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The ecosystem service of property protection and exposure to environmental stressors in the Gulf of Mexico

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ABSTRACT

Environmental stressors such as sea-level rise, erosion, and increased storm frequency and intensity are exposing coastal properties to greater amounts of damage. Coastal habitats like beaches, dunes, seagrasses, and wetlands can help reduce exposure and property damage. Using InVEST's Coastal Vulnerability Model, an exposure index value was calculated for every 250 m^2 segment along the coastline in Escambia and Santa Rosa counties in Florida, USA. Nineteen sea level-by-habitat management scenarios were evaluated for a suite of shoreline segments across multiple exposures that can be used to inform local decision making as part of larger strategies for coastal management. Overall, a rise in sea level and degradation of coastal habitats could decrease the number of lower exposed shoreline segments and increase the number of higher exposed shoreline segments. These results were used to identify changes in the amount of potential residential property damage among different scenarios. Under high sea levels, additional protection to coastal habitats could reduce the amount of residential property damage resulting from one tropical cyclone event by $50.4 million (2018 US dollars (USD)) (by the year 2050) and by $71.8 million (2018 USD) (by the year 2100) in Escambia and Santa Rosa counties. This research demonstrates the effects that habitat type/abundance and sea-level rise could have on vulnerable coastlines. The results of the modeled scenarios can be incorporated into several recent community resiliency planning initiatives in the region to develop more robust management plans and preparations for a changing environment.

1. Introduction

Ecosystem goods and services (EGS) have received increased attention in scientific and economic research around the world because they help in understanding the flow of benefits the environment provides to humans (Costanza et al., 2014, 2017). Identifying the goods and services provided by an ecosystem allows stakeholders, lawmakers, and community decision makers to assess the values associated with these otherwise "free" services, which helps establish a need to protect and restore them (Costanza et al., 2014; de Groot et al., 2012). In 2012, the monetary value of erosion prevention provided by coastal systems was 25,368 $/ha/year (estimated $27,743 in 2018 US dollars (USD)), and the monetary value of climate regulation provided by coastal systems was 479 $/ha/year (estimated $523 in 2018 USD; de Groot et al., 2012). Environmental change is affecting the delivery and availability of coastal EGS (Epanchin-Niell et al., 2017; Munang et al., 2013); thus, more research is needed to better understand the effects these changes will have on human beneficiaries.

In the United States, over 124 million people, or 40% of the total population, live along the coastline (NOAA, 2019b), and these numbers continue to rise. Coastal populations depend on many valuable EGS provisioned by diverse habitats along coasts (Barbier, 2013), with coastal counties producing more than $7.9 trillion in goods and services per year (NOAA, 2019b). The science of ecosystem services has advanced over the last two decades such that decision makers have been able to rely on more than just screening-level cost-benefit analyses (Costanza et al., 2017). Final EGS (FEGS) are defined as those "components of nature directly enjoyed, consumed, or used to yield human well-being" (Landers and Nahlik, 2013) and are specific to an individual or group of human beneficiaries that can be directly connected to what people value (Boyd and Banzhaf, 2007; Landers and Nahlik, 2013; Nahlik et al., 2012). There is a need for an easy way for coastal

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communities to incorporate and prioritize FEGS information into land-use decision making to make sustainability and resiliency focused decisions. Establishing the linkage between beneficiaries and coastal habitats can facilitate the evaluation of how changes in coastal habitats may affect FEGS, and in turn the welfare of human beneficiaries (Littles et al., 2018). Some argue that rather than build artificial structures that cannot adapt to changing environmental conditions and that could potentially harm the environment, it is better to focus on restoring and conserving the natural defense strategies provided by the environment (de Groot et al., 2012; Feagin et al., 2005; Kuriyama and Banno, 2016). Seagrass beds, wetlands, and sandy habitats such as beaches, dunes, and barrier islands, provide a natural source of protection to coastlines by serving as sediment reserves that help support coastlines and provide adaptation to sea-level rise (Barbier et al., 2011; Barbier, 2015; Epanchin-Niell et al., 2017; Spalding et al., 2014).

While there are many examples of ecosystem services mapping and assessment studies in the literature, there are fewer examples of how changes in ecosystem structure, function, and processes change the provisioning of a good or service, and how this in turn affects human beneficiaries (Barbier, 2013). Because environmental changes such as sea-level rise, erosion, and increased storm frequency and intensity have been shown to have a negative influence on habitats such as seagrass beds, wetlands, beaches, and dunes (Feagin et al., 2005; Hinkel et al., 2013; Ranasinghe, 2016), and because these coastal habitats provide FEGS to beneficiaries (Barbier et al., 2011; Epanchin-Niell et al., 2017; Spalding et al., 2014), the loss or degradation of these habitats can affect their ability to deliver FEGS. There are numerous examples demonstrating significant loss of coastal FEGS, including property protection, when valuable ecosystems such as seagrass beds, wetlands, beaches, and dunes are lost (Mendoza-Gonzalez et al., 2012; Munang et al., 2013; Pérez-Maqueo et al., 2007). It is important that community decision makers, community members, and stakeholders for a given decision context understand the value of the local FEGS and the consequences that would occur if these FEGS were lost as part of a larger discussion on coastal management decision making. Indeed, a consideration of ecosystem services and potential tradeoffs associated with alternative actions, in the context of coastal planning, offers a transparent way of evaluating how multiple stakeholders may be affected by land-use decisions. This consideration of FEGS and direct beneficiaries can greatly enhance ecosystem-based management (EBM) frameworks (Granek et al., 2010). For example, a human-made structure might be less expensive to implement than applying resources to preserving or restoring a natural resource, but in the long run, natural resources provide more than just monetary goods and services to the community, and where practical, these additional benefits should be incorporated into the decision-making process and coastal management strategies.

This study evaluated the potential changes in coastal FEGS related to shoreline and property protection due to environmental change in the northern Gulf of Mexico to add to the knowledge base being developed under a handful of focused coastal management activities in the region. The extent to which coastal habitats may provide property protection was examined under multiple levels of habitat change and sea-level rise scenarios. Specific goals of this study were to identify the exposure of coastal segments to environmental stressors (i.e., sea-level rise) and evaluate how changes in the presence and abundance of coastal habitats might affect coastal exposure levels under various management scenarios. Nineteen scenarios were constructed, starting with one "current" scenario based on current (2018) observed rates of sea level and habitat management. Then, 18 "potential" scenarios were created, nine for the year 2050 and nine for the year 2100. The "potential" scenarios depicted changes in natural habitat management ranging from protecting habitats, to maintaining status quo (i.e., unchanged), to degrading habitats, and three different sea-level rise projections from Low, to Intermediate, to High levels. The specific research objectives were to demonstrate how a change in: 1) the presence and abundance of coastal habitats (e.g., seagrass beds, wetlands, beaches, dunes); 2) sea-level rise projections; or 3) both 1 and 2, could affect levels of exposure on the coastline, ultimately shaping ecosystem service delivery. The outcome of these analyses is intended to inform coastal management decision making.

2. Background

Coastal habitats provide defense mechanisms for people and properties by reducing exposure of vulnerable populations and properties to storms (Arkema et al., 2013). However, coastal habitats are vulnerable to environmental change, including projected changes in tropical cyclones and sea-level rise. Extreme weather events are expected to significantly increase by 2050 (Arkema et al., 2013), and tropical cyclones cause the most destruction of any natural disaster in the U.S. (Emanuel, 2005). The upper limits of tropical cyclone intensity are reported to increase due to ocean warming and changes in the thermodynamics of the tropical atmosphere, however, an increase in tropical cyclone frequency is less certain (Knutson et al., 2010). While many studies have stated that global tropical cyclone frequency has increased from the rise in sea-surface temperature, other studies have reported that this recorded increase in tropical cyclones could be due to limitations in the quality and availability of historical records and past observations (Knutson et al., 2010). Still, models suggest that the frequency of more intense tropical cyclones will increase in the Atlantic Ocean (Knutson et al., 2010; USGCRP, 2018), thereby affecting storm wave characteristics and storm surge along the northern Gulf of Mexico (Ranasinghe, 2016).

Sea-level rise has the potential to affect many coastlines. Increased sea level can alter land cover, increase erosion, and expose more areas to flooding and inundation (Epanchin-Niell et al., 2017). One model, DIVA (Dynamic Interactive Vulnerability Assessment), assesses biophysical and socio-economic consequences of sea-level rise and socio-economic development, and estimates that up to 17,000 km^2 of beach worldwide could be lost by 2100 (Hinkel et al., 2013). The estimate for global mean sea-level rise by the year 2100 is up to 0.91 m (Epanchin-Niell et al., 2017), which may increase the exposure of people and properties by 30–60% (Arkema et al., 2013). In the northern Gulf of Mexico, local sea-level rise projections can be up to 2.48 m by the year 2100 according to the National Oceanic and Atmospheric Administration's (NOAA) Sea Level Rise Viewer (NOAA, 2017). In Florida, 60% of the land area is in shoreline counties, with 77% of the population living within these same areas (Epanchin-Niell et al., 2017).

