Calculating the Value of Nature & The Cost of Hurricane Harvey: Leveraging Eco-Adaptation Valuation in American Policy & Practice

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Abstract
Ecosystem-based Adaptation (EbA) is a strategy that “uses biodiversity and ecosystem services…to help people adapt to the adverse effects of climate change” by taking “into account the multiple social, economic and cultural co-benefits for local communities” (SCBD, 2009). EbA valuation is a holistic process that calculates the cost, benefits, and impacts of ecosystem services in adaptation strategies. This research provides methods for valuing ecosystem services and a justification of ecosystem-based adaptation (EbA) in order to leverage effective resilience planning decisions. The goal of this research is to a) show that proactive, land-based adaptation is more cost-effective than reactive mitigation in resilience projects (i.e. EbA is more beneficial than grey infrastructure) and b) provide guidelines for understanding the EbA valuation process and recommendations for communicating EbA to stakeholders. The costly impacts of Hurricane Harvey on Texas are explored to highlight problems that can be addressed by EbA principles to potentially alleviate flooding from future storm surge. EbA valuation trends in policy, practice, and messaging are assessed to provide communication guidelines as methods for influencing resilience policy. This study culminates in visual aids and recommendations based on specific stakeholder values with the aim of generating EbA buyin from American planners, policymakers, and the public. The goal is to influence decisionmakers into utilizing the example of Texas and this study’s recommendations to potentially leverage EbA policy and mainstream EbA valuation in American resilience practice. The overall objective is to alleviate the increasing cost burden of storm surge impacts.

Disciplines
Environmental Sciences
CALCULATING THE VALUE OF NATURE &
THE COST OF HURRICANE HARVEY

LEVERAGING ECO-ADAPTATION VALUATION

IN AMERICAN POLICY & PRACTICE

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Master of Environmental Studies
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ABSTRACT

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Ecosystem-based Adaptation (EbA) is a strategy that “uses biodiversity and ecosystem services…to help people adapt to the adverse effects of climate change” by taking “into account the multiple social, economic and cultural co-benefits for local communities” (SCBD, 2009). EbA valuation is a holistic process that calculates the cost, benefits, and impacts of ecosystem services in adaptation strategies. This research provides methods for valuing ecosystem services and a justification of ecosystem-based adaptation (EbA) in order to leverage effective resilience planning decisions. The goal of this research is to a) show that proactive, land-based adaptation is more cost-effective than reactive mitigation in resilience projects (i.e. EbA is more beneficial than grey infrastructure) and b) provide guidelines for understanding the EbA valuation process and recommendations for communicating EbA to stakeholders. The costly impacts of Hurricane Harvey on Texas are explored to highlight problems that can be addressed by EbA principles to potentially alleviate flooding from future storm surge. EbA valuation trends in policy, practice, and messaging are assessed to provide communication guidelines as methods for influencing resilience policy. This study culminates in visual aids and recommendations based on specific stakeholder values with the aim of generating EbA buy-in from American planners, policy-makers, and the public. The goal is to influence decision-makers into utilizing the example of Texas and this study’s recommendations to potentially leverage EbA policy and mainstream EbA valuation in American resilience practice. The overall objective is to alleviate the increasing cost burden of storm surge impacts.
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Introduction

Robust natural ecosystems, particularly wetland ecosystems, are rapidly diminishing and being depreciated on a global scale. This has caused an extreme biodiversity crisis. In the United States, this issue is exacerbated by inaction on sea-level rise and ineffective governmental policies. This is especially true in the extreme case of Texas, which has experienced a staggering amount of billion-dollar natural disasters in the past five years. Despite overwhelming scientific evidence, U.S. legislators, including President Donald Trump, continue to discredit legitimate studies showing the detrimental hazards of anthropogenic climate change. Nevertheless, in the wake of the devastating 2017 Atlantic Hurricane Season (i.e. Hurricane Harvey, Hurricane Irma, and Hurricane Maria), local planners and government officials are confronted with the challenge of instituting effective measures to mitigate the adverse impacts of sea-level rise and commensurate storm surge. At the same time, many decision-makers are looking to implement resilience practices while also not burdening or impeding development or growth of their local economies.

In many instances, the impacts of these catastrophic hurricane events were exacerbated by rising sea levels in areas prone to flooding. Although a definitive connection has not yet been made between climate change and tropical storms, substantial scientific evidence shows that climate change causes sea level rise. Sea level rise exacerbates storm surge, major flooding and the level of damage after a disaster event. The reactionary, post-disaster approach to combating sea-level rise negatively impacts not only the environment, but also human health and the economy. In an effort to influence proactive climate adaptation planning, researchers are now providing detailed inundation data and maps illustrating the extent of the coastal hazards attributed to sea-level rise. Such data has been used to support climate action plans, municipal stormwater management plans, and local coastal mitigation programs. Nevertheless, inundation maps only provide scientific measurements and predictive sea-level rise models without contextualizing their bearing. This type of data does not illustrate the nuances of the economic, environmental and social value of at-risk ecosystems as well as the relevance to community stakeholders. While studies that include an economic analysis of coastal areas do exist, they typically provide a one-dimensional, market-based analysis. Most mainstream studies tend to focus on a monetary calculation of future damages caused as a result of a
100-year event, while other studies may show the cost of a specific stormwater mitigation strategy (The Nature Conservancy, 2016). These studies lack a comprehensive analysis and calculation of the economic, social, and environmental benefits natural ecosystems provide at no cost. For example, wetland areas provide valuable natural services, including storm surge mitigation, recreational opportunities, and many others that generate benefits with no monetary collateral attached (see Fig. 1). However, the value of ecosystem services is not often included in the resilience planning process, even though they aid in implementing proactive adaptation measures. Nevertheless, there are already systems and case studies in place that can facilitate their inclusion in mainstream American resilience practice, which is reactionary mitigation.

The United Nations Convention on Biological Diversity defines Ecosystem-based Adaptation (EbA) as a strategy that “uses biodiversity and ecosystem services…to help people adapt to the adverse effects of climate change”, and may consist of “sustainable management, conservation, and restoration of ecosystems, as a part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities” (SCBD 2009, 2010). Ecosystem-based Adaptation (EbA) Valuation is a newly defined, holistic process that emphasizes the worth of natural ecosystems and their adaptation services. Specifically, EbA valuation is “the process of describing, measuring and analyzing how the benefits, costs and impacts arising from the implementation of ecosystem-based approach to adaptation are generated, received, and perceived” (Emerton, 2017) (See Fig. 2). It is important to stress that EbA valuation is not a conventional cost-benefit analysis or resilience planning appraisal. Rather, EbA Valuation is a comprehensive approach to measuring not only the market value of land-based adaptation, but also the biophysical impacts, effects on quality of life, and societal influence (influence on human behavior and understanding). EbA valuation considers a wide-range of future impacts from the beginning of the planning process, rather than in reaction to the problem after the fact. However, while EbA valuation is supported by experts, it is not well-understood or implemented by mainstream decision-makers or local communities.

In December 2017, the German Society for International Cooperation (GIZ) released the first EbA valuation resource book, followed by an an illuminating learning brief from an international EbA conference (Sckeyde, 2017). The resource book was comprised of 48 exemplary EbA valuation case studies from around the world (Emerton, 2017). These studies used EbA valuation principles without using the “EbA” label. Thus, GIZ gave the idea for land-based adaptation strategies a name (EbA) and used studies to support the claim that there are benefits to calculating the value of ecosystem services (EbA valuation).
Goal
This research uses lessons learned from GIZ’s resource book, scientific studies, and the case of Texas to illustrate EbA best practices. The goal of this study is to:

a) Provide evidence that proactive adaptation is a superior, more cost-effective solution than reactive mitigation strategies in resilience projects (i.e. EbA is more beneficial than grey infrastructure - like sea walls or other concrete armoring projects).

b) Provide guidelines for understanding the process of EbA valuation and recommendations for communicating the strategy to decision-makers and affected communities.

Approach
This study provides new visual aids that can illuminate understanding of the EbA valuation process and can serve as a model for strategic decision-making. An infographic is provided that illustrates an original, simplified five step process specifically categorized by tools needed for EbA action. In order to provide context and relevance, this research uses Texas and Hurricane Harvey as an exemplary case study. The costs and impacts of the ineffective resilience actions taken preceding Hurricane Harvey are assessed using the five step EbA model. Assessment through a natural disaster lens will convey urgency and impact action-based knowledge, a strong motivator for communities. Natural disasters also have inflated impact values that are costly in comparison to the impacts, costs and benefits of ecosystem services. The circumstances in Texas show that the simple EbA model can be applied to the most extreme of cases. A resilience project currently underway in Texas, called the Lone Star National Recreation Area (LSNRA), is discussed as an example of proactive, real-world adaptation solutions that can leverage policy change and mainstream EbA practice.

Purpose
This paper provides methods and justification to local planners and government officials at the federal, state, and local levels about the use of EbA valuation to make decisions regarding resilience planning. The objective is to provide sufficient evidence and messaging strategies acknowledging the economic, social, and environmental value of ecosystem services and adaptation in order to effectively alleviate the increasing cost burden of storm surge flooding. In the future, the recommendations can be used to leverage EbA policies or mainstream use of EbA valuation in American resilience studies or practice.
Background

Ecosystem-based adaptation (EbA) valuation is a holistic process that involves integrating the views and values of the affected community into resilience planning. Whereas it is intrinsically difficult to ascribe monetary value to intangible things, it is important for public policy decision-makers and government officials to understand this concept. Society not only places value on nature for the services we receive; we place value on nature to account for the damages we cause as well. Therefore, consideration of human health impacts is integral to creating successful ballot measures that seek to provide funding for ecosystem-based adaptation strategies. In order to fully understand the significance of EbA valuation, however, we must first understand the concept of valuation with regard to nature and intangible things and acknowledge the magnitude of damages caused by climate change and the inherent worth of ecosystem services.

