Published in final edited form as:
Landsc J. 2017 January ; 36(1): 37–57. doi:10.3368/lj.36.1.37.

Repurposing Vacant Land through Landscape Connectivity

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Abstract

Storm surge protection systems have proven effective in protecting populations in developed areas and can allow for development in otherwise potentially flood-prone areas. Resultant intensification of land conversion can result in large scale habitat fragmentation. Simultaneously, urbanized areas worldwide are increasingly accumulating large amounts of vacant land, creating an unprecedented opportunity to improve green space networks and natural systems. This article describes creation of a regional growth framework that balances the need to repurpose vacant lots with the provision of ecosystem services. The analysis seeks to maximize the structural connectivity of the landscape by using high ecological potential of vacant lands as a device for linking existing habitat patches, wildlife conservation areas, wetlands, riparian corridors, and small-scale green spaces. The research uses raster-based suitability models generated in ArcGIS to determine development potential and ecological values of vacant land parcels. Vacant lands having low development potential and high ecological value are linked spatially to create ecological corridors among patch areas using a least cost path connectivity model generated with Linkage Mapper software. Results indicate that vacant land can connect existing ecological patch and core areas with relatively minimal negative impact on development potential while simultaneously enhancing provision of ecological services. The approach provides a model for an ecological based solution to repurposing vacant urban land.

Keywords

urban regeneration; landscape corridor modeling; landscape ecology; ecosystem services; storm surge protection

INTRODUCTION

Urbanized areas in the United States (U.S.) are increasingly becoming ecologically and socially fragmented due to the accumulation of vacant land (Díaz et al. 2011). As populations fluctuate, land uses recurrently transform from occupied to unoccupied producing vacant land (Greenstein and Sengu-Eryilmaz 2004; Berger 2007). While many industrial areas such as the U.S. Rustbelt are rapidly depopulating, population in many coastal cities is increasing. In either scenario, the increasing abundance of interstitial and/or parcel level non-productive space creates an unprecedented opportunity to improve green space networks and natural systems (Hollander et. al. 2009). While redevelopment is often viewed as the primary objective in repurposing vacant space, it can potentially provide land for recreational, ecological, hydrological and other non-traditional land uses, resulting in the creation of productive, sustainable, and ecologically sound places. If managed properly, vacant land can act as a catalyst for reconnecting natural systems, creating connective social tissue, and providing ecosystem services to areas undergoing transformation.

Damage from flooding and storm surge can increase the amount of vacant land. Storm surge protection infrastructure systems have proven effective in protecting developed areas, often allowing for increased development in otherwise potentially flood-prone coastal areas (Hallegatte et al. 2011). They can, however, also diminish important ecological services once provided in pre-existing undeveloped conditions. Land use intensification can amplify the exchange between fresh, salt, and brackish waters, increase sedimentation deposits, and create extreme topographic alteration, resulting in large scale habitat fragmentation (Phillips and Jones 2006).

Spatial relationships involving the process of vacating use of land in urban areas have not been fully integrated with corridor ecology studies (Batty 2008). While parcel-scaled approaches for repurposing (providing a function, ecological or otherwise) vacant parcels are common, there is no existing framework to guide the repurposing of vacant land on a regional scale. Using computer programs such as Geographic Information Systems (GIS), researchers and practitioners have developed digital software to help construct multi-scalar landscape corridor frameworks in developed or developing areas.

Vacant Land, Green Space, and Multiple Ecosystem Services

The population of many urban areas is declining at rapidly accelerating rates (Oswalt and Rieniets 2007). For example, as of 2007, population in nearly 370 cities globally decreased by at least 10 percent (Oswalt and Rieniets 2007). While depopulating cities report higher levels of structural abandonment, urban areas experiencing significant expansion actually report higher ratios of vacant land to city size than do non-expanding cities (Bowman and Pagano 2004; Newman et al. 2016a).

In 2000, vacant land accounted for an average of 15.4 percent or one-sixth of the urban areas in the United States (U.S.) (Pagano and Bowman 2000); the ratio of vacant land to city size has since increased by 1.3 percentage points (Newman et al. 2016b). Urban areas in the U.S. experienced declining densities of more than 50 percent between 1946 and 2006 (Berger 2007). Between 2000 and 2010 population densities decreased by 6 percent and vacant housing units increased by over 44 percent (Mallach 2012). Density is also decreasing in expanding urban areas, regardless of their population dynamics (Hollander et al. 2009; Pallagst 2012). Planners face the difficult challenge of repurposing vacant or abandoned urban land (Hollander and Németh 2011).

Declining densities are attributable to many factors, including demographic shifts, deindustrialization, disinvestment, sectorial shifts in technology and/or intra-metropolitan locational changes (Greenstein and Sengu-Eryilmaz 2004). While vacant land may be neglected or uncared for, it is capable of providing a beneficial use whether developed or not. In either case, it should be converted to a use that is productive to society (Civic Trust 1988).

Typically, vacant lands are managed on a parcel by parcel basis, with most solutions dependent upon estimated return on investment for developmental purposes. Low economic return on investment is a significant reason why sites become and remain vacant. Most vacant urban spaces tend to be relatively small in size, occur in odd shaped parcels, and reside in areas with low development potential (Pagano and Bowman 2000; Newman et al. 2016b). The existence of a vacant parcel can also decrease the development potential of neighboring areas. (Greenstein and Sengu-Eryilmaz 2004). Vacant land exists in many forms including abandoned housing, landfills, rail yards, industrial areas, military installations, harbors, parking lots, open space, transmission corridors, agricultural parcels, rights of way and historic structures, among others (Mathey and Rink 2010; Coleman 1982; Kivell 1993; Greenberg, Popper and West 1990).

If managed properly, vacant land can be an important asset for reclaiming valuable lost ecosystem services. The current charge to produce new options for vacant land through re-greening has been based primarily on temporary uses and applied on a small scale. Multiple forms of re-programming these spaces include the conversion of non-productive commercial areas into park space in Atlanta, GA (Caravati and Goodman 2010), urban gardens on abandoned lots in Cleveland, OH (Yadav, Duckworth and Grewal2012), greenway planning in vacant parcels Leipzig, Germany (Rößler 2008), and the implementation of temporary uses based on neighboring functional needs (Németh and Langhorst 2014).

There is a growing abundance of non-productive space in urban areas and nearly half of these urban areas are located in flood-threatened locations. Structural and property damage created by storm surge and flooding can increase the amount of vacant land. Storm surge and flood protection barriers afford opportunities for new development in vacant areas but creation of these barriers can also produce negative ecological effects such as exacerbating habitat fragmentation (Phillips and Jones 2006).

Increased use of non-structural flood storage solutions in disaster protection systems can help alleviate flooding and expand the extent of green space to decrease the negative ecological effects of structural-based mechanisms. The connection of these green spaces enhances landscape connectivity, thereby increasing habitat opportunities while also decreasing flood vulnerability. The resultant large-scale increases in green space, however, can limit development opportunities and, if not applied appropriately, little help in solving the urban vacant land epidemic.

Geographic Setting for the Study

The Texas coast has been adversely impacted by nearly 40 hurricanes since 1900, including Hurricane Ike in 2008. The “Ike Dike” is a projected 6 billion dollar structural storm surge protection system that is estimated to protect the Houston-Galveston Metropolitan Statistical Area (H-G MSA) from a 10,000 year flood (Figure 1). The proposed coastal spine extends parallel to Galveston Island, Texas to protect the port of Houston, the second-busiest port in the U.S. with an economic base of $178.5 billion a year. If implemented, this infrastructure will likely alter the existing land use matrix by promoting newer, more protected, development that is likely to result in increased habitat fragmentation. Much of this development is likely to occur on vacant lands that currently occupy approximately 40 percent of the land area in the H-G MSA.

