Addressing climate change and development pressures in an urban estuary through habitat restoration planning

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## Abstract

Native habitats in Florida face dual pressures at the land-sea interface from urban development and sea-level rise associated with climate change. To address these pressures, restoration practitioners require robust tools that identify reasonable goals given historical land use trends, current status of the habitat mosaic, and anticipated future impacts from coastal stressors. A target-setting approach for native habitats was created for the Tampa Bay watershed that identifies current restoration opportunities and establishes short (2030) and long-term (2050) goals. The approach was informed through a three-decade habitat change analysis and over forty years of habitat restoration experience in the region. Restoration goals were defined based on what is possible today and the projected needs for the future, rather than attempting to replicate past ecological conditions. The new paradigm also accounts for the expected impacts of sea-level rise, climate change, and watershed development - stressors which are pervasive in Florida. The resulting habitat goals are spatially explicit with maps that identify remaining restoration and conservation opportunities, while also providing an approach for the entire watershed that targets subtidal, intertidal, and coastal uplands. This approach represents a general framework to support coastal planning decisions that need to address competing interests and could be applied in other coastal settings where sustainable urbanization practices need to co-exist with natural environments. Methods for repeatable analyses are also available using an open source workflow to update progress over time and for adoption by others.

## Introduction

The health of estuarine systems and coastal habitats is inextricably linked to land uses and management of the watershed (Yoskowitz and Russell, 2015). Coastal habitats provide multiple ecosystem services, including wildlife shelter and migratory corridors (Yoskowitz and Russell, 2015), fisheries production (Houde and Rutherford, 1993), water quality improvement (Kushlan, 1990; Sprandel et al., 2000; Ávila-García et al., 2020), erosion and flood attenuation (Calil et al., 2015; Menéndez et al., 2018), carbon sequestration (Dontis et al., 2020) and recreation (Chung et al., 2018). Pervasive stressors can negatively impact the services provided by these habitats. Anthropogenic land development can remove or substantially modify existing habitats, and can alter hydrology of nearby streams and rivers (Theobald et al., 1997; Sim and Mesev, 2014). Related changes in habitats in response to climate change (sea-level rise and warming) include landward migration of mangroves into salt marshes, upstream migration of salt marshes within tidal tributaries, and upland forest migration (Brinson et al., 1995; Vogelmann et al., 2012; Cavanaugh et al., 2019). Management of coastal habitats requires an understanding of how stressores impact these resources, while balancing competing societal uses.

The combined effects of land development and climate change are especially problematic for prioritizing habitat restoration or conservation activities in coastal environments. Landward migration of critical habitats in response to sea-level rise may not be possible due to anthropogenic barriers in the watershed. Sea-level rise can occur quicker than landward migration of salt marshes and the upland slope may already be lost to urban development and hardening (Titus et al., 2009). The coastal squeeze of development and climate change diminishes the available space for future restoration in urban estuaries, thereby impacting the variety of ecosystem services provided by these habitats and the wildlife they support (Enwright et al., 2015). Given projected habitat losses without management intervention and the limited resources available (i.e., time, land, funding, and labor force), appropriate and realistic sites for restoration need to be identified that account for future stressors and past trends.

Past approaches for guiding restoration planning have been successfully used in other contexts, but they do not fully balance competing needs among public and private sectors, nor do they fully account for anticipated effects of multiple stressors. For example, an integrated watershed approach (Environmental Protection Agency, 1996) has been utilized since the early 1990s to diagnose and manage water quantity and quality problems by addressing issues within hydrologically-defined geographic areas. Additionally, the habitat mosaic approach (Henningsen, 2005) of including multiple habitat types within restoration projects has been recognized as an effective means of allowing ecosystem state changes in response to different environmental pressures (Duarte et al., 2009; Palmer, 2009). Adaptive management (Holling, 1978; Gregory et al., 2006) components have been increasingly used to address challenges of sea-level rise, climate change, and development stressors, including monitoring to identify critical restoration decision points and needed intervention with contingency plans. Elements of each of these approaches could be combined to create a more holistic approach to guide restoration and conservation activities for coastal habitats in urban settings.

The Tampa Bay watershed (Florida, USA) is a valuable case study for developing a habitat restoration and conservation plan that addresses pervasive coastal stressors. Compared to other estuaries, the ratio of watershed to estuary area is small and the area is heavily developed with 42% of land use classified as urban and suburban residential (Southwest Florida Water Management District, 2018). A retrospective approach to setting habitat protection and restoration targets in Tampa Bay was previously employed (Lewis and Robison, 1996; Robison, 2010; Cicchetti and Greening, 2011; Russell and Greening, 2015). Priority was given to restoration activities focused on habitat types that were important for a suite of estuarine faunal guilds disproportionately lost or degraded compared to a benchmark period. Criticisms of this approach included a lack of consideration for future sea-level rise and other climate change factors (Yoskowitz and Russell, 2015), use of expanded and different habitats outside the Tampa Bay watershed (Robison, 2010), lack of attention to upland or freshwater wetland habitats, and little recognition of land development trends or actual available space for restoration efforts. These challenges are shared by restoration practitioners in other coastal environments and an approach that accommodates these challenges for planning would be highly transferable.