An increase in storm frequency, storm surge, and wave heights can also lead to higher and more severe levels of coastal erosion (Ranasinghe, 2016), especially when combined with an increase in sea level. Following storms, beaches have rapid, short-term erosion and then rapid, short-term accretion, so the net amount of sediment on the beach usually balances out (Hinkel et al., 2013). However, when waves and storm surge repeatedly narrow a dune, sediment begins to slump and the waves overwash the dune, pushing the sediment landward and causing long-term dune erosion (Pries et al., 2008). Because the northern Gulf of Mexico coast is flat, a small sea level increase may cause a significant loss of sediment and land (Feagin et al., 2005). When the sea level rises, it allows high-energy waves to reach further up the shore, redistributing sediment offshore and causing sediment deficiencies (Hinkel et al., 2013; Leatherman et al., 2000). Barrier islands have been able to survive storm surge and rising seas for thousands of years because of their continuous landward migration, or rollover, and redistribution of the sediment deposits just offshore (Lorenzo-Trueba and Ashton, 2014). However, as sea-level rise erodes coasts, people turn to artificial structures such as seawalls for protection. These seawalls are built to replace the natural protective barriers that coastal habitats provide, but they alter the environment and have the potential to cause harm in the long run (Feagin et al., 2005). Artificial submerged breakwaters are often built further offshore to counteract erosional processes caused by the presence of seawalls (Kuriyama and Banno, 2016). However, artificial breakwaters stop erosion by allowing sand to fall out of suspension from longshore currents, taking sediment away from other lands downdrift and increasing erosion in these areas (Brunn, 1995). Higher sea levels also create a greater distance between the sea level and the crest of the breakwater, leading to a decrease in the dissipation of wave energy (Kuriyama and Banno, 2016). When wave energy dissipation decreases, the incoming wave energy flux increases, leading to more severe beach erosion (Kuriyama and Banno, 2016).

The exposure of coastal FEGS to environmental change differs from place to place, depending on the beneficiary portfolio of the region (e.g., Littles et al., 2018) and how land cover may change as a result of management practices (Epanchin-Niell et al., 2017). Cities along the Gulf of Mexico have a heavy concentration of human activities (e.g., tourism) and beach use (including major real estate development) along the coastline (Ariza et al., 2014). The warm weather, recreational opportunities, and abundant natural resources attract visitors and new residents (Ariza et al., 2014). Because of this, much of the $30 million Florida receives each fiscal year from a state fund set up for beach preservation and repair is spent on beach nourishment (Montgomery, 2000). While people may understand the current suite of environmental problems and challenges, and support the protection of natural resources, most do not make choices solely for the benefit of the environment or that help decrease negative environmental effects (Halpenny, 2010). In 2006, the Gulf Coast of Mexico lost over $800,000 per hectare (2018 USD) worth of EGS in the areas of property protection, recreation, food, and waste treatment due to land use change and coastal habitat loss (Mendoza-Gonzalez et al., 2012). While these losses in Mexico were due to urbanization, it shows that the services provided by those habitats would not exist if the habitats were lost, including a loss from environmental change. The long-term losses of the EGS exceeded the short-term gains of urbanization (Mendoza-Gonzalez et al., 2012). Habitat loss that is already occurring due to development and urbanization can only be exacerbated by increasing environmental stressors. With strong linkages between coastal habitats and FEGS supplied to beneficiaries, environmental stressors and changes are increasing the exposure of these FEGS. EBM strategies can be tailored to address climate effects on ocean and atmospheric processes that may, in turn, affect coastal communities (Fernandino et al., 2018). Fernandino et al. (2018) outlined five broad categories that management plans can follow for climate intervention: non-intervention, managed retreat, hold the line, accommodate, and expand into the coastal zone. Because coastal habitats and their FEGS respond to changes in the environment differently based on location, environmental drivers, and coastal processes, it is vital that informational gaps at the local level be filled to ensure the most effective EBM strategies are chosen for each coastal community (Fernandino et al., 2018). Additionally, information gained from a consideration of how the availability and suite of coastal FEGS may differ under different management scenarios can bring diverse stakeholders together to develop more holistic and balanced EBM plans (Granek et al., 2010).

The Florida Panhandle's coastal systems are dynamic, naturally shaped by waves, wind, and sand (UF/IFAS and Florida Sea Grant, 2018). The Gulf side of the Florida Panhandle is lined with beaches, dunes, grasslands, and shrub, while the numerous bays along the coastline are lined with wetlands and seagrasses (UF/IFAS and Florida Sea Grant, 2018). These habitats not only provide protection for roads, buildings, and coastal properties, but they are home to unique wildlife and plants such as beach mice, gopher tortoises, shorebirds, sea turtles, endemic plants, and many more (UF/IFAS and Florida Sea Grant, 2018).

The Florida Panhandle is vulnerable to environmental stressors such as sea-level rise, erosion, and storms which puts people and property at risk, especially with increasing population and tourists. Since 2002, the Northern Gulf Coast has been struck by 15 tropical storms, with some of the most devastating being Hurricane Ivan, a Category 3 hurricane in 2004 and Hurricane Dennis, a Category 3 hurricane in 2005 (NOAA, 2019a). Recently, the Northern Gulf Coast was hit by Tropical Storm Nate in 2017 (MBNEP, 2013) and Tropical Storm Alberto, Tropical Storm Gordon, and Hurricane Michael, a Category 5 hurricane, in 2018 (NOAA, 2019a). The increasing population and tourism numbers make both prominent tropical cyclones, and the mean sea-level trend of 2.31 mm/year (NOAA, 2019c), important environmental stressors necessitating both the education of the community and incorporation into local decision making and coastal management strategies.

3. Materials and methods

3.1. Study site

Escambia and Santa Rosa counties located along the Panhandle of Florida were the focus of this study. Within Escambia (population of 313,512 in 2017) and Santa Rosa (population of 174,272 in 2017) counties (Fig. 1) are many bodies of water including Pensacola Bay, Escambia Bay, East Bay, Santa Rosa Sound, Big Lagoon, and Perdido Bay. The beach front portion of the counties located right along the Northern Gulf Coast includes Santa Rosa Island and Perdido Key. The shoreline of the bays and the Gulf coast are mostly lined with sandy beach habitat, while highly protected areas of the bayous are lined with emergent marsh. Pensacola and Perdido Bays do contain seagrass beds, but historic seagrass loss has been extensive. Quartz, the primary component of beaches in this area and along the Florida Panhandle, gives the sand its sugary white appearance and texture and makes the area a popular tourist destination (SRIA, 2015). The economy of Santa Rosa and Escambia counties relies heavily on tourism, with prominent activities including boating, diving, fishing, nature trails, restaurants, residential property, and nightlife (SRIA, 2015).

3.2. Coastal vulnerability model

It is difficult to assign values to EGS that are not directly marketed, such as property protection, recreation, and spiritual enrichment (Barbier, 2013). Similar processes and functions might contribute to multiple EGS, and it is important to treat the valuation of each good or service separately (Barbier et al., 2011). While there are many tools that are designed to estimate the value of EGS (e.g., Coastal Defense App (The Nature Conservancy, 2016), CCVATCH (CCVATCH, 2018), ARIES (ARIES, 2017)), the Coastal Vulnerability Model (CVM) housed within Integrated Valuation of Environmental Services and Tradeoffs (InVEST 3.7.0; Natural Capital Project, 2018) best fit the needs of this study because: it includes relevant habitats and relevant environmental stressors; it incorporates an EGS component into its calculations; it is free, open-source software; and it is a well-established model that has been used successfully in the literature (Arkema et al., 2013, 2015; Cabral et al., 2017; Chung et al., 2015; Guerry et al., 2012; Langridge et al., 2014). The CVM measures how changes in the environment can affect the exposure of coastal development to erosion and flooding caused by storms (Natural Capital Project, 2018). These results can be combined with community demographic information to illustrate areas along the coastline where people are most vulnerable to waves and storm surge (Natural Capital Project, 2018). This model can run relatively quickly and easily and can be used in most regions of the world contingent on available and obtainable data (Natural Capital Project, 2018). The output is assessed based on the inputs of different model variables (relief, natural habitats, sea-level change, wave exposure, surge potential, and social exposure) related to coastal exposure and highlights the protection services that natural coastal habitats provide to coastal communities (Natural Capital Project, 2018). This information can help coastal decision makers, property owners, and other stakeholders identify coastal areas at greater risk to hazards by informing areas along the coast that should receive focus or be avoided, which can in turn better inform development strategies and permitting (Natural Capital Project, 2018).

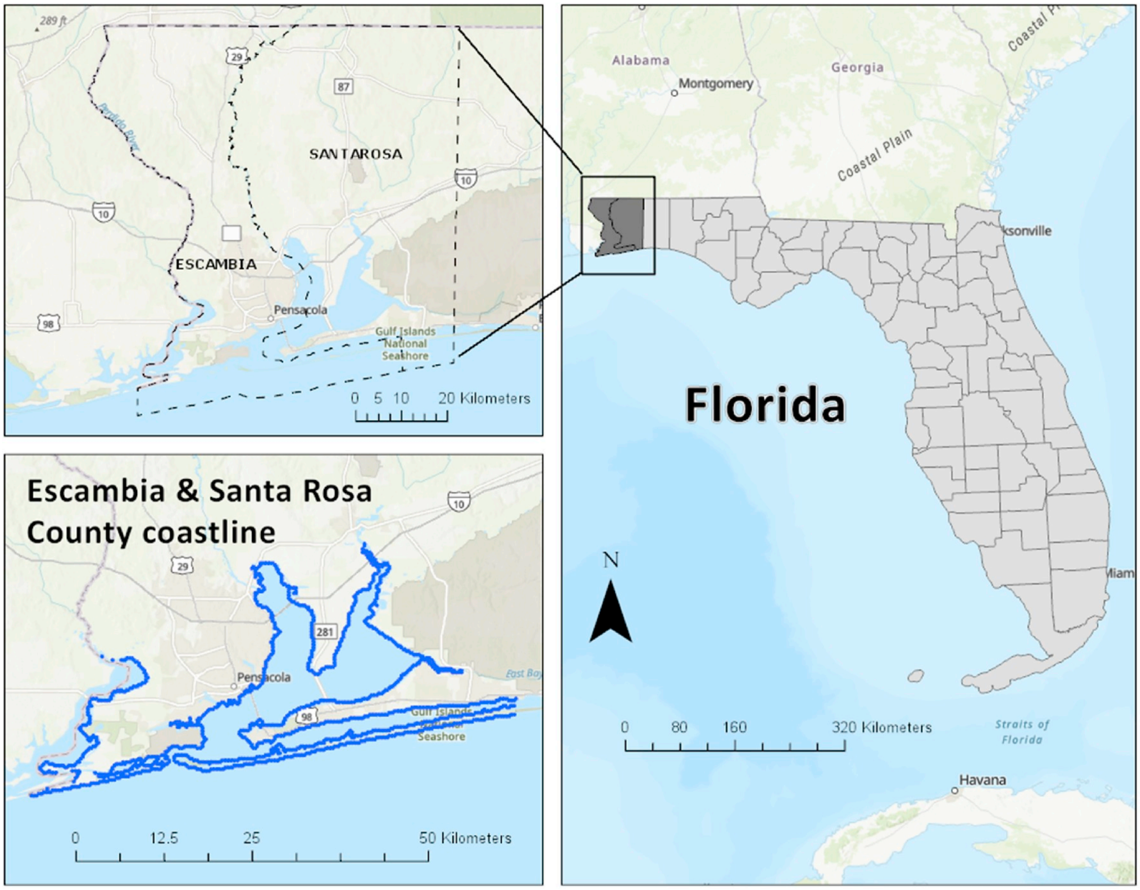

Fig. 1. Map of the study site location – Escambia and Santa Rosa counties (outlined by dashed black lines in top left) – in relation to Florida (right). The coastal segments analyzed are plotted in blue along the Escambia and Santa Rosa county coastline (bottom left). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.3. Design of scenarios