Research Objectives

By integrating ecological science into the fields of landscape architecture, regional planning and land use management, this article presents a method for assessing both the development and ecological values of vacant land on the western portion of Galveston Island, TX. The study seeks to create a framework for identifying and designating vacant lots that are better suited for either developmental or ecological purposes. Developed on a regional scale and using data from the flood-prone H-G MSA, the framework examines the western portion of Galveston Island, TX to identify vacant lands having high potential as a significant component for increasing or maintaining ecological services in the storm-surge susceptible area.

This research focuses on maximizing connectivity in the landscape by using vacant land as a linkage device for connecting existing habitat patches, wildlife conservation areas, wetlands, riparian corridors and small-scale green-space while also accommodating new development. The successful repurposing of vacant land through landscape connectivity is based on each vacant parcel's developmental and/or ecological potentials. A vacant parcel is classified as repurposed if the output ultimately creates a lasting improvement in the economic, physical or environmental condition in the study area through the provision of a new land use (Roberts and Sykes 1999).

This study uses landscape connectivity as a means to integrate flood protection and the repurposing of vacant land. Specific objectives of this study include determining the effects landscape corridor development can have on: creating new uses for vacant land; and maintaining or increasing ecological services in storm surge prone areas. Landscape corridor modeling is used to develop a regional scaled framework to repurpose vacant land and increase ecosystem services. We apply this framework on a local scale using the western portion of Galveston Island.

LITERATURE REVIEW

Greenspace, Habitat Value, and Landscape Connectivity

The conversion of farmlands, forests and shrub/grasslands to sprawling development, fragments natural habitats into isolated green spaces, compromises biodiversity and decreases the ability of land to provide multiple ecosystem services (benefits that human populations derive, directly or indirectly, from ecosystem functions) (Costanza 1998; Bryant 2006). Ecosystem services can positively impact the agricultural, hydrological, recreational, cultural and/or aesthetic value of the landscape (Carpenter and Folke 2006). The multiple negative ecological effects of land use intensification make it imperative to create alternative development strategies that do not result in ecosystem fragmentation (Lovell and Johnson 2009).

Vacant lands afford numerous opportunities to improve ecological functionality and increase biodiversity. These opportunities will remain hidden unless the gap between research in landscape ecology and landscape architecture/urban planning is linked (Lovell and Johnston 2009). The patch–corridor–matrix (Foreman 1995) concept was developed to help establish a cross-disciplinary language for bridging these professions (Blaschke 2006). It classifies the landscape into three primary components: “patches” (separate areas of natural vegetation), “corridors” (connections between patches), and the “matrix,” (the remaining existing mixture of landscape components) (Dramstad et al. 1996; Forman and Godron 1986; Perlman and Milder 2004).

The theories of island biogeography (MacArthur and Wilson 1967) and metapopulation dynamics (Hanski 1994) provide the premises upon which the patch-corridor-matrix concept was developed (Diamond et al. 1976; Wilson and Willis 1975). Hanski and Gilpin (1997) found that species dispersal, establishment, and extinction in habitats were based on differentiated spatial configurations (Dunning, Danielson and Pulliam 1992; Fahrig and Merriam 1994). These studies suggest that habitats that become increasingly fragmented experience declines in species populations and, in some cases, extinction. Turner (2005) strengthened the patch-corridor-matrix concept by quantitatively revealing that spatial patterns of both natural and anthropogenic spaces were interrelated, suggesting that human development patterns could disrupt landscape connectivity (McGarigal et al. 2002; Turner and Gardner 1991).

The patch-corridor-matrix concept spatially designates habitat components for landscape connectivity studies, a growing field which mitigates impacts of habitat fragmentation through landscape alteration and preservation of ecological habitat. Species type plays a key role in habitat preservation selection. It is important to connect and preserve habitat for: 1) umbrella species, or large predatory species which signal the presence of smaller species that are lower on the food chain (Frankel and Soulé 1981); 2) keystone species, or smaller predatory animals which enrich ecosystem functions (Davic 2003); 3) indicator species, or threatened or endangered species which signify the existence of ecological integrity (Carignan and Villard 2002); and 4) existing or representative species which represent the full spectrum of existing conditions (Hobbs, Higgs and Harris 2009). Conservation of only one species habitat cannot ensure the conservation of all co-occurring species and can result in declines in biodiversity or increased habitat fragmentation (Lindenmayer 1999). Multi-species strategies are more beneficial (Roberge and Angelstam 2004) and species synthesis will result in hybrid ecosystems which reclaim some original characteristics as well as conform to current conditions (Hobbs, Higgs and Harris 2009). Protection and connectivity of habitat for each species type is imperative for successful landscape connectivity (Taylor et al. 1993) and alleviating problems associated with habitat fragmentation (Crooks and Sanjayan, 2006), which is a causal driver for declining biodiversity (Dirzo and Raven 2003; Sih et al. 2000).

The extension of green tendrils through urbanizing areas and the construction of green space into underutilized areas has influenced landscape design/planning for many years (Bryant 2006). Small scale urban ecological elements (e.g. street trees, pocket parks, right-of-way planting strips, et cetera) can help increase connectivity, but in many cases tend to be mostly aesthetic (Yadav, Duckworth and Cialone 2012). In other cases, corridors can be generated haphazardly, with no systematic thought, and applied to spaces which may merit more important developmental purposes (Chetkiewicz, et. al. 2006). Corridors ease ecological problems caused by development by increasing the connection of otherwise isolated populations of plant and animal species (Gilbert et al. 1998; Gonzalez et al. 1998). As a result, local extinctions or extirpations are reduced (Brown and Kodric-Brown 1977; Reed 2004), species richness is increased (Hale et al. 2001; Mech and Hallett 2001), and ecological services are retained or strengthened (Haddad and Tewskbury 2006; Levey et al. 2005).

Ecology and Flood Protection

Protecting open space in floodplains significantly reduces the adverse effects of flooding (Brody and Highfield 2013). Local parks, play fields, and undeveloped lands consisting primarily of green space can act as a storm buffer to surrounding properties. For example, a national study of localities participating in the National Flood Insurance Program (NFIP) Community Rating System (CRS) demonstrated that they save, on average, approximately $200,000 per year in flood-related losses by protecting open space in the 100-year floodplain (Brody and Highfield 2013). Coastal areas prone to storm surge can also benefit from green space preservation. While naturally occurring or human generated wetlands have the potential to attenuate storm surge, this attribute is dependent on the surrounding coastal landscape and the specific characteristics of the surge.

Wetlands store, hold, and disseminate floodwater and can reduce peak riverine flows, suppress storm surge, and mitigate the adverse impacts of flooding events (Borsje et al. 2011). In coastal Texas, Brody et al. (2008) found that the loss of wetlands across 37 coastal counties from 1997 to 2001 significantly increased the amount of property damage from floods. Issuance of wetland alteration permits in these counties added an average of over $38,000 in property damage to each jurisdiction in a typical flood. The loss of an acre of naturally-occurring wetlands from 2001 to 2005 along the Gulf of Mexico coast increased property damage caused by flooding by an average of $7,457,549, which amounts to approximately $1.5 million per year (Brody et al. 2012).