Understanding Valuation

Why do we ascribe monetary value to intangible things and why is it important? In a study conducted by the Proceedings of the National Academy of Sciences of the United States (PNAS) called “The Economic Value of Tropical Forest to Coffee Production”, the authors argue that “although the societal benefits of native ecosystems are immense, they remain largely unquantified” (Ricketts et al., 2004). The authors go on to argue the case for preserving wild bees and tropical forests, stating that the way wild bees pollinate is a valuable natural service more cost-effective than producing coffee through managed bees. Author of the Frontiers article “The Value of Nature,” Bernd Blossey, is skeptical of this reasoning, arguing that we simply base these valuations on the “goods and services that we humans receive” (Blossey, 2012, p.1). Author Marion Fourcade of “Cents and Sensibility: Economic Valuation and the Nature of ‘Nature’,” mentions that we attribute value in order to legally reimburse noncommercial, natural losses due to accidents, such as oil spills (2011). Nevertheless, Blossey argues that outdated or incomplete market-based valuations of natural services could cause the extinction of a species that experts had undervalued in the past (2012, p.1). These concerns raise questions about “accounting, governance, and enforcement, as well as the length of time economic models need to cover to account for cumulative or long-term effects” (2012, p.1).
How do these monetary values shape social practices and representations? PNAS argues that the results from their study revealed increased yields from forest bee pollination vs. managed bee pollination, and that should be compelling enough to increase the conservation of forests near farms. However, Blossey concludes his article pleading for conservationists to appeal to the public’s hearts, rather than their wallets (2012, p.1). In the following month’s Frontiers editorial, in an article titled “The Value of Nature Revisited”, author Michelle Marvier assesses Blossey’s article and argues that conservation efforts, specifically ballot measures that she mentions, are successful because they focused on how ecosystems benefited human health rather than conserving for nature’s sake (Marvier, 2012, p.1). According to the results of focus groups conducted in 2009 by The Nature Conservancy, “messages that highlight health and economic benefits for people enjoy the greatest support” (2012, p.1). There are valuable lessons to learn from Mavier’s assessment. Decision-makers should consider natural capital not just in terms of gains and losses of commodities. They should focus on human health and reduced healthcare costs in order to gain long-term community buy-in.

**EbA Factors & Variables**

EbA valuation is a comprehensive assessment that incorporates qualitative and quantitative data into a wide variety of valuation methods. The combination of measured or collected data and the valuation of costs, benefits, and impacts attributed to these metrics help to aggregate and compare evidence obtained throughout the land-use adaptation and resilience planning process. EbA valuation methods can be organized into five general themes or categories: biophysical effects, risk exposure and vulnerability, economic costs and benefits, quality of life impacts, and social and institutional outcomes (Emerton, 2017). Box 1 below defines these impacts in relation to adaptation:
Box 1. 5 EbA Impact Categories, (adapted from GIZ resourcebook)

**5 IMPACT CATEGORIES FOR EbA VALUATION**

1. **Biophysical effects** – variations in the degree or form of ecosystem services that aid in climate change adaptation.

2. **Risk exposure and vulnerability** – variations in degree of impact climate change has on humans and in human capacity to withstand or adapt to climate change.

3. **Economic costs and benefits** – variations in the limitations and opportunities that dictate society’s ability to participate in the financial market.

4. **Quality of life impacts** – variations in the limitations and opportunities that dictate society's livelihood and ability to maintain a healthy level of wellbeing.

5. **Social and institutional outcomes** – variations in societal behavior, policies, and conditions.

These five impact or valuation categories illustrate how in-depth and complex the EbA process can be. The categories are also what sets EbA valuation apart from a standard appraisal or cost-benefit analysis.

**The Cost Burden of Climate Change**

The costly impacts of climate change are already being felt throughout the United States. Natural events and disasters, such as floods, droughts, heat waves, and hurricanes, are the most extreme occurrences exacerbated by climate change. Overall financial losses from
these storms are astronomical and can cripple any large city’s economy. The top five most expensive disasters in U.S. history were all tropical cyclones that occurred between the years 2005 and 2017 (see Table 1). Three out of the five disasters occurred between August and September of 2017 alone. According to The National Centers for Environmental Information, during 2017 the U.S. experienced 16 billion-dollar disasters with a cumulative cost exceeding $300 billion (CPI adjusted) — a new U.S. annual record (2018).

On August 17th, 2017, a Category 4 tropical cyclone known as Hurricane Harvey made landfall in the United States. Before Hurricane Harvey arrived, Houston had already seen dramatic storm surge due to heavy rainfall and sea-level rise. In fact, Houston has seen three 500-year events in the past three years alone (Ingraham, 2017). The entire state of Texas experiences more billion-dollar disaster events than any other state (NOAA, 2018). According to data from NOAA, between 1980 and 2000, a span of 20 years, Texas experienced a total of 31 billion-dollar disaster events (see Table 2). Between 2013 and 2017, a span of only 4 years, Texas experienced nearly the same amount of billion-dollar events - 27 total (see Fig. 3). That means that Texas is now experiencing a nearly similar amount of billion-dollar disasters in a fifth of the time. Texas encountered a total of 95 billion-dollar disaster events in the past 37 years (1980-2017), far more than any other state (NOAA, 2018). To put this into context, Illinois, which has the second highest rate, has encountered 70 billion-dollar disaster events since 1980 (NOAA, 2018). In addition, this measures the combination of various types of disaster events. These events included drought events, flooding events, freeze events, severe storm events, tropical cyclone events, wildfire events, and winter storm events.

Nevertheless, Houston was extremely ill-prepared for the destruction brought by Hurricane Harvey. The impacts of Hurricane Harvey emphasized the problems with FEMA and oversights contained within the National Flood Insurance Program. While Harris County, TX ranks third in overall amounts paid by the National Flood Insurance Program, more homes than ever are now subject to flooding in areas not protected by the program due to outdated maps. FEMA estimates that around 40% of the flooded buildings in Harris County, TX, are located on parcels of land FEMA designated as “of minimal flood hazard” (Fessenden et al., 2017). In addition, only “26 percent of people who applied for aid from the Federal Emergency Management Agency and Small Business Administration said the agencies approved their applications” (Fessenden et al., 2017). Nevertheless, FEMA has still approved a total of over 1.5 billion dollars in individual and household assistance (FEMA, 2017).
These figures may cause alarm, but it would be unwise to suggest that the effects of each event or series of events are a direct result of climate change. Hurricanes are complex and difficult to analyze. However, an overwhelming majority of experts are confident that climate change brings higher storm surges due to sea level rise (CDC, 2017). Flooding due to storm surge exacerbates flood insurance rates, increases the cost of disaster response, creates costly storm and flood damage, increases death tolls and hospital bills, and destroys the poorest minority communities. Therefore, this paper will primarily focus on the damages caused by flooding from storm surge brought on by sea level rise.

Problems:

Assessing Climate Impacts in the U.S.

Cumulative data suggests that the record high storm surges seen in 2017, previously considered historical flooding, may be the new normal in the United States (Ingraham, 2017). This leaves decision-makers with the question of how to design for resilient cities if flooding is now a problem seen further inland and historical precedent is no longer relevant. Planning for a 100-year event may be futile when a city, like Houston, continuously experiences 500-year events (that is, storm events that statistically should only occur once every 100 or 500 years, respectively). In fact, according to the Union of Concerned Scientists, “when communities plan for historical climate conditions that no longer exist, they can make themselves more vulnerable to current and future climate risks” (Spanger-Siegfried et al., 2016).

1. Inaccurate Inundation Maps

The city of Houston has experienced three 500-year floods in three years (Ingraham, 2017), but the city was not equipped to deal with flooding past the 100-year floodplain designated by FEMA’s flood maps. Researchers at Texas A&M University and Rice University concluded that there is “a growing disconnect between the 100-year floodplain and the location of the actual losses.” (Fessenden et al., 2017). In fact, Fig. 4 illustrates the plethora of buildings that were flooded outside the areas FEMA designated as flood zones in Houston (shown as red dots). FEMA estimates that around 40% of the flooded buildings in Harris County, TX, are
located on parcels of land FEMA designated as “of minimal flood hazard” (Fessenden et al., 2017). It is important to note that there are changes being made. For example, as of April 2018, FEMA has raised insurance premiums for frequently flooded homes under the National Flood Insurance Program (Havemeier, 2018). This will directly impact what areas can be developed, as flood insurance is a prerequisite to getting a mortgage. However, there are still problems with FEMA and NFIP’s maps that need to be addressed. This shows the leverage policy-makers have on the use of accurate scientific tools, such as flood-inundation mapping, to drive government programs. More accurate maps means a more accurate measure of biophysical impacts as well as risk exposure and vulnerability.

2. Lack of Comparison to Land-based Adaptation Strategies

The severe impacts of Hurricane Harvey were exacerbated by rapid developmental growth as a result of absence of zoning laws in Houston, the largest U.S. city to have no zoning laws (Boburg, 2017). In addition, most adaptation projects involve grey infrastructure, such as elevated roads and concrete sea walls. However, according to the United Nations Framework Convention on Climate Change (UNFCCC), the most cost-effective strategies are those that supplement healthy ecosystems and their natural hazard management services (UNFCCC, 2017).

The unrestricted, rapid growth in Houston encouraged more non-porous development covering 100-year floodplain areas. This resulted in more wetland loss and diminished soil in the area, which is already among the least-absorbent soil in the country, according to USGS (Boburg, 2017). In fact, between 1992 and 2010, the Houston area experienced wetland loss that is “equivalent to at least 12,000 acre-feet, or nearly 4 billion gallons, of stormwater detention. [...] This loss corresponds to no less than $600 million” worth of stormwater detention services (Jacob et al, 2017). Meanwhile, grey infrastructure that was built for storm water detention in Houston failed to prevent excessive inland flood damage.

Sam Brody, director of the Center for Texas Beaches and Shores at Texas A&M University, told the Washington Post that “Houston is the Wild West of development, so any mention of regulation creates a hostile reaction from people who see that as an infringement on property rights and a deterrent to economic growth” (Boburg, 2017). Prevention of zoning laws or other proactive safeguarding policies has been seen across the United States. For example, conservative policy-makers in Tampa have blocked several attempts to levy taxes in support of
shoring-up Tampa’s storm water drainage system to properly prepare for projected sea-level rise and storm surge (Fears, 2017). There is a lack of initiative taken to compare land-based strategies to grey infrastructure options. Using a table of variables involved in each strategy, including costs, benefits, and impacts, can aid decision-makers in gathering evidence of EbA’s cost-effective properties.