In order to evaluate the effect of potential sea-level rise and changes in habitat management, nineteen scenarios were constructed for the area of interest and include the following:

- One "current" condition scenario based on current (2018) rates of sea level and habitat management.
- Eighteen "potential" scenarios (nine for the year 2050 and nine for the year 2100) constructed using projected sea-level changes and habitat management (Table 1). These scenarios depicted changes in natural habitat management from protecting habitats ("Protect"), to no change ("Unchanged"), to allowing habitats to degrade ("Degrade") (defined in Table 2), and sea-level rise ranging from Low (0.26 m by 2050; 0.5 m by 2100), to Intermediate (0.4 m by 2050; 1.11 m by 2100), to High (0.73 m by 2050; 2.48 m by 2100) levels (based on NOAA's local 2050 and 2100 projections; NOAA, 2017).

3.4. Data

The CVM requires a geographical information system (GIS) to run and view results. Some of the necessary data to run the model were provided within InVEST (e.g., global land mass polygon, wind and wave data, and the location of the continental shelf), but most data had to be collected for the specific community of study (e.g., a polygon outlining the area of interest, bathymetry data, elevation data, natural habitat locations, sea-level rise projections, and median residential property values). The default model resolution, 250 m^2, was used to run the model for this study because it provided a high enough resolution to show changes in the Exposure Index (EI) value for specific areas within the study site but did not require extensive computation time. More details regarding the source and formatting of the data within the model, along with additional inputs required to run the model, are provided in the supplemental material (Appendix A).

3.5. Calculating coastal hazard

The model provided an output that ranked the exposure of each 250 m^2 segment either Very Low ($\leq$1.99), Low (2–2.99), Moderate (3–3.99), High (4–4.99), or Very High ($\geq$5) based on the coastal hazard index variables (see Appendix A). The index weighted all variables (natural habitats, relief, wave exposure, surge potential, and sea level change) equally based on methods proposed by Gornitz (1990) and Hammar-Klose and Thieler (2001). Additionally, each natural habitat was given its own protective distance and exposure rank variable for input into the model (see Appendix A). The habitat rankings were proposed by InVEST authors after extensive literature review (Natural Capital Project, 2018). The EI value, or the geometric mean of all the variable ranks (Natural Capital Project, 2018), was calculated from the following formula:

$$\text{Exposure Index} = (R_{NaturalHabitats} R_{Relief} R_{WaveExposure} R_{SurgePotential} R_{SeaLevelChange})^{1/5}$$

where R represents the ranking of each variable based on data provided by the user to calculate the EI. The results are a qualitative estimate of the relative exposure of each 250 m^2 coastal segment to storm-induced erosion and flooding across the 19 scenarios.

Table 1
A table outlining the 18 "potential" scenarios. The first number in each box is the change to the natural habitat exposure rank produced by the model: (−0.5) indicates decreasing the habitat exposure rank by one-half a level to represent a "Protect" scenario; ("As Is") indicates keeping the habitat exposure rank the same to represent an "Unchanged" scenario; and (+0.5) indicates increasing the habitat exposure rank by one-half a level to represent a "Degrade" scenario. While the natural habitat exposure rank produced by the model is based on real data, the small incremental change made to the rank in the three scenarios is not a predicted number, but rather an arbitrary number simply meant to illustrate the impact that habitat presence and abundance has on the exposure of the coastline. The second number in each box is the increase in the sea level (in meters) for Low, Intermediate, and High Sea-Level Rise scenarios.

Year 2050				
Sea Level Trend	Natural Habitats			
		PROTECT	UNCHANGED	DEGRADE
	LOW	−0.5; 0.26 m	As Is; 0.26 m	+0.5; 0.26 m
	INTERMEDIATE	−0.5; 0.4 m	As Is; 0.4 m	+0.5; 0.4 m
	HIGH	−0.5; 0.73 m	As Is; 0.73 m	+0.5; 0.73 m
Year 2100				
Sea Level Trend	Natural Habitats			
		PROTECT	UNCHANGED	DEGRADE
	LOW	−0.5; 0.5 m	As Is; 0.5 m	+0.5; 0.5 m
	INTERMEDIATE	−0.5; 1.11 m	As Is; 1.11 m	+0.5; 1.11 m
	HIGH	−0.5; 2.48 m	As Is; 2.48 m	+0.5; 2.48 m

Table 2
Habitat scenarios defined.

Scenario	Definition
Protect	Adds protection and regulation beyond current management conditions. Assumes improvement and a positive change in the landscape (e.g., taller/wider dunes, wider beach, an increase in seagrass coverage).
Unchanged	Makes no changes to current management; enforces current regulations. Assumes no changes in landscape and habitats remain constant.
Degrade	Removes current protection and regulation. Assumes degradation and a negative change in the landscape (e.g., smaller dunes or loss of dune habitat, narrow beach, loss of seagrass coverage).

3.6. Quantifying risk

In order to quantify potential risk to residential coastal property, the median residential property values (U.S. Census Bureau, 2016) under EI levels High and Very High were compared among the sea level-by-habitat management scenarios. To do this, ArcGIS was used to join the point shapefile containing EI values generated by the CVM to a polygon shapefile containing the median residential property values at the census block level for the area of interest. This assigned a median residential property value to each 250 m^2 coastal shoreline segment. Because Cabral et al. (2017) found a positive correlation between areas with High/Very High EI levels and the amount of property damage and/or loss caused by coastal climate events, median residential property value results from this study were distilled down to only include coastal shoreline segments with EI levels High or Very High, as these coastal shoreline segments were at the greatest risk for property damage. The median residential property value for coastal shoreline segments under EI levels High and Very High were then summed and graphed for each sea level-by-habitat management scenario for the years 2050 and 2100. The median residential property values for the "current" scenario were also included in both graphs for reference. All dollar values are presented in 2018 US dollars.

4. Results

4.1. Exposure index values by scenario

Six habitats were included in the analysis – scrub shrub, coastal forest, dunes, emergent marsh, seagrass beds, and beach. Maps showing the EI values for "Protect," "Unchanged," and "Degrade" habitat management levels were grouped by Low, Intermediate, and High Sea-Level Rise scenarios for the "current" year (2018), year 2050, and year 2100 (Figs. 2–5). For interpretation purposes, dark green points indicate a Very Low exposure level (i.e., very good; EI level 1), light green points indicate a Low exposure level (i.e., good; EI level 2), yellow points indicate a Moderate exposure level (EI level 3), orange points indicate a High exposure level (i.e., bad; EI level 4), and red points indicate a Very High exposure level (i.e., very bad; EI level 5). The maps show that among each sea-level rise scenario, the EI values of coastal shoreline segments went from higher amounts of dark green points (i.e., lower levels of exposure and minimal risk) under a Low Sea-Level Rise 2050 scenario to higher amounts of yellow, orange, and red points (i.e., higher levels of exposure and greater risk) under a High Sea-Level Rise 2100 scenario.

In the scenarios with higher sea levels and degraded habitats, the areas along the coast with the highest increase in the amount of coastal shoreline segments classified with High/Very High EI levels were located along the Perdido Bay side of the North Shore area, the Gulf side of Perdido Key, the Santa Rosa Sound side of Pensacola Beach, the Pensacola Bay side of Gulf Breeze, and Garcon Point (Fig. 6). The areas along the coast that maintained Low EI values, even under a "Degrade" habitat scenario with high sea levels in 2100, were northern Escambia Bay, northern Blackwater Bay, and the mouth of East Bay River (Fig. 6).

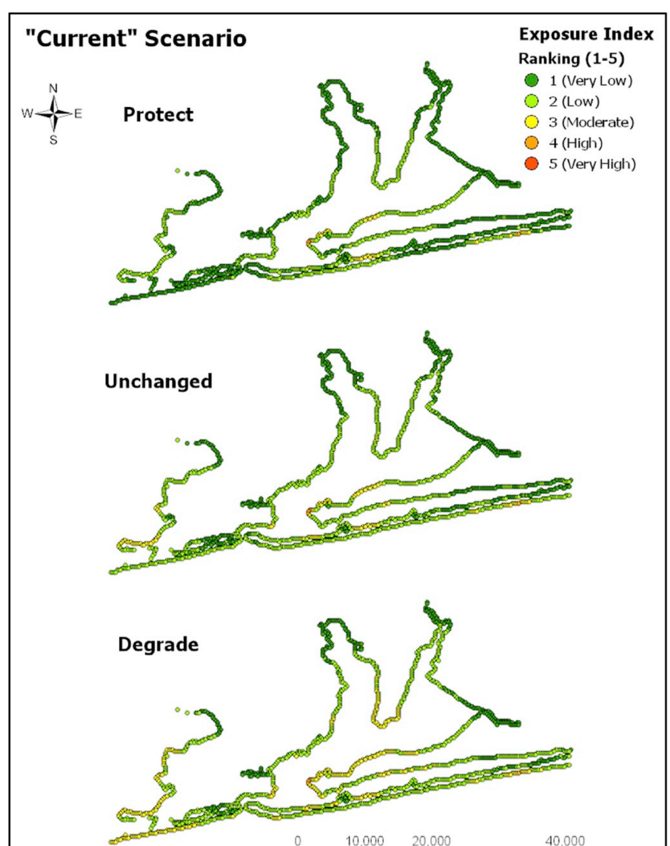

Fig. 2. Exposure Index (EI) values under a Current Sea-Level Rise scenario.

