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Ecosystem Services

Quantifying Wildlife and Navigation Benefits of a Dredging Beneficial-Use Project in the Lower Atchafalaya River: A Demonstration of Engineering with Nature®

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ABSTRACT

The US Army Corps of Engineers (USACE) operates and maintains numerous projects in support of its various civil works missions including flood damage risk reduction, navigation, and ecosystem restoration. Originally authorized on an economic basis, these projects may produce a broad array of unaccounted for ecosystem services (ESs) that contribute to overall human, societal, and environmental well-being. Efforts are underway to capture the full array of environmental, economic, and social impacts of these projects. Methods are needed to identify relevant ESs generated by these nature-based projects and to measure their contribution to societal well-being with an emphasis placed on use of readily available data. Performance metrics were collected to capture the benefits of strategic placement of dredged material in river systems to allow formation of islands that produce a wide array of ESs. These performance metrics can be converted to ESs with market value or combined in a decision analytical approach to demonstrate the relative gain in utility. This approach is demonstrated on a riverine island created on the Atchafalaya River, Louisiana, as a result of the strategic placement of dredged material. The outcomes foster integration of ES assessment into project design and management practices and support more comprehensive project evaluation and widespread application. *Integr Environ Assess Manag* 2018;14:759–768. Published 2018. This article is a US Government work and is in the public domain in the USA.

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INTRODUCTION

Natural features (e.g., oyster reefs) are created through the action of physical, biological, geologic, and chemical processes operating in nature; nature-based features (e.g., reef balls) are created by human design, engineering, and construction. Engineering with Nature® (EWN) solutions are engineered and constructed by humans to emulate natural features and function within the natural ecosystem, establishing a systemic continuum between ecosystem structure, processes, services and resultant economic, engineering, environmental and social benefits (Bridges et al. 2014). EWN projects are designed to sustainably perform ecosystem functions. Those functions in turn provide ecosystem services (ESs) that are either directly or indirectly used by humans (e.g., flood protection or damage reduction, clean water, biodiversity, recreation, tourism). Benefits, defined as the ways in which people use nature to improve their well-being, result in socioeconomic welfare gains derived from these ESs. Society determines the value or worth of these benefits. Shifts in these perceived values can be driven by any number of factors, including the state of the economy and the dynamics of supply and demand of the services themselves (Goldenberg et al. 2017).

The concept of ESs has rapidly evolved in its scope and application. Costanza et al. (1997) argue that ESs are the benefits that human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997). The Millennium Ecosystem Assessment (MEA 2005) stated that ESs were all the benefits that people obtain from ecosystems. More recently, the concepts have been defined as the aspects of ecosystems used (actively or passively) to produce well-being by people (Fisher et al. 2009). ESs are assessed in a wide variety of units; their economic value need not be determined in order to use them in informing decision making (see Diaz et al. 2018).

The characterization of ESs has not been previously investigated in terms of waterborne navigation, but it shows significant promise in providing a method to broadly assess a wide array of benefits associated with project implementation. The US Army Corps of Engineers (USACE) operates and maintains a multitude of water resource projects supporting

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its civil works missions, including flood damage risk reduction and navigation. The USACE expends billions of dollars annually to maintain over 12 000 miles of commercially important inland navigation channels. Originally authorized on a purely economic basis, these projects regularly produce a broad array of unaccounted for ESs that contribute to the well-being of society and the environment. As the USACE increases its use of nature-based principles and practices, capturing the full array of environmental, economic, and social benefits generated by these solutions becomes essential to their implementation.

The overall objective of this study was to develop a prescriptive approach that can be used to identify relevant ESs and consider their value. A project on the Atchafalaya River was used to demonstrate the approach that used the strategic placement of dredged material to create a riverine island. Project-specific indicators of ecosystem response to the creation of the island were generated, and market values for some of the ESs were identified and compared to 2 reference locations: a more traditional island created from dredged material and a nearby disposal and dispersion area. The performance metrics were combined within a flexible decision-making process to evaluate trade-offs between the nonmonetized benefits generated by the island. The intent is to provide decision makers, stakeholders, and the public with a strategy that transparently communicates returns on investment and supports the formulation and implementation of EWN principles from a variety of perspectives.

MATERIALS AND METHODS

Study areas

During the 1990s, placement of shoal material dredged from Horseshoe Bend occurred at 8 wetland development sites located along the river's shorelines adjacent to the channel. Capacity of these placement sites was nearly exhausted by 1999. Thus, to meet the anticipated disposal requirements for future channel maintenance, mounding of material at midriver open-water placement sites immediately adjacent to the navigation channel and upriver of a small naturally forming sandbar was selected on a demonstration basis to investigate the effects of midriver placement on shoaling trends downriver of the site (Berkowitz et al. 2014; Suedel et al. 2014; Berkowitz et al. 2015; Suedel et al. 2015; Berkowitz et al. 2016) (Figure 1).