This paper describes an approach for habitat restoration and conservation planning that addresses the above challenges by considering the whole watershed, addressing historical changes, focusing on trajectories that have occurred during contemporary time periods, and considering both current and future stressors – particularly land development and sea-level rise. Relatively consistent data are available for most Tampa Bay habitats of interest (1988 to 2018), representing a time period when federal, state and local regulations were in effect and regional impacts from climate change are documented (Raabe et al., 2012; Cavanaugh et al., 2014). The approach establishes a framework that can guide both watershed-level habitat planning and site-level restoration activities and incorporates applicable elements of other habitat restoration paradigms discussed above (Palmer, 2009). The general approach includes 1) designation of habitat types by strata relative to the aquatic-terrestrial gradient, 2) quantification of historical trends by habitat types to identify appropriate future targets in coverage, and 3) identification of opportunity areas that could be used by practitioners to achieve restoration goals based on habitat type and past trajectories. The outcomes are spatially-specific by providing maps to identity opportunity areas and reproducible using an open science workflow (Lowndes et al., 2017) that allows regular updates as new data become available.

## Methods

### Study area

Tampa Bay is a large open water estuary (surface area approximately 983 km2) on the west-central coast of Florida ([Figure 1](#fig-lulcmap)). The watershed covers approximately 5,872 km2, for a total combined area of approximately 6,855 km2. The climate is subtropical and within the current (2020) ecotone for mangrove and salt marsh habitats. The upstream watershed includes multiple habitats, including pine flatwoods, forested freshwater wetlands and non-forested vegetated wetlands. The watershed is heavily developed with an estimated population of 3.3 million people in the four major counties of the watershed (Rayer and Wang, 2020)*.* Numerous anthropogenic changes have altered the natural habits of Tampa Bay, including direct removal of habitat (e.g., dredge and fill of bay bottom, mining activities), alteration of hydrology, and destruction and fragmentation of habitat from development.

### Habitats of Tampa Bay

The major habitat types of Tampa Bay were stratified relative to tidal influence and location in the watershed. Subtidal habitats included those that are submerged all or most of the time; intertidal habitats included emergent tidal wetlands that are submerged during high tides but exposed during low tides; and supratidal habitats included those that occur above the high tide line (i.e., the remainder of the watershed).

Subtidal habitats included hard bottom (Jaap and Hallock, 1990; Ash and Runnels, 2005), artificial reefs (Dupont, 2008), tidal flats (Moore et al., 1968; Eisma, 1998)*,* seagrasses (Heck et al., 2003; Sherwood et al., 2017), and oyster reefs (Coen et al., 2007; Ermgassen et al., 2013). Intertidal habiats (or emergent tidal wetlands) included mangroves (Odum and McIvor, 1990), salt marshes (Comeaux et al., 2012; Raabe et al., 2012), salt barrens (Bertness, 1985; Hsieh, 2004)*,* tidal tributaries (Sherwood, 2008; Janicki Environmental, Inc. and Mote Marine Laboratory, 2016, 2020; Wessel et al., 2022), and living shorelines (National Oceanic and Atmospheric Administration, 2015; Restore America’s Estuaries, 2015; Smith et al., 2018). Supratidal habitats included non-developed uplands (Meyers and Ewel, 1990), freshwater forested wetlands (Conner et al., 2007), and freshwater non-forested wetlands (Kushlan, 1990)*.* Uplands were further sub-divided into coastal and non-coastal uplands based on location relative to the 5-foot contour that extended landward from the bay shoreline (described below). This 5-foot contour area was considered the most likely to be impacted by sea-level rise based on current estimates. Since 1946, the St. Petersburg tidal gauge (NOAA gauge 872650) has documented a nearly 20 cm increase in mean tidal height to present day. Projections to the year 2100 suggest sea levels can increase from 58 to 259 cm in the region (M. Burke, L. Carnahan, K. Hammer-Levy, G. Mitchum, 2019).

### Approach

Opportunity areas for restoration and recommended coverage targets for habitat types were identified by integrating multiple datasets available for the region. First, habitat status and historical trends were quantified using land use/land cover and subtidal datasets to understand relative changes that have occurred over time. Second, historic habitat restoration efforts conducted in the Tampa Bay watershed were synthesized as a guide for understanding a feasible level of effort for future projects that could be conducted by restoration practitioners. The first two steps were used to identify short-term (2030) goals and long-term (2050) targets for coverage (hectares) of native habitats. Finally, remaining opportunities for restoration were spatially identified by combining current coverages with existing or proposed protected areas and areas anticipated to be impacted by sea-level rise. As such, the approach identifies goals and targets and provides spatially explicit information that identifies where restoration practitioners should pursue projects to meet these goals and targets.

### Habitat status and trends

For the majority of subtidal, intertidal and supratidal habitats, coverages were quantified from two routine spatial assessment programs conducted by the Southwest Florida Water Management District (SWFWMD). For subtidal habitats, 2018 source data were used to estimate current coverage of seagrasses, tidal flats, and oysters (Southwest Florida Water Management District, 2019). Historical datasets for subtidal habitats began in 1988 with updates occurring on an approximate bi-annual basis (Sherwood et al., 2017; Tomasko et al., 2020)*.* Oyster bed coverage has been routinely estimated in these data products beginning in 2014.

Current intertidal and supratidal habitat coverages were estimated using the 2017 SWFWMD Land Use Land Cover (LULC) geospatial database (Southwest Florida Water Management District, 2018). Land use and cover types (natural and developed) are classified pursuant to the Florida Land Use Cover and Forms Classification System (FLUCCS, Florida Department of Transportation, 1999; Southwest Florida Water Management District, 2014)*.* Mangroves, salt barrens, and salt marshes were reported individually. While the photointerpretation of specific freshwater wetland types is often difficult, forested wetlands and non-forested wetlands can be distinguished with these data. Therefore, all applicable FLUCCS codes representing the suite of natural freshwater wetlands were combined within those two classifications. Native upland habitats were also combined in one classification. Historical estimates for these habitat coverages were also quantified starting with the earliest database in 1990 and occurring every two to three years until the current estimate in 2017.

