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Aligning Natural Resource Conservation, Flood Hazard Mitigation, and Social Vulnerability Remediation in Florida

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Aligning Natural Resource Conservation, Flood Hazard Mitigation, and Social Vulnerability Remediation in Florida

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1. INTRODUCTION

Flooding continues to be the most common and damaging of all natural disasters in the United States. According to the Federal Emergency Management Agency (FEMA), 44 of the 46 major disaster declarations in 2016 were related to storms, with flooding being a significant factor in almost 70% of them (30 events) (FEMA 2017). In 2016, severe floods in the U.S resulted in more than $17 billion in damages (six times higher than in 2015). Twelve individual weather and climate events caused more than $1 billion in damages each (NOAA and Smith 2017), and at least five severe 1000-yr precipitation events occurred in the U.S. in 2016 (NOAA 2016).

The National Flood Insurance Program (NFIP), created by FEMA in 1968 following a series of severe floods, aimed at providing flood loss coverage for home owners, as well as promoting risk-reduction measures for properties located in floodplains across the country. Until 1986, NFIP finances were self-sustainable, with premiums collected roughly balancing the total claim payments (King 2012). However, due to disastrous recent flood seasons, coupled with insurance rates that do not reflect real flood risks, NFIP has accrued a total debt of more than $23 billion during the last decade (FEMA and Wright 2017). Roughly $16.3 billion was paid to claims related to Hurricane Katrina (2005), and $8.5 billion paid to claims related to superstorm Sandy (2012) ($24.8 billion total) (FEMA 2017c). One critical component of NFIP losses are repetitive loss properties, which account for roughly 1% of all policies, but received roughly 30% of all NFIP claims payments until 2011(King 2013).

To bring stability and fiscal soundness to the national flood insurance program, in July of 2012 Congress approved the Biggert Waters Flood Insurance Reform Act (BW-12). Among other provisions, BW-12 reauthorized NFIP for an additional five years (from 2013 to 2017), and defined a gradual adjustment of insurance rates to reflect true risk (FEMA 2014a). However, in response to strong public reaction and concerns that the new flood insurance rates triggered by BW-12 would affect the housing market, as well as drive home owners from their properties, in March of 2014 Congress enacted the Homeowner Flood Insurance Affordability Act of 2014. This modified and repealed several provisions of BW-12 by implementing measures including: limiting the increase of annual flood insurance premiums to

18%, repealing any rate increases triggered by property sales or the acquisition of new and voluntary flood insurance policies, refunding select policy holders for recent rate increases, and authorizing additional funds for the National Academy of Sciences to complete a series of affordability studies (FEMA 2014a). According to the "Affordability of National Flood Insurance Program Premiums, Report 1", published in 2015, 60% of the nearly 5.5 million NFIP policies are located in Florida, Texas, and Louisiana (National Research Council 2015).

As of November, 2016, property owners in Florida held the highest number of NFIP polices in the nation (almost 1.8 million policies, roughly 35% of all NFIP claims at the time), with insured property values reaching $429 billion (almost 35% of the entire NFIP coverage of $1.25 trillion) (FEMA 2016). However, from 1978 to 2008, home owners in Florida paid roughly four times more in premiums than they received in flood claim payments from NFIP ($16.1 billion vs. $4.5 billion) (Michel-Kerjan 2011). As of September 2011, there were more than 15,000 repetitive loss properties in FL. From 1978 to 2011, these RLP received payments for almost 40,000 claims (an average of 2.7 claims per property). A stunning 808 RLP filed at least 5 claims against NFIP during that same period, with 70 RLP having filed at least 9 claims. Nationwide, the number of RLP has outpaced FEMA mitigation efforts by a factor of 10 (King 2013).

FEMA continues to offer significant funds in Flood Mitigation Assistance (FMA) grants destined to reduce or eliminate the risk of repetitive flood damage to NFIP customers. In 2016, FEMA allocated almost $200 million in FMA funds, eligible to be used in pre-disaster planning and mitigation activities including: property acquisition and structure demolition or relocation, and structure elevation and building retrofitting (FEMA 2017b).

The U.S. Department of Housing and Urban Development (HUD) is another potential source of significant funds for projects within the scope of this study. In the aftermath of superstorm Sandy, HUD offered $930 million through the Rebuild by Design competition (HUD 2013) to seven proposals that developed innovative regionally-scalable, locally-contextual approaches to increase coastal resilience in the region affected by Sandy. In 2015, through the National Disaster Resilience Competition, HUD offered almost $1 billion in additional funding for disaster recovery and long-term community resilience (HUD 2015). More recently, in October of 2016, HUD proposed new rules requiring that critical properties, including hospitals, police, and fire facilities must be elevated at least three feet above the 100-year floodplain elevation, or above the 500-year floodplain elevation, whichever is higher (Sullivan 2016). The new rule also states that non-critical facilities must be elevated at least two feet above the 100-year floodplain elevation (Sullivan 2016).

Losses related to coastal hazards are not uniformly distributed, and depend greatly on socioeconomic conditions of the population exposed to environmental hazards (Cutter, Boruff, and Shirley 2003). Social vulnerability relates to the characteristics of a person or group and their capacity to anticipate, cope with, resist, or recover from the impacts from hazards (Wisner et al. 2003). Some of the major factors that increase social vulnerability include: lack of access to resources, limited access to political representation, beliefs and customs, building stock and age, and frail and physically limited individuals. Additionally, socioeconomic status, gender, race and ethnicity, and special needs, are also relevant drivers of vulnerability (Cutter, Boruff, and Shirley 2003). Social vulnerability becomes much more apparent after the onset of a disaster, when impacts can be observed in specific groups of the population (Cutter, Boruff, and Shirley 2003). Flood events cause disproportionate impacts on more vulnerable groups (e.g. the poor, minorities, the elderly, and the disabled), which usually live in high-risk areas, lack basic resources to prepare for floods and other natural hazards, and are not aware of available resources that may improve their sustainability (Dunning and Durden 2013).

Social Vulnerability is a complex subject and difficult to evaluate at large scales. However, multiple social vulnerability analysis tools are available in the United States, including: The Social Vulnerability Index (SoVI ©) (University of South Carolina, Hazards and Vulnerability Research Institute), Social Vulnerability Mapping Tools (Texas Coastal Planning Atlas), the Roadmap for Adapting to Coastal Risk (NOAA, Coastal Services Center), and the USA – Social Vulnerability Thematic Maps (ESRI). Most of the tools above are either based on SoVI ©, or mention it as a more comprehensive tool (Dunning and Durden 2013), therefore, and despite some known SOVI © limitations - such as the complexity of the statistical methods applied, including principal component analysis - SoVI © was chosen as the social vulnerability index for this analysis.

The Social Vulnerability Index (SoVI ©) measures community vulnerability, defined as a reduction in the community's ability to prepare for, respond to, and recover from hazards (Hazards and Vulnerability Research Institute 2017c). From

2006 to 2010, nearly 30 variables were reduced to seven independent components, which describe social vulnerability: (i) race (Black) and class (poverty); (ii) wealth; (iii) elderly residents; (iv) Hispanic ethnicity; (v) special needs individuals (nursing home residents); (vi) Native American ethnicity; and (vii), service industry employment (Hazards and Vulnerability Research Institute 2017a).

Conservation objectives can also align with those of flood exposure reduction, and social vulnerability remediation. Ecosystems provide numerous services to humans, beyond just coastal and flood protection, including fisheries improvement, water filtration, transportation, and recreation. While the benefits provided by nature are widely accepted, there is still a great need to account for natural habitat in multidisciplinary community decision making processes. To address this need, in this study we include various ecosystems in Florida in the Conservation Priority Index (CPI). Furthermore, we give CPI the same weight as flood exposure and social vulnerability in our final calculations and land prioritization. Recognizing the value of various habitats, CPI includes marine, terrestrial, and freshwater ecosystems in Florida.