Beginning in 2002, strategic placement of the sediment dredged from the Horseshoe Bend section of the federal navigation channel occurred at a midriver open-water placement area. Placement of between 0.4 to 1.4 million cubic meters of sediment was conducted every 1 to 3 years, which influenced and contributed to the development of a 35-ha island midriver (Figure 2).

The outcome of placement of material leading to the development of Horseshoe Bend Island was compared to outcomes from a historic placement method near the river's bank line that resulted in the formation of "Island E" and the hypothetical placement of dredged material at a dispersive site (Shell Island Pass) that may have enriched land formation

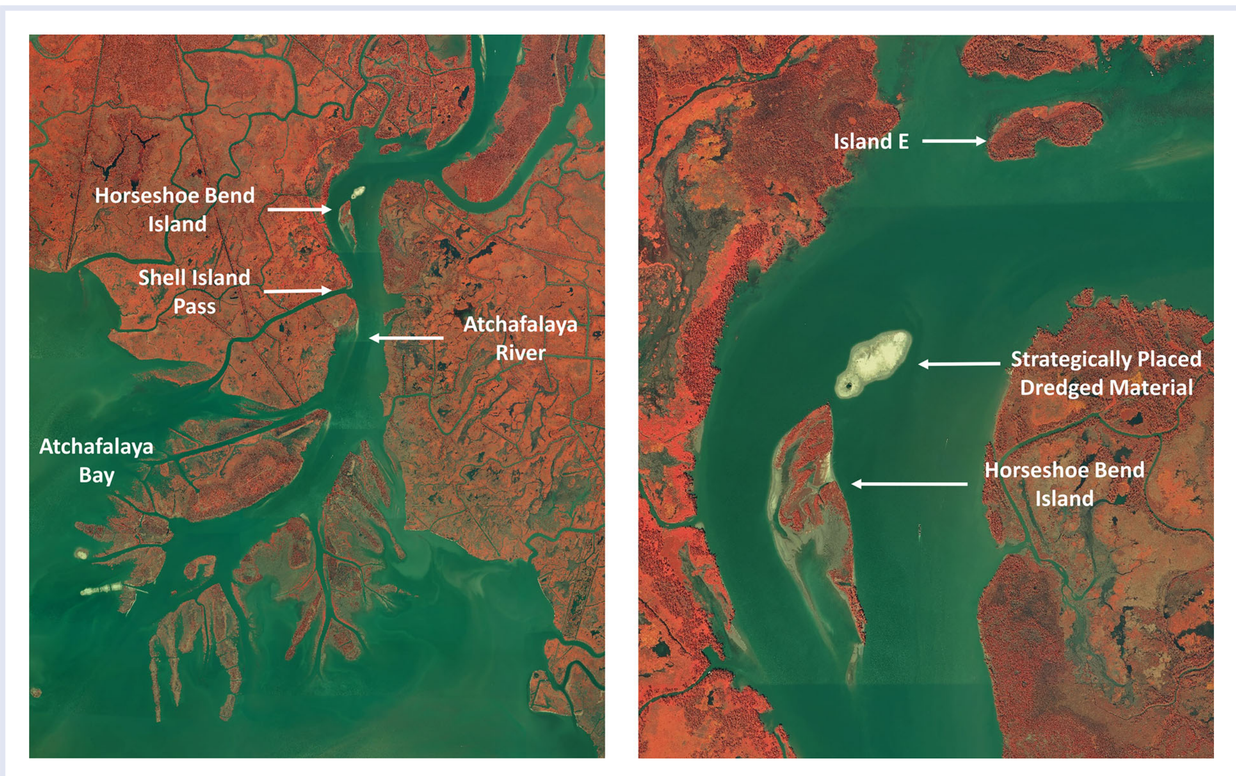

Figure 1. Study location within the lower Atchafalaya River, St. Mary Parish, Louisana, showing the Shell Island Pass alternative (**left image**) and close-up of Horseshoe Bend Island, the Island E alternative, with strategically placed dredged material mounded upriver of Horseshoe Bend Island (**right image**).