3. Lack of Communication with Affected Community

Those who suffered the most after Hurricane Harvey were vulnerable, low-income and minority communities. According a survey conducted by The Kaiser Family Foundation (KFF), while 66 percent of Texas residents suffered property damage, employment disruptions, and/or a loss of income due to Hurricane Harvey, 79 percent of Hispanic residents and 73 percent of black residents were negatively affected; compared to 55 percent of white residents (KFF, 2018). The study also suggests that low-income residents were also disproportionately affected after the storm (see Fig. 5). The surrounding community and vulnerable citizens are the most important stakeholders when it comes to resilience planning, as they are the ones who will be most affected by climate impacts. In fact, according to a study by TEEB, a subgroup of the U.N. Environmental Programme, there is a “deep link between ecosystem degradation and the persistence of rural poverty” and policy-makers must recognize this to better align policies with community needs (Brink et al, 2009).

In order for their needs to be met, decision-makers must realize that local communities are significant stakeholders to survey and educate to see which resilience solution works best for the public. Better communication yields a stronger measure for quality of life impacts.

4. Lack of Ecosystem Service Valuation

Ecosystem services are the benefits society receives from nature. The ongoing loss and degradation of natural ecosystems is directly linked to economic consequences severely underestimated by policy-makers. In only fifty years, nearly two thirds of ecosystem services have been degraded (Brink et al., 2009). However, our valuable natural capital has the potential to heavily support economies and underfunded communities through cost-effective natural resource management and ecosystem-based development. The value of nature is not typically conveyed in the market or in mainstream urban planning, even though natural ecosystems
provide a vast amount of inherent valuable services at no upfront cost (see Fig. 1). For example, forests provide carbon sequestration, timber, as well as shelter, and microbes in the ocean produce half of the oxygen humans breathe. In the coastal United States, wetland ecosystems and coral reefs provide services with highly significant benefits.

Wetlands and mangroves provide flood protection and filter water. According to the Houston Wilderness Inc., an environmental nonprofit organization, nontidal wetlands provide storm water regulation and flood protection services worth $7,990/acre/year (2010 dollars) (2012). Nontidal wetlands can typically store one million gallons of floodwater per acre and can reduce hurricane storm surge by 2.5-9.5 inches for every mile of wetland traversed (see Table 3) (Houston Wilderness Inc., 2012). In fact, New York City found that it "could avoid spending $3-8 billion on new wastewater treatment plants by investing $1.5 billion in the purchase of wetlands around the reservoirs upstate" because the wetlands purify the drinking water at no cost (Setegn et al., 2015, p.173).

Coral reefs also provide natural hazard management as well as a wealth of other valuable services. According to a study by the U.N.’s The Economics of Ecosystems and Biodiversity (TEEB) initiative, coral reefs "have a critical range of ecosystem service values – for natural hazard management (up to 189,000 US$/hectare/year), tourism (up to 1 million US$/hectare/year), genetic materials and bio-prospecting (up to 57,000 US$/ha/year), fisheries (up to 3,818 US$/ha/year) (Brink et al., 2009). The value and range of these benefits vary by location, in turn affecting each community differently. However, coastal communities that face recurring flooding, depend on tourism, and rely on fishing as a major source of income and food intake face the most dramatic losses as a result of wetland and coral reef degradation (Brink et al., 2009).

The valuation of ecosystem services does not only highlight the benefits of preserving wetlands and coral reefs. It is important to note that these ecosystem services provide benefits that can make coastal communities more resilient to the costly damages of storm surges. Thus, local governments and planners in coastal areas should incorporate the valuation of ecosystem services in adaptation strategies not only to prevent further land degradation, but also to provide solutions that are more in tune with the community's needs. While certain communities may not have the expertise, time, and resources to develop original valuations, they can base strategies on valuations made in the past by other decision-makers. For example, in Houston, decision-makers can use data and values gathered and calculated by the Houston Wilderness Inc. (see Table 3). The values Houston Wilderness ascribed to ecosystem services can be used
to assess the cost, benefits, and impacts within a certain adaptation strategy. By calculating the value of natural capital, decision-makers can more accurately account for costs, benefits, and impacts on all five EbA impact categories.

5. Lack of Long-term Planning & Follow-through

U.S. cities are looking to build resilience in response to the damaging effects of climate change. Resilience planning involves adapting to the extreme weather events that come with climate change. Nevertheless, while ecosystem services naturally protect areas from flooding, they are also under threat from climate change and overdevelopment, in turn weakening said services. For example, coral reefs destroyed by ocean warming and acidification lose the ability for storm surge protection. Therefore, when planning for resilience, communities must consider future impacts to the natural ecosystems and continuously monitor current projects.

According to a UNFCCC report, there are three major insights worth acknowledging when considering ecosystem-based adaptation strategies (2017). The first is that there is a strong connection between robust ecosystems and the surrounding communities’ ability to adapt to the climate. The second is that robust ecosystems are also responsible for reducing greenhouse gas emissions. Thus, not only do they aid with resilience, healthy ecosystems also contribute to climate mitigation. Grey infrastructure may help with adaptation temporarily, but is more costly and actually contributes to ecosystem degradation as well as the concentration greenhouse gas emissions in the atmosphere. Thus, the third factor to consider is that ecosystem-based adaptation and valuation is a more holistic approach to sustainable development that should be integrated into resilience development policy and plans. This way, cities like Houston that experience frequent disasters can better adapt over the long term.

It is important to understand the difference between the costs, benefits, and impacts between adaptation methods and mitigation. In order to effectively curb the impacts of climate change, society must narrow what is called the “resilience gap” (see Fig. 6). Funding mitigation projects will in turn reduce future climate affects as well as lower the costs of adaptation. Nevertheless, even if greenhouse gas emissions are completely eliminated worldwide, there will still be a record high concentration of heat-trapping gases in the atmosphere that will wreak havoc on the climate. Therefore, adaptation measures are an essential complement to mitigation efforts. According to a report by the Union of Concerned Scientists (UCS), the “resilience gap” “represents the degree to which a community or nation is unprepared for
damaging climate effects—and therefore the degree to which people will suffer from climate-related events” (Spanger-Siegfried et al., 2016). The arrows in Fig. 6 convey the two avenues communities can take to fill the gap. We can “adapt (left arrow) by preparing for climate impacts, and mitigate carbon emissions (right arrow) to slow the pace at which climate risks grow more severe or more common over time” (Spanger-Siegfried et al., 2016). Thus, the shifting range of the resilience gap in the year 2025 compared to 2050 shows how we can narrow the gap by making a combined effort through both avenues.

It is not feasible or fiscally possible to close the resilience gap completely. It is impractical to assume that we can effectively prepare for every climate disaster. Nevertheless, by applying a hybrid of adaptation and mitigation measures, society can build better resilience to storm surge while also taking actions to reduce future impacts. By committing to follow-through and monitoring existing adaptation projects over the long-term, decision-makers can more accurately assess future social and institutional outcomes.

Decision-makers can develop a more definitive account of the costs, benefits, and impacts of adaptation strategies by enhancing the necessary tools needed for implementing effective plans. For example, the five problems in Texas listed above can be evaluated by focusing on the tools needed to value nature and choose adaptation strategies. Utilizing accurate inundation maps, strategy tables, surveys, and calculations can support the understanding and implementation of land-based resilience projects. Laying out the EbA system step-by-step based on tools needed can be resourceful and simplify the process for decision-makers.

Literature Review:

EbA Valuation Process & Best Practices

In addition to evaluating infrastructure plans, the EbA valuation process also aids in analyzing the coherence of relevant policies and laws, such as zoning or tax laws. Cohesive valuation methods are not isolated systems but rather processes that build on real-world relationships between multiple variables and stakeholders. Tools such as inundation maps,
tables comparing adaptation strategies, community surveys, and mathematical matrices, establish holistic valuations that can shape important legislation. While EbA valuation often involves a cost-benefit analysis, it also requires analyzing the impacts a project has on a community. A simple appraisal or cost-benefit analysis (CBA) compares the costs and benefits of different policy options, culminating into a single value representing each option, the Net Present Value (NPV) (Arampatzis, 2013). Decision-makers often use CBA to determine which policy option maximizes net benefits, or has the most favorable benefits-to-costs ratio. While measuring NPV is vital, however, CBA excludes potential impacts from the valuation process, propagating reactive short-term planning. CBA often does not measure long-term cost-effectiveness or resulting impacts, negating potential social, environmental, and economic consequences (triple-bottom-line). Contrarily, integrated valuation and contingent valuation are comprehensive EbA methods that account for impacts to biophysical effects, economy, human health, and societal outcomes, which includes public perception and knowledge gaps (Emerton, 2017).

The extent of each EbA impact category can be determined using a wealth of different valuation methods (see Table 4). Table 4, which is adapted from GIZ’s EbA resource book, illustrates the five EbA impact categories and corresponding valuation methods commonly used to measure their variables (Emerton, 2017). Table 4 distinguishes these categories and provides valuation methods commonly used to evaluate their variables. Evaluating the series of variables is essential for decision-makers to create important tools such as accurate mathematical EbA matrices incorporated in Environmental Impact Statements. Fig. 7 illustrates the first EbA Valuation matrix, developed for a 2017 case study that assessed the use of EbA practices by farmers in Central America (Harvey et al, 2017). This matrix was used to calculate integrated relationships between all EbA components and variables, with p values highlighted in black representing the strongest relationships. The matrix is a decision-making exercise to choose between strategies by measuring probable significance of impact, rather than a strictly qualitative method that can be applied broadly to any case. In an interview with a state public environmental official, the official stated that such a matrix is needed as an example for how to account for environmental services. To understand the significance of valuing impacts and risks, we must first understand how to communicate with the the desired target audience.
Environmental Communication

In order for EbA valuation to be better integrated into mainstream practice, there needs to be better communication and messaging promoting the process. Studies on environmental psychology and communication are helpful in this case, as they shed light on how to approach targeted audiences with such controversial, complex topics. Environmental communication is defined as “the strategic use of communication processes and media products to support effective policy-making, public participation and project implementation geared towards environmental sustainability” (Schultz et al, 2018). This means that better environmental communication can leverage policy, community support, and physical practice of EbA procedures in resilience projects.