Research examining design approaches for integrating ecological based design in flood control and management is typically conducted at a local scale. These approaches examine the integration of dyke systems utilization of revitalized riparian areas for flood retention, allocation of additional space for water detention and the development of architectural standards for future development in flood prone areas (Nillesen and Singelenberg 2011; Prominski et al. 2012). Ecological services are related to a regional system, not just the stability of individual components (Adger 2000). Flooding and storm surge disturb entire coastlines, not just isolated parcels. While local scaled research can provide information on how to integrate natural processes into individual parcels, corridor modeling involves a broader, more interconnected web of networks. These networks correspond to needs within an entire eco-region. Therefore, a regional scaled approach is necessary to provide a proper framework within which local scaled measures can then be implemented.

METHODOLOGY

Model Overview

New analytical tools have made it possible to better understand relationships between ecological processes and landscape patterns (Chetkiewicz et. al. 2006). The necessity for conservation and linkages among fragmented habitats gave rise to a multitude of methods for increasing landscape connectivity including least-cost paths (LCP), graph theory, circuit theory, and/or step selection functions (Chetkiewicz et al. 2006). The most popular method used to inform corridor design is LCP analysis. It designates a landscape resistance surface based on hypothetical costs that landscape elements may impose on species movement and identifies paths that minimize total costs between identified locations. Modifications of these costs make the simulated spatial pattern adjustable, which allows for a systematic investigation and the potential to generate alternative scenarios associated with the effects of varying types of cost on connectivity.

In this research, we identified landscape corridors using Linkage Mapper, an extension program of ArcGIS designed to support regional wildlife habitat connectivity analyses. The tool effective in conducting regional-scale wildlife habitat connectivity analyses (McRae and Kavanagh 2012). ArcGIS has a system of computer programming language known as Python scripts built into the Linkage Mapper tool which automate the corridor mapping process when using the LCP method. It uses ArcGIS maps of core habitat areas and user set resistance areas to classify and then map linkages between designated core areas. Each pixel or raster cell in a resistance map is attributed with a value determined by the cell's characteristics (e.g. land cover type, development potential, etc.), which reflects the cost to a specific species, of moving across that cell. As animals move away from the specified core areas, ArcGIS based cost-weighted distance analyses produce maps of accumulated resistance to movement. The ability to easily set cells as either high or low cost resistance variables (based on developmental or ecological value) makes the tool especially appropriate to this analysis.

Use of Model

Listed below is the sequential flow of specific steps involved in using the model in this research.

Step 1: GIS data inventory analysis—Initial steps in the use of the model involved the acquisition of GIS data for the H-G MSA from the cities of Houston and Galveston (vacant land inventory dataset), the Texas Natural Resource Information System (TNRIS) (land cover, canopy density, and protected lands/wetland datasets), the US Geological Survey (USGS) National Gap Analysis Program (species distribution datasets) and the U.S. Census Bureau (demographic and economic datasets). The Houston-Galveston Area Council (2000) defined vacant land in the inventory as "land which was cleared but had no current land use." These lands were coded by city as a separate land use within the dataset. Agricultural land was considered a separate land use in the inventory. Defined as still largely vegetated with no major apparent alterations, "undeveloped land" was differentiated from "vacant land" (Houston-Galveston Area Council 2000).

Dataset assessment used descriptive statistics to examine species populations present in the area, populations vulnerable to floods (100 year and 500 year), current land cover conditions, land cover change, existing vacant land locations, and existing land uses. This inventory describes dominant land cover are in the area, those cover types that are being lost to development, how much of the population is vulnerable to flooding and storm surge, and what lands are considered vacant. Conduct of a series of site visits helped confirm the conditions of ecological core areas, existing corridors, and vacant land based on the GIS suitability outputs (described in the following steps).

Step 2: Construction of the development potential map—Measuring development and ecological potential for each parcel involved the creation of a series of suitability maps using weighted overlay models. Land-use suitability mapping is an ArcGIS application that identifies appropriate future land uses based on specified requirements and raster map overlays (Malczewski 2004). The Development Potential map identified parcels which had the highest quality for future development. Generation of this map involved overlaying maps that depicted nine socio-environmental factors, including: population, soil type, property value, land cover type, land use type, protected/wetland areas, flood risk areas, hurricane risk zones, and proximity to amenities.

Each factor was strategically chosen due to its proven effects on development potential (Table 1). A high population in an area can be indicative of a high development potential both within the population cluster and in tangential lands, especially to promote sustainable growth (Dueker and Delacy 1990). Simultaneously, the use of soil maps and the interpretations of soil classifications have been continuously used over the years to better predict the behavior of each soil type under defined situations such as development potential (Karlen et al. 1997). Market conditions such as fluctuations in property values can also highly contribute to development potential (Newman et al. 2016c). While each property has an inherent value, it also has its own land use and land cover. Whether a property is commercial, industrial, residential, green space, or highly/lowly vegetated highly impacts not only it potential for future development opportunities, but what types of development should occur in it in the future, if any (Van der Merwe 1997). For example, certain institutional land uses such as libraries, museums, parks, hospitals and other landmark/icon developments can spur development in properties in close proximity; these are known as anchor developments which increase the development potential of nearby properties (Wang and Moskovits 2001). Inversely, properties located within protected or conservation designated areas are severely restricted their ability to attract future development (Van der Merwe 1997). Relatedly, properties in high hazard risk zones such as hurricanes or flooding may merit a lower development potential than those outside of these zones due to the threat of disaster (Allen and Lu 2003).

Each map depicted an individual data layer. Converting the layers to raster maps allowed reclassification of each raster cell on a scale of one to five (one = less developable; five = more developable). Reclassification allowed for a simplified interpretation of the assigned values for each raster cell. For example, cells with the lowest populations were assigned a value of one while cells with the highest populations were assigned a score of five, as it was assumed that areas with higher population would generate an increase in future development. It should be noted that while the development potential ratings were ranked from 1 (lowest) to 5 (highest), the ecological potential ratings were ranked from 1(highest) to 5 (lowest). This was done to help define high resistance (e.g. high development/low ecological potential areas) versus low resistance (low development/high ecological potential areas) when developing the corridor.

Reclassification of each layer from analogue to digital format used numerical values having equal intervals. Overlaying and synthesizing the nine maps into a single map used a weighted sum tool (Table 1). This process multiplied each raster by a given weight and summed the weighted values (Marinoni 2004). All nine input rasters were weighted equally in an effort to: a) allow natural conditions (e.g. soil and land cover) to have as much influence as cultural conditions (e.g. land use and property value); and b) not prioritize development potential based on a single variable.