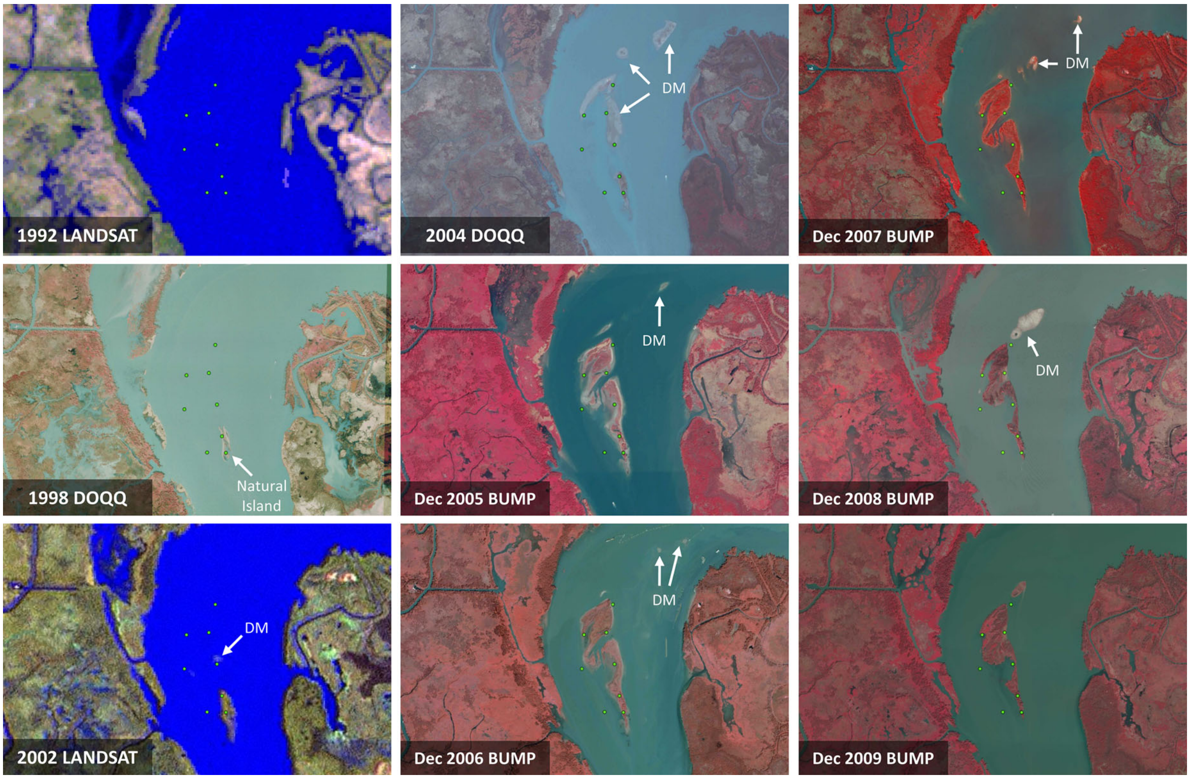

Figure 2. Imagery displaying island location prior to dredged material (DM) placement and subsequent formation (1992 and 1998 images), establishment, and growth since strategic dredged-material placement began in 2002 (imagery provided by US Army Corps of Engineers New Orleans District).

in the receiving Atchafalaya Bay. The unconfined placement of dredged material at Island E occurred in a low-flow portion of the river and resulted in the development of marshlands that retained the shape formed at the time of dredged material discharge. The proposed placement of dredged material into the dispersive Shell Island Pass site was a contemporary alternative to Horseshoe Bend Island that was screened out during the planning phase because of concerns that the method might inadvertently infill (block) the pass. It was believed that placement of material into Shell Island Pass would enrich the supply of sediment to the Atchafalaya Bay and enhance the formation of mud flats and other delta features. These 3 placement sites were compared in the following analyses.

Ecosystem service identification and quantification

For the purposes of this study, the following services were quantified on the basis of available data: (1) improvement of the environment or enhancement of ecosystems, (2) C sequestration, (3) nutrient sequestration, and (4) navigation support and maintenance. These ESs are designed to capture a broad array of potential benefits associated with EWN initiatives (Bridges et al. 2015; Ranganathan et al. 2008). Other ESs were not considered because they are not relevant to the area. Notably, the area has minimal value for production of crops or other goods and provides little coastal protection from storms. The alternative placement sites are not expected to differ in their delivery of these other services.

The change in the environment, specifically the populations of flora and fauna that colonized the island, is a key service created with the island's formation. Although this service is difficult to value, the new habitat provides several performance measures that indicate gains. Berkowitz et al. (2017) present results of a survey of the island and a direct comparison of it with 2 nearby reference areas, Island E (composed of wetlands that developed atop of relatively undisturbed dredged-material mounds) and a naturally occurring island in the same area.