A study published in the journal “Environmental Communication” utilized interviews with communicators, psychologists and a survey of Louisiana residents to support this idea. According to the study, “communication of complex environmental hazards and proposed solutions increasingly requires knowledge of local contexts, target audience concerns and values, and psychological principles” (Schultz et al, 2018). The study later revealed a few best practices related to environmental communication worth considering:

Environmental Communication Best Practices:

1. **Connect with the community** - Know your audience and use local narratives to establish relationships with the target audience - or “tap into place attachment and sense of community among coastal residents to promote action” (Schultz et al, 2018).

2. **Impart action-based knowledge** - Action-based knowledge means to know what available options and potential courses of action can be taken to directly address an environmental problem. Imparting action-based knowledge is proven to be a stronger motivator for others to take action than information-based communication.

3. **Show immediate benefits of action** - Another strong motivator that can be implemented through highlighting benefits, such as cost-effectiveness and protecting public health.

4. **“A picture is worth 1,000 words”** - People have a stronger, more emotional response to images than text-based messaging. Another study published in the journal “BioScience” builds on this idea but in terms of informing practitioners rather than the public, stressing that for “visualization products created early in the data-exploration and
analysis stages are tools to understand trends and relationships that inform analysis methods, constraints, and interpretations” (Hampton et al, 2017).

5. Adapt language & avoid controversial terms to simplify complex issue - Replicate language used by the target audience to develop better understanding and a deeper connection with what initially seemed like a technical or scientific problem. In addition, it is important to “avoid controversial terms and focus on the issues, impacts, and solutions with which the target audience can relate” (Schultz et al, 2018). For example, using the terms “sea level rise” or “storm surge” rather than “climate change” can help communities connect with the conversation about coastal impacts more, as they have seen and felt these changes (Schultz et al, 2018). Perhaps we should even follow the suggestions made by GIZ at a conference in Thailand and use a term less confusing than EbA. “Eco-Adaptation” might be a better alternative (Sckeyde, 2017).

6. Interdisciplinary expert collaboration is necessary - Communication is the bedrock of collaborative scientific practice as well as effective messaging that facilitates use of sustainable practices in society. Collaboration is necessary for “successful scientific endeavors particularly for data-intensive environmental research, which implicitly requires a broader suite of cross-disciplinary data, skills, and knowledge” (Hampton et al, 2017).

Implementing these best practices in EbA messaging and communication can generate community support as well as evaluate the public’s perception of natural capital. Nevertheless, societal perceptions are often not measured or even acknowledged in a standard cost-benefit analysis.

Contingent Valuation & Vulnerable Communities

According to FAO, contingent valuation is a non-market method that “asks people to directly report their willingness to pay (WTP) to obtain a specified good, or willingness to accept (WTA) to give up a good, rather than inferring them from observed behaviors in regular market places” (FAO, 2000). Scientific studies incorporating contingent valuation can play a large role in influencing ballot measures. Successful survey questions highlight the knowledge gaps decision-makers have of the public’s perceptions of ecosystem values. For example, through contingent valuation, researchers can discover how much a community is willing to pay in taxes
in order to fund ecosystem preservation or mitigation. Policy-makers may be surprised to discover that a community is willing to pay higher taxes to preserve a wetland. An example of such a referendum-style contingent-valuation survey was utilized in a study conducted by the International Council for the Exploration of the Sea (Kim et al, 2013). The survey integrated a questionnaire with 37 questions surrounding the respondents’ “general awareness of wetland loss and restoration efforts, the perceived relationship between wetland loss (and wetland restoration) and increased (decreased) storm risk, willingness to pay for wetland restoration projects in Louisiana to prevent expected future losses, as well as individual demographic information” (Kim et al, 2013). A random sample of 3,000 Louisiana households were asked to vote on proposed coastal restoration projects that would preserve Louisiana’s disappearing wetlands. However, this would involve applying a supplemental tax on Louisiana’s citizens for the next 10 years. The range of the proposed tax was between 50 dollars to 1,189 dollars per household per year (Kim et al, 2013). The results were encouraging, showing that 90 percent of Louisiana residents were aware of wetland loss and wanted to contribute to a solution. Additionally, 94 percent contended that the state of Louisiana must respond immediately. The average WTP per household was 580 dollars per year, and average WTP with the promise of a tax refund was 1,042 dollars per household per year. This means that in aggregate, the public valued coastal wetland restoration in Louisiana at a range of $0.4 billion-$4.1 billion.

This survey conveys how important it is to survey the public on their perceptions and willingness to protect local ecosystems that in turn protect their community. Surprisingly, there is not much research that delves into the opinions of the public even though they are the most affected by wetland degradation. While it is important to gather measured scientific data, this study conveys methodology that can inform resilience planners and decision-makers of community concerns and values. It is also important for researchers and decision-makers to acknowledge that, as shown in the survey from this study (see Table 5), vulnerable, minority, and low-income communities within these areas suffer the most from storm surge. At the same time, these communities have a more direct relationship with ecosystems and rely more on their natural services, which means EbA would be strongly suited for such communities (Emerton, 2017).

**Integrated Valuation & the Status Quo**

Integrated valuation is a method that plays an integral role in making comprehensive EbA decisions. This method often combines scientific projections of inundation impacts as well as an
economic and societal analysis of benefits and costs. An example of such a study was a study conducted by the Nature Conservancy in Monterey, California (Leo et al., 2016). This case study weighed costs, benefits, and impacts between adaptation options to address coastal erosion and flooding from storm surge. The study integrated assessments of hazard protection, biophysical modeling, and economic analysis. The goal was to present policy-makers and planners with the evidence to determine which adaptation strategy is most effective.

The study, much like several done by the EPA (see Table 6), initially determined which sites, adaptation options, and climate hazard scenarios to pinpoint and assess through stakeholder input. Both structural (grey infrastructure/coastal armoring) and non-structural (ecosystem/land-use based) adaptation options were considered and compared. Management strategies included scheduled beach nourishment, shoreline armoring, managed retreat (fee simple property acquisition), elevating infrastructure, rolling easements, as well as a baseline of simply doing nothing (see Table 7). Physical impacts of the different adaptation options were evaluated through mapping sea level rise projections. The analysis then considered the physical, market and project budget-based costs of each infrastructure and land-use based strategy (Leo et al, 2016). The costs of structural adaptation strategies often involved calculating engineering and construction costs as well as remedial costs of actions such as elevating highways. The costs of land-use based strategies were based on the costs of purchasing property and a baseline cost of doing nothing and allowing erosion. Table 8 shows different methods used for estimating and how to acquire values. Resources like the Engineering News Record (ENR) helped estimate damage to pump stations, and the Ecological Society of America (ESA) provided replacement cost metrics. Benefits were measured by calculating costs prevented, including property loss, infrastructure damage, as well as public damages. Public benefits were determined based on how much the public valued recreational areas that would be impacted by coastal hazards (see Table 9). The researchers conducted a stakeholder workshop in order to gather this integral data on issues, assets, and areas of concern.

This assessment provides a more accurate distribution of market and non-market costs and benefits of each adaptation strategy by accounting for physical impacts and benefits of avoiding damage. Much like the contingent valuation study, this study also conveys knowledge gaps in conventional decision-making. The most important consequence of this study is that it questions the validity behind the idea that mitigation strategies based on grey infrastructure (such as seawalls and coastal armoring) are the most effective solutions to coastal erosion. Using this broad approach, the researchers were able to emphasize that coastal armoring was
actually the least fiscally responsible option, especially over the long-term (see Table 10). As shown in Table 10, by having the highest NPV, scheduled beach nourishment was actually the most cost-effective option. Therefore, this study shows that taking a wider perspective leads to more holistic decision-making about coastal protections and justifies policies that protect a larger segment of the population’s interests.

In order for areas like Houston to reduce future impacts from disasters like Hurricane Harvey, they must apply EbA and EbA valuation methods rather than utilizing grey infrastructure or shore-armoring strategies. To properly account for the cost-effectiveness of each adaptation strategy, decision-makers must apply EbA principles, such as evaluating impacts using integrated and/or contingent valuation as well utilizing environmental communication best practices. In fact, decision-makers in Houston and nationwide can base resilience planning and adaptation decision-making on the Eco-Adaptation Valuation Process infographic shown in Fig. 8.

Methods

This research focuses on GIZ’s resource book as a general guide to inform the research process as it defined the term EbA and was the most current reference on the topic. The over 200-page resource book was unique in that it included a collection of 48 international EbA case studies that served as a foundation for this study. In December 2017, GIZ published a learning brief summarizing dialogue and lessons learned from a summer EbA workshop in Bangkok, Thailand. The brief, titled “Evidence of EbA Effectiveness”, addressed EbA knowledge gaps and communication issues (Sckeyde, 2017).

This study takes a mixed-methods approach to collecting and analyzing data. This research evaluates quantitative and qualitative data from multiple studies and expert interviews. This research also assesses trends in impact variables, themes, problems, and benefits of EbA valuation.

EbA Case Studies

Data Collection Method

Case studies from the United States are selected from GIZ’s EbA resource book to exemplify integrated valuation and contingent valuation methods (Emerton, 2017). In addition,
This study assesses trends in process and methodology among the other 46 case studies included in the resourcebook, absorbs lessons learned, and applies best practices to the Texas case study. Additional studies not included in the resource book are also analyzed and typically included a cost-benefit analysis, as well as various natural capital valuation methodologies.