Step 3: Construction of the ecological potential map—Development of the Ecological Potential map also used suitability modeling and the weighted sum tool. The USGS National Gap Analysis (GAP) Program Land Cover Data Sets include vegetation and land use patterns for the continental United States. The maps identify places containing a sufficient amount of quality habitat to support a given species. Initial identification of existing habitat patches within the region used 16 GAP datasets that included eight endangered/keystone, four umbrella/keystone, and four representative species (Table 2). These species were chosen based on their range of habitat, species classification, and GAP data availability. As noted earlier, umbrella/keystone species more strongly increase species richness and they were weighted higher in the overlay process, therefore they were given a weighting value of 3. Endangered/indicator species were weighted higher than typical species due to their ability to help maintain ecological integrity (weighting value of 2). Typical species were weighted with a value of 1 as their common existence, while still deemed important, was not as indicative of higher species richness. The overlay of the GAP datasets was integrated with land cover (reclassified in a range from one to five with one being denser vegetation and five being less dense/barren areas), canopy density (reclassified in a range from one to five with one being denser canopy and five being less dense canopy), and protected lands/wetland datasets (reclassified in a range from one to five with one being wetlands and protected lands and five being all other areas), to create an Ecological Potential map (Figure 2). While the overlay of the GAP habitat data could create a small amount of redundancies with the information within the land cover and canopy density data, the researchers found integrating these data sets because 1) the selection of only a sample of GAP species does not necessarily capture all of the land cover data and 2) GAP data does not specify vegetation density, only where a species could be located based on land cover conditions. Therefore, both land cover and campy density were still utilized to increase the reliability and accuracy of the output. It should be noted that other important ecological features, such as water and soil, were not fully integrated. Soil was previously captured in the development potential map which is eventually integrated into the ecological potential map while water is captured in the land cover data through wetlands and aquatic types. The highest classes of habitat suitability within the Ecological Potential map based on the average value for each raster cell were then identified as core areas for future connection.

Step 4: Map synthesis and vacant land potential—The Ecological Potential map and the Development Potential maps were then reclassified and overlaid with equal weighting using the weighted overlay tool to produce a composite Land Use Suitability map (Figure 3). As noted earlier, weighted overlays combine multiple raster datasets by applying a common measurement scale of values to each raster. The values in each raster can be weighted according to their relative importance and then integrated into a single output (Mutke et al. 2001). The Land Use Suitability map integrated both the development and ecological value of each parcel and was then clipped by the vacant land inventory for separate analysis. This map allowed the researchers to determine which vacant parcels were prime for repurposing for developmental versus ecological purposes. A small number of lands were designated as Conservation Based Development zones which were neutral in regards to their development or ecological value. These sites were neither high nor low in regards to their values and were designated as spaces which had opportunities for both uses. Therefore, they are well suited for low impact development schemes or more ecologically friendly or low density approaches to new land uses.

Step 5: Least cost path and corridor development—The LCP model connected existing core areas by analyzing the least-cost paths between core areas based on the development and ecological potentials of vacant lands. Vacant lands having high ecological potential were used as the primary land type to link existing core areas using the Linkage Mapper software. To connect core areas, a modified cost-surface was developed, which was then used as part of a landscape connectivity modeling framework (McRae et al. 2008) to develop a regional-scaled network of structurally connected natural lands. A cost-surface takes a starting point (core areas) and assesses the raster cells as it traverses to the end point (another core area) and can be modified based on the designer's input resistance settings. Designated resistance values in LCP models reflect high or low movement suitability based on different landscape factors and reflect the total cost, or ease of species movement, of a path between habitat patches (Adriaensen et al. 2003; Beier, Majka, and Spencer 2008). The Land Use Suitability map and the Vacant Land map were integrated to create a resistance raster. Vacant cells having a high ecological/low development potential value were defined as having low resistance while vacant cells having low ecological/high development were characterized as high resistance. Linkage Mapper then performed the LCP to generate corridors by connecting core area cells with neighboring cells having low resistance values (Figure 4).

RESULTS

The GIS data inventory analysis conducted prior to generating the landscape corridor model revealed several salient results. The U.S. Census (2010) population for the H-G MSA was

6,087,133 with a total land area of 8,911,186 acres (36,062,290,295 square meters).Vacant land occupied 3,103,600 acres (12,559,823,593 square meters) or 51 percent of the H-G MSA, making it the most abundant land use. According to the census tract GIS data, nearly 725,000 people currently live within the 100-year floodplain while 686,000 inhabit the 500-year floodplain. Wetland areas are rapidly disappearing with land cover analyses showing a loss of approximately 25 percent of estuarine marshes and 40 percent of tidal flats from 1950–2002 (Jacob and Lopez 2005). According to the TNRIS GIS data inventory, among the U.S. Fish and Wildlife designated wetland areas, Estuarine and Marine Deep-water wetlands account for nearly 60 percent of the wetland areas in the H-G MSA followed by Freshwater Emergent Wetlands (15 percent). Other wetland types each occupy between 1–6 percent of the H-G MSA. Developed areas currently occupy around 1.5 million acres (607,028 hectares) or 17 percent of the SMA and it is projected to increase. Impervious surface increased by 12 percent between 1996 and 2006 (Yoskowitz et al. 2012). Forested areas occupied 2.2 million acres (890,308 hectares) (25 percent of the total SMA area). Core forested areas decreased by nearly 17 percent between 1996 and 2006 (Yoskowitz et al. 2012).

Evaluations of the GIS data on existing vacant patches, reinforced by site visits, revealed that many existing green spaces are small, oddly shaped, weakly connected, characterized by stark edge conditions, and they have a distant proximity from one another. Corridors are almost nonexistent. The few existing linked habitats are narrow in width and have simple and sparse vegetative structures. Research suggests that larger patch sizes that are in close proximity to one another and connected through corridors that have less edge abruptness can increase biodiversity, species richness, and species movement (Dramstad, Olson, and Forman 1996).

The merged Land Use Suitability map shows that approximately 53 percent of the H-G MSA is prime for future development and 21 percent is better suited for ecological purposes. Because a broad set of species were selected in this model for corridor development, linkages created between patches enable habitat mobility for the highest number of species possible at a given time. The resultant network creates a series of highly connected ecological core areas within a dendritic green framework which minimizes competition with developable areas while maximizing ecological services (Figure 5).

After modeling the regional scale corridor, application of this network on a local scale required mitigating human constructed infrastructure within the existing land use matrix to assess the finer-grained obstacles and disturbances to corridor implementation. The local scale analysis focused 10,000 acres in size (4046 hectares) located on the western portion of Galveston Island. The entire proposed ecological network for the local area occupies more than 4,700 acres (1902 hectares). Existing development accounts for approximately 2,200 acres (890 hectares) and areas shown to have a high development potential include almost 1,600 acres (647 hectares). Rmaining area consists of primarily beach line and waterfront shore space. The large discrepancy between proposed developable and non-developable areas is due largely to the fact that western Galveston Island is composed of 41 percent vacant land and 25 percent saltwater marsh, most of which is in the 100-year floodplain, making many soil conditions better suited for ecological purposes.

Core areas within the corridor network include approximately 2,005 acres (811 hectares), or 52 percent of the entire ecological network, with 1025 acres (414 hectares) or 22 percent designated as new patch space. These new patch spaces serve as pockets of vegetation which provide stepping stones for corridor connectivity to the core areas. This leaves approximately 1,729 acres (699 hectares) or 36 percent of the network as designated corridor space. The large amount of core space is attributable to the abundance of protected lands and wetlands existing on the island. The increase in patchiness due to the high ecological potential in existing vacant lands aided in corridor linkage to these core areas. This characteristic was key to the succeful LCP navigation among the corridors within the developed land use matrix.

Most conflict areas in the matrix contain existing buildings located in projected corridor space. The corridor must be effectively and strategically maneuvered through or around 769 acres (311 hectares) of existing building footprint and infrastructure and 770 acres (311 hectares) of proposed future development sites (Table 3). Weaving the corridor through or around existing and proposed development is essential to connecting the proposed 3,734acres (1511 hectares) of core and patch area (Figure 5). The local scaled corridor output shows that nearly 70 percent of western Galveston Island's vacant land could be repurposed through either developmental or ecological functions (4,120 total vacant and 2,940 vacant land repurposed) (Table 3). Any connection created by Linkage Mapper was designated specifically as a corridor while higher ecological value vacant lands identified by the ecological potential suitability process are designated as potential patch areas. Due to the large size and abundance of vacant land on the island, over half of the ecologically repurposed vacant lands (59 percent) serve as patch areas that could be connected to core areas thorough corridors (15 percent).