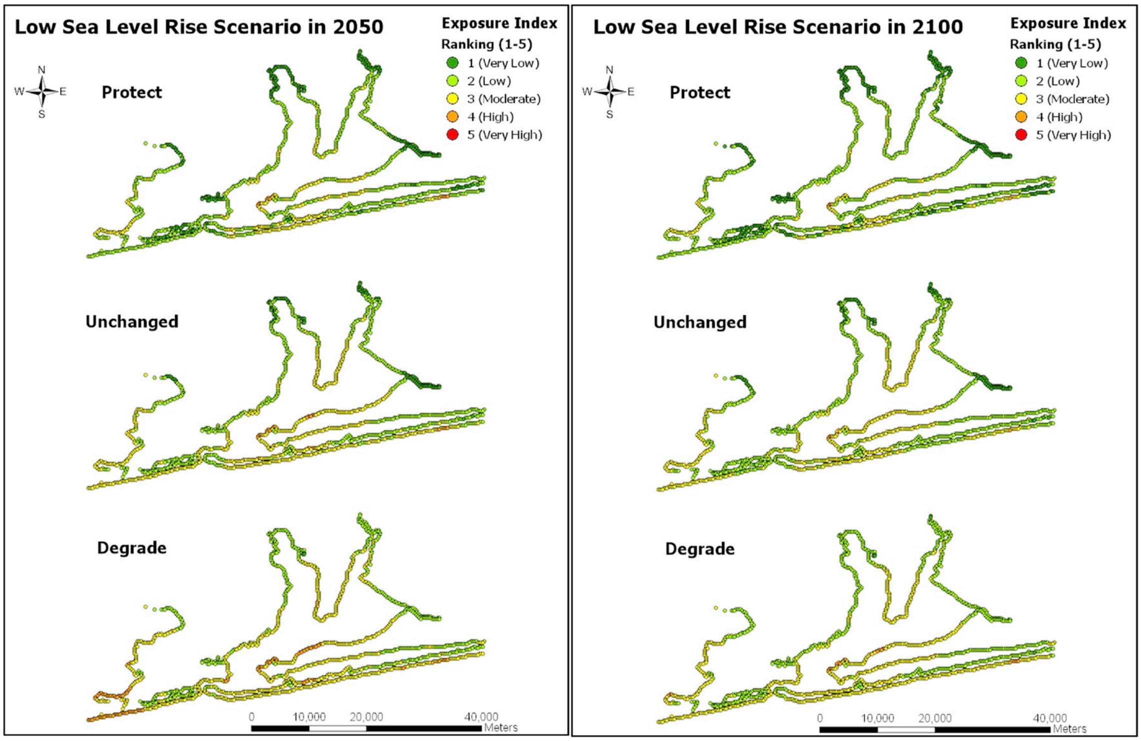

Fig. 3. Exposure Index (EI) values under a Low Sea-Level Rise scenario in 2050 (left) and 2100 (right).

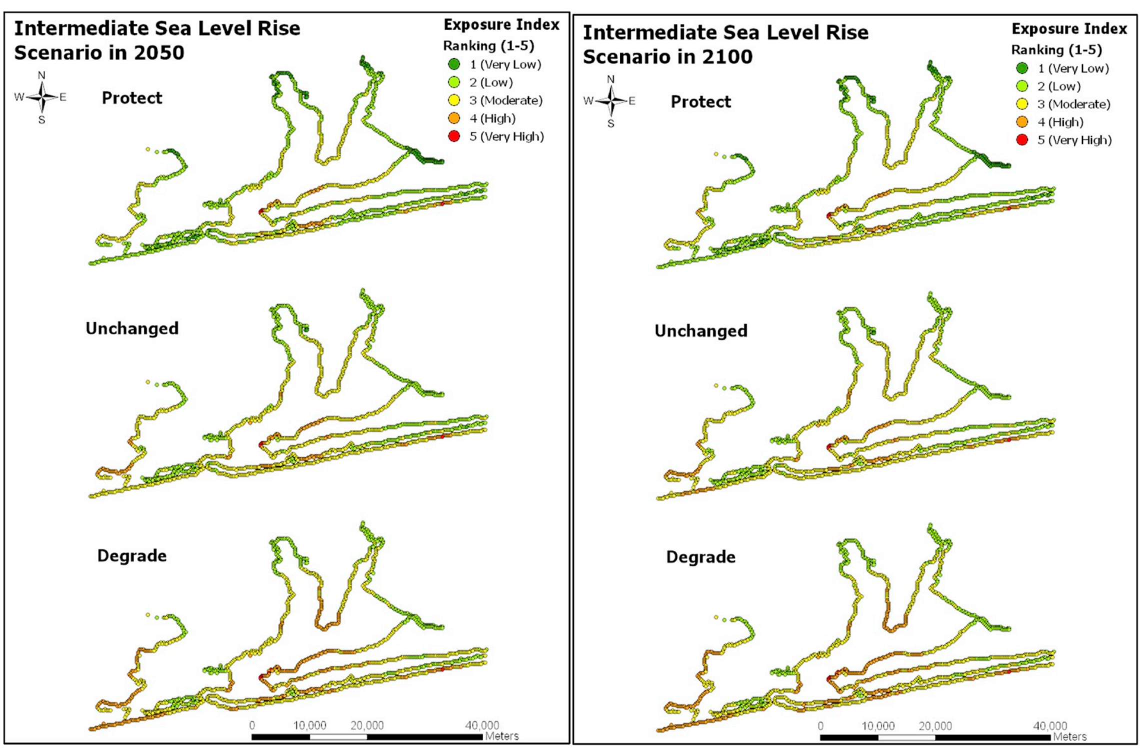

Fig. 4. Exposure Index (EI) values under an Intermediate Sea-Level Rise scenario in 2050 (left) and 2100 (right).

4.2. Percentage distribution of exposure index values by scenario

The percentage distribution of EI values changed among habitat management scenarios based on abundance of the habitats (Table 3). The "Unchanged" habitat scenario resulted in 45% of the coastal segments to be classified as Very Low/Low exposure and 14% of the coastal segments to be classified as High/Very High exposure. In the "Degrade" habitat scenario, the percent of coastal segments with Very Low/Low exposure decreased 12% from the "Unchanged" scenario and the percent of coastal segments with High/Very High exposure increased 10% from the "Unchanged" scenario (based on the "percent difference": subtraction of one data point from another). For the "Protect" habitat scenario,

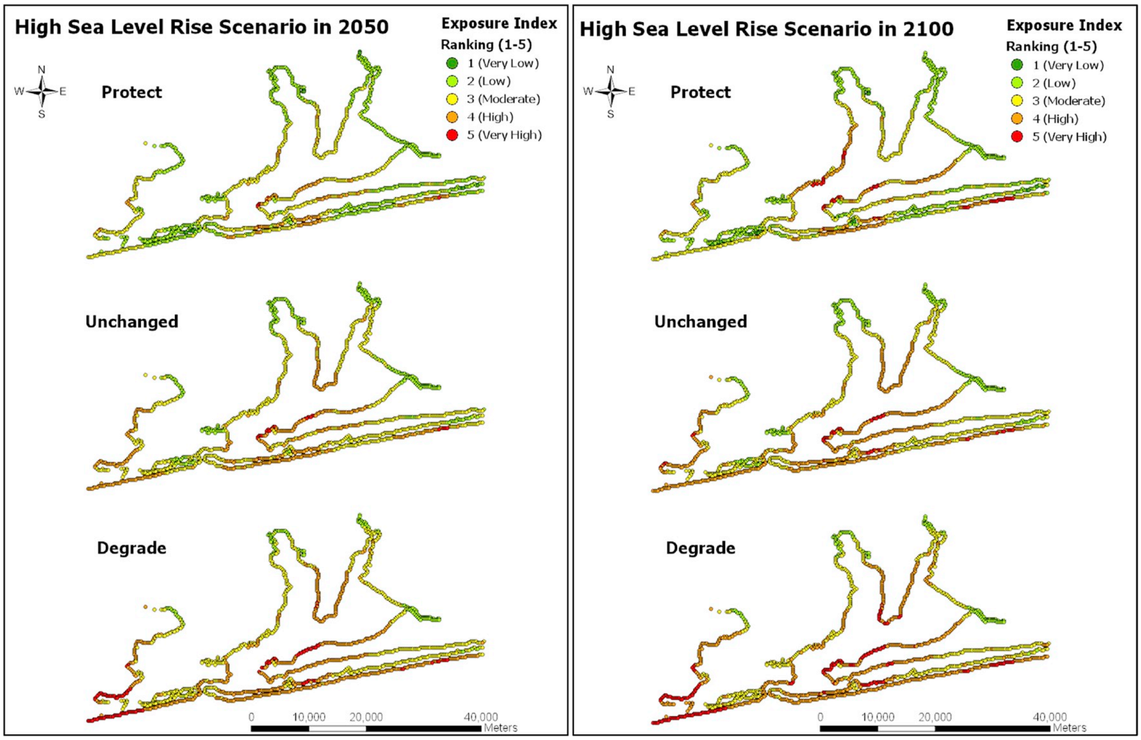

Fig. 5. Exposure Index (EI) values under a High Sea-Level Rise scenario in 2050 (left) and 2100 (right).