Data Analysis Method

Case studies used valuation methodologies to show that EbA strategies were more cost-effective than grey infrastructure options. This study supports the argument in favor of EbA strategies by sharing calculated costs, benefits, and impacts. General steps in the EbA process are categorized in this study, as well as specific EbA impact variables based on information included in GIZ’s EbA resource book (Emerton, 2017). Common valuation methodologies are included in the original “Five EbA Impact Categories & Methods Key” (Table 4), which are also based on patterns and trends outlined in the EbA resource book. These methodologies are plugged into a table together to serve as a helpful visual key for decision-makers. The most valuable studies contained at least one if not all of the following tools or factors:

a) Map: utilized dynamic inundation maps based on up-to-date projections of biophysical impacts and risk exposure and vulnerability (i.e. sea level rise, erosion, storm surge, wave impacts)

b) Table: listed (or laid out in a table) land-based adaptation strategies and methodologies, at times in comparison to mitigation strategies. The table was used as a tool to aid in integrated valuation of impacts to economic costs and benefits.

c) Survey: surveyed affected stakeholders or beneficiaries in communities. The survey would account for vulnerable citizens and be used in contingent valuation methods to derive WTP and WTA values for an accurate measure of impacts to the public’s quality of life.

d) Calculation: incorporated the integrated valuation of ecosystem services in adaptation strategies by using mathematical methodologies to calculate values such as NPV, accurately accounting for costs, benefits, and impacts on all five Impact categories.

e) Monitor Results: monitored existing adaptation projects over the long term to more accurately assess social and institutional outcomes and the costs, benefits, and impacts of the strategies.
Many studies integrated the methods listed above in aggregate to measure the value of adaptation approaches, including general costs, benefits, and impacts to the five impact categories. Costs and benefits were typically represented by gains or losses to private property, public goods (such as recreational sources), and to the ecological function of coastal habitats (Leo et al., 2016). Combined projections of coastal hazard impacts with an economic analysis of impacts on both at-risk, human-made infrastructure (buildings, roads) and natural capital (ecological functions, recreational assets) helped to develop an estimated value of various adaptation approaches (Leo et al., 2016). The calculated ecosystem services in this study, particularly the extensive data in Table 3, are done using a multitude of regression models and values from previous studies.

This study also lists communication best practices based on recent environmental communication case studies (Schultz et al, 2018) as well as expert interviews. Experts that are interviewed include a state environmental public servant [name withheld]; Dr. Carolyn Kousky, Director of Policy Research and Engagement at the Wharton Risk Center; and Ms. Lucy Emerton, the international environmental economist who authored the GIZ resource book on EbA. The interviews reveal communication problems that remain a challenge for decision-makers.

During the interview with the state public servant, he expresses the importance of capturing ecosystem benefits, stating “when doing a cost-benefit analysis, one of the biggest issues is ‘how do we account for environmental services?’.” He continues by affirming the need for EbA valuation so as to confront a lack of “taking everything into account, including ecosystem values”. The environmental expert states this problem persists in his state mainly because the resilience project teams do not have an established matrix in which they can determine the value of natural capital. This statement reveals the significance of the matrix shown in Fig. 7, the first known example of a matrix that illustrated the correlation between EbA impact categories and EbA strategies. While the methodologies used to develop the matrix in Fig. 7 may be considered only pertinent to existing projects, it provided a foundation for developing future matrices. The public servant adds that it can be a struggle to convey a threat to public health when the affected community is focused on other environmental concerns posing less of a threat: “we had a site that [contained] a lot [hazards]. We were knocking door to door explaining what we were doing and why. What we heard predominantly was ‘are you going to clean up the refrigerators and couches that have been dumped on the side of [the] street?’.” The public servant goes on to mention how there can be difficulties with regards to getting local
communities to understand the “real environmental and potential public health issue, [if it is] not on their radar”. Nevertheless, his team responded to the community’s concerns, removed the materials and closed off the street to prevent future dumping at the site. This anecdote illustrates how public concern can be challenging and how messaging must relate to community values in order to generate buy-in.

Dr. Carolyn Kousky, a risk expert, provides insight on measuring risks and highlights the importance of enhancing mapping tools: “Flood maps are not designed to be flood risk communication tools, but that is how they’re being used. People are required to know if they’re in or out of the floodplain, for a federal disclosure requirement, but that’s not useful to people. So what is useful, what can they understand that is tangible? For instance, has their property flooded before? How much damage did [the former owners] have to pay? Maybe the property already flooded in 1995 and 2003, and in 1995 it was $15,000 of damage. That would start to be useful information that needs to be integrated into platforms [the public] is already using. It should be on Zillow. It should be on Trulia. Then I think you start to give people what they need.”

Here Dr. Kousky not only details the need for better messaging but also discusses how adaptation tools can evolve to support community values and concerns. This statement corroborates the idea that communication with affected communities through enhanced tools can potentially lead to lower public health risks and exposure to natural hazards.

During her interview session, Ms. Emerton is asked about interdisciplinary communication issues amongst experts and responds by detailing the problems with the collaborative approach: “if you are looking at solutions to adaptation problems, you will get different answers. The idea of collectively developing a solution is not really there. If you talk to the economist, you will be given the most cost-effective solution. If you talk to the hydrologist, they will focus on the most technically appropriate solution. If you talk to a social scientist - who are rarely included and that is part of the problem - they will look at solutions which are sustainable and meet the public’s needs. One of the biggest challenges is we do not actually have an integrated perspective of what the problems and solutions are, so how can we come up with a clear and coherent message when we likely have five?” Ms. Emerton answers this by sharing her opinion on Fig. 8, or the Eco-Adaptation Valuation Process Infographic, saying “not only does the infographic communicates process, but also expresses how an argument can be made to decision-makers based on existing problems.” Ms. Emerton follows this statement with a warning, saying that “needless over complication or academicization does not help to
mainstream EbA, but actually detracts momentum.” The discovery of these issues show why stronger communication with stakeholders and actors is pertinent to the EbA process.

**Applied Texas Case Study**

**Data Collection Method**

Data about Hurricane Harvey and other natural disasters are collected using a recent study on billion-dollar disaster events by NOAA (NOAA, 2018). This study’s assessment also includes studying disaster maps, investigative news articles, and financial data from FEMA (NOAA, 2018). The case of Hurricane Harvey and the impacts on Houston are appropriate because Texas is the most extreme case in the U.S. with regards to natural disasters and poor adaptation planning. The infographic in Fig. 9 illustrates the reasoning behind studying Texas and how certain “Texan superlatives” affect the capacity for adaptation. The impacts of Hurricane Harvey illustrate how problematic it is that Houston is the largest U.S. city with no zoning laws (Boburg et al, 2017). In addition, Texas experiences the highest frequency of billion-dollar disaster events at a record 95 events since 1980 (NOAA, 2018). This is exacerbated by the soil in Texas that is among the least absorbent in the nation (Boburg et al, 2017). What’s more, Harvey is in competition with Katrina as the most expensive disaster in US history at a whopping $125 billion, according to NOAA (although some estimate that the value is even higher) (2018). Harvey also holds the record for heaviest rainfall totaling at 52 inches (over 4 feet). Hurricane Harvey amplifies the fact that Texas should be the poster-child for American EbA. All of these factors are exacerbated by the fact the Texas is the energy hub of America and is the leading state in oil production, which incidentally degrades the land and water even more.

Nevertheless, Texas is also home to a recent, inspiring EbA valuation project, the Lone Star Coastal National Recreation Area (LSCNRA). The LSCNRA project, which is elaborated on further in the Discussion section, reveals an approach that challenges the status quo in Texas with regards to adaptation. LSCNRA serves as a potential model for projects around the country. Methods of evaluating ecosystem services, tourism, recreation and job growth are exemplified in addition to community engagement.
**Data Analysis Method**

Applying the simple EbA model to assessing the Hurricane Harvey scenario illustrates common resilience problems in the United States. The issues can be addressed through enhancement of tools shown in the simple, central EbA infographic in Fig. 8. Assessment of case studies reveal the simple five step structure, however, to the best of our knowledge, the process has never been formatted based on EbA tools and their enhancement (especially in Texas). The purposes, methods, and best practices needed to understand, implement, or legislate successful EbA and EbA valuation can be better understood using Fig. 8. EbA valuation practical purposes and decision questions are thus represented in a simpler, action-based fashion (see Fig. 10 and Fig. 11). This basic concept and infographic are a scaffold for Houston decision-makers to follow in the planning and legislative process. In addition to the deliverables, this research provides a case-specific example of solutions for Texas (see LSCNRA in Discussion section).

**Discussion**

In the United States, the full capacity of EbA practices has not been fully explored, and thus not taken into account in mainstream resilience decision-making. The GIZ learning brief asserts that, “as EbA evidence does not lead to the consideration and integration of EbA in decision-making per se, processes on how actors take decisions need to be analysed. Complementary, evidence-based communication is required to leverage change” (Sckeyde, 2017). Thus, the research needed is not necessarily EbA valuation and effectiveness in contrast to grey infrastructure. Rather, developing a method that clarifies core EbA concepts and terminology is crucial in order to leverage policy (Sckeyde, 2017).

The valuations and methods included in the case studies examined convey how EbA is a more cost-effective and beneficial strategy than utilizing grey infrastructure. Evidence from the case studies fulfills the first part of this paper’s purpose, which is to provide evidence that EbA is a more cost-effective process than grey infrastructure. However, despite the evidence of cost-effectiveness, EbA advocates are struggling with leveraging actual policy through valuation research. Experts say that strengthening EbA evidence does not actually lead to more
well-informed decision making (Sckeyde, 2017). This statement makes sense, as the aforementioned study on environmental communication states that “information-based communication strategies, especially those that ignore the role of values, routinely fail in promoting pro-environmental and resilient planning and behavior among key publics” (Schultz et al, 2018). In practice, EbA strategies and valuation are often overlooked or underestimated, even though there are over 240 field-proven tools available to facilitate the process (Sckeyde, 2017). In the United States government, scientific practice in general is under siege and dismissed, making the struggle even more difficult to overcome. So how do we leverage U.S. policy if EbA is not generally supported by public practice or project implementation?