DISCUSSION

It is important to note that the physical conditions of the western portion of Galveston Island are not typical of most deindustrializing and depopulating cities experiencing abundant structural abandonment. Vacant lands in the local scale study area, due to their location and proximity to wetlands, may have a higher ecological value than the typical vacant parcel found in a conventional urban location in the Midwest or Northeast of the U.S. While this research was able to show that a large percentage of vacant land could be repurposed using landscape connectivity, this may not always be true when applied in other areas. The actual incorporation of new functions into vacant lots will be a product of the accumulated efforts of individual landowners. While the overall process can be transferred as a method to other urban areas, the amount of vacant land, the capacity to link core areas, corridor sizes, and the ecological value per vacant lot will be different as the method is applied in different locations. However, the approach could serve as a model for a more flexible solution to urban regeneration in cities experiencing widespread vacancy. While corridor development must be strategically integrated with green infrastructure in areas of existing development, the use of vacant land as a device to connect ecologically valuable areas can enhance habitat value and reduce storm surge flooding in urban areas.

CONCLUSION

The focus of this research used landscape corridor modeling to integrate use of vacant land into a regional framework to enhance habitat quality and reduce flood/surge effects. The framework was applied on a local scale for repurposing vacant lots. Objectives included determining the effects landscape corridor development could have on creating new uses for vacant land and increasing ecological services in storm surge prone areas. Results indicate that implementation of the framework could aid in stabilizing the amount of disturbance in an ecosystem, thereby enhancing, connecting, and protecting patch/core areas having ecological and hydrological significance. Existing developed areas in the matrix must be strategically redesigned using green infrastructure to provide corridor linkages. The ecological framework should be used as a green skeleton to guide future layout of new development. Further, vacant parcels with high development potential can serve as readily available parcels for infill development. This can decrease the chance of future vacancies, which will prevent abandonment of surrounding parcels (Pagano and Bowman 2000). This type of strategic clustering of development can help increase densities, mixed uses, and social interaction.

The linkage of vacant lands having ecological potential with existing and evolving core areas, patches and corridors will have minimal negative impacts on future development opportunities. The repurposing of vacant land to facilitate creation of landscape corridor systems will enhance habitat values and retain and distribute floodwater to increase flood attenuation. The research also suggests that implementation of the projected structural and non-structural coastal storm surge barrier infrastructure will help enhance, retain, and restore wetland and green space areas to enhance provision of valuable habitat, flood regulation, and development ecosystem services. The vacant lands could be repurposed as basins that act as drainage areas for leakage and overflow from the structural surge protection system (that is the Ike Dike) and catchment areas for runoff collection during periods of high rainfall. The basins will mitigate the costly and negative consequences of flooding associated with surge overflow and intense rainfall events. These newly constructed wetlands and large scale detention pools will also provide valuable wetland habitat.

Realization of these benefits will enhance the ability of the Ike Dike and associated no-structural system of connected landscape corridors to cultivate ecological processes while generating long term and resilient community development patterns. For newly developed areas, this will aid in decreasing the amount of property damage caused by flooding through the preservation, reclamation and generation of wetland and green space areas. The consequences of framework implementation will decrease the negative social and monetary impacts typically caused by storm surge and excessive rainfall while also enhancing habitat quality and diversity.

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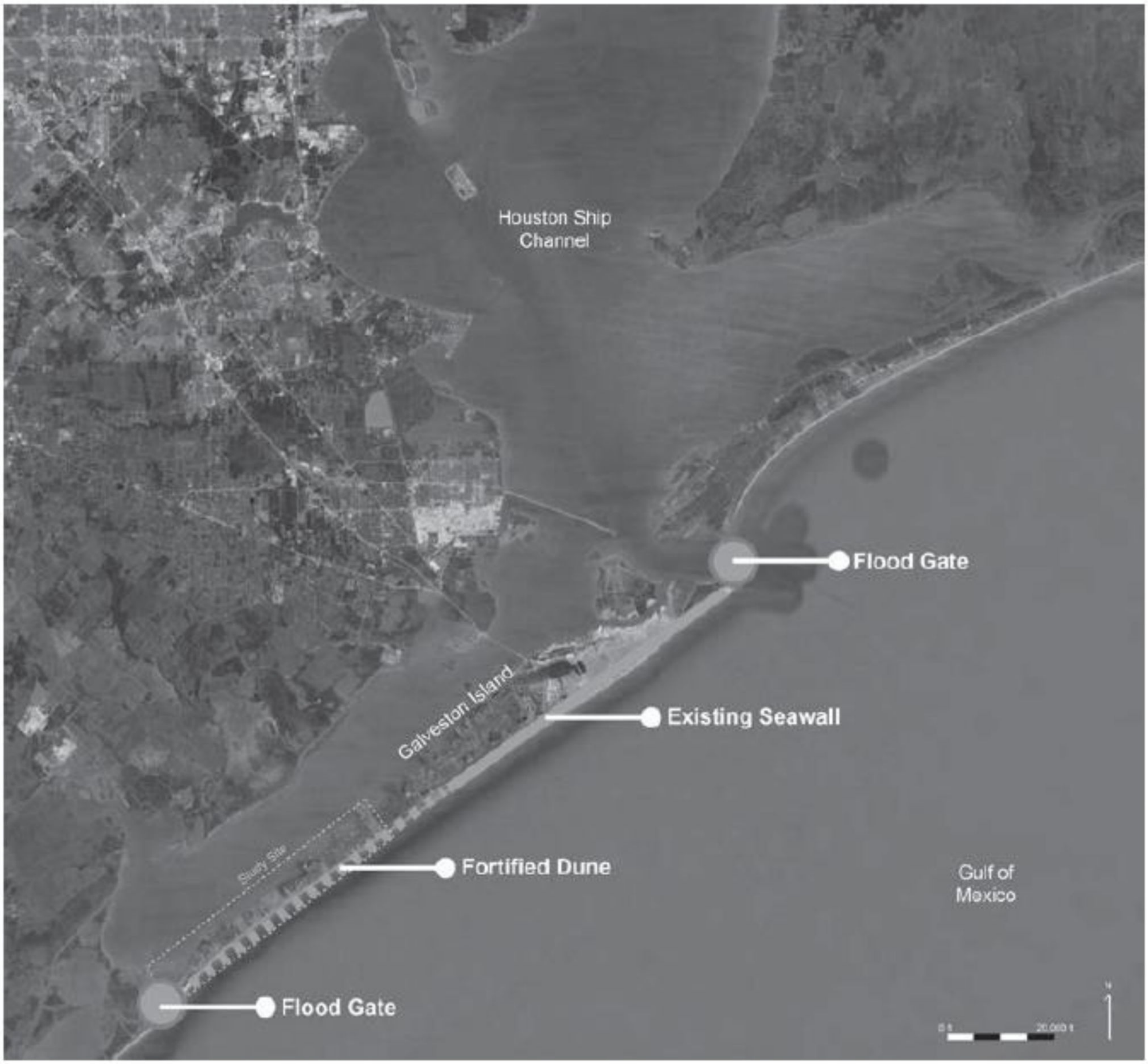

Figure 1.