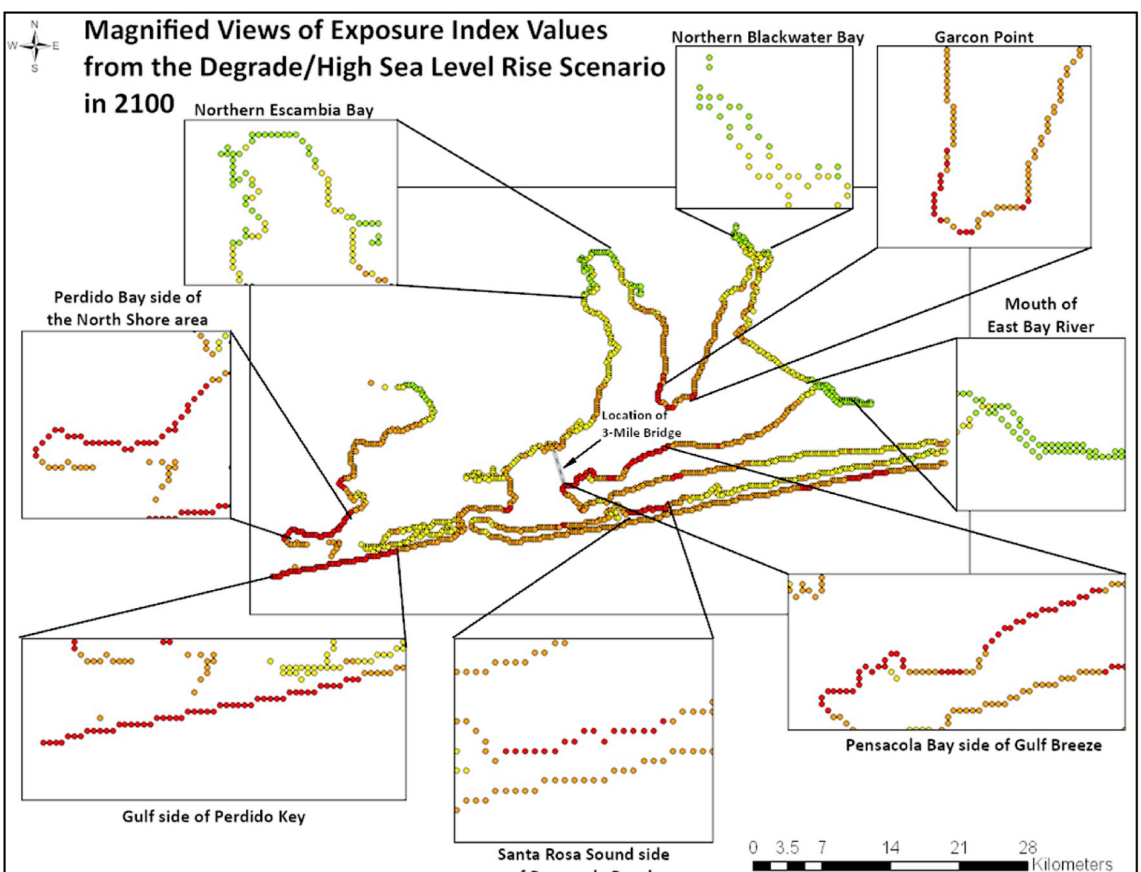

Fig. 6. Magnified views of Very High and Very Low Exposure Index (EI) values from the "Degrade" habitat and High Sea-Level Rise scenario in 2100. The location of Pensacola's 3-Mile Bridge is also included.

Table 3
Percentage distribution of Exposure Index (EI) values among three different habitat management scenarios described in Table 1.

	Degrade	Unchanged	Protect
Very Low (1)	3%	7%	18%
Low (2)	30%	38%	51%
Moderate (3)	44%	41%	26%
High (4)	21%	13%	5%
Very High (5)	3%	1%	1%
Total	100%	100%	100%

the percent of coastal segments with Very Low/Low exposure increased 24% from the "Unchanged" scenario and the percent of coastal segments with High/Very High exposure decreased 8% from the "Unchanged" scenario. The largest percentage of High (21%)/Very High (3%) EI values were found under the "Degrade" habitat scenario, whereas the "Protect" habitat scenario had the largest percentage of Very Low (18%)/Low (51%) EI values.

Fig. 7 illustrates the percentage distributions of EI values under each sea level-by-habitat scenario. In looking at the total number of coastal segments across all the "potential" scenarios (Scenarios 2–7 in Fig. 7), 0% of the coastal segments maintained a Very Low EI value under a "Degrade" scenario, while 11% of the coastal segments maintained a Very Low EI value under a "Protect" scenario. The "Degrade" scenario caused 4% of the coastal segments to reach Very High exposure levels while the "Protect" scenario only allowed 1% of the coastal segments to reach Very High exposure levels.

For both the "Unchanged" and the "Degrade" habitat scenarios, the Moderate EI level held the highest percentage of coastal segments at 47%, compared to the Low EI level, which held the second highest percentage of coastal segments for both the "Unchanged" scenario at 35% and the "Degrade" scenario at 25%. In comparison, the Low EI level held the highest percentage of coastal segments under the "Protect" scenario at 53%, compared to the "Moderate" EI level, which held the second highest percentage of coastal segments at 29%.

Overall, the results from Table 3 and Fig. 7 show that a degradation of habitats, or even maintaining the habitat abundance status quo, could increase the number of moderately-to-highly exposed coastal segments, whereby habitat protection and an increase in habitat abundance could lower coastal segments' EI level, decreasing the amount of moderately-to-highly exposed coastal segments and increasing the amount of lower exposed coastal segments.

The percentage distribution of EI values also changed among the sea-level rise scenarios (Table 4). Under the Current sea level, 89% of the coastal segments were at a Very Low/Low exposure level and 0% of the coastal segments were at a Very High/High exposure level. In the Low Sea-Level Rise scenario of 0.26 m by the year 2050, the percent of coastal segments with Very Low/Low EI values decreased 32% from the Current scenario and the percent of coastal segments with High/Very High EI values increased from 0% to 4%. In the most extreme projection of a 2.48 m rise in sea-level by the year 2100, the percent of coastal segments with Very Low/Low EI values decreased 67% compared to the Current scenario and the number of coastal segments with High/Very High EI values increased from 0% to 41%.

Overall, results from Table 4 showed that the largest percentage of High EI values occurred under the High Sea-Level Rise scenarios for both the 2050 and 2100 projections. The largest percentage of Low EI values occurred under the Current Sea-Level Rise scenario and the Low/Intermediate Sea-Level Rise scenarios for both the 2050 and 2100 projections. The only sea-level rise scenarios that projected any Very High EI values were the High Sea-Level Rise scenarios in both 2050 and 2100, indicating that it would take the highest projection of sea-level rise to occur for properties to be the most exposed to coastal hazards.

4.3. Potential residential property damage

Results of the modeled scenarios showed that in areas with High/Very High EI values, the amount of potential residential property damage from one tropical cyclone event increased under scenarios with degraded habitats and higher sea levels compared to scenarios with protected habitats and lower sea levels (Fig. 8). Under a Current Sea-Level Rise scenario for all three habitat scenarios, the amount of potential residential property damage from one tropical cyclone event reached $2.3 million.

For the year 2100 under the Low Sea-Level Rise scenario, results showed that maintaining current management strategies and making no changes ("Unchanged") exposed an additional $1.2 million in residential property to damage from one tropical cyclone event. Under a scenario with Degraded habitats, the potential residential property damage increased by $8.3 million. However, adding habitat protection kept the potential residential property damage at a consistent $2.3 million, even with a Low rise in sea level.

In the worst-case High Sea-Level Rise scenario in 2100 with no changes (i.e., "Unchanged") to habitat management strategies, the potential amount of residential property damage from one tropical cyclone event surged to a total of $127.9 million. In the same High Sea-Level Rise scenario but with Degraded habitats, the amount increased an additional $37.4 million. However, a scenario with habitat protection projected to reduce cyclone related damages to residential properties by $69.5 million.

Overall, results showed that under a High rise in sea level, additional habitat protection and an increase in the size/health of coastal habitats reduced the amount of residential property damage from one tropical cyclone event in Escambia and Santa Rosa counties $50.4 million by the year 2050 (a 58% decrease in property value amount) and $71.8 million by the year 2100 (a 56% decrease in property value amount).

5. Discussion

This work provides a valuable evaluation of how exposure to sea-level rise and subsequent degradation of shorelines can affect habitats and residents in two Florida coastal communities. Results illustrate the difference that management strategies can have on long-term sustainability and highlight the importance of coastal habitat protection. If the sea level continues to rise, maintaining a "status quo" approach, or allowing for the active degradation of habitats, could dramatically increase exposure to storm-induced erosion and flooding in certain areas and the total cost of damages to property. In fact, some parts of the coastline would be highly vulnerable to storms and flooding under a high projected sea-level rise, even with efforts to maintain existing habitat.

5.1. Exposure index values by scenario

Exposure Index maps show how decreasing habitats' exposure level by one-half an EI level could help maintain the coastline of Florida's Escambia and Santa Rosa counties at Moderate to Low exposure levels, assuming Low-to-Intermediate rises in sea level. Conversely, habitat degradation that increases exposure levels one-half an EI level could increase the exposure in some areas to levels of concern under an Intermediate-to-High rise in sea level. Protecting existing natural coastal habitats could reduce the exposure of water-resource related infrastructures, coastal residents, and farmland (Langridge et al., 2014). The loss of coastal habitats could result in greater damage to residential property or substantially increase investments in human-made defenses (Arkema et al., 2013; Cabral et al., 2017), both of which have implications for local economies, natural habitats, and delivery of ecosystem services.