The goal of this study is to identify and prioritize lands in Florida that are potential targets for projects with multiple potential benefits: reduced flood exposure, conservation benefits, and remediation of social vulnerability.

The availability of sophisticated technology, supported by well-developed climate science, well-known floodplain processes, and abundant high-resolution data, can provide decision-makers with the key tools required to design approaches that can reduce flood exposure, improve livelihoods, and restore natural habitats simultaneously. Using spatial data related to flood exposure, natural habitats, and SoVI©, we build on the methods proposed by Calil et al. (2015), who demonstrated that flood losses could be mitigated through action that meets both flood risk reduction and conservation objectives (Calil et al. 2015). Calil et al. (2015) identified federally-insured properties in California located in areas prone to flooding, and therefore not ideal for development, that also hold valuable natural resources, such as salmon habitat or estuaries. Furthermore, that study described federal funding programs that could be applied to achieve both flood mitigation and conservation objectives.

We propose that flood losses can also be mitigated through action that remediates social vulnerability. The present study greatly improves on Calil et al.

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(2015). In addition to flood exposure and natural habitats, we include social vulnerability in the prioritization scheme. Furthermore, we include inland habitats, expanding the focus of the analysis beyond just the coast. Our results identified lands in Florida that are eligible to receive federal funds to attain multiple benefits: (i) reduce flood risk to home owners; (ii) reduce FEMA's financial burden (from future flood claim payments); (iii) restore/protect natural habitats; (iv) remediate social vulnerability, and (v) identify potential sources of funding for projects. To our knowledge, this is the first study to present a detailed, spatially explicit analysis of the overlap between flood exposure, natural habitats, and social vulnerability in Florida.

2. MATERIALS AND METHODS.

Our model identifies and prioritizes land in Florida where valuable habitats and socially vulnerable population are exposed to flooding. Flood exposure was evaluated based on data from FEMA's Repetitive Flood Claims program and Digital Flood Insurance Rate Maps (DFIRM), as well as sea-level rise projections from the National Oceanic and Atmospheric Administration (NOAA). Conservation priority lands were identified in two ways. First, we used The Nature Conservancy's (TNC's) Priority Areas, a conservation prioritization scheme developed through comprehensive eco-regional assessments of species and habitats. Second, we developed a Conservation Priority Index (CPI) based on habitats data from the Cooperative Land Cover dataset, published by Florida's Fish and Wildlife Conservation Commission in 2016. Areas of high social vulnerability were identified using the social vulnerability index (SoVI ©).

We used an equal-weight overlay spatial model developed in a geographic information system (ESRI ArcGIS 10.5), and applied it to all census tracts in Florida. The total study area covers roughly 170,000 km^2 (over land and water). Four indices were considered in the study (at a resolution of 50m by 50m, or 0.0025 km^2): (i) Flood Exposure Index (FEI); (ii) TNC's Priority Areas; (iii) Conservation Priority Index (CPI); and (iv) SoVI ©. Note that these indices are intended to be qualitative and relative, rather than quantitative measures of specific features.

First, we developed a Flood Exposure Index, by combining four attributes: the 100 yr. and 500 yr. floodplains as defined by FEMA; proximity to repetitive loss properties; (also based on FEMA's data), [1] and the area projected by NOAA to be below the mean high-high water levels in the year 2100.

Second, we evaluate conservation priority utilizing The Nature Conservancy's (TNC's) priority areas, and develop a custom conservation priority index (CPI). CPI is based on selected natural habitats in Florida, as identified by the Cooperative Land Cover dataset, recently published by Florida's Fish and Wildlife Conservation Commission (see detailed habitat list below). It is useful to have a comparison of prioritization schemes to demonstrate that this approach can be adjusted to reflect specific users' interests and available data.

Third, we use the pre-existing Social Vulnerability Index (SoVI ©) in the study to identify areas of high social vulnerability in Florida. To support calculations, original SoVI © categories were replaced by numerical scores. SoVI © values equal to low, medium-low, and medium, were replaced by scores of 0, 25, and 50, respectively. Medium-high and high SoVI © values received numerical scores of 100.

The final step of the model was the calculation of overlapping scores across the indices, as explained below. Results are presented in overlapping scores (from 0 to 100) and area (in km^2).

2.1 Flood Exposure Index (FEI)

An overall FEI was calculated by summing values of individual flood exposure indicators within each grid cell (Table 1, Fig 1), per equation 1:

[1] The RLP data used in this study is based on a former definition of RLP. Prior to July of 2012, Repetitive Loss Properties were classified as any federally insured property for which two or more claims, of more than $1,000 each, were paid by the NFIP within any rolling ten-year period (FEMA 2013). As of July of 2012, through the approval of the Biggert-Waters act, FEMA has redefined RLP as structures covered by flood insurance under the NFIP that: (a) incurred flood-related damage on 2 occasions, in which the cost of the repair, on the average, equaled or exceeded 25 percent of the market value of the structure at the time of each flood; and (b), at the time of the second incidence of flood-related damage, the contract for flood insurance contains increased cost of compliance coverage (FEMA 2014a).

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$$FEI = F100 + F500 + RLP + SLR$$

Equation 1. Flood exposure index

where *F100* represents the 100-year floodplain score, *F500* represents the 500-year floodplain score, *RLP* is the proximity to RLP score, and *SLR* is the area inside the Mean High Water Mark (MHWM) at the year 2100 score. FEI score values range from 0 to 400 (Table 1). Each FEI indicator was assigned a value of 100, and values were added for each raster cell. Results ranged from 0 (i.e. absence of all FEI indicators) to 400 (i.e. presence of all four FEI indicators. Finally, FEI scores were normalized from 0 to 100 to enforce consistency with the other indices used in the study (equation 2):

$$Flood\ Exposure\ Index = \frac{(X - Min)}{(Max - Min)} * 100$$

Equation 2. Flood exposure index normalization

where *X* is the value of the FEI for each grid cell before the normalization, *Min* is the minimum value of the index before normalization (i.e. 0), and *Max* is the maximum value of the index before normalization (i.e. 400).

Table 1. Flood Exposure Index (FEI)

FEI Components – data sources in parenthesis	**Normalized Score**
Area located within the 100-year Floodplain (FEMA)	25
Area located within the 500-year floodplain (FEMA)	25
RLP and surrounding areas (1,000m buffer) (FEMA)	25
Area inside the projected MHHWM at the year 2100 (NOAA)	25
Maximum possible FEI score (normalized)	**100 Points**