The Ike Dike's potential storm surge structural infrastructure components; Galveston Island's proposed coastal spine is designed to protect the Houston-Galveston Metropolitan Statistical Area (H-G MSA) from a 10,000 year flood.

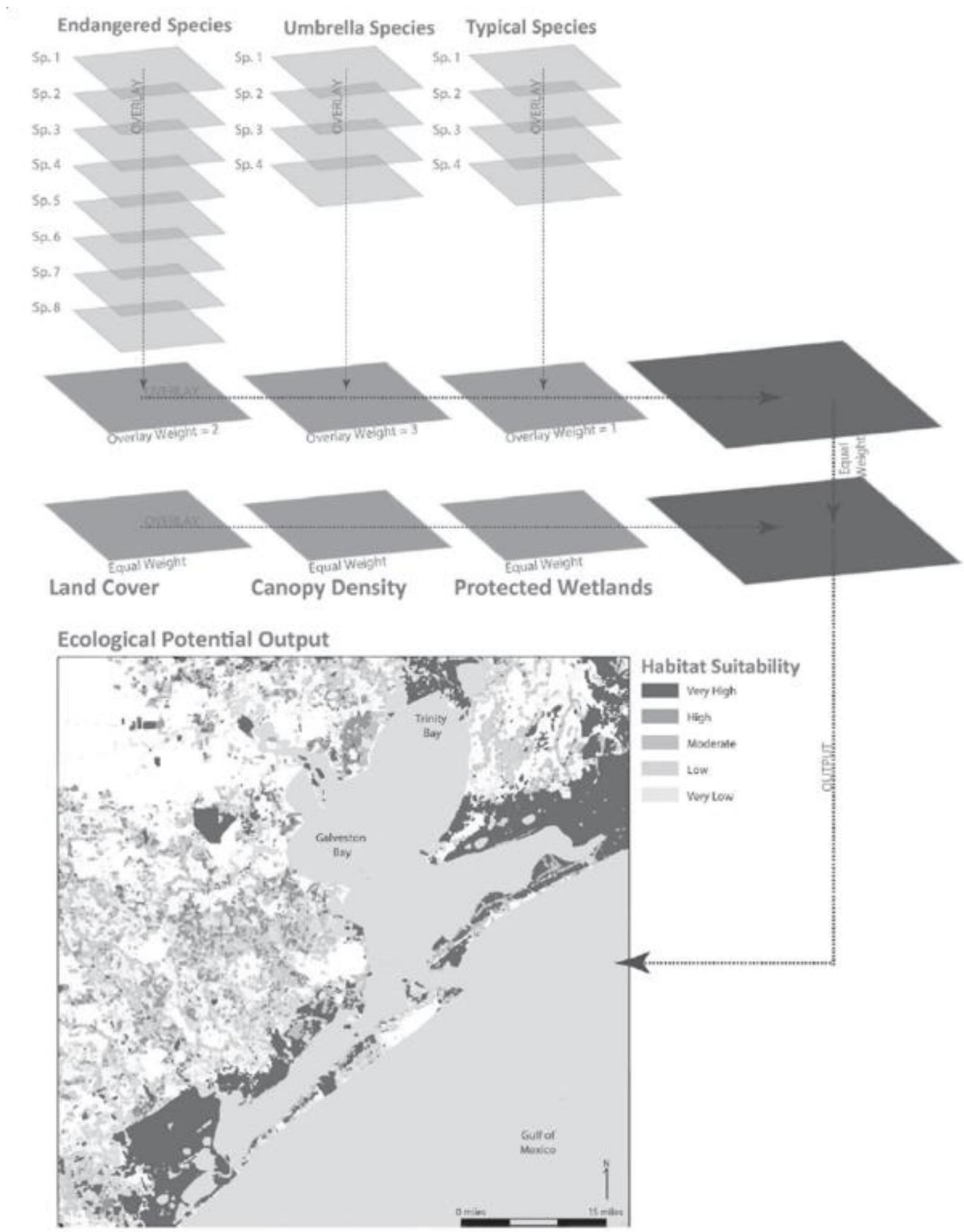

Figure 2.

Ecological Potential overlay process showing classification and weighting for USGS National Gap Analysis Program (GAP) Land Cover Data Sets and land cover reclassification output, which were then overlaid using equal weighting.

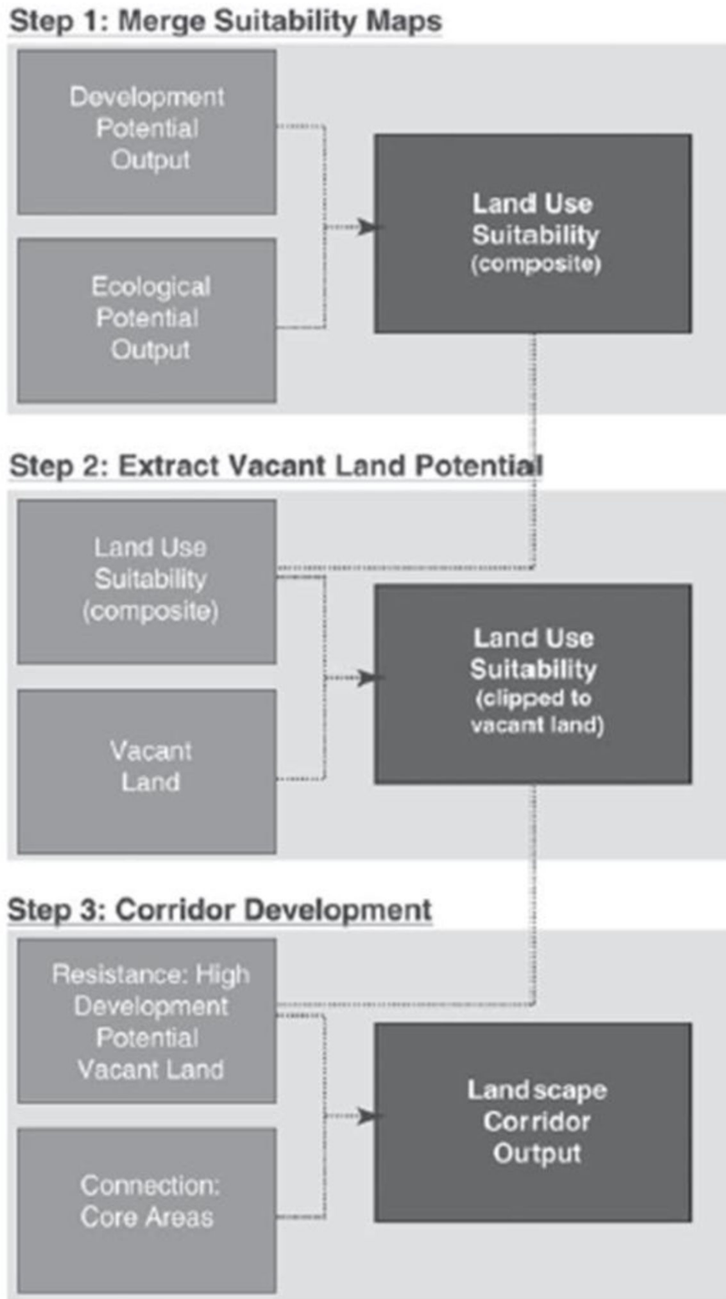

Figure 3.

Landscape Corridor Output process showing map integration for the Land Use Sustainability output which was clipped by the vacant land inventory. Low resistance was then set for high ecological/low development potential vacant cells and high resistance for the inverse. Linkage Mapper then performed the LCP creating the corridor output.

