjrr.domains.unf.edu/>. Accessed 20 July 2020
- St. Johns River Water Management District (SJRWMD) (2020a) GIS permit search tool. <http://webapub.sjrwmd.com/agws10/sjrwmdpermit>. Accessed 20 July 2020
- St. Johns River Water Management District (SJRWMD) (2020b) Mitigation banking. <http://webapub.sjrwmd.com/agws10/mt/>. Accessed 20 July 2020
- Sweet WWV, Dusek G, Obeysekera JTB, Marra JJ (2018) Patterns and projections of high tide flooding along the US coastline using a common impact threshold. NOAA Technical Report NOS CO-OPS 086. [https://tidesandcurrents.noaa.gov/publications/techrpt86\\_PaP\\_of\\_HTFlooding.pdf](https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf). Accessed 20 July 2020
- Torio DD, Chmura GL (2013) Assessing coastal squeeze of tidal wetlands. *J Coast Res* 29:1049–1061
- United States Army Corps of Engineers (ACOE) (2019) Sea-Level Change Curve Calculator 1 (Version 2019.21). [http://corpsmapu.usace.army.mil/rccinfo/slc/slcc\\_calc.html](http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html), Accessed August 5, 2020
- United States Army Corps of Engineers (ACOE) (2020) Regulatory In-lieu fee and bank information tracking system. <https://ribits.ops.usace.army.mil/>. Accessed 20 July 2020

US Census Bureau (2020) Quick facts. <https://www.census.gov/quickfacts/>. Accessed 20 July 2020

US Inflation Calculator (2021) Inflation calculator. <https://www.usinflationcalculator.com>. Accessed 14 May 2021

Vázquez-González C, Moreno-Casasola P, Peláez LAP, Monroy R, Espejel I (2019) The value of coastal wetland flood prevention lost to urbanization on the coastal plain of the Gulf of Mexico: an analysis of flood damage by hurricane impacts. *Int J Disast Risk Red* 37:101180. <https://doi.org/10.1016/j.ijdr.2019.101180>. Accessed 20 July 2020

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.