There needs to be better incorporation and assimilation of EbA tools in the planning and decision-making process (Sckeyde, 2017). The problem with EbA is not the values or numbers, because that evidence is apparent. The problem is communication. What the research shows is that better communication, between experts as well as to the public, policy-makers, and planners, leads to better results. Lessons learned from the communication and data visualization studies that are assessed in this study support this argument. EbA messaging needs to connect more with the target American audience for the process to enter the mainstream and in turn encourage policymakers to make sweeping changes nationwide. That is the objective of the simple visual aids and other deliverables in this study.

In addition to visual aids and valuation, for us to effectively leverage change in the United States, we must use the most extreme real-world cases as dynamic examples to capture public attention. Hurricane Harvey’s impacts on Texas are still being felt throughout the city of Houston, making the event still very relevant and visible. By making communities in Texas the target audience or poster child, American advocates of EbA valuation can provide a perfect example of problems that can be mitigated using the tools laid out in our EbA Valuation Process infographic. The problems in Texas, laid out in the literature review, directly connect with these tools. However, highlighting Texas’ problems alone will not generate buy-in. Advocates of EbA must use communication best practices and provide action-based solutions as well. The Lone Star Coastal National Recreation Area is the perfect example of effective implementation of EbA principles in Texas.

**Accomplishments in Texas: The Lone Star Coastal National Recreation Area**

While Texas may be experiencing a litany of problems, it is not completely hopeless. A new project is being implemented in Texas that addresses these problems using EbA best
practices. In 2011, multiple stakeholders along the upper Texas Gulf coast met to develop a strategy that would improve regional economic development and reinforce coastal resilience (LSCA, 2017).

The stakeholder partnership was an interdisciplinary collaboration between more than two dozen organizations and agencies owning over 20,000 acres of land. It also received support from more than two dozen community leaders, including private landowners, residents, local government representatives, businesses, and most importantly, managers of parks, preserves, refuges, and historic sites (LSCA, 2017). The coalition’s goal was to use a nonstructural strategy to establish a recreational and nature-based economy that can withstand inundation. As one project leader explained, “it is ‘economy’ as a flood mitigation alternative. In other words, the coast would not suffer economic harm from flooding if flooding were designed into, and compatible with, the structure of the economy” (Wartell et al, 2013). This means that the coalition used the EbA principle defined by GIZ of looking at adaptation goals first and work backwards from there, as opposed to the reactionary grey infrastructure strategies that seek to immediately mitigate issues without thinking about resulting impact (Sckeyde, 2017). The resulting project is called the Lone Star Coastal National Recreation Area (LSCNRA), and it sets a great national example for projects seeking to use EbA and EbA valuation principles.

The LSCNRA project (scope mapped in Fig. 12) is summarized as “a coalition of non-contiguous sites along the upper Texas Gulf coast joined in a voluntary partnership with the National Park Service with the goals of enhancing Texas-led stewardship and conservation, developing a coastal economic sector compatible with periodic flooding, and expanding and promoting nature and heritage tourism and outdoor recreation opportunities” (LSCA, 2017). The National Park Service (NPS) is an appropriate partner, as they have the brand, means, and local clout to coordinate the project without imposing heavy land-use restrictions on the managed site. A National Recreation Area is section of land and water designated by Congress due to its significant contribution to outdoor recreation. This legal designation is appropriate for Texas as it allows for the local community to manage and enhance the natural and economic value of their own community.

LSCNRA project leaders used EbA principles by aiming to protect community values and concerns while also using natural areas to store hurricane storm surge water and support a resilient coastal economy. From the beginning, the project set out to protect property rights, using EbA communication best practices to account for community values and concerns as shown through the challenges with Houston’s zoning laws. The project also sought to preserve
recreational and tourism values, such as fishing, hunting, birding, and other outdoor activities already popular in upper Texas Gulf coast communities.

LSCNRA project leaders also used enhanced EbA tools like mapping, valuation calculations, and surveys of the public to support implementation of the idea (see LSCNRA visualization aid in Fig. 13). They used valuation methods to calculate the projected economic and social impact of the project. Projections from a joint study by the National Parks Conservation Association (NPCA) and Rice University’s Severe Storm Prediction, Education and Evacuation from Disasters (SSPEED) Center determined that “within its first five years, the LSCNRA would add 5,260 jobs in the four-county region and infuse $192 million per year into the local economy” (Wartell et al, 2013). In addition, they used contingent valuation methods to calculate how much local NPS visitors spent, which totaled to “an estimated $288.5 million locally, supporting 4,400 jobs and $410.3 million in economic output in the Texas economy” (LSCA, 2017). In addition to valuations that appeal to the local community, LSCNRA project leaders also generated values and economic impact valuations that would appeal to policy-makers.

A study of three counties included in the scope of the project found that increasing economic value of the local open lands can reduce costs for local governments over time. The results show that the service provided by the LSCNRA project would “cost local governments $0.28 for each dollar of revenue from these lands. Serving residential areas cost $1.17 for each dollar of revenue” (Archie et al, 2011). The project also reduces government costs by adapting existing dredging sites rather than constructing new mitigative infrastructure. The project area includes existing disposed dredge material, and would plug into these dredge sites, in turn reducing costs and environmental impact while also increasing water and sediment quality. In addition to showing how project implementation cuts costs, the project leaders provided suggestions for how to fund the project, a strong action-based motivator for policy-makers. The suggested “changes to roadways paid with transportation money; work on the areas of the mid bay dredging to be combined with dredging operations; and bond issues as necessary to fund the project for the gate and cover some initial investment, the cost of which might be offset by reduced insurance costs” (Reeder, 2017). These EbA-centered measures worked. The project leaders successfully leveraged policy change in the fall of 2017, only a few months after Harvey’s arrival, when the Jefferson County Commissioners Court approved the proposed Lone Star Coastal National Recreation Area plan (Meaux, 2017). If this National Recreation Area law
in Texas, arguably the most conservative state in the nation, yields positive results, it can potentially motivate several other states to use EbA.

Challenges & Uncertainties

There are several variables that challenged the outcomes of this research, especially with concern to climate change data and ecosystem-service values. For one, lack of sufficient data from local or federal U.S. government bodies is a concern. In addition, climate change and sea-level rise data is constantly shifting at a rapid rate. The issue is that all the recently released data shown in this research may be accurate in the present but may no longer be relevant in just one year. In addition, valuations from other studies are not applicable to every case. There will be varying spatial and temporal distributions of EbA costs and benefits. This can also be said about the scale of each study. The values expressed through these studies cannot predict potential impacts for studies with a much larger scope. There are several uncertainties that should be addressed as well.

One uncertainty is the actual physical measurements or methods for measuring impacts, for example, the matrix in Fig. 7 that is provided as a model EbA matrix. The matrix provided measures of impacts from strategies already put in place, not potential or future impacts. It also does not necessarily measure the extent of a strategy’s relationship with an impact and mostly indicates the significance of the relationship. However, it does lay out a format that may inspire development of other EbA matrices in future studies. In any case, EbA valuation can be very subjective in general. There will always be a level of uncertainty surrounding the valuation of benefits, the measurement of ecosystem services, and economic variables.

Conclusions

Ecosystem-based adaptation is an achievable and more cost-effective alternative to grey infrastructure mitigation. However, this study is not only an economic justification of EbA to leverage conservation legislation, but also a tool for understanding and communicating the EbA valuation and implementation process. Enhanced tools are needed to integrate EbA into the mainstream. In addition, this paper seeks to fill the knowledge gap amongst decision-makers and EbA advocates concerning communicating effectively to generate support from stakeholders. Interdisciplinary communication and holistic programming is the bedrock of
This study discusses costs, benefits, and impacts of EbA valuation as they apply to policy, practice, and messaging. These discussions are targeted to stakeholders such as policy-makers, planners, and the public. Texas is used as a local example for problems that can be addressed by unconventional EbA-based ideas.

The EbA infographic is arguably the most important deliverable in this study, as it provides a roadmap for the entire EbA process and valuation tools. It can even be used as a way to organize our policy recommendations. For example, in the case of Texas it is recommended that decision-makers, (in addition to the LSCNRA project):

1. **MAP climate hazard projections:**
   FEMA should utilize updated climate impact projections and inundation maps, in addition to any other helpful visual aids. Maps that use future projections based on the changing climate will more accurately distinguish floodplain zones outlined in the National Flood Insurance program.

   - **Best practices:** future projections up to the year 2100 for example. Basing floodplain zones on 500-year events, use GIS maps drawn by USGS or amalgam of academic data to base floodplain data and National Flood Insurance policy on.

2. **TABLE comparing adaptation strategies:** much like the Monterey study (The Nature Conservancy, 2016), or the study done by the U. S. EPA (2009), decision-makers in Texas should look at possible adaptation strategies and list potential costs, impacts, and benefits. Tables are helpful in illustrating these comparisons in an easy-to-digest format.

3. **SURVEY stakeholders and the public:** Surveying the community would give a voice to residents, as well as the vulnerable, minority and low-income households. Much like the Louisiana (Kim et al, 2013) and Monterey studies showed, this will give decision-makers an idea of how much value people place on their surrounding wetland ecosystems.

   - **Best Practices:** Referendum-style questions or ballot measures that make sure to highlight human health concerns will lead to more positive reactions from the public. A survey like this will help policy-makers implement resilience plans that pay explicit respect to the value the community places on recreation, ecology, and tourism. Surveys should be designed in a way that defines the problem and questions that need to be answered, is transparent about the issue, understands
the resident’s decision process (so as to fill in any information gaps or reinforce correct beliefs), and details the risks and benefits of the situation (Robinson et al., 2007). This will help to establish strong risk communication and a partnership with the residents in order to make them feel empowered and like an integral part of the decision-making process.

4. **CALCULATE VALUE:** Decision-makers in Texas should apply the basic rules of the EbA valuation process when calculating values. They should calculate the values of costs, benefits, and impacts of proposed land-based adaptation, and possible grey infrastructure options.
   - Best Practices: Table 4, the Five EbA Impact Categories & Methods Key, can serve as a key for selecting valuation methods. Decision-makers should calculate Net Present Value (NPV) to show that adaptation methods or even doing nothing (a baseline value) is superior to mitigation methods. Calculating Willingness to Pay (WTP), a value which would be acquired through the survey step, is also imperative.