To address data gaps for habitats not included in the routine SWFWMD datasets, results from special studies were compiled to obtain current estimates. These included hard bottom subtidal habitats, artificial reefs, tidal creeks, and living shorelines, only available as current estimates with no information on historical trends.

Current and historical coverage estimates were obtained for all habitat types, including estimates of developed lands, for each year of available data spanning approximately three decades at two-year time steps. In addition, a habitat coverage change analysis between the terminal years of data (1988 to 2018 for subtidal, 1990 to 2017 for intertidal and supratidal) was conducted to understand how habitats were changing between types. This required an intersection of the data layers to quantify if habitat types were unchanged or changed for any given location and identifying the type of change (e.g., seagrass to tidal flats). The results were summarized as Alluvial diagrams showing relative proportions of habitat change by type and between years (Allaire et al., 2017).

### Restoration database

Past restoration projects were quantified for each of the major habitat types, when available, to inform expectations for setting short-term goals and long-term targets. Information regarding habitat restoration and enhancement activities in the Tampa Bay area over the past 40 years were compiled, reviewed, and consolidated into a single database. Data were gathered from the SWFWMD Surface Water Improvement and Management Program, Federal Government Performance and Results Act reporting, the Tampa Bay Water Atlas (<https://www.tampabay.wateratlas.usf.edu/>), Tampa Bay Watch, and the Technical Advisory Committee of the Tampa Bay Estuary Program. The collected data included project name, year, description, size (area or length), and location (latitude and longitude). Data gaps were supplemented by archival research, site visits, contacting the responsible entities, and expert knowledge form local professionals. Living shoreline projects, including seawall enhancements and oyster reef installations, were inventoried separately.

### Creating and combining opportunity layers

Spatially-explicit estimates of the opportunity areas and their restoration potential in the Tampa Bay watershed were obtained using a spatial analysis shown in [Figure 2](#fig-gisworkflow). The two main processes included 1) binning existing datasets into relevant categories and 2) overlaying multiple datasets to identify restoration opportunities. Opportunity areas were defined as locations where habitat protection and restoration activities are possible and where they could occur to attain defined goals and targets. The definition and mapping of opportunity areas is necessary to quantify the restoration potential for a particular habitat type, which is a measure of what is actually possible under current and future projected conditions, related to anticipated land use change and sea-level rise.

The Land Use Land Cover 2017 dataset from SWFWMD was used for binning existing coverages into the relevant habitat types in the intertidal and subtidal strata. All FLUCCS classification codes were placed into one of three categories. First, native habitats were those that included the full range of natural plant communities and other habitats that are endemic to the watershed, and were further grouped into three major habitat types (tidal wetlands, freshwater wetlands, and uplands). Second, restorable habitats included existing altered but non-hardened and pervious FLUCCS codes that could potentially support native habitats through restoration. Third, existing development included developed land FLUCCS codes that are hardened and impervious (e.g., structures and pavement) and not suitable for habitat restoration.

After binning, the native and restorable lands were overlaid with additional layers to identify 1) reservation native and reservation restorable areas, and 2) existing and proposed native and restorable areas. Collectively, each of these unique products are considered the opportunity areas in the Tampa Bay watershed. The reservation native and reservation restorable areas are native and restorable habitats, respectively, that occur in the 5-foot contour or coastal stratum. This area extends from the local Mean Lower Low Water elevation to elevation 5 feet above Mean Sea Level and is likely to be affected by frequent tidal flooding or inundation (M. Burke, L. Carnahan, K. Hammer-Levy, G. Mitchum, 2019). Native habitats in this stratum were identified as those to be reserved, whereas restorable habitats were identified as those where tidal wetlands could be restored.

The existing and proposed native and restorable areas were those that occured in public lands and parcels currently acquired or targeted for acquisition. To identify these areas, native and restorable lands were intersected with data created from the Florida Natural Areas Inventory, consulting staff from various federal, state and local entities, and inventorying conservation and drainage easements data. This workflow created the existing conservation and proposed (i.e., planned to be acquired) conservation layers in [Figure 2](#fig-gisworkflow) . Intersecting the native and restorable lands in these areas produced four unique opportunity areas: existing conservation native, proposed conservation native, existing conservation restorable, and proposed conservation native.

All opportunity areas identified as restorable included reservation restorable (in the coastal stratum), existing conservation restorable, and proposed conservation restorable. These layers were further grouped into their restoration potential as discrete habitat types that could be the goal of future restoration projects. The restoration potential was defined using the coastal stratum, soil types, and salinities of adjacent waters.

Compared to vegetation communities, soil characteristics typically change slowly (e.g., decades to centuries) in response to hydrologic impacts, unless physically disturbed (Osland et al., 2012; Stockmann et al., 2014). Therefore, soil distributions can be used to estimate historical habitat distribution and restoration potential. Ries and Scheda (2014) created a soils suitability analysis for wetland mitigation and restoration and classified all soils in the Tampa Bay watershed as xeric, mesic, or hydric. The mesic and hydric categories were combined to represent wetland restoration potential, while the xeric category was used to represent upland restoration potential.

A distinction was made between tidal and freshwater wetland restoration potential by intersecting the mesic and hydric soils with the coastal stratum. Mesic or hydric soils that occur below the 5-foot contour were assigned a restoration potential for tidal wetlands, while mesic or hydric soils occurring above the 5-foot contour were assigned a restoration potential for freshwater wetlands. A final restoration potential category was created for low salinity salt marshes (*Juncus* spp.) in the coastal stratum. These included restorable lands with mesic or hydric soils and also lands adjacent to waters with average salinity values less than 18 psu (Eleuterius and Eleuterius, 1979). The salinity values were identified using salinity isohalines created from a long-term water quality data set provided by the Environmental Protection Commission of Hillsborough County.