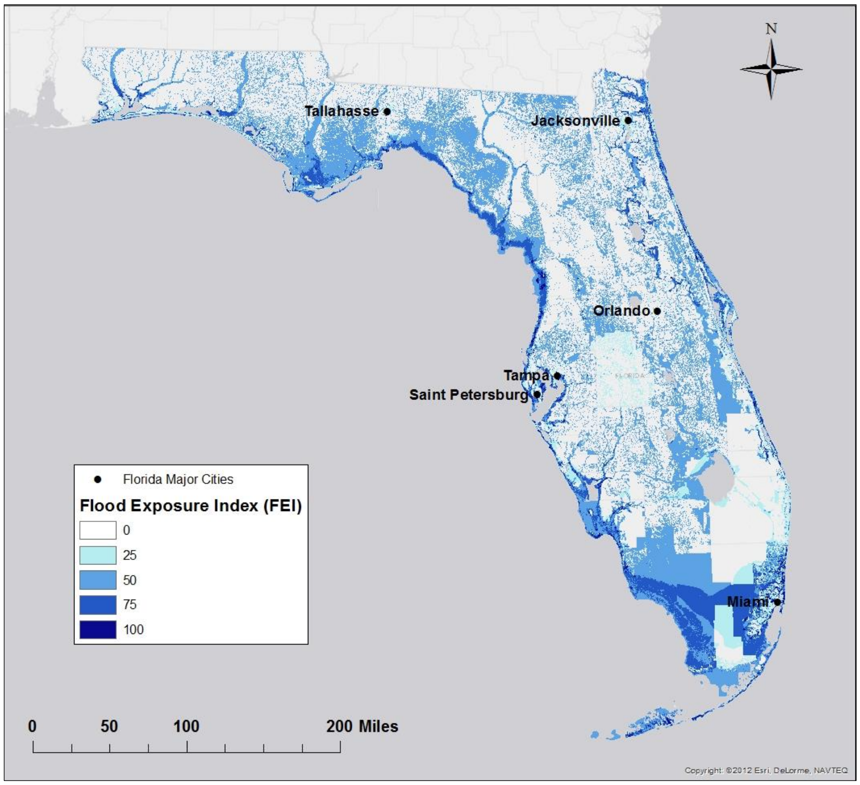

Figure 1. Flood Exposure Index (FEI)

Note that some areas in southeastern and southwestern Florida contain non-natural boundaries (i.e. straight lines in Figure 1). These boundaries were inherited from FEMA's flood maps, which contain artificial lines between certain flood zones. Parts of the region above are classified as "D" or "undetermined" flood zones by FEMA (FEMA 2017d). Special Flood Zone "D" contains areas for which FEMA has neither conducted any flood hazards analyses nor prepared any flood maps. Additionally, as such areas are not inside the projected mean high-high water mark at the year 2100 and do not contain any RLP, they received a FEI score of 0. The large area north of Miami, with FEI values of zero, is an example of an area without any FEI components.

2.2 TNC's Priority Areas and the Conservation Priority Index (CPI)

Following the model outlined by Calil et al. (2015) (Calil et al. 2015), we include an example of an existing conservation prioritization scheme in the study. We use TNC's Priority Areas, developed through comprehensive eco-regional assessments

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of species and habitat types (The Nature Conservancy 2014) (Figure 2). TNC's priority areas cover approximately 60.8% of Florida (roughly 103,000 km^2), across four ecoregions (areas with similar climate and topography that support a range of habitats): Tropical Florida, Florida Peninsula, and part of the East Gulf and South Atlantic Coastal Plains located within state boundaries (The Nature Conservancy 2005; The Nature Conservancy 2004; The Nature Conservancy 2014).

Additionally, following the approach proposed by Calil et al. (2015)—and to illustrate that the proposed approach is flexible and can be adjusted to represent specific conservation interests—we have substituted a custom conservation priority index (CPI) for TNC's priority areas.

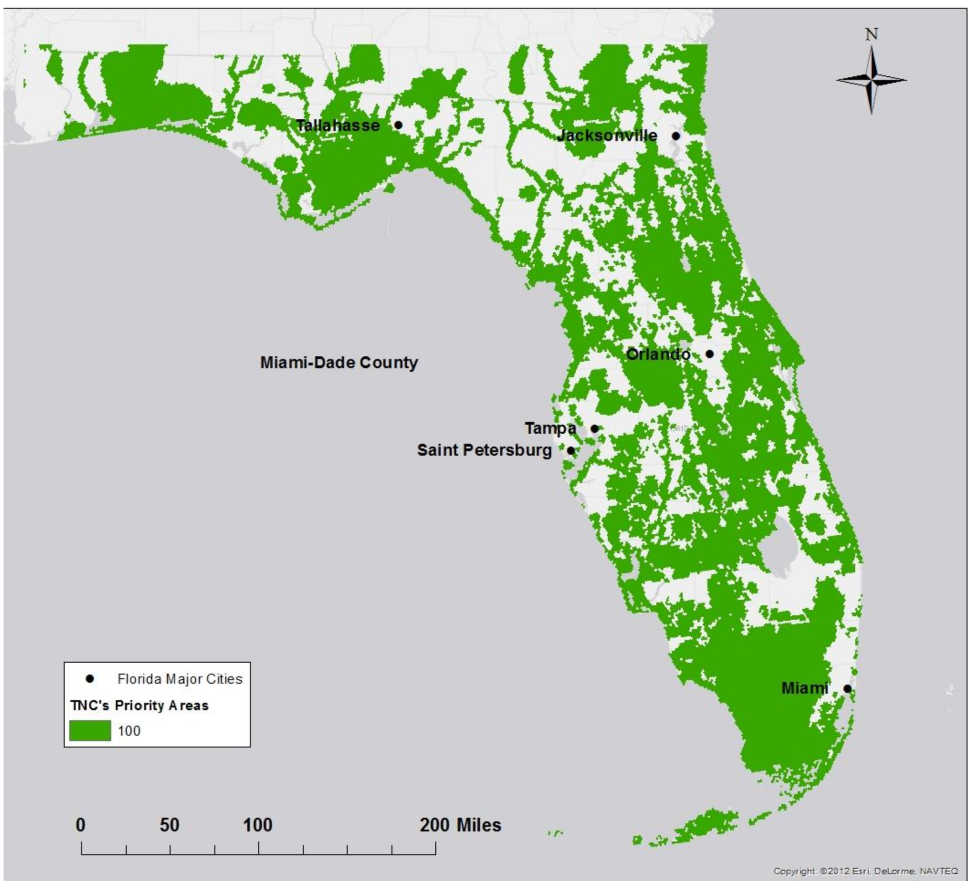

Figure 2. TNC's priority areas

The CPI is based on habitat data derived from the Cooperative Land Cover dataset, published by Florida's Fish and Wildlife Conservation Commission in

October of 2016 (Florida Fish and Wildlife Conservation Commission 2016). The original dataset was developed based on ecologically-based statewide land cover from existing sources and expert review of aerial photography, and is used to inform various conservation and management activities in Florida (Florida Fish and Wildlife Conservation Commission 2016). The following habitats (extracted from the Cooperative Land Cover dataset) were included in the CPI:

Upland Hardwood Forest; Mesic Hammock; Rockland Hammock; Slope Forest; Xeric Hammock; High Pine and Scrub; Sand Pine Scrub; Coastal Scrub; Upland Pine; Sandhill; Pine Flatwoods and Dry Prairie; Dry Flatwoods; Mesic Flatwoods; Scrubby Flatwoods; Dry Prairie; Palmetto Prairie; Mixed Hardwood-Coniferous; Coastal Strand; Maritime Hammock; Sand Beach (Dry); Upland Glade; Freshwater Non-Forested Wetlands; Prairies and Bogs; Marshes; Isolated Freshwater Marsh; Floodplain Marsh; Freshwater Forested Wetlands; Cypress/Tupelo(including Cy/Tu mixed); Cypress; Isolated Freshwater Swamp; Strand Swamp; Floodplain Swamp; Other Coniferous Wetlands; Wet Flatwoods; Other Hardwood Wetlands; Baygall; Hydric Hammock; Non-vegetated Wetland; Lacustrine; Riverine; Natural Rivers and Streams; Estuarine; Tidal Flat; Salt Marsh; Mangrove Swamp; Scrub Mangrove; Dome Swamp; Basin Swamp.

In addition to the data above, seagrass coverage based on data from Florida’s Fish and Wildlife Conservation Commission (NOAA 2017) was also included in the CPI (Figure 3).