There were several areas along the coastline of the two Florida communities that were classified with High/Very High EI values under

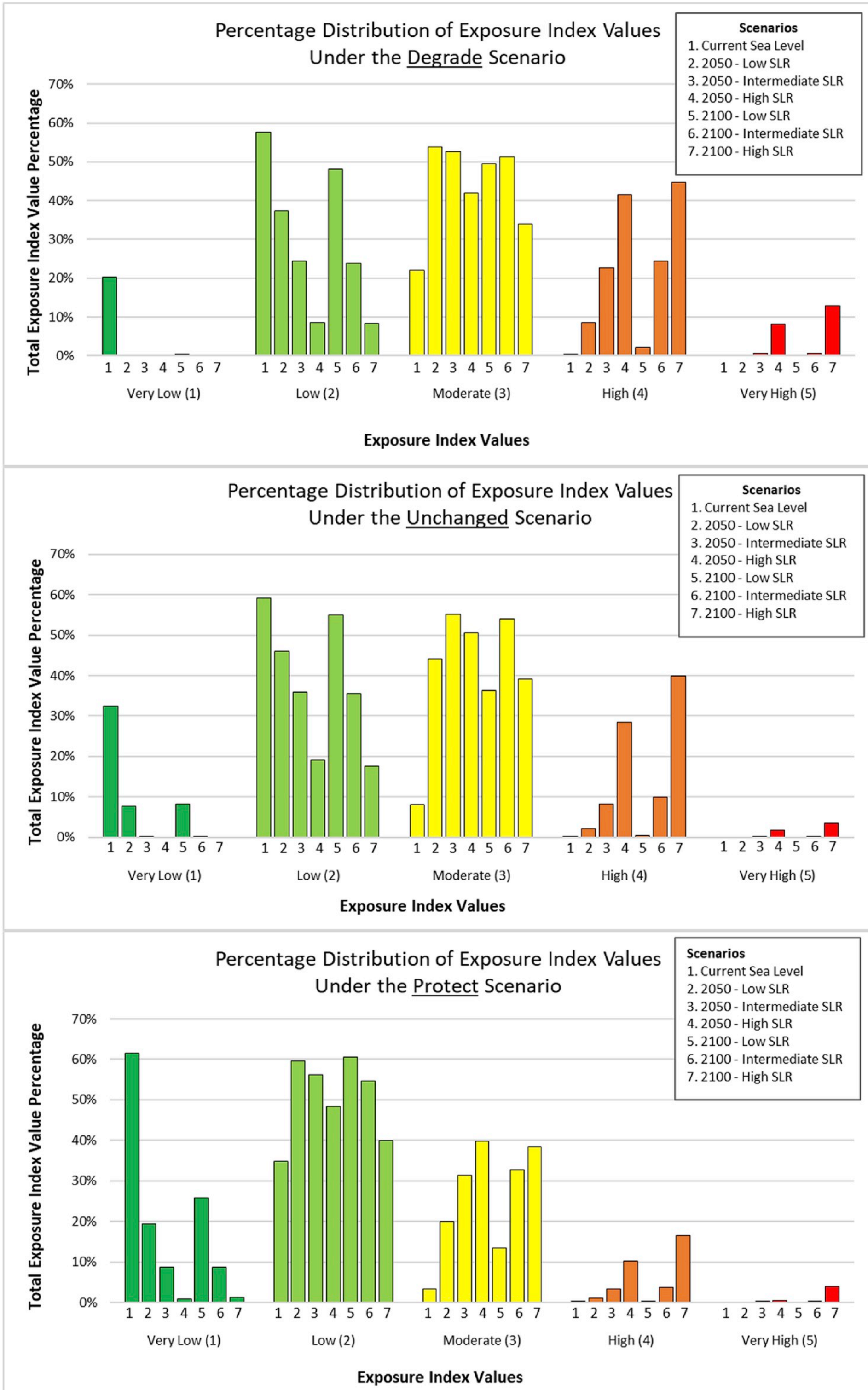

Fig. 7. Percentage distribution of Exposure Index (EI) values for each of the three habitat management scenarios; "Degrade" (top), "Unchanged" (middle), and "Protect" (bottom).

scenarios with Degraded habitats and High sea levels. The Perdido Bay side of the North Shore area and the Pensacola Bay side of Gulf Breeze is lined with only a very narrow beach in some areas and has properties closely abutting the water. The Gulf side of Perdido Key Beach and Pensacola Beach is lined with a wider beach and dunes, but this area typically receives the initial impact from wind and waves and is highly exposed when storms come from the Gulf. Both beaches are popular destinations for locals and tourists with features including shops, restaurants, bars, hotels, and condominiums. For both 2050 and 2100 projections, under the "Unchanged," High Sea-Level Rise scenario, most of Pensacola Beach reached High/Very High exposure levels. Under the "Degrade," High Sea-Level Rise scenario, all of Pensacola Beach reached High/Very High exposure levels. The Santa Rosa Sound side of Pensacola Beach, specifically the part of the coastline to the east of the Bob

Table 4
Percentage distribution of Exposure Index (EI) values projected for 2050 and 2100 among three different sea-level rise (SLR) scenarios (Table 1).

	Current	2050 Low SLR	2050 Intermediate SLR	2050 High SLR	2100 Low SLR	2100 Intermediate SLR	2100 High SLR
Very Low (1)	38%	9%	3%	0%	11%	3%	0%
Low (2)	51%	48%	39%	25%	55%	38%	22%
Moderate (3)	11%	39%	46%	44%	33%	46%	37%
High (4)	0%	4%	11%	27%	1%	13%	34%
Very High (5)	0%	0%	0%	3%	0%	0%	7%
Total	100%	100%	100%	100%	100%	100%	100%

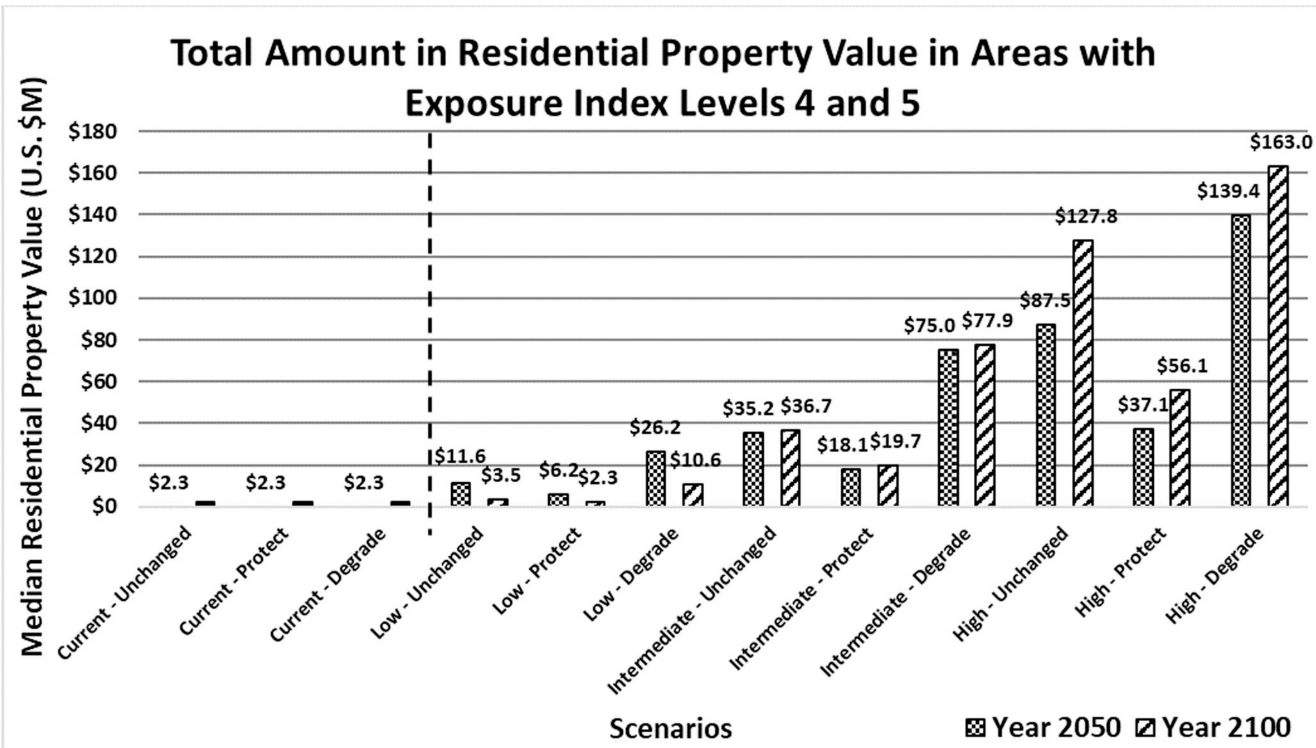

Fig. 8. Total amount in residential property values (potential damage in $ Million; 2018 US dollars) in areas with Exposure Index (EI) levels High (i.e., level 4) or Very High (i.e., level 5) under each habitat management scenario for the Current (2018; left of dashed line), 2050, and 2100 sea-level rise scenarios.

Sikes Bridge, has only a narrow beach with properties lining the back side of the beach. This area of Pensacola Beach is also a popular location for locals and tourists with features including a boardwalk, shops, restaurants, and bars. Garcon Point is fronted with a very narrow beach and emergent marsh behind the beach but extends out into both Pensacola and Escambia Bays and therefore is more exposed. The focal sites of this study were akin to locations in a recent study of regional exposure levels in the U.S. (Arkema et al., 2013). Low-relief coastal areas with softer substrates, such as beaches and deltas, that lack extensive coastal habitats such as wetlands to act as a buffer had higher rates of sea-level rise and storm surge potential, but also greater exposure (Arkema et al., 2013). This was synonymous to the higher EI values for Perdido Key Beach and Pensacola Beach in this study.