Two distinct mapping products were created from the above analysis. The first was an opportunities map that showed areas in the watershed identified as existing conservation native, existing conservation restorable, proposed conservation native, proposed conservation restorable, reservation native, and reservation restorable. The second was a map that identified the restorable lands (either proposed, existing, or reservation) based on their restoration potential as coastal uplands, freshwater wetlands, native uplands, or tidal wetlands (which included salt marshes). All analyses were conducted using the R statistical programming language (R Core Team, 2022), specifically leveraging tools from the tidyverse package for data wrangling (Wickham et al., 2019) and the simple features (sf) package for geospatial analysis (Pebesma, 2018). The workflows and data are provided in an open-access repository available on GitHub (<https://github.com/tbep-tech/hmpu-workflow>) for use by others (Beck et al., 2022).

## Results

### Habitat status and trends

Current estimates for subtidal habitats without historical trend information included 171 ha for natural hard bottom and 67 hectares for artificial reefs. The former estimate was obtained from previous mapping work to locate and quantify these habitats using sonar mapping (CSA Ocean Sciences, 2019). The latter estimate was obtained from county governments that manage artificial reefs in the bay.

Current estimates and trend information were available for seagrasses, tidal flats, and oyster bars (Table 1). Oyster bars were estimated at 67 ha in 2018 (Table 1), showing a 29% increase since mapping began in 2014. This increase may represent improved ground-truthing and photointerpretation of oyster bars from aerial photography. Tidal flats have generally increased in area from 1988 to the mid-2000s, followed by a decrease to 2018. The current estimate for tidal flats is 6,569 hectares, showing a 24% decline compared to the 1988 estimate of 8,700 hectares. Seagrasses have increased by 75% since 1988 to a current estimate of 6,986 ha. The change analysis comparing 1988 to 2018 for subtidal habitats ([Figure 3](#fig-subtchgdatalluv)) confirmed trends in Table 1 and showed that the seagrass increases were primarily associated with the colonization of non-vegetated areas of tidal flats, as well as unclassified areas of open water.

Total intertidal habitat (mangroves, salt barrens, and salt marshes) showed a 12% increase of 835 ha from 1990 to 2017, with a current estimate of 8,340 ha (Table 2). Mangroves increased by 15% to 6,276 ha, salt barrens increased by 7% to 203 ha, and salt marshes increased by 3% to 1,861 ha. The current estimate of the extent of mangrove forests in Tampa Bay is 6,192 ha. Mangrove forest coverage increased by 684 ha (12%). Salt marshes in Tampa Bay cover 1,844 ha, and coverage increased by 30 ha (2%). Despite a net increase in salt marsh habitat, the change analysis showed that 153 ha were changed to mangrove habitat ([Figure 4](#fig-chgdatalluv)). The current extent of tidal tributary length is 622 km (no trend information is available).

Trend assessments for supratidal habitats showed the effects of increasing land development in the Tampa Bay watershed (Table 2). Developed lands showed a 44% increase to 217,047 ha from 1990 to 2017, with a notable 30% decrease to 1,446 ha for coastal uplands, a 38% decrease to 57,836 ha for native uplands, and an 18% decrease to 189,512 ha for restorable lands. Non-forested freshwater wetlands showed a 24% increase to 27,358 ha, while forested freshwater wetlands decrased by 5% to 61,667 ha. The change analysis ([Figure 4](#fig-chgdatalluv)) showed that a majority of land conversion to developed came from restorable lands (21,292 ha) and native uplands (7,184 ha), with smaller proportions converted from forested freshwater wetlands (1,407 ha) and coastal uplands (193 ha). Supratidal habitats converted to restorable primarily included native uplands (8,304 ha), forested freshwater wetlands (1,700 ha), and developed (2,794 ha). The increase in non-forested freshwater wetlands was primarily from restorable lands (2,759 ha).

### Habitat restoration

A total of 460 projects were documented between 1971 and 2019 (Table 4), addressing the full range of habitat types, including Estuarine (n=228), Freshwater (n=53), Uplands (n=119), and Mixed (n=60). A total of 1,978 ha have been restored, and 12,930 ha and 42.8 km of linear projects were enhanced during the time period. Forty lead partners were documented as responsible for the projects, although some of these lead partners are departments within the same overall agency. Eighty-nine living shoreline projects, seawall enhancements, and oyster reef module installations along shorelines were inventoried, with a linear footprint of 18.2 km.

### Habitat restoration opportunities

[Figure 5](#fig-oppmap)

In 2017, 1,555 km2 of land (26.5%) in the Tampa Bay watershed above the MLLW line was classified as natural and 2,144 km2 (37%) was considered restorable. Developed areas in the Tampa Bay watershed encompassed 2,172 km2 (36.5%) of the 5,872 km2 watershed area. Between 2014 and 2017, the developed footprint increased by seven percent (7%, Fig 2).

The Tampa Bay watershed included a total of 1,260 km2 of existing conservation lands, either publicly owned or in conservation easements. However, excluding subtidal areas owned by the State of Florida results in a total of 816 km2 of conservation lands, about 13.9% of the watershed area occurring above the MLLW line. (Fig 3). Proposed conservation lands in the Tampa Bay watershed total 1,254 km2. The mapped proposed conservation lands generally link eastward and provide wildlife connectivity to the larger-scale Florida Wildlife Corridor (Fig 3).