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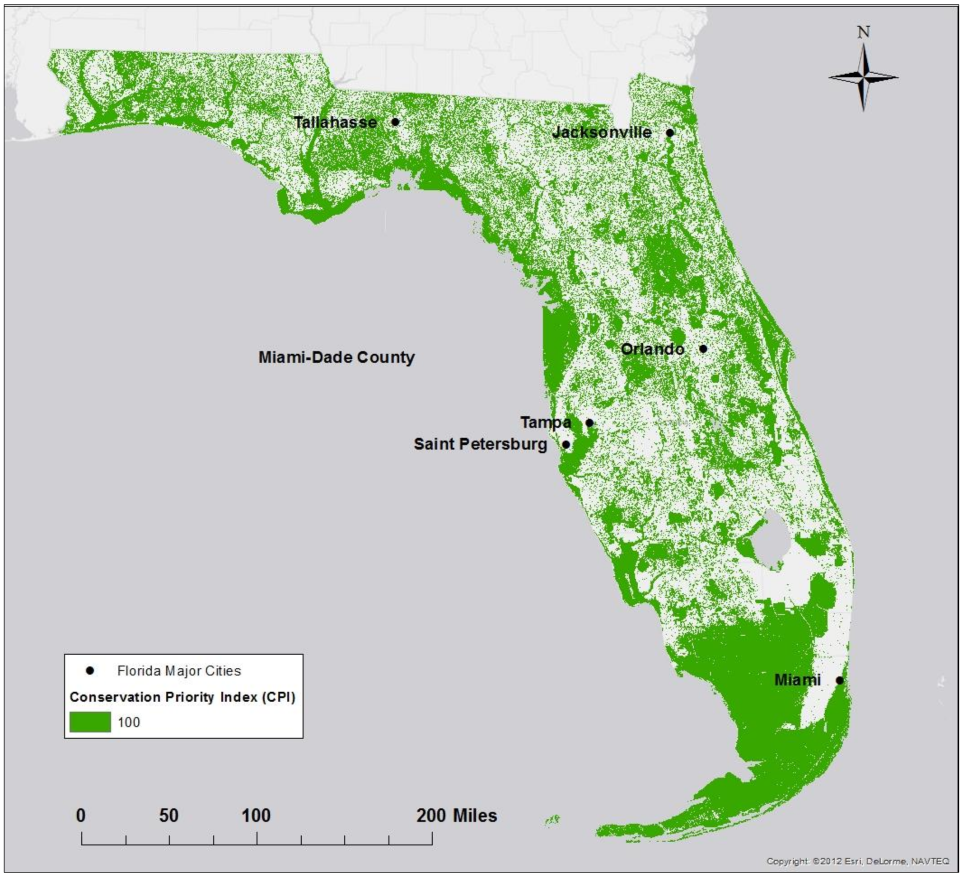

Figure 3. Conservation Priority Index (CPI)

2.3 Social Vulnerability Index (SoVI ©)

Cutter et al. (2003), developed the Social Vulnerability Index (SoVI ©), which measures community vulnerability defined as a reduction in the community's ability to prepare for, respond to, and recover from hazards (Hazards and Vulnerability Research Institute 2017c). The 2006-2010 version of SoVI © for Florida was calculated at the census tract level using principal component analysis. Principal component analysis reduces several correlated variables into a smaller number of uncorrelated variables called principal components. The first component explains as much of the variability in the data as possible, with succeeding components accounting for as much of the remaining variability in the data as feasible (Dunteman H.G. 1989). In Florida, the 2006-2010 SoVI © reduces 29 independent socioeconomic variables into seven components that explain 72% of the variance in the data (Hazards and Vulnerability Research Institute 2017a).

Positive and negative values are then assigned to each of the seven components based on their impact on social vulnerability. Values are tallied up at the census tract level, thereby determining a numerical social vulnerability score. The seven independent components that describe social vulnerability in Florida are: race (Black) and class (poverty) combined; wealth; old age; Hispanic ethnicity; special needs individuals (nursing home residents); Native American ethnicity; and service industry employment (Hazards and Vulnerability Research Institute 2017a). The 2006-2010 SoVI® data sources include primarily the United States Census Bureau (from 2005 to 2009). SoVI® is a dynamic index and future iterations of the index are expected to include additional variables including: homeless population, physical mobility constraints, and social capital (Hazards and Vulnerability Research Institute 2017b). However, in this study, SoVI is not used dynamically and is not iterated with changing variables.

One of the main focal points of social vulnerability in Florida is in urban areas in the southeast of the state, north from Miami-Dade, through Broward, and into Palm Beach County, where 76%, 31%, and 29% of the respective populations live in areas with high vulnerability (Emrich et al., n.d.). Miami-Dade contains the most vulnerable census tract in the state (Emrich et al., n.d.).

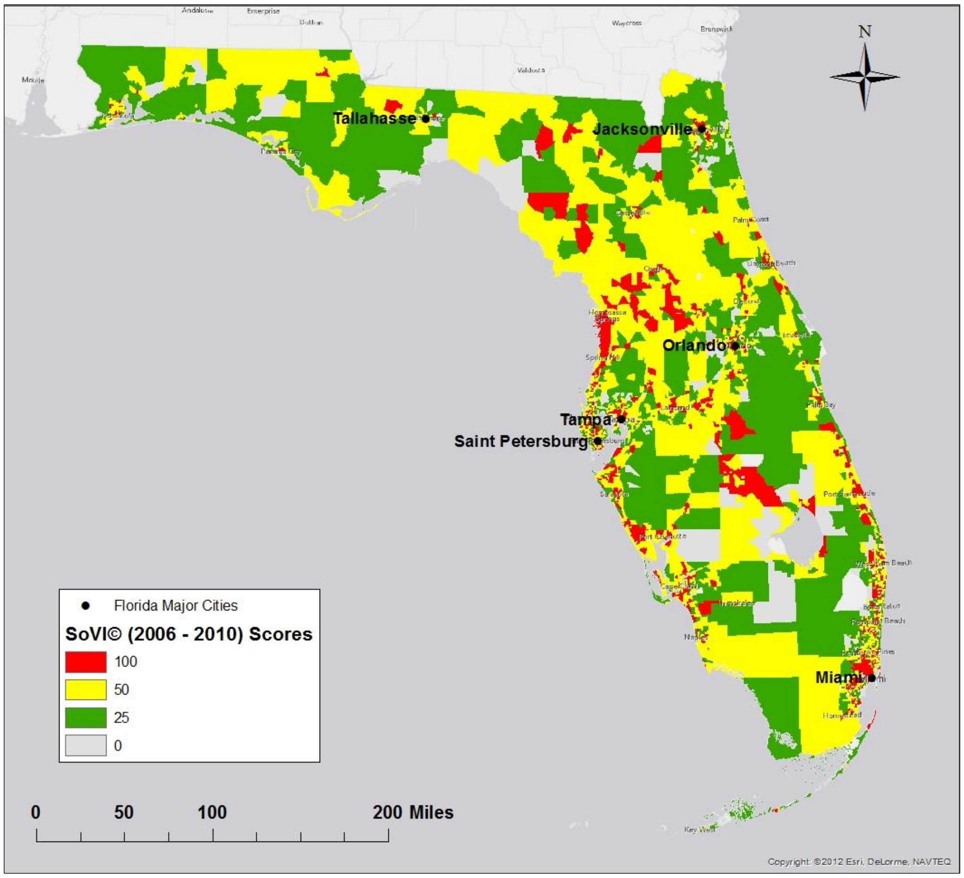

Figure 4. SoVI © 2006 - 2010

2.4 Spatial Model Description

First, the four spatial layers above (FEI, TNC's Priority Areas, SoVI ©, and CPI) were converted into raster format at the same resolution (0.0025 km^2). Next, geometric means were calculated between raster values (i.e. individual values for each index), resulting in overlapping scores (equations 3, 4, and 5), ranging from 0 to 100. Since one of the objectives of the present study is to prioritize areas where multiple spatial layers are present, geometric means were chosen to calculate the indices. Thus, any cells where at least one of the spatial layers is not present received a value of 0 in the resulting indices, effectively being filtered out from the results. An equal weights approach was applied, but the model is flexible enough so that different weights may be used in the future to represent specific values of model users. For example, a future application of the model may give a heavier weight to high social vulnerability. Finally, results were grouped into five classes per the Natural Breaks method (Jenks), and labeled "Low", "Medium Low", "Medium", "Medium-High", and "High".