5. **MONITOR RESULTS** – Follow through and evaluate and monitor the project over the long-term to assess any further issues and concerns. Continue to measure impacts and record disturbances or observed benefits.

Additional recommendations include:

- **Use Texas as an EbA example:** use as America’s poster child for EbA, look at Texas problems and LSCNRA as a good example of the most extreme problems and their EbA counterparts.
- **Utilize simple, value-based communication:** use better data visualization tools and simplify the process using less technical language. Connect with the community using public health impacts, stories and place connection. Avoid controversial terminology and perhaps even rename EbA altogether (Emerton, 2017). “Eco-Adaptation” might be a better alternative. Use any additional communication best practices outlined.
- **Implement EbA Valuation**: Utilize the Fig 8, the Eco-Adaptation Valuation Process Infographic, and Table 4, the Five EbA Impact Categories & Methods Key (and any other additional tools) to value ecosystem services. Think about desired adaptation results from the beginning.

Flooding from storm surge will become a more frequent occurrence and will only worsen as time passes. As a result, standard mitigation and grey infrastructure projects will be the largest tax-funded effort ever imposed on the American people. However, there is no way we can mitigate the issue without also adapting. Many fiscally-minded politicians do not view the issue from this lens. Whether or not one believes in climate change, or believes that sea-level rise is caused by it, storm surge is an observable, rapidly intensifying problem based in reality. There is no way to deny that we need to adapt to the changing climate. Environmental lobbyists and legislative assistants have often expressed the significant need for more research connecting natural services and climate adaptation to long-term economic consequences. The intent is to show that the two are not mutually exclusive and provide enhanced tools, visual aids, a public health and disaster lens to create better understanding and support of ecosystem-based adaptation.

The hope is that experts and decision-makers can use these tools as a stepping stone for future research or to leverage change in policy, practice, or messaging. Mainstreaming ecosystem-based adaptation, or “eco-adaptation,” is viable with the correct tools and messaging. Ecosystem-service valuation has advanced, yet the same cannot be said for its implementation in adaptation strategies. We can generate community leader buy-in by communicating through a public health lens and relating to local concerns. We can attract planner buy-in by simplifying the EbA process framework using visual aids like the Eco-Adaptation infographic. By garnering support from the community and local planners/organizers and having a well-thought-out economic plan, we can follow the example set by LSCNRA project leaders and leverage policy-maker buy-in. The hope is to inspire others to follow the examples expressed in this study, and that it contributes to changing the status quo by mainstreaming EbA in American society.
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Table 1: Five Most Expensive U.S. Weather & Climate Disasters

<table>
<thead>
<tr>
<th>EVENT</th>
<th>DATES (RANGE, YEAR)</th>
<th>COST* (IN BILLIONS)</th>
<th>DEATHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricane Katrina August 2005</td>
<td>08/25 – 08/30, 2005</td>
<td>$161.3</td>
<td>1,833</td>
</tr>
<tr>
<td>Hurricane Harvey August 2017</td>
<td>08/25 – 08/31, 2017</td>
<td>$125.0</td>
<td>89</td>
</tr>
<tr>
<td>Hurricane Maria September 2017</td>
<td>09/19 – 09/21, 2017</td>
<td>$90.0</td>
<td>65</td>
</tr>
<tr>
<td>Hurricane Sandy October 2012</td>
<td>10/30 – 10/31, 2012</td>
<td>$70.9</td>
<td>159</td>
</tr>
<tr>
<td>Hurricane Irma September 2017</td>
<td>09/06 – 09/12, 2017</td>
<td>$50.0</td>
<td>97</td>
</tr>
</tbody>
</table>

* (CPI-adjusted estimated cost)

Source: NOAA, 2018

Table 2: Increasing Frequency of Costly Billion Dollar Disasters

<table>
<thead>
<tr>
<th>CALENDAR YEARS</th>
<th>TIME-SPAN (YEARS)</th>
<th>ENCOUNTERS WITH BILLION-DOLLAR DISASTERS (EVENTS)</th>
<th>AVERAGE FREQUENCY (EVENTS PER YEAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980 - 2000</td>
<td>20</td>
<td>31</td>
<td>1.55</td>
</tr>
<tr>
<td>2000 - 2017</td>
<td>17</td>
<td>65</td>
<td>3.82</td>
</tr>
<tr>
<td>2010 - 2017</td>
<td>7</td>
<td>43</td>
<td>6.14</td>
</tr>
<tr>
<td>2013 - 2017</td>
<td>4</td>
<td>27</td>
<td>6.75</td>
</tr>
<tr>
<td>OVERALL</td>
<td></td>
<td></td>
<td>95</td>
</tr>
<tr>
<td>1980 - 2017</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecosystem Services</td>
<td>Houston Wilderness Ecosystem Services Reference Chart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Source: Houston Wilderness Inc., 2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table 3. Houston Wilderness Ecosystem Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reference Chart</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Five EbA Impact Categories & Methods Key

<table>
<thead>
<tr>
<th>Valuation Category</th>
<th>Valuation Methods</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biophysical effects</strong></td>
<td>1. Ecological</td>
<td>Habitat composition, flora and fauna, catchment runoff, groundwater recharge, water flow/quality, flood dynamics, erosion, sedimentation, topography, tides, water-borne disease incidence, food intake, vitamin deficiencies, crop yields, etc. (tend to yield more quantitative measures)</td>
</tr>
<tr>
<td></td>
<td>2. Biological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Hydrological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Hydraulic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Morphodynamic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Meteorological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Epidemiological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Nutrition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9. Agronomic</td>
<td></td>
</tr>
<tr>
<td><strong>Risk exposure &amp; vulnerability</strong></td>
<td>1. Allocation of weights</td>
<td>Via disease, drought, floods, rainfall, temperatures, fires, etc. (tend to yield more quantitative measures)</td>
</tr>
<tr>
<td></td>
<td>2. Probability analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Monte Carlo simulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Risk-benefit analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Decision analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Real option analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Acceptable risks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Robust decision-making</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9. Delphi method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10. Sensitivity analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11. Scenario analysis</td>
<td></td>
</tr>
<tr>
<td><strong>Economic costs &amp; benefits</strong></td>
<td>1. Cost-benefit analysis</td>
<td>National, household, corporate, or individual purchases, sales, production, consumption, savings, investment, trade, income, employment, etc. (tend to yield more quantitative measures)</td>
</tr>
<tr>
<td></td>
<td>2. Cost-effectiveness analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Least cost analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Value for money approaches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Input-output analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. General/partial equilibrium models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. National income/ecosystem accounting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Ecosystem services valuation (NPV)</td>
<td></td>
</tr>
<tr>
<td><strong>Quality of life impacts</strong></td>
<td>1. Sustainable livelihood analysis</td>
<td>Food, fuel, shelter, money, health, education, happiness, prosperity, employment, safety, freedom, etc. (tend to yield more qualitative measures)</td>
</tr>
<tr>
<td></td>
<td>2. Household livelihood security assessment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Participatory risk &amp; vulnerability assessment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Participatory ecosystem valuation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Stakeholder-focused or locally-driven cost-benefit analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Participatroy rural appraisal (PRA)</td>
<td></td>
</tr>
<tr>
<td><strong>Social &amp; institutional outcomes</strong></td>
<td>1. Participatory techniques</td>
<td>Power, status, roles, responsibilities, relationships, participation, governance, sanctions, etc. (tend to yield more qualitative measures)</td>
</tr>
<tr>
<td></td>
<td>2. Agent-based models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Stakeholder mapping &amp; assessment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Social network analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Institutional and context analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Knowledge-attitude-practices surveys</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Contingent valuation (WTP &amp; WTA)</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from: Emerton, 2017
Table 5. Willingness to Pay (WTP) & Willingness to Accept (WTA) Values for Louisiana Wetland Restoration (ICES)

Turnbull lower bound welfare estimates for wetland restoration projects.

<table>
<thead>
<tr>
<th>Bid</th>
<th>WTP</th>
<th>WTA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual estimates (per household)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>$580</td>
<td>$1,042</td>
</tr>
<tr>
<td>95% CI</td>
<td>$465–696</td>
<td>$968–1,115</td>
</tr>
<tr>
<td><strong>10 years estimates (per household)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r^* = 0%</td>
<td>$5,800</td>
<td>$10,420</td>
</tr>
<tr>
<td>$r = 50%</td>
<td>$1,140</td>
<td>$2,048</td>
</tr>
<tr>
<td><strong>Aggregate estimates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All households</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r = 0%</td>
<td>$10.0 billion</td>
<td>$18.0 billion</td>
</tr>
<tr>
<td>$r = 50%</td>
<td>$2.0 billion</td>
<td>$3.5 billion</td>
</tr>
<tr>
<td><strong>22.7% of all households</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r = 0%</td>
<td>$2.3 billion</td>
<td>$4.1 billion</td>
</tr>
<tr>
<td>$r = 50%</td>
<td>$0.4 billion</td>
<td>$0.8 billion</td>
</tr>
</tbody>
</table>

Source: Kim et al, 2013
Table 6. Adaptation Options for Maintaining/Restoring Wetlands (EPA)

<table>
<thead>
<tr>
<th>Adaptation Option</th>
<th>Climate Stressor Addressed</th>
<th>Additional Management Goals Addressed</th>
<th>Benefits</th>
<th>Constraints</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allow coastal wetlands to migrate inland (e.g., through setbacks, density restrictions, land purchases)</td>
<td>Sea level rise</td>
<td>Preserve habitat for vulnerable species; Preserve coastal land/development</td>
<td>Maintains species habitats; maintains protection for inland ecosystems</td>
<td>In highly developed areas, there is often no land available for wetlands to migrate, or it can be costly to landowners</td>
<td>Buzzards Bay, Massachusetts</td>
</tr>
<tr>
<td>Promote wetland accretion by introducing sediment</td>
<td>Sea level rise</td>
<td>Maintain sediment transport</td>
<td>Maintains sediment transport to wetlands, which protects coastal land from storms</td>
<td>Requires continual management; can be very costly</td>
<td>Southern Louisiana</td>
</tr>
<tr>
<td>Prohibit hard shore protection</td>
<td>Sea level rise</td>
<td>Preserve habitat for vulnerable species; Maintain sediment transport</td>
<td>Allows for species migrations inland</td>
<td>Alternatives of bulkhead construction are more expensive and more difficult to obtain permits for</td>
<td>Numerous states and local governments have drastically reduced permits for hard protection (e.g., King County, Washington)</td>
</tr>
</tbody>
</table>