Reservation lands, from the MLLW line landward to elevation 5-feet (NAVD 88), currently (2017) include 4,622 ha proposed for conservation in the Tampa Bay watershed, with 3,303 ha of native habitats and 1,319 ha of restorable habitats (Fig 1).

Xeric soils were roughly aggregated in an east-west band through the middle of the watershed (Fig 4). Approximately 2,107 km2 was classified as xeric, while 3,760 km2 was classified as mesic/hydric.

[Figure 6](#fig-restmap)

Table 3

Integration of all of the opportunity layers provides a summary of the available restoration for the TBEP habitats of interest (Table 5). The “Native Habitats” columns show the total current extent as well as the portion of the current extent occurring on existing conservation lands and proposed conservation lands, respectively. The “Restorable Habitats” columns show the total restoration opportunity as well as the portion of the total restoration opportunity on existing and proposed conservation lands. The majority of restoration opportunities on existing conservation lands are for native uplands and freshwater wetlands (Table 5). However, there are approximately 627 ha of emergent tidal wetland restoration opportunities on existing conservation lands, including 530 ha applicable to higher salinity mangrove forests and salt barrens, and 16 ha applicable to lower salinity salt marsh (e.g., *Juncus roemerianus*) restoration and creation.

The best estimates of total restoration opportunities for urban shorelines and tidal tributaries are provided by the Tampa Bay Living Shoreline Suitability Model (LSSM) prepared by the Florida Fish and Wildlife Conservation Commission (Boland and O’Keife, 2018). There is 2,566 km of shoreline in Tampa Bay, and approximately 33% is recommended for living shoreline enhancement.

### Establishment of goals and targets

Table 4

Recommended targets were based on habitat status and trends, habitat restoration data, identified restoration opportunities, and current and anticipated trends in development, available funding, and regulations (Hilderbrand et al., 2005; Hobbs, 2007).

The targets and goals (Table 6) identify where the 2017 CCMP Bay Habitat goals and strategies and the 2021-2025 Strategic Plan (Burke and Amaral, 2020) thriving habitats and abundant wildlife programmatic priorities can be implemented. However, it also recognizes that the identified habitat protection and restoration areas will change over time, and will be revisited on a 10-year recurring cycle. A 30-year planning horizon (2050) is also identified based upon sea-level rise projections developed specifically for Tampa Bay (Burke et al., 2019). The coastal stratum (from the existing mean low water line to the approximate 5-foot contour) is projected to directly experience the effects of sea-level rise by 2050, and is the primary focus area for coastal habitat protection and restoration activities. Land acquisition or protection (through conservation easements or other mechanisms) will be needed to ensure completion of targets and goals for both salt marsh and upland habitats (Fig 3).

Targets that maintain current coverage (“hold-the line strategies”) were identified for habitats that appear to currently be sustained at acceptable levels. Evolving information such as an Oyster Habitat Suitability Index (Boswell et al., 2012) and ongoing mapping exercises will be used to identify optimal locations to conduct restoration activities that help achieve targets and goals. Coordination with the establishment of state-mandated minimum flows (Munson et al., 2007) will be necessary for restoration and maintenance of low-salinity salt marsh habitats that will experience higher salinities and rapid transition to mangroves under existing sea-level rise scenarios (Sherwood and Greening, 2014; Geselbracht et al., 2015).

## Discussion

Because of multiple stressors such as encroaching development and climate change, habitat protection and restoration priorities should be tempered and “reality tested” by what is actually possible today, and what is possible in the future. Many native and potentially restorable habitats are limited, and there will always be restrictions on the financial resources that can be dedicated to public conservation land acquisition and habitat restoration activities.

This replicable method for setting restoration targets and goals provides a systematic attempt to identify habitat protection and restoration targets that are based on what is actually achievable within those limitations. It focuses on existing opportunities for all habitat types, and what is realistically possible in the future, rather than attempting to mimic previous ecological conditions.

### Habitat trends

When viewed as a whole, the most significant and meaningful trends in the TBEP habitats of interest over the periods of record examined include: 1) the 75 percent gain in seagrasses since 1988; 2) the slight gains in emergent tidal wetlands (10%) and freshwater wetlands (2%) since 1990; and 3) the 39% loss in native upland habitats since 1990.

The intertidal zone in Tampa Bay is currently experiencing dynamic change, driven by sea-level rise and climate change, whereby mangrove forests are outcompeting salt marshes and salt barrens for the available niche space. Without increasing the total area of the intertidal zone, restoring a greater coverage of mangroves would reduce the niche space available for salt marshes and salt barrens. This phenomenon has been observed throughout the Gulf of Mexico, and has been attributed to both climate change (e.g., fewer freeze events) and sea-level rise (Comeaux et al., 2012).

The observed gains in wetlands (Table 3b) are likely a reflection of: 1) the effectiveness of state and federal wetland regulatory programs; and 2) the cumulative gains resulting from, primarily, publicly-funded habitat restoration projects (Table 4). Minor gains in some emergent tidal wetlands (e.g., salt barrens) may also be a reflection of the landward expansion of the complex suite of these habitats associated with climate change and sea-level rise. Gains in vegetated non-forested freshwater wetlands are related to the clearing of forested wetlands followed by the creation of herbaceous mitigation areas and stormwater systems.

The decrease in native uplands (Table 3b) is the result of continued development in the Tampa Bay watershed, combined with the lack of regulatory protection of native uplands. Attaining the target and goal will require concerted restoration of native upland habitats on existing conservation lands, as well as new conservation lands to offset the continued loss of these habitats to development, and amendments to existing planning, zoning and land development policies or regulations. While federal and state regulations related to listed species management impart some protection to certain rare habitats, such as scrub jay (*Aphelocoma coerulescens*) habitat, common and historically abundant native habitats, such as pine flatwoods, are left largely unprotected. Unless local governments in the Tampa Bay watershed improve local protections for native uplands, such as strengthening language within comprehensive plans and development ordinances, this trend will likely continue.