The total extent of overlapping land was calculated in three ways:

(i) extent of overlap between FEI and SoVI ©:

$$\text{Overlap between FEI and SoVI ©} = \sqrt{(FEI\ *\ SoVI\ ©)} \tag{3}$$

(ii) extent of overlap between FEI, SOVI ©, and CPI:

$$\text{Overlap between FEI, SoVI ©, and CPI} = \sqrt[3]{(FEI\ *\ SoVI\ © *\ CPI)} \tag{4}$$

(iii) the extent of overlap between FEI, SOVI ©, and TNC's Priority Areas:

$$\text{Overlap between FEI, SoVI ©, and TNC'sPriority Areas} = \sqrt[3]{(FEI\ *\ SoVI\ © *\ TNC\ Areas)} \tag{5}$$

The distribution of Repetitive Loss Properties in Florida and their overlap with the three land prioritizations above were evaluated, and a case study was conducted for Miami-Dade, the county with the highest number of repetitive loss claims in Florida. In cases where raster cells covered two or more counties, cell values were assigned to the county that intersected with the largest area of each cell. Finally, based on data from The National Hydrographic Dataset, published by the U.S. Geological Survey (USGS 2017b), all named lakes and reservoirs in Florida were removed from the results.

3. RESULTS

3.1 Extent of Overlap between SOVI © and FEI

The first step in the analysis was to evaluate the extent of overlap between flood exposure and social vulnerability in Florida. Results are presented as scores, calculated by Equation 3, with overlapping scores ranging from 0 to 100.

The state of Florida contains a total area of 170,310 km^2 (138,887 terrestrial km^2) (USGS 2017a). Our results indicate the extent of overlap between FEI (values> 0) and medium SoVI © (values >=50) covers nearly 18.7% of the state's total area (31,820km^2). As expected, the areal extent of overlap diminishes as the scores increases: There are roughly 960 km^2 in the state where medium-high and high SoVI © (i.e. score is 100) overlap with FEI values >= 75 (red categories in Figure 5). Finally, there are 204 km^2 in Florida where maximum SoVI © scores (100) and high flood exposure (FEI >75) overlap (Figures 5). The complete extent of overlapping scores between SoVI© and FEI is shown in Figure 6.

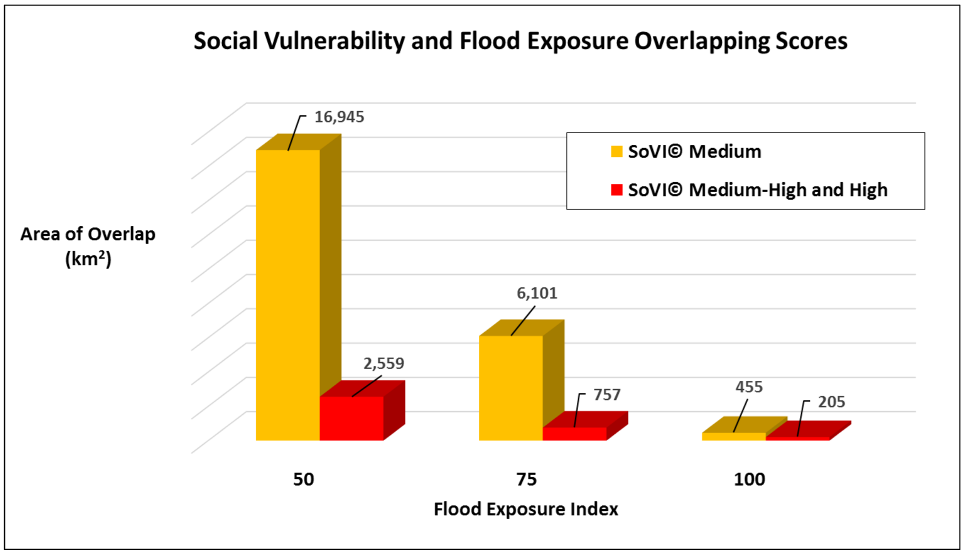

Figure 5. Area of overlap between FEI scores >= 50, and SoVI © values medium, medium-high, and high.

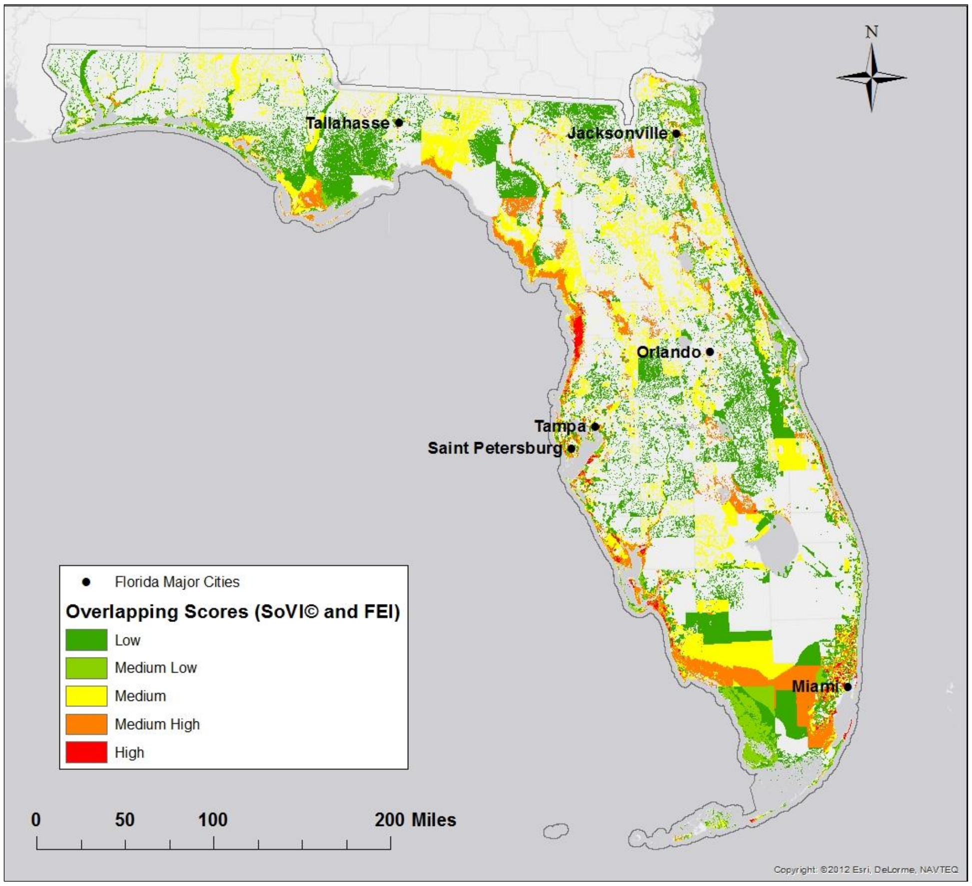

Figure 6. SoVI © and FEI overlap

3.2 Extent of Overlap between FEI, SoVI ©, and TNC's Priority Areas

Nearly 42% of the approximately 103,000 km^2 of TNC's priority areas (roughly 42,400 km^2) overlap with areas that have both SoVI © and FEI. Overlapping scores range from 0 to 100. There are almost 600km^2 of land in Florida where TNC's areas overlap with high SoVI © and FEI values >= 75 (red categories in Figure 7). Finally, there are 98.9 km^2 of land in Florida where TNC's priority areas overlap with highest values of FEI and SoVI © (Figure 7). Figure 8 contains all overlapping scores between FEI, SoVI ©, and TNC's Priority Areas.