In contrast to areas with High levels of exposure, the top of Escambia Bay, the top of Blackwater Bay, and the inlet on the east side of East Bay maintained Low EI levels, even under a "Degrade" habitat scenario and High sea levels in 2100. The tops of Escambia and Blackwater Bays both lack coastal property and have wetlands that, even when Degraded, provide enough shoreline protection to keep exposure levels low. This is not surprising considering that wetlands have been well documented to provide protection from storm surge and flooding (Costanza et al., 2008; Narayan et al., 2017). The inlet in East Bay likely maintained Low exposure levels because of the protection from surrounding land.

The coastline along Pensacola Bay to the west and east of the 3-mile bridge (Fig. 6) remained at Low-to-Moderate EI levels for both 2050 and 2100 projections, with the exception of a High rise in sea level, for the "Degrade," "Unchanged," and "Protect" scenarios. This area has living shorelines that presumably offer some protection from storm surge and sea-level rise. Extensive research has been done on coastal protection by natural habitats and human-made approaches. For example, Sutton-Grier et al. (2015) suggested taking a hybrid approach to coastal protection (e.g., living shorelines) by incorporating both natural ecosystems and built-environment into coastal protection plans. Natural habitats help mitigate the impact of small-to-medium storms while removable sea walls or openable flood gates placed along coastal properties can be used for additional protection when a large storm, such as a tropical cyclone, comes through (Sutton-Grier et al., 2015). The Nature Conservancy, along with a team of experts, installed oyster reefs in the Gulf of Mexico and found that the living shorelines not only reduced the height and energy of the highest 10% of waves, the living shorelines also contributed to an improvement in other ecosystem services such as commercial and recreational fishing and nitrogen removal (Joint-Industry White Paper, 2013). Other management strategies, such as raising homes on stilts and moving homes away from the water, could also be considered in coastal protection plans (Sutton-Grier et al., 2015). Escambia and Santa Rosa counties may benefit from this multi-faceted approach that continues to incorporate the installation of living shorelines in the area. Future efforts could also include monitoring the success rate of these structures when combined with natural habitats.

5.2. Percentage distribution of exposure index values by scenario

Starting from the Current scenario, the percentage of Very Low and Low EI values increased under a "Protect" habitat scenario and decreased under a "Degrade" habitat scenario, while the percentage of Moderate, High, and Very High EI values decreased under a "Protect" habitat scenario and increased under a "Degrade" habitat scenario. Adding protection to coastal habitats in the area will improve protection of the coastline and adjacent properties, whereas removing protection and allowing degradation to occur will have the opposite effect. A study done by Hopper and Meixler (2016) found that the frequency of higher EI values increased when habitats were not present. Another study found that the absence of coral reefs increased shoreline vulnerability along the Archipelago of Tinhare and Boipeba, increasing the amount of Moderate-to-Very High levels of vulnerability by 12.7% and leading to a recommendation that the archipelago apply high intensity management strategies that facilitate coral reefs to recover their natural resilience (Elliff and Kikuchi, 2017). Cabral et al. (2017) found that coastal areas classified as High and Very High exposure corresponded with unfavorable geomorphology in lowland areas. When natural habitats were removed from the modeled scenarios, the percent of High/Very High coastal shoreline segments increased by 34.4% (average EI value increase of 0.45) and projected an increase of 276% in the number of people exposed to coastal climate hazards and erosion (Cabral et al., 2017).

Based on results from this study and from similar sources (Cabral et al., 2017; Elliff and Kikuchi, 2017; Hopper and Meixler, 2016), it is clear that a decrease in habitat abundance leads to an increase in the percentage of high-level exposure areas. In Escambia and Santa Rosa counties, providing enough protection to coastal habitats to decrease their exposure level by at least one-half an EI level could increase the percentage of lower exposed areas by 24% and decrease the percentage of higher exposed areas by 8%.

5.3. Potential residential property damage

A decrease in habitat abundance and an increase in sea level led to an increase in the amount of potential residential property damage from one tropical cyclone event. Given that areas with a higher EI level of High/Very High are positively correlated with property damage and/or loss caused by coastal climate events (Cabral et al., 2017), coastal managers should consider focusing on potential property damage within these areas. Maintaining the "status quo" of existing management practices within Escambia and Santa Rosa counties, even under a Low rise in sea level, could increase the amount of potential damage in residential property from one tropical cyclone event. In Florida alone, the presence of natural habitats such as seagrasses, corals, and mangroves could reduce the exposure of coastal properties by an estimated $4 billion by the year 2100 (Arkema et al., 2013).

Sigren et al. (2018) found that dune volume and vegetation significantly reduced property damage along the coast of Texas following Hurricane Ike in 2008. The presence of sand dunes helped reduce the total amount of property damage by an estimated $8 million, the equivalent of about $8,200 per homeowner. Narayan et al. (2017) found that along the East coast, wetlands reduced the damage from Hurricane Sandy by 1%, totaling $625 million in avoided damages. Costanza et al. (2008) found a significant relationship between damages from hurricanes and wetland area along the Gulf of Mexico, with the average annual storm protection value of wetlands in Florida equaling $7,879.50 per ha per yr (estimated $10,622.81 in 2018 USD; Costanza et al., 2008). In a sea-level rise scenario for 2100, Arkema et al. (2013) calculated that the protected property value from storms and sea-level rise for the highest coastal hazard segments in Florida equaled $80.7 billion USD (Arkema et al., 2013). In Escambia and Santa Rosa counties, protection, restoration, and re-nourishment of habitats could substantially decrease the amount of residential property highly exposed to coastal hazards.

Given that this analysis only included data for median residential property values at the census block level from 2016 (U.S. Census Bureau, 2016) and considering that there is a likely increase in population and property values along the coast in the future, the projected amount of property damage under various scenarios is likely underestimated.

5.4. Local community planning efforts and recommendations for future coastal management

An important element of a successful "coastal management framework" (sensu Cicin-Sain and Belifiore, 2005) is the creation of institutional arrangements of different levels of governments, private, and non-governmental entities focusing on designing and supporting implementation of policies and strategies for coastal management for the local decision contexts. Results suggest that Escambia and Santa Rosa counties could work together, and with local partners, to develop more comprehensive land management plans and prepare for a changing environment. Ecosystem-based management strategies can incorporate results such as this to strengthen arguments for using ecosystem services to mitigate climate effects (Fernandino et al., 2018). For example, rather than the "non-intervention" path that represents "doing nothing" or a "business-as-usual" approach, the community could focus on the "hold the line" strategy that implements either hard protection (e.g., living shorelines) or soft protection (e.g., beach nourishment) to the area at risk (Fernandino et al., 2018). The focus could be on those areas that are projected to become highly exposed under higher sea levels where more extensive assessments would be run to determine how much additional habitat area is needed to keep exposure levels at a moderate or lower level, and what management steps could be taken to increase the habitat to the necessary size (e.g., establish a wetland protected area). Where multiple habitats are present, multiple scenarios may be run with differing habitat areas to identify which habitats would provide the most protection to a certain area. Scenarios could also include living shorelines to evaluate trade-offs between an all-natural and a hybrid approach. The areas highlighted as the most exposed can be identified as areas to further examine development status (e.g., not continuing development in or behind).

Over the past 45 years, both counties have invested in plans for research, conservation, restoration, and recommendations on how to implement these plans (Lewis et al., 2016). Lewis et al. (2016) provides 20 recommendations resulting from their review on the ecological condition of the Pensacola Bay System to maintain and improve the environmental quality of this system. Other local efforts include the implementation of a Climate Mitigation and Adaptation Task Force in January 2017 by the City of Pensacola, FL, along with regional partners from counties and other local governments. This Task Force put together a draft report that outlined specific actions that the City of Pensacola and surrounding region could take to mitigate weather and climate effects (Climate Mitigation and Adaptation Task Force, 2018). One of the Task Force's goals is to "Advance adaptation and mitigation strategies to enhance the City's and regional resilience and preparedness for withstanding the likely adverse effects of climate change, including flooding resulting from heavy precipitation, rising sea levels, intense hurricanes, heat waves, and other extreme events." The Florida Department of Economic Opportunity (FDEO) performed a Coastal Vulnerability Assessment for Escambia County as part of a Community Resiliency Initiative Pilot Project funded by NOAA (FDEO, 2016). The project looked at impacts that an increase in flooding and precipitation will likely have on community vulnerability and developed strategies to improve resilience to these impacts (FDEO, 2016). The Climate Mitigation and Adaptation Task Force recommended the City of Pensacola conduct a Vulnerability Assessment and establish resilience strategies based on findings from the assessment, incorporating results from the FDEO's Vulnerability Assessment of Escambia County. Additionally, a Pensacola and Perdido Bay Estuary Program (PPBEP) was recently established through the EPA's National Estuary Program (MyEscambia, 2016). A long-term plan will be developed that will address water quality and living resource challenges and priorities in Pensacola and Perdido Bays (MyEscambia, 2016). The PPBEP seeks to build upon existing assets, watershed management plans, and scientific data to restore and conserve the environment in the Bays (MyEscambia, 2016).

Results from our study, recommendations listed in the Lewis et al. (2016) report, recommendations from the Climate Mitigation and Adaptation Task Force (2018) draft report, and FDEO's Coastal Vulnerability Assessment (FDEO, 2016) all suggest that potential environmental hazards and continued development along the coast be considered in the PPBEP's long-term planning efforts, including the development of their Comprehensive Conservation and Management Plan, a 5-year strategic planning effort. The PPBEP is an ideal program for long-term monitoring of coastal habitats in the area and studying how protecting these habitats can help us better understand how to ensure coastlines are resilient to climate related stress.