### Habitat restoration

Increases observed in tidal and freshwater wetlands are primarily due to publicly-funded habitat restoration projects, state and federal wetland regulatory programs, and to a lesser extent, regulatory mitigation. While restoration activities date to 1971, few projects were completed prior to 1990, and from 1990-2010, an annual mean of 68 ha of habitat was restored. Over the past decade (2010-2019), this rate of restoration project completion has increased to over 81 ha/yr. Assuming that funding levels remain in the same range as the past decade, this annual mean can be used to set reasonable limits on restoration potential and targets.

While existing development areas are not considered feasible for major habitat restoration activities at this time, there are many opportunities to enhance and restore habitat functions and improve coastal resilience in urbanized locations. Examples include the construction of living shorelines, placement of submerged habitat modules along developed urban shorelines and seawalls, and creation of backyard habitats. Tidal tributary restoration could also entail improvements including removal of salinity barriers and filling of dredged channel sections with low dissolved oxygen.

Four major types of disturbed sites around the Tampa Bay coastline have been identified as priority estuarine habitat restoration sites by TBEP stakeholders over the past two decades, including dredged holes, filled and spoil disposal areas, abandoned aquaculture ponds; and coastal borrow pits and stormwater ponds. Substantial opportunities also exist for upland restoration on reclaimed mined lands within the watershed.

There is a general consensus among restoration practitioners and natural resource managers that habitat restoration and management is most cost-effective on publicly-owned conservation lands and provides long-term benefits. Furthermore, given current development trends in the Tampa Bay watershed, public acquisition of remaining critical lands (e.g., coastal uplands, river floodplain wetlands) is a high priority, and some restoration targets (e.g., salt marshes) will not be feasible without additional public acquisition or public-private partnerships (Holl and Howarth, 2001; Benson et al., 2018). Therefore, varied approaches to leverage resources, including traditional grants, partner funding, and use of volunteers for habitat restoration are recommended to maximize the potential for successful target and goal achievement.

### Rolling easements, mitigation, and restoration consortium

As discussed, land acquisition for coastal habitat restoration must prioritize adjacent low-lying coastal uplands to serve as buffers to accommodate future landward migration of tidal wetlands in response to sea-level rise. Where public acquisition is not possible, other conservation mechanisms need to be explored. Coastal setbacks, buffers, or public easements are traditionally used to restrict development within a given distance from the shoreline. A rolling easement is a dynamic mechanism that “rolls” landward as sea levels rise and cause tidal encroachments onto low-lying coastal uplands (Titus et al., 2009). The application of rolling easements in Tampa Bay could disincentivize more intense urban development (e.g., discourage up-zoning) of low-lying coastal uplands that may be currently in less intense agricultural or recreational (e.g., golf courses) land uses. Under a rolling easement, landowners would be able to maintain current economic uses, while “reserving” such lands to accommodate tidal wetland migration with advancing sea-level rise.

Wetland impacts and associated compensatory mitigation projects authorized under wetland regulatory programs have historically been conducted independent of watershed-level planning and monitoring processes. This disconnect has contributed to fragmented implementation and inconsistent compliance monitoring of mitigation projects, as well as historically poor documentation of wetland losses and gains in the Tampa Bay watershed. However, if properly focused and comprehensively coordinated, compensatory mitigation activities could significantly contribute to the attainment of wetland habitat restoration goals and targets for the Tampa Bay estuarine system and its contributing watershed.

TBEP will form a public-private partnership to provide the framework for the development of a coordinated approach linking regulatory (compensatory mitigation) and resource management (publicly funded habitat enhancement, restoration, and establishment) programs in the watershed. The creation of the Habitat Management Consortium is expected to provide benefits such as optimizing and improving the cost-effectiveness of habitat protection, restoration and mitigation activities in the watershed.

### Conclusion

The establishment of targets and goals considering climate change, development, land availability, and past achievements, expands the restoration palette to a more comprehensive list of habitats within the system. If successfully implemented, the 2050 goals would total over 4,000 ha of habitat restoration throughout the Tampa Bay watershed. Land acquisition will be an important component of successful completion of different targets and goals, including the salt marsh restoration target for the first ten years. Land acquisition will also provide new opportunities for outdoor access, given that these projects often have a public recreation component.

Our new approach will continue to engage multiple partner agencies, non-governmental organizations, and private citizens in the successful implementation of the restoration plan. Emphases will include recognition of land types particularly vulnerable to climate change or development stressors and these needs will be communicated to restoration partners. Consistent education, targeted funding opportunities, and reporting will also ensure that these newly established targets and goals lead to successful restoration projects, land acquisition, and enhanced ecosystem services.