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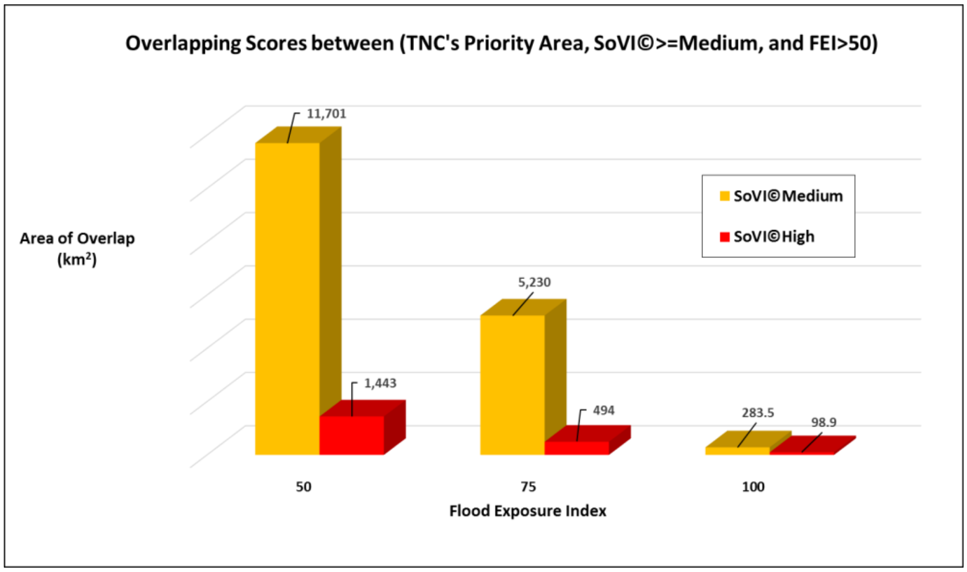

Figure 7. TNC, SoVI ©, and FEI overlapping scores (excludes areas where TNC's areas are not present)

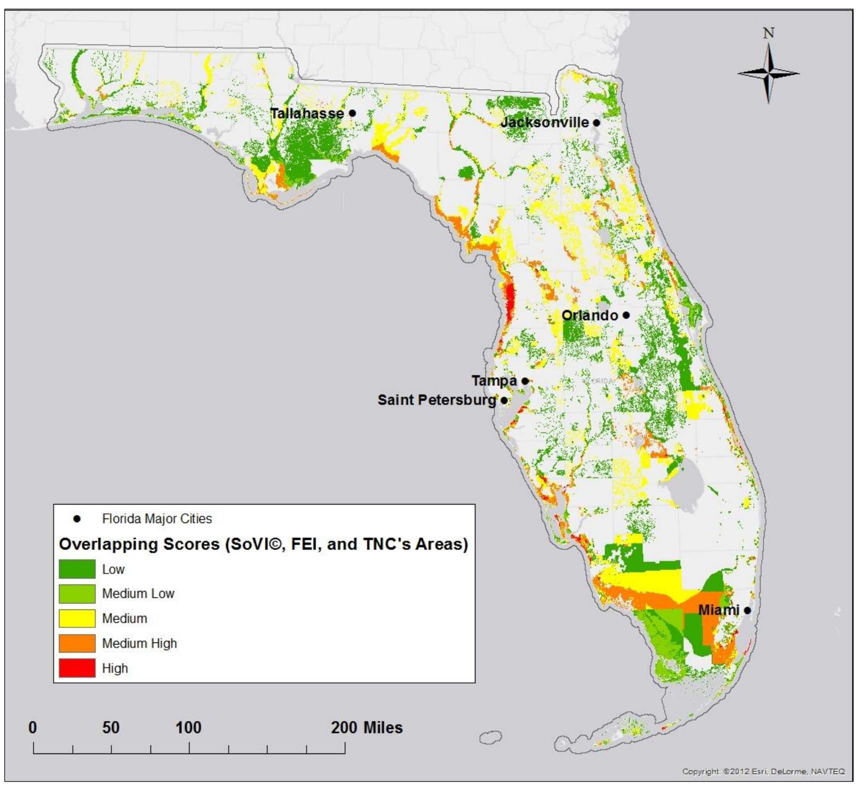

Figure 8. TNC, SoVI ©, and FEI Overlapping Scores

3.3 Extent of Overlap between SoVI ©, FEI, and CPI

Nearly 23% of the state (38,800 km^2) has an overlapping score greater than zero. Overlapping scores range from 0 to 100 (Equation 4). Roughly 2,200 km^2 show overlap with values of FEI >0, CPI >0, and SoVI © =100 (Figure 6). Generally, the amount of land where the three indices overlap diminishes as indices values increase. The areal extent where overlapping scores are 80 or higher is 504 km^2. Figure 9 contains all overlapping scores between SoVI ©, FEI, and CPI.

As expected, the total areal extent with maximum overlapping scores (100) covers a smaller area, roughly 74 km^2. As previously mentioned, the fact that the areal extent of overlap between the indices generally diminishes as the values of each index increase demonstrates that the proposed approach is a valuable land prioritization tool.