Overall, results from this study are relevant to local decision makers and coastal planners within the community. Results emphasize the importance of natural coastal habitats in mitigating environmental changes, including the following key points:

- With the risk of NOAA's highest projected sea-level rise scenario taking place, the habitats surrounding and lining the coast may benefit from additional protection and restoration.
- Local programs and the local government may benefit from working together to develop long-term climate adaptation plans that incorporate projected sea-level rise and the vital role that natural habitats play in climate resilience. Engagement with stakeholders across a number of planning entities can be valuable to help determine best strategies.
- Escambia and Santa Rosa counties may benefit from incorporation of a hybrid approach (i.e., human-made structures along with efforts to protect, enhance, and restore natural habitats) into coastal plans for greater protection against storm surge and sea-level rise.
- Coastal managers in this region may consider prioritizing protection and restoration of the areas highlighted as highly exposed (i.e., the Perdido Bay side of the North Shore area, the Gulf side of Perdido Key, the Santa Rosa Sound side of Pensacola Beach, the Pensacola Bay side of Gulf Breeze, and Garcon Point).
- Efforts such as the City of Pensacola's Climate Mitigation and Adaptation Task Force and development of the Pensacola and Perdido Bay Estuary Program's Comprehensive Conservation and Management Plan may benefit from considering the various scenarios evaluated in this study and, in particular, factors that influence levels of exposure.

Given that restoration is expensive, timely, and not always successful, it is imperative to protect existing habitats and prevent further degradation. However, restoration on top of protection of existing natural habitats will maximize the amount of property protection service the local coastal property owners receive. Based on initial results from this assessment and previous and on-going coastal planning and management by the local community, suggested strategies for the areas ranked as highly exposed under a rise in sea level by 2100 are detailed below, and summarized in Table 5, for consideration in future coastal management. These strategies contribute to an initiative suggested by the Climate Mitigation and Adaptation Task Force to "Protect the natural shoreline zones of water bodies and incentivize living shorelines instead of hardening" (Climate Mitigation and Adaptation Task Force, 2018), and include the following:

Table 5
Considerations for future coastal management.

Potential Management Strategies
- Living Shorelines (LS): Install living shorelines to act as a buffer
- Seagrass (SG): Plant seagrass to act as a buffer
- Beach Re-nourishment (BR): Re-nourish beach to increase beach width and elevation
- Dune Vegetation (DV): Plant dune vegetation and install sand fences to maximize plant growth
- Saltmarsh (SM): Plant native saltmarsh grass to increase the marsh area behind the beach

Coastal Area	Applicable Strategies
Perdido Bay side of the North Shore area	LS; SG; BR
Gulf side of Perdido Key Beach and Pensacola Beach	BR; DV
Santa Rosa Sound side of Pensacola Beach	LS; SG; BR
Pensacola Bay side of Gulf Breeze	LS; SG; BR
Garcon Point	LS; SG; BR; SM

- Living shorelines help mitigate the impact of small-to-medium storms (Sutton-Grier et al., 2015) and have been successfully implemented in both Escambia and Santa Rosa County coastal management projects (Florida Living Shorelines, 2018; Natural Resilient Communities, n.d.). For example, living shorelines were installed along the coastline of Pensacola Bay to the west and east of the 3-mile bridge (Fig. 6). Living shorelines utilizing sand islands and native saltmarsh grass were installed along the shoreline of downtown Pensacola and help reduce wave action and erosion (Natural Resilient Communities, n.d.). The installation of living shorelines along highly exposed coastlines in the inner bays (i.e., the Perdido Bay side of the North Shore area, the Santa Rosa Sound side of Pensacola Beach, the Pensacola Bay side of Gulf Breeze, and Garcon Point) can provide an initial buffer against waves and storm surge.
- Seagrass beds provide friction to moving water and can capture and store sediment, which helps mitigate erosion and provide protection to the coast (Barbier et al., 2011; Barbier, 2015; Spalding et al., 2014). Pensacola has incorporated seagrass planting into restoration actions (Lewis et al., 2016) and can continue to utilize buffering services provided by seagrasses along highly exposed coastlines in the inner bays (i.e., the Perdido Bay side of the North Shore area, the Santa Rosa Sound side of Pensacola Beach, the Pensacola Bay side of Gulf Breeze, and Garcon Point).
- Sandy habitats such as beaches and dunes act as a natural barrier to waves (Barbier et al., 2011; Barbier, 2015; Pries et al., 2008; Silva et al., 2016). Since 2002, the beach on Santa Rosa Island has been re-nourished three times – once in 2002–2003, once in 2005–2006 after Hurricane Ivan, and again in 2016 (Olsen Associates, Inc., 2018). Given that the five coastal areas classified as highly exposed (i.e., the Perdido Bay side of the North Shore area, the Gulf side of Perdido Key Beach and Pensacola Beach, the Santa Rosa Sound side of Pensacola Beach, the Pensacola Bay side of Gulf Breeze, and Garcon Point) all contain important beach habitat, beach re-nourishment can continue to be considered as an important management strategy.
- Dune vegetation plays a big role in dunes' resilience to disturbance and ability to protect the coast against storms by increasing dune height and promoting greater sand supply along the beach (Barbier et al., 2011; Barbier, 2015; Silva et al., 2016). Structures such as sand fences have been used on sandy beaches to build up dune areas and prevent trampling by humans (Nordstrom et al., 2012). Since 2002, sand fences have been installed and dune vegetation species have been planted along the Gulf side of Escambia and Santa Rosa County coastlines to help build up dunes (UF/IFAS and Florida Sea Grant, 2018) and can continue to be considered as an important management strategy for areas along the Gulf classified as highly exposed (i.e., the Gulf side of Perdido Key Beach and Pensacola Beach).

- Wetlands (e.g., saltmarsh) serve as a buffer against wind and waves and provide sediment stabilization and soil retention (Barbier, 2013; Costanza et al., 2008; Engle, 2011). Projects are currently underway to restore the historic wetlands and wildlife habitats at Garcon Point (Westervelt Ecological Services, 2018), and this site can benefit from continued monitoring and restoration of the emergent marsh behind the beach.

5.5. Limitations

The InVEST Coastal Vulnerability Model is a useful tool but cannot fully account for the quality of habitats or quantify the role of habitats in reducing coastal hazards (Natural Capital Project, 2018) and it is important to recognize that complex coastal processes cannot be fully represented by five variables and exposure categories. In the simplest case, scoring is uniform across the area of interest and does not take into account any interactions between different variables (Natural Capital Project, 2018). While the model can be used for smaller areas and communities, it was built for, and is best suited to, larger-scale, regional applications. At the smaller, community scale, there tend to be similar habitat types, habitat sizes, sea-level rise projections, and other environmental factors. This makes comparison more difficult, especially if there are insufficient data available at the necessary scale. Yet, the CVM is a model that allows coastal managers to evaluate various land management scenarios without extensive training or technical expertise, requiring minimal resources.

This work also assumes that EGS change linearly with habitat variables such as size, seasonality, and disturbance (Barbier et al., 2008; Koch et al., 2009). This assumption could lead to an all-or-nothing decision when it comes to preserving the habitat or using it for human development, which stems from a misrepresentation of the economic value of the service (Barbier et al., 2008). Thus, it is important for decision makers to consider that EGS respond dynamically and nonlinearly to changes in habitat size, and that there are more management options than a binary preserve-or-convert scenario when it comes to natural habitats (Barbier et al., 2008; Koch et al., 2009). Future work may parse out EGS under the "Protect," "Unchanged," and "Degrade" habitat management scenarios to move away from an all-or-nothing assumption. Additionally, InVEST applications, as part of a larger coastal management effort, could be developed for specific planning scenarios identified by the City of Pensacola's Climate Mitigation and Adaptation Task Force or the Pensacola and Perdido Bay Estuary Program.

6. Conclusion

Final EGS concepts allow stakeholders, lawmakers, and community decision makers to assess benefits received from the environment, which may ultimately aid in articulating coastal habitat protection and restoration values. Results from this study highlight the importance of local FEGS, specifically those that provide property protection, and the effects that could occur if FEGS are lost. Escambia and Santa Rosa counties are dependent on the property protection service provided by natural coastal habitats, especially given the projected rise in sea level. Understanding where natural habitats protect property within the community is an important step in informing the smart use of natural habitats for environmental adaptation planning and can help guide prioritization and funding.

Both a rise in sea level and degradation of coastal habitats could decrease the amount of lower exposed coastal shoreline segments and increase the amount of higher exposed coastal shoreline segments. The areas along the coast with the highest increase in the amount of coastal shoreline segments classified with High and Very High EI levels were located along Perdido Bay side of the North Shore area, the Gulf side of Perdido Key, the Santa Rosa Sound side of Pensacola Beach, the Pensacola Bay side of Gulf Breeze, and Garcon Point. These locations either lacked extensive coastal habitats as a buffer or were directly exposed to the Gulf of Mexico, risking frontline exposure to storms. The areas along the coast that maintained Low EI levels were the top of Escambia Bay, the top of Blackwater Bay, and the inlet on the east side of East Bay. These locations were associated with wetlands and fewer properties lining the coast. The largest percentage of High EI values occurred under the "Degrade" habitat scenario and the largest percentage of Very Low or Low EI values occurred under the "Protect" habitat scenario. The amount of property value exposed could increase under scenarios with a higher rise in sea level and degraded habitats. Under higher rises in sea level, additional protection to coastal habitats could reduce the amount of potential residential property damage from one tropical cyclone event in Escambia and Santa Rosa counties $50.4 million (2018 USD) by the year 2050 and $71.8 million (2018 USD) by the year 2100.

Although results in this study may seem intuitive, the ability to display the results quantitatively in both maps and graphs is an important addition to other available information that can facilitate discussion and local planning processes. The InVEST Coastal Vulnerability Model is a general, flexible, and freely available tool that can aide in initial assessments to inform where more detailed research is warranted. Escambia and Santa Rosa counties, along with numerous local partners, are beginning to incorporate effects from environmental changes into planning efforts. As two coastal counties with rich environmental resources, local residents, and tourists, long-term initiatives will no doubt benefit from a variety of methods for evaluating habitats and livelihoods, and the interlinkages between the two.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2019.105017.

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