## Figures

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| Figure 1: Land use and land cover for the Tampa Bay watershed, Florida, USA. The watershed includes the natural hydrologic boundary with minor modifications to include partners working with the Tampa Bay Estuary Program. |

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| Figure 2: Spatial analysis workflow used to identify opportunity areas and restoration potential in the Tampa Bay watershed. Workflows are divided into binning of land use/land cover categories into relevant habitat types and spatial overlay of datasets to identify the opportunity areas. |

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| Figure 3: Change analysis of habitat categories in the subtidal strata of the Tampa Bay watershed. The left column shows relative areas in 1988 and the right column shows relative areas in 2018 for each habitat category. The grey lines show the proportional change of each habitat category between the years. |

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| Figure 4: Change analysis of habitat categories in the intertidal and supratidal strata of the Tampa Bay watershed. The left column shows relative areas in 1990 and the right column shows relative areas in 2017 for each habitat category. The grey lines show the proportional change of each habitat category between the years. |

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| Figure 5: Opportunity areas for habitat conservation and reservation in the Tampa Bay watershed. Green indicates existing conservation, blue indicates proposed conservation, and pink indicates reservations opportunities. Each category is also grouped into native and restorable habitats. The outline is the Tampa Bay watershed. |

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| Figure 6: Habitat restoration potential in the Tampa Bay watershed. Areas are identified as those where habitat restoration could target the four identified categories as coastal uplands, freshwater wetlands, native uplands, or tidal wetlands. Categories are based on the opportunity areas and soil types. The outline is the Tampa Bay watershed. |

## Tables

**Table**:Change over time in hectares for subtidal habitats in Tampa Bay. Columns show years with available data and the final two columns show the change and percent change from 1988 to 2018. Oyster bars were not meaningfully quantified prior to 2014.

| Habitat Type | 1988 | 1990 | 1992 | 1994 | 1996 | 1999 | 2001 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018 | 1988 to 2018 | % change |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Seagrasses | 9,307 | 10,086 | 10,299 | 10,609 | 10,758 | 9,920 | 10,417 | 10,795 | 11,309 | 11,862 | 13,171 | 13,874 | 16,153 | 16,701 | 16,293 | 6,986 | 75 |
| Tidal Flats | 8,700 | 8,207 | 8,272 | 8,117 | 8,199 | 10,878 | 10,300 | 11,601 | 11,387 | 10,878 | 9,617 | 8,714 | 5,976 | 5,557 | 6,569 | -2,130 | -24 |
| Oyster Bars | - | - | - | - | - | - | - | - | - | - | - | - | 52 | 65 | 67 | - | - |

**Table**:Change over time in hectares for intertidal and supratidal habitats in Tampa Bay. Columns show years with available data and the final two columns show the change and percent change from 1990 to 2017.

| Stratum | Habitat Type | 1990 | 1995 | 1999 | 2004 | 2007 | 2011 | 2014 | 2017 | 1990 to 2017 | % change |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Intertidal |  |  |  |  |  |  |  |  |  |  |  |
|  | Mangrove Forests | 5,472 | 5,808 | 5,793 | 6,318 | 6,300 | 6,299 | 6,266 | 6,276 | 804 | 15 |
|  | Salt Barrens | 189 | 194 | 199 | 197 | 185 | 203 | 199 | 203 | 14 | 7 |
|  | Salt Marshes | 1,814 | 1,795 | 1,798 | 1,877 | 1,874 | 1,863 | 1,939 | 1,861 | 47 | 3 |
| Supratidal |  |  |  |  |  |  |  |  |  |  |  |
|  | Coastal Uplands | 2,055 | 2,122 | 2,014 | 1,672 | 1,515 | 1,498 | 1,999 | 1,446 | -609 | -30 |
|  | Developed | 150,724 | 159,180 | 171,066 | 193,986 | 203,438 | 209,081 | 214,710 | 217,047 | 66,324 | 44 |
|  | Forested Freshwater Wetlands | 64,573 | 63,766 | 62,726 | 63,109 | 62,258 | 62,081 | 63,562 | 61,667 | -2,906 | -5 |
|  | Native Uplands | 93,076 | 83,850 | 75,313 | 64,482 | 61,277 | 60,319 | 62,794 | 57,836 | -35,239 | -38 |
|  | Non-Forested Freshwater Wetlands | 22,037 | 20,831 | 20,710 | 23,662 | 26,363 | 27,893 | 27,972 | 27,358 | 5,320 | 24 |
|  | Open Water | 15,523 | 17,397 | 19,000 | 19,394 | 22,405 | 22,422 | 23,485 | 23,955 | 8,432 | 54 |
|  | Restorable | 231,288 | 232,195 | 228,531 | 212,549 | 201,609 | 195,529 | 184,342 | 189,512 | -41,777 | -18 |

**Table**:Summary of habitat restoration opportunities in the Tampa Bay watershed. Summaries are based on 2017 land use data, 2018 subtidal data, best estimates for habitat types not in existing GIS layers, and current extent of existing and proposed conservation lands.

|  | | Native Habitats | | | Restorable Habitats | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Stratum | Habitat Type | Current Extent | Existing Conservation Lands | Proposed Conservation Lands\* | Total Restoration Opportunity\*\* | Existing Conservation Lands Restoration Opportunity | Proposed Conservation Lands Restoration Opportunity\* |
| Subtidal | | | | | | | |
|  | Hard Bottom | 171 ha | 171 ha | N/A | N/A | N/A | N/A |
|  | Artificial Reefs | 88 ha | 88 ha | N/A | N/A | N/A | N/A |
|  | Tidal Flats | 6,569 ha | 6,569 ha | N/A | I/D | I/D | N/A |
|  | Seagrasses | 16,293 ha | 16,293 ha | N/A | 5,719 ha | 5,719 ha | N/A |
|  | Oyster Bars | 67 ha | 67 ha | N/A | I/D | I/D | N/A |
| Intertidal | | | | | | | |
|  | Living Shorelines | 18 km | LSSM | N/A | LSSM | N/A | N/A |
|  | Mangrove Forests | 6,276 ha | 4,516 ha | 1,604 ha | 1,044 ha | 521 ha | 522 ha |
|  | Salt Barrens | 203 ha | 177 ha | 25 ha |
|  | Salt Marshes | 1,861 ha | 881 ha | 917 ha | 527 ha (JU) | 102 ha (JU) | 424 ha (JU) |
|  | Tidal Tributaries | 622 km | N/A | N/A | LSSM | N/A | N/A |
| Supratidal | | | | | | | |
|  | Coastal Uplands | 1,446 ha | 722 ha | 664 ha | 513 ha | 128 ha | 385 ha |
|  | Non-Forested Freshwater Wetlands | 27,358 ha | 4,761 ha | 10,353 ha | 63,705 ha | 11,034 ha | 52,671 ha |
|  | Forested Freshwater Wetlands | 61,667 ha | 24,052 ha | 22,399 ha |
|  | Native Uplands | 57,836 ha | 27,083 ha | 21,256 ha | 17,637 ha | 5,419 ha | 12,217 ha |
| N/A - Not Applicable; I/D - Insufficient Data; LSSM - Living Shoreline Suitability Model; JU - Potential*Juncus* Marsh Opportunity | | | | | | | |
| \*All lands identified for acquisition by partners, does not represent a 2030 target or 2050 goal | | | | | | | |
| \*\*Does not account for lands neither currently protected nor currently under consideration for acquisition | | | | | | | |