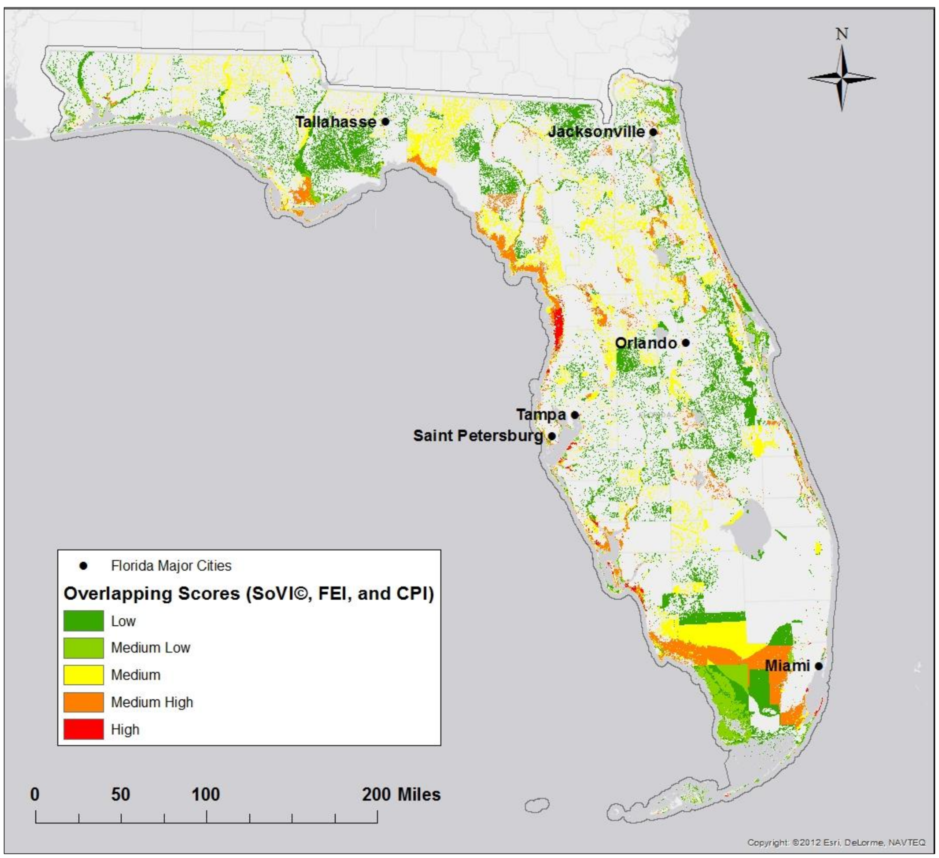

Figure 9. SoVI ©, FEI and CPI Overlap

3.4 Repetitive Loss Properties in Florida

According to FEMA, as of December 31, 2011, there were 16,546 RLP located throughout Florida (Table 2, Figure 10). Collectively, these RLP filed 42,092 claims against NFIP, with total claim payments reaching more than $1.35 billion. The average claim value was almost $32,300 (King 2013). Five counties were responsible for 52% of claims and 52% of all repetitive loss properties in Florida during the same period: Miami-Dade, Pinellas, Escambia, Santa Rosa, and Broward (Table 2). Note that about 1,200 RLP did not have their correct address included in the database used in this study (provided by FEMA), therefore only the remaining 15,274 RLP were included in the present study (total number of RLP in Table 2).

Table 2. Repetitive Loss Properties and Claims in Florida (Top 12 Counties)

County	Number of Claims	% of Claims	Number of RLP	% of RLP
Miami-Dade	7,886	20%	3,415	22%
Pinellas	4,226	11%	1,418	9%
Escambia	3,956	10%	1,373	9%
Santa Rosa	*2,380*	6%	953	6%
Broward	*1,834*	5%	724	5%
Monroe	1,702	4%	747	5%
Okaloosa	1,699	4%	715	5%
Pasco	1,610	4%	650	4%
Lee	1,575	4%	641	4%
Hillsborough	1,238	3%	424	3%
Manatee	1,051	3%	333	2%
Sarasota	1,010	3%	326	2%
Other	8,961	23%	376	23%
Total	**39,128**	**100%**	**15,274**	**100%**

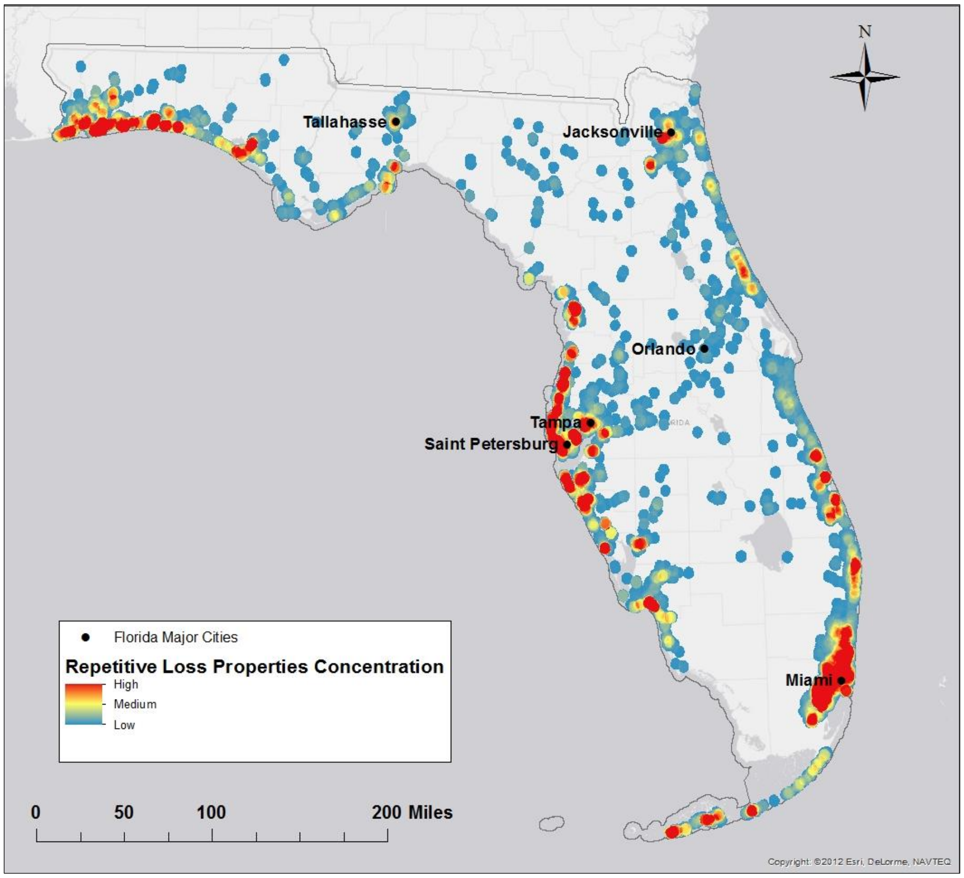

Figure 10. Repetitive loss properties in Florida.

Roughly 44% of all RLP in Florida are in areas where SoVI ©, FEI, and TNC areas overlap. The approximately 6,700 RLP located in such areas filed almost 16,800 claims against NFIP from 1978 to 2011. More than 530 RLP are in areas where the overlapping scores between SoVI ©, FEI, and TNC is high (scores>80), and filed more than 1,300 claims against NFIP in the same period. Almost 380 RLP are in areas where the overlapping scores between SoVI ©, FEI, and TNC have maximum value (i.e. score equal 100). Combined, these 380 RLP filed almost 1,000 claims against NFIP through 2011.

4. MIAMI-DADE COUNTY CASE STUDY

Miami-Dade County is an ideal geography for a targeted case study of our methods, as it contains extensive areas with high exposure to floods, high social vulnerability, and valuable natural habitats.

Miami-Dade County is the 7th most populous county in the United States (U.S. Census Bureau 2017a), and it covers a total area of approximately 6,300 km^2, 78% of which (4,900 km^2) is terrestrial. Miami-Dade County contains the largest number of RLP in Florida; from 1978 to 2011, more than 3,400 RLP filed almost 7,900 claims against NFIP in the county. Roughly 48% of the county's dry land (2,400 km^2) has medium-high or high FEI values (FEI > 75).

Nearly 84% of Miami-Dade County (4,200 km^2) is classified as TNC's Priority Areas, with extensive coverage of marshes (2,264 km^2), estuaries (650 km^2), and other natural habitats (Florida Fish and Wildlife Conservation Commission 2016). Nearly 67% of the county (3,400 km^2) has overlapping FEI and TNC values. (SoVI© values exist throughout the county). There are 98 km^2 of areas where overlapping scores between FEI, SoVI ©, and TNC areas are considered very high (i.e. scores = 100). The extent of land in the county where FEI, SoVI©, and PCI areas overlap (over land) is slightly smaller, roughly 55% of the county (2,800 km^2).

Finally, Miami-Dade has high levels of social vulnerability. The county is Florida's most vulnerable census tract, and in 2010, almost 54% of its population, nearly 1.4 million people, lived in areas with high social vulnerability (Hazards and Vulnerability Research Institute 2017c). In 2016, more than 20% of Miami-Dade's population (nearly 540,000 people) were living in poverty, and almost 500,000 people in the county did not have health insurance in 2015 (U.S. Census Bureau 2017b).