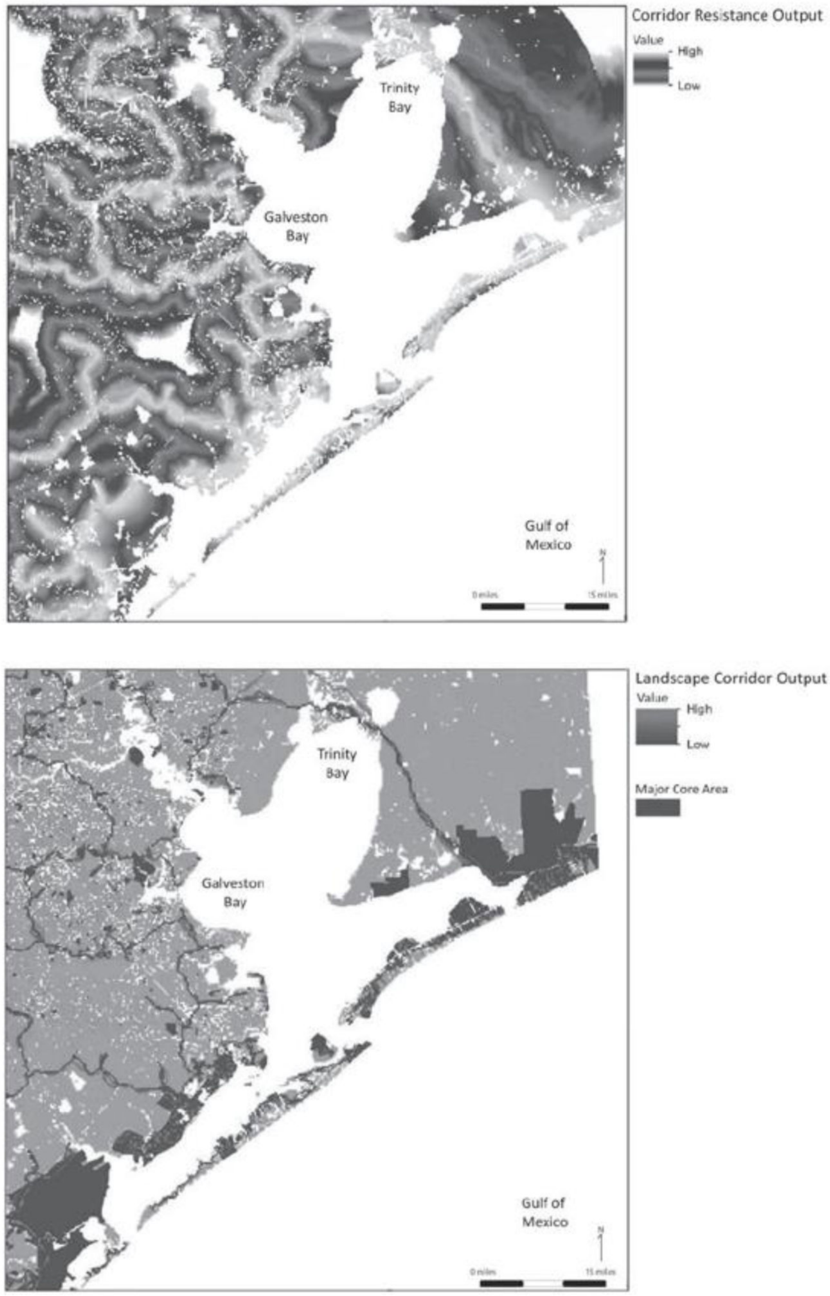

Figure 4.

Linkage Mapper outputs showing the high to low resistance areas when applied to low development potential/high ecological potential vacant lands (top) and the regional landscape corridor output based on these resistance settings (bottom).

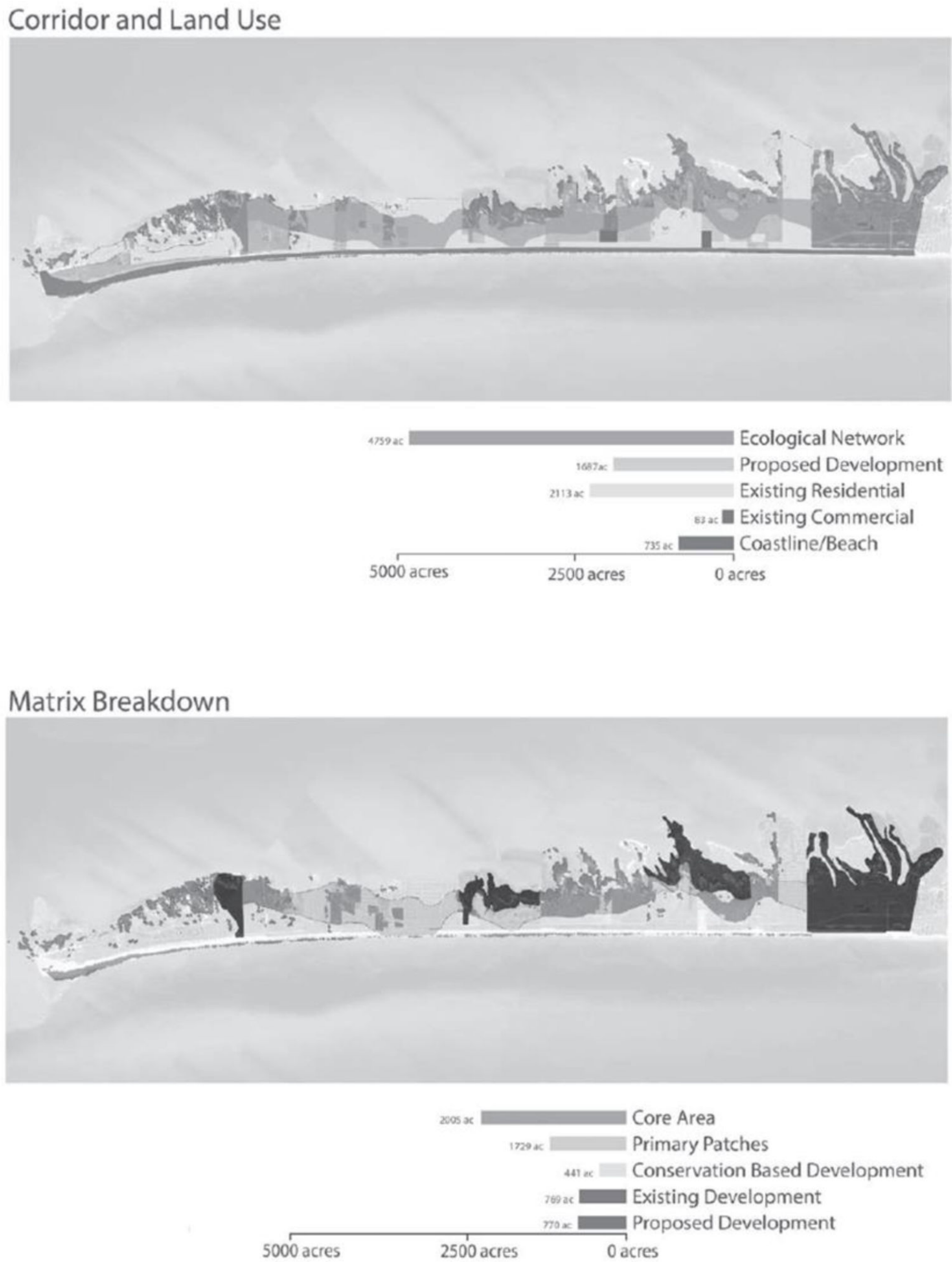

Figure 5.