**Table**:Recommended 2030 targets and 2050 goals for habitat restoration and protection in the Tampa Bay watershed. Targets and goals are based on 2017 land use data, 2018 subtidal data, best estimates for habitat types not in existing GIS layers, and current extent of existing and proposed conservation lands.

| Stratum | Habitat Type | Current Extent | Total Restoration Opportunity\* | 2030 Target | 2050 Goal | Target Narrative and Restoration and Protection Rationale |
| --- | --- | --- | --- | --- | --- | --- |
| Subtidal | | | | | | |
|  | Hard Bottom | 171 ha | N/A | >171 ha | >171 ha | Protect existing hard bottom; continue to identify new hard bottom area using proven mapping techniques |
|  | Artificial Reefs | 88 ha | N/A | >67 ha | >67 ha | Protect existing artificial reefs; enhance habitat complexity where feasible; expand reef area to promote fish and wildlife benefits |
|  | Tidal Flats | 6,569 ha | I/D | 6,564 ha | 6,564 ha | Identify and protect existing persistent tidal flats; assess restoration potential of other non-vegetated subtidal areas |
|  | Seagrasses | 16,293 ha | 5,719 ha | >16,188 ha | >16,188 ha | Protect existing seagrasses; establish new HMPU lower limit of 16,188 hectares; assess restoration potential of non-vegetated subtidal areas |
|  | Oyster Bars | 67 ha | I/D | 89 ha | 191 ha | 2030: Protect existing oysters + restore 20 hectares; increase target by 20 hectares each out-decade; consider filtration rate to refine long-term goal; an oyster habitat suitability index (HSI) will inform opportunity space |
| Intertidal | | | | | | |
|  | Living Shorelines | 18 km | LSSM | 34 km | 90 km | 2030: Construct 1.6 kilometers of LS each year; includes privately owned seawalls; need better definition of opportunity areas; increase target to 2.4 & 3.2 kilometers per year for out decades |
|  | **Total Intertidal** | **8,340 ha** | **1,570 ha** | **8,641 ha** | **9,633 ha** | **2030: Protect existing intertidal mosaic + restore 405 hectares (based on hydric soils); increase target by 61 hectares each out-decade; includes the mosaic of mangrove, salt barren, and salt marsh habitats** |
|  | Mangrove Forests | 6,276 ha | 1,044 ha | >6,192 ha | >6,192 ha | Protect existing mangrove forests; restore opportunistically within the intertidal mosaic |
|  | Salt Barrens | 203 ha | 221 ha | 322 ha | 2030: Protect existing salt barrens + restore 20 hectares; increase target by 20 hectares per out decade |
|  | Salt Marshes | 1,861 ha | 527 ha | 1,945 ha | 2,208 ha | 2030: Protect existing low salinity salt marshes + restore 101 hectares; increase target by 20 hectares each out-decade; significant land acquisition and/or Public Private Partnerships required to achieve this 2030 target and 2050 goal |
|  | Tidal Tributaries | 622 km | I/D | 6 km | 29 km | Inventory mapped tidal tributaries and assess/rank restoration potential; restore ~6.4 kilometers (1%) of urban tidal creek habitat where feasible; increase target by 3.2 kilometers per out decade |
| Supratidal | | | | | | |
|  | Coastal Uplands | 1,446 ha | 513 ha | 1,525 ha | 1,707 ha | 2030: Protect existing coastal uplands + specifically restore 61 hectares (upland restoration total = 243 hectares); increase target by 20 hectares each out decade |
|  | Non-Forested Freshwater Wetlands | 27,358 ha | 63,705 ha | 27,898 ha | 29,052 ha | 2030: Protect existing non-forested freshwater wetlands + restore 546 hectares; increase target by 20 hectares each out decade |
|  | Forested Freshwater Wetlands | 61,667 ha | 61,628 ha | 61,810 ha | 2030: Protect existing forested freshwater wetlands + restore 61 hectares; increase target by 20 hectares each out decade |
|  | Native Uplands | 57,836 ha | 17,637 ha | 57,082 ha | 57,507 ha | 2030: Protect existing native uplands + specifically restore 182 hectares (upland restoration total = 243 hectares); increase target by 20 hectares each out decade; focus on pine flatwoods and protect current extent (22,953 hectares) |
| N/A - Not Applicable; I/D - Insufficient Data; LSSM - Living Shoreline Suitability Model; JU - Potential*Juncus* Marsh Opportunity | | | | | | |
| \*Does not account for lands neither currently protected nor currently under consideration for acquisition | | | | | | |

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