We found 144 RLP in Miami-Dade in the 92 km^2 where the overlapping scores between FEI, SoVI, and TNC areas are high (overlapping scores > 75) (Figure 11). Collectively, these 144 RLP filed at least 320 claims against NFIP, between 1978 and 2011. Such properties are eligible for HMA grants, which support flood-risk mitigation activities that can improve the livelihoods of socially vulnerable neighborhoods and promote the conservation of critical habitats. Finally, there are 96 RLP in Miami-Dade where the overlapping scores between FEI, SoVI, and TNC areas are very high (overlapping scores > 90) (Figure 11).

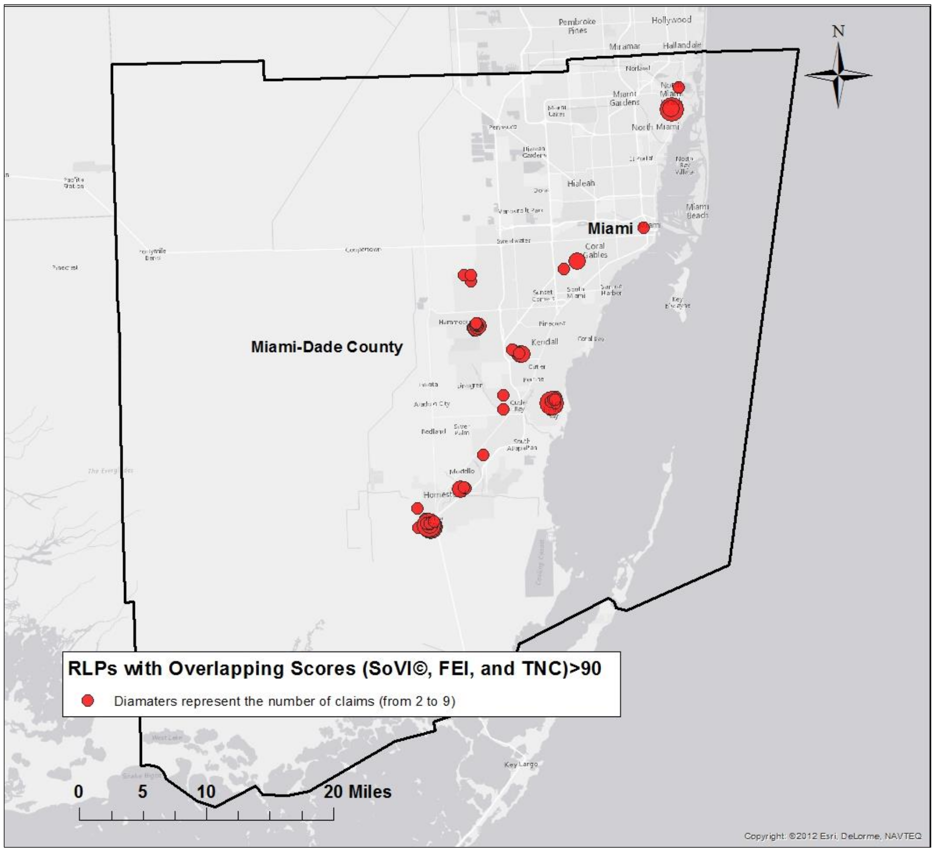

Figure 11. 96 RLP in Miami-Dade County. Diameters represent the number of claims filed (from 2 to 9).

5. DISCUSSION

Our methods identified and prioritized multiple locations in Florida where multi-objective projects can be implemented to simultaneously reduce flood exposure, restore natural habitats, and improve social vulnerability. As an example, in a targeted case-study, we identified 144 RLP in Miami-Dade County located in areas where these objectives are very well aligned.

It is important to note that, due to privacy concerns, FEMA restricts the accuracy of RLP locations to a city block level, not individual parcels. However, such accuracy is adequate for the objectives of the present study and sufficient for identifying potential locations for acquisition projects. Another limitation of the study is that in addition to the 15,274 RLP records used in the model, there are roughly 1,200 RLP records for which FEMA did not provide adequate geolocation information and were therefore excluded from the study. Other limitations are related to SoVI © as follows: Since the index is calculated at a census tract level, some uninhabited areas (e.g. Biscayne National Park) receive high overlap scores between the indices used, but are not necessarily relevant. Furthermore, small pockets of social vulnerability may be diluted by nearby richer census block groups. It is important to ground-truth the index, validate its assumptions, and incorporate local knowledge before implementing any project.

The presented approach identifies a valuable opportunity for the coordinated use of funds previously designated for single objective projects. Since the 1993 floods in the Midwest, FEMA has spent hundreds of millions of dollars to remove repetitive loss structures from the floodplains across the country (King 2013). In recent years, the U.S. Department of Housing and Urban Development (HUD) offered almost $2 billion in funding, designated for disaster recovery and long-term community resilience (HUD 2013; HUD 2015; Brian Sullivan 2016).

Adaptation approaches are slowly transitioning from large engineered solutions to more creative approaches that better align with natural processes, cost less in the long term, and reduce future impacts on socially vulnerable communities and others (Revell et al. 2016; The Nature Conservancy 2016). For example, building a seawall on a sandy beach, which in theory protects a community from flooding, does very little to improve social vulnerability. Moreover, because of coastal dynamics, seawalls may result in beach loss, thereby diminishing the social, economic, and ecosystem benefits the lost beach provided, further impacting social vulnerability. Conversely, the relocation of properties to safer areas, followed by the restoration of the floodplain to a more natural state, or managed retreat, is an example of an integrated approach. Understandably, retreating is a controversial topic, and not always viable in the short-term, especially in denser urban areas where other structural measures (e.g. engineered coastal defenses including building seawalls and elevating properties) will continue to be important for some time.

The above comparison between seawalls and managed retreat is illustrative of two contrasting approaches, and is not all inclusive. A second example of creative adaptation approaches would be to allow existing structures to remain in areas exposed to flooding until they are damaged beyond a specific threshold. This approach, however, must be implemented carefully; damaged thresholds must be clearly defined, and an effective evacuation plan must be established to reduce physical risks to residents.

Nevertheless, the focus of this paper is the identification and prioritization of suitable areas where government-funded buyouts, followed by structure demolition or relocation, and the restoration of floodplain habitats can support social, environmental, and economic objectives simultaneously. It is important to note that buyouts must be done from voluntary sellers, and relocation projects must be executed in a thoughtful and fair manner. Kick et al. (2011) found through interviews with flood victims from repetitive loss sites and FEMA officials that a community-based system is the most effective approach to such projects. Kick et al. (2011) show that financial variables are not the only critical factor; perceptions of future risk, attachments to home and community, and the relationships with flood management officials are also critical decision factors that homeowners must consider (Kick et al. 2011). Additionally, the timing of relocation is critical. While it is harder to make the case for relocation before the onset of a disaster, the occurrence of disasters reduces income and consumption levels, further aggravating poverty (Juneja 2009). Moreover, availability of affordable housing in economically thriving areas where relocated families can find work and become productive members of the community should be a key component of the relocation process. As previously mentioned, input from vulnerable communities must be taken into consideration during all phases of potential projects, from the early planning stages, to actual implementation.

Future related research should identify additional creative adaptation approaches, identify potential sources of funds, and compare costs and benefits related to their implementation. Future studies should focus on hotspots (e.g. Miami-Dade County), and explore partnerships with local communities, government agencies and officials, NGOs, and the private sector. Our model can also be improved by the addition of population data and property values. Despite these limitations and opportunities for future improvement, our results provide a valuable first step in the identification of candidate neighborhoods for implementing multi-objective projects.

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