Source: U.S. EPA, 2009

Table 7. Management Strategies (The Nature Conservancy)

<table>
<thead>
<tr>
<th>Reach</th>
<th>Management Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Del Monte</td>
<td>Opportunistic/scheduled beach Nourishment: smaller local beach nourishment projects scheduled every 10 years</td>
</tr>
<tr>
<td></td>
<td>Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped</td>
</tr>
<tr>
<td></td>
<td>Managed Retreat (Fee Simple Acquisition): erosion continues unimpeded; property purchased at fair market value</td>
</tr>
<tr>
<td></td>
<td>Medium scale Nourishment as Needed with Groins: groins installed, beach nourished to 25% wider than current (2010) conditions</td>
</tr>
<tr>
<td></td>
<td>Elevating Structures</td>
</tr>
<tr>
<td>Sand City</td>
<td>Large scale Nourishment as Needed: large scale nourishment needed to maintain 25% wider beach</td>
</tr>
<tr>
<td></td>
<td>Managed Retreat (Conservation Easements): easements are acquired to allow erosion of upland property</td>
</tr>
<tr>
<td></td>
<td>Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped</td>
</tr>
<tr>
<td></td>
<td>Elevating Infrastructure: HWY 1 elevated to column-supported causeway</td>
</tr>
<tr>
<td>Marina</td>
<td>Rolling Easements: allows erosion to continue naturally; coastal property boundaries move landward with high water lines</td>
</tr>
<tr>
<td></td>
<td>Managed Retreat (Fee Simple Acquisition): erosion continues unimpeded; property purchased at fair market value</td>
</tr>
<tr>
<td></td>
<td>Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped</td>
</tr>
</tbody>
</table>

Source: The Nature Conservancy, 2016
Table 8. Method for Estimating Benefits and Costs (The Nature Conservancy)

<table>
<thead>
<tr>
<th>Item</th>
<th>Method for Estimating</th>
<th>Final Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach Recreation</td>
<td>CSBAT</td>
<td>Recreational Value for given Beach Width</td>
</tr>
<tr>
<td>Ecological Value</td>
<td>Beach ecological index score</td>
<td>Cost of Replacement</td>
</tr>
<tr>
<td>Land</td>
<td>Commercial Data</td>
<td>Market Value</td>
</tr>
<tr>
<td>Buildings</td>
<td>FEMA</td>
<td>Replacement Cost</td>
</tr>
<tr>
<td>Flood Damages</td>
<td>USACE</td>
<td>Depth Damage Curves</td>
</tr>
<tr>
<td>Water Infrastructure</td>
<td>ESA</td>
<td>Replacement Cost</td>
</tr>
<tr>
<td>Roads</td>
<td>ESA</td>
<td>Replacement Cost</td>
</tr>
<tr>
<td>Nourishment</td>
<td>ESA</td>
<td>Cost of Hopper Dredge, etc.</td>
</tr>
<tr>
<td>Revetments</td>
<td>ESA</td>
<td>Construction Cost</td>
</tr>
</tbody>
</table>

Source: The Nature Conservancy, 2016

Table 9. Selected Summary Statistics from Survey of Beach Visitors (The Nature Conservancy)

<table>
<thead>
<tr>
<th>Item</th>
<th>Survey Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of visitors from Monterey County</td>
<td>38.7%</td>
</tr>
<tr>
<td>Percentage of visitors on overnight trips</td>
<td>51%</td>
</tr>
<tr>
<td>Average party size</td>
<td>3.5</td>
</tr>
<tr>
<td>Percentage arriving by car</td>
<td>78.4%</td>
</tr>
<tr>
<td>Average expenditures per visitor – overnight</td>
<td>$48.66</td>
</tr>
<tr>
<td>Average expenditures per visitor – day tripper</td>
<td>$12.32</td>
</tr>
</tbody>
</table>

Source: The Nature Conservancy, 2016
Table 10. Distribution of Costs & Benefits for Sand City (The Nature Conservancy)

<table>
<thead>
<tr>
<th>Year</th>
<th>Nourish as Needed</th>
<th>Allow Erosion</th>
<th>Shoreline Armoring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Public Benefits</strong> (recreational and ecological value)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>$73,879,019</td>
<td>$55,517,865</td>
<td>$46,714,719</td>
</tr>
<tr>
<td>2060</td>
<td>$156,974,550</td>
<td>$128,161,523</td>
<td>$88,872,613</td>
</tr>
<tr>
<td>2100</td>
<td>$258,312,180</td>
<td>$215,278,285</td>
<td>$105,318,207</td>
</tr>
<tr>
<td></td>
<td><strong>Property Losses/Damages</strong> (infrastructure, MRWPCA, public and private property)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>-$22,317,371</td>
<td>-$22,405,393</td>
<td>-$7,307,244</td>
</tr>
<tr>
<td>2060</td>
<td>-$22,656,590</td>
<td>-$25,107,555</td>
<td>-$7,768,865</td>
</tr>
<tr>
<td>2100</td>
<td>-$57,879,464</td>
<td>-$70,474,388</td>
<td>-$8,435,046</td>
</tr>
<tr>
<td></td>
<td><strong>Adaptation Costs</strong> (nourishment, groins, revetments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>-$42,040,402</td>
<td>$0</td>
<td>-$79,876,764</td>
</tr>
<tr>
<td>2060</td>
<td>-$42,040,402</td>
<td>$0</td>
<td>-$187,707,339</td>
</tr>
<tr>
<td>2100</td>
<td>-$136,692,248</td>
<td>$0</td>
<td>-$260,132,083</td>
</tr>
</tbody>
</table>

Source: The Nature Conservancy, 2016
Figures

Fig 1. Wetland Services Valuation Graph

[Graph showing values of seven ecosystem services in wetlands in US$ per ha per year. Source: TEEB, 2009]

Fig 2. Benefits, Costs, Impacts

[Diagram illustrating "pluses", "minuses", and "so what?" for benefits, costs, and impacts. Source: Emerton, 2017]
Fig 3. 2013-2017 Billion Dollar Weather and Climate Disasters (CPI-Adjusted)

Fig 4. Building damage estimates in Houston from FEMA, through Aug. 31
Fig 5. Share of Texas Gulf Coast Population Affected by Hurricane Harvey Differs by Geography, Race/Ethnicity, and Income

Among Texas Gulf Coast Residents in 24 Harvey-affected Counties: Percent who report home or vehicle damage or income effects as a result of Hurricane Harvey:

- By Geographic area:
  - Harris County: 65%
  - Outside Harris: 63%
  - Golden Triangle: 77%
  - Coastal: 74%

- By Race/Ethnicity:
  - White: 55%
  - Hispanic: 79%
  - Black: 73%

- By Self-reported Income:
  - <100% FPL: 79%
  - 100 to <200% FPL: 65%
  - 200 to <400% FPL: 67%
  - 400% FPL+: 53%

Source: Kaiser Family Foundation/Episcopal Health Foundation Texas Post-Harvey Survey (conducted Oct. 17-Nov. 20, 2017)

Source: Kaiser Family Foundation, 2017

Fig 6. The Resilience Gap

Source: Union of Concerned Scientists, 2016
Fig 7. Redlined EbA Valuation Matrix

Source: Harvey et al, 2017
Fig 8. Eco-Adaptation Valuation Process Infographic

1. **Map Projections**
   Map inundation data conveying need for climate adaptive strategies.

2. **Table Strategies**
   List EbA strategies & factors then use to compare costs, impacts & benefits.

3. **Survey Public**
   Survey using health & values related questions. Account for vulnerable populations.

4. **Calculate Values**
   Calculate values for costs, benefits & impacts of proposed adaptation strategies.

5. **Monitor Results**
   Implement strategy, monitor & evaluate results.

Chart Template Adapted From: New7ducks, Freepik.com
# Texas: Disaster Capital of America

## Why? Texas Holds the National Record For:

<table>
<thead>
<tr>
<th>Award Description</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest City with No Zoning Laws</td>
<td>Houston is the largest U.S. city to have no zoning laws.</td>
</tr>
<tr>
<td>Heaviest Rainfall (Hurricane Harvey)</td>
<td>Heaviest rainfall from a U.S. storm at 52 inches (over 4 feet).</td>
</tr>
<tr>
<td>Highest Frequency of Billion-Dollar Disasters</td>
<td>Since 1980, 95 billion-dollar disaster events</td>
</tr>
<tr>
<td>Least Absorbent Soil</td>
<td>Texas soil is among the least absorbent in the nation.</td>
</tr>
<tr>
<td>Most Expensive Natural Disaster</td>
<td>Harvey caused damages worth $125 billion (and counting).</td>
</tr>
<tr>
<td>Leading Fuel Producer</td>
<td>Produces &gt; 30% of U.S. crude oil. Oil-production also means more land degradation &amp; soil erosion. Harvey rose gas prices.</td>
</tr>
</tbody>
</table>
Fig 10. EbA Mainstreaming Cycle

Source: Emerton, 2017

adapted from GIZ (2016)

Fig 11. EbA Valuation Practical Purposes and Decision Questions

Source: Emerton, 2017
Fig 12. LSCNRA Scope of Projects

Source: LSC, 2017

Fig 13. Total Economic Impact of LSCNRA Could Double in Ten Years

Growing visitation is expected to double the economic impact of the Lone Star Coastal National Recreation Area in its first ten years of operation.

**Prior to Designation**
- Attract: 2.6 million annual visitors
- Support: $263 million local sales
- 6,240 local jobs*
- $109 million personal income

**Year Ten of Operation**
- Attract: 3.8 million annual visitors
- Support: $535 million local sales
- 13,325 local jobs*
- $234 million personal income

* full-time and part-time jobs

Source: LSC, 2017