Local scale corridor application and elements showing components of the corridor output with potential land uses (top) and a breakdown of the matrix through which the corridor must traverse (bottom).

Table 1

Nine Factors Utilized to Create the Development Potential Map

Variable	Rating Scale	Criteria	Scale	Method/Rationale	References
Population	1	0–250 persons	Census block	The H-G MSA census block data was compiled and classified into 5 intervals. Lowest population areas were ranked as lower development potential while higher population areas were given the highest ranking score. This was done because, currently, the density of the region is quite low compared to many large cities striving for sustainable growth. Coupled with the large amount of vacant land in the region (40%), the research assumed that the high population areas still had ample amount of room for future growth. Also, because we used data at the census block scale, the population densities will fluctuate in different areas within these blocks. To assign population per cell, cells were assigned with population values at the census block scale. Each block was then given an interval population range and each interval was assigned a score.	Dueker and Delacy 1990
	2	250–500 persons			
	3	500–1000 persons			Allen and Lu 2003
	4	1000–2000 persons			
	5	2000–5,930 persons			Newman et al. 2016c
Soil	0	Not rated	Municipality	Each soil type was researched individually based on the code provided and ranked according to its pre-identified development potential. Soils were only given a 3-point maximum score based on the large scale they were analyzed. Because the data was not as fine grained as necessary, its influence was limited purposely by the analytical approach.	Karlen et al. 1997
	1	Very limited			
	2	Somewhat limited			Wu 1998
	3	Not limited			
Property Value	1	0–8,500 (dollars)	Parcel	This variable was extracted from the parcel data and classified according to Jenks natural breaks. Higher property value areas were assumed to have a higher development potential, while in lower valued areas it was assumed the inverse.	Dueker and Delacy 1990
	2	8,500–40,000 (dollars)			
	3	40,000–150,000 (dollars)			Newman et al. 2016c
	4	150,000–650,000 (dollars)			
	5	650,000–3,000,000 (dollars)			
Land Cover	0	Salt marsh/open water	30 × 30 meter pixels	While all other datasets were initially assessed as vector data, then converted to raster data for suitability overlay, land cover was analyzed consistently as raster data. In this case, currently developed areas were deemed highly developable while periodically flooded and aquatic areas were deemed to have little to no development potential. Sparsely vegetated areas were also given a high ranking score while forested and more densely vegetated areas, a lower rank.	Van der Merwe 1997
	1	Temperate flooded and swamp forest			
	2	Warm and cool temperate forest			Want and Moskovits 2001
	3	Temperate grass land/meadow/ shrub land/boreal shrub/herb coastal vegetation/warm semi desert shrub and grass land/ herbaceous agriculture/ introduced semi-natural			Allen and Lu 2003
	4	Developed and Urban/recently			
	5	Modified			

Variable	Rating Scale	Criteria	Scale	Method/Rationale	References
Land Use	0 1 2 4 5	Water/undevelopable Parks/open spaces Government/medical/ educational Vacant developable Residential/industrial/ commercial	Parcel	Rankings for each individual land use were based on the assumption that areas currently within land uses designated for future development purposes would have the highest development potential. Vacant land uses deemed as developable were also given high scores. Undevelopable parcels or those within a water body, land uses designated as open spaces and those devoted to institutional uses were deemed as less developable.	Van der Merwe 1997 Wu 1998
FEMA Flood Plains	1 2 3	A/AE/AO/VE/D X500 X100	Region	Lands outside of the 100 and 500 year floodplains were designated as higher developable lands while areas within the 100 and 500 year flood plains were ranked as less developable. Again, due to the large scale of the flood plain data, scores were only provided with a maximum of 3 for this variable. We also believe that land cover, land use, and conservation areas capture some of the information provided by this data set.	Allen and Lu 2003 Brody et al. 2012
Hurricane Risk Zones	1 2 3 4 5	Risk 5 Risk 4 Risk 3 Risk 2 Risk 1	Region	Each hurricane risk zone is based on the category of hurricane (1, 2, 3, 4, or 5) which would impact a certain set of land. In this case, the development potential rankings were scored assuming that the lower the risk of hurricane impact, the higher the development potential.	Allen and Lu 2003 Brody et al. 2012
Conservation Areas	0 2	Wetlands/refuges/state parks/ protected areas Remaining areas		Because the intent for this research was to ultimately create a landscape corridor model linking patches, conservation areas were listed as having no development potential. Lands outside of these parcels were given a score of two at maximum because the other variables utilized capture their potential more in-depth. In this case, we sought to only represent the need to protect conserved green spaces.	Van der Merwe 1997 Allen and Lu 2003
Proximity to Amenities	1 4	Remaining areas Library/museum/parks/ hospitals		Because existing amenities can serve as anchors spurring new development, we created buffer zones around current landmarks and civic institutions. Areas within these buffer zones were scored at a higher level than those outside of them.	Wang and Moskovits 2001 Birch et al. 2013 Newman et al. 2016c

Table 2

USGS National Gap Analysis Program (GAP) Land Cover Data Sets for Selected Species and Their Classification for Use in the Corridor Model Development

Selected Species			Species Status		
Classification	**Common Name**	**Latin Name**	**Endangered/ Indicator**	**Umbrella/ Keystone**	**Representative Species**
Amphibians	Texas Blind Salamander	*Eurycea rathbuni*	X		
	Lesser Siren	*Siren intermedia*			X
	Northern Cricket Frog	*Acris crepitans*			X
	Southern Dusky Salamander	*Desmognathus auriculatus*			X
Birds	Whooping Crane	*Grus americana*	X		
	Red Cockaded Woodpecker	*Picoides borealis*	X		
	Attwater's Greater Prairie Chicken	*Tympanuchus cupido attwateri*			X
	Piping Plover	*Charadrius melodus*	X		
Mammals	Cougar	*Puma concolor*		X	
	Red Fox	*Vulpes vulpes*		X	
	Long Tailed Weasel	*Mustela frenata*		X	
	Ringtail Raccoon	*Bassariscus astutus*		X	
Reptiles	Kemp's Ridley Sea Turtle	*Lepidochelys kempii*	X		
	Atlantic Hawksbill Sea Turtle	*Eretmochelys imbricata*	X		
	Leatherback Sea Turtle	*Dermochelys coriacea*	X		
	Green Sea Turtle	*Chelonia mydas*	X		

Table 3

Vacant Land Repurposing Results Showing Local Scale Amounts of Existing and Vacant Land, Amounts of Repurposed Vacant Lands, and the Approach Used in the Repurposing of Use to Either Developmental or Ecological Uses.

Land Typologies	Acres	Hectares	Ratio (in percentage)
Existing Vacant Land	4,120 (total area)	1,667 (total area)	41% (of total land area)
Repurposed Vacant Land	2,940 (of total vacant land)	1,190 (of total vacant land)	71% (of total existing vacant land)
Repurposing Methods	**Acres (of repurposed vacant land)**	**Hectares (of repurposed vacant land)**	**Ratio (to repurposed vacant land)**
Proposed Development	770	312	26%
Proposed Patch Areas	1,729	700	59%
Proposed Corridor Areas	441	178	15%
Existing Conditions	**Acres (of total land)**	**Hectares (of total land)**	**Ratio (to total land area)**
Core Areas	2,005	811	20%
Developed Matrix	769	311	8%