Benefits to navigation and channel maintenance have also been realized and can be compared across alternative placement sites. Establishment of the island was coincident with the development of a more efficient river channel to the east. This channel was designated by the US Coast Guard in 2015 as the new federal navigation channel because of its shorter length and lower shoaling rates, which thereby substantially reduced dredging requirements. Horseshoe Bend Island has also resulted in a measurable benefit to navigation in the reduction in necessary maintenance dredging.

Valuation and relative utility

The valuation of services, especially monetized valuation, is increasingly important, yet economic studies are not always possible for individual projects (Richardson et al. 2015). The dredged-material placement resulting in Horseshoe Bend Island provides measures of services that can be valued in a tradable market currency (Table 1). The valuation of Horseshoe Bend Island can be compared to estimates of the ES estimates for both Island E and Shell Island Pass (Table 2). The nutrients sequestered in the island's sediments reduce the load delivered to the northern Gulf of Mexico, where hypoxia is an ongoing concern (Rabalais et al. 2007) for its economic effect. Only those ESs that can be assigned a market value were considered. Not included in this table, therefore, are environmental improvements that can be difficult to monetize or trade.

A decision model was also developed to determine the relative utility of Horseshoe Bend Island compared to 2 alternative placement options. One is Island E, which was created from traditional direct placement of dredged material (not self-formed). The other alternative is disposal in Shell Island Pass, which would have dispersed material in the pass and receiving bay but produced no emergent lands. To quantify the differences in benefits gained from these alternative placement sites, it was estimated what portion of the utility is derived from each of the broad ESs (Figure 3). Use of the decision model allows consideration of environmental improvements in habitat value, including species richness for plants and animals, amount of each type of habitat gain and loss, and the number of wading bird nests. The importance of environmental improvement should be determined relative to the other services. Climate regulation was created as a service composed of C sequestration and emissions reduction. Another service considered was nutrient sequestration, including both sediment retention reduction in hypoxia in the Gulf and the associated denitrification of retained sediment. Navigation support and maintenance was considered to be a service composed of improved safety, reduction in channel length, reduced need for channel maintenance, risk associated with changes in channel route, and the loss of native river bank. When there are multiple measures supporting services, as is the case with all these ESs, the contribution of each measure to providing that service should be elicited from the decision maker (Belton and Stewart 2002).

For all decision models, the alternative placements were compared on their performance on metrics that addressed environmental improvement, climate regulation, nutrient sequestration, research support, and navigational support services (Figure 3). The relative utility was calculated using the multi-attribute value theory set at a local scale (i.e., the range of scores reported) for each metric (Linkov and Moberg 2012). The reported score was normalized with the highest value given a score of 1, and the lowest value given a 0. The relative utility, $U(a)$, for that alternative, a, was calculated as a weighted sum across the 5 services:

$$U(a) = w_1 \cdot V_1(a_1) + \ldots + w_n \cdot V_n(a_n),$$

where a_i was the performance score of alternative a on objective O_i for $i = 1$ to n, $V_i(a_i)$ was the value of alternative a reflecting its performance on metric O_i, and w_i was the weight of metric O_i, where $\Sigma w_i = 1$. Multi-attribute utility theory provides a consistent, if arbitrary, means to aggregate disparate data streams (Keeney and Raiffa 1976).

The relative utility of these services was considered for decision makers with potentially different perspectives. The weights reflecting each perspective were not elicited from decision makers but chosen to represent a best understanding of the different perspectives that are taken into account when choosing a dredged-material placement option. First, a set of hypothetical weights were developed to correspond to a navigational operations focus (Nav Ops). For this perspective, navigational support provided 84% of the utility of the alternatives. The remaining 16% was allocated mainly to environmental service (8%). The remaining weight was split evenly between climate regulation and nutrient sequestration (4% each). A second set of weights was selected to reflect an emphasis on wildlife, as might be expected from an environmental management agency. This perspective had little emphasis on navigational support (8%) and the most emphasis on environmental improvement service (58%). The remaining 36% of the weight was split evenly between climate regulation and nutrient sequestration. The third perspective was chosen to reflect a focus on climate change issues. The majority of the weight, 65%, was allocated to climate regulation. This

Table 1. Reported marketable gains per service realized from the formation of Horseshoe Bend Island

Service	Horseshoe Bend amount	Conversion	Value	Units
Carbon sequestration	6.15-ha (15-ac) emergent wetlands	86 g C/m^2 each year over 100 yr	5220 kg	Average C per year
Hypoxia reduction	35-ha (85-ac) wetlands	7% reduction estimated for 10 093 km^2	0.00028%	Nitrogen reduction in Gulf
Emission reductions	49 L (13 gal)/trip fuel savings each year by 1400 tugs and cargo ships annually 1.27 million gal in dredging reduction over 10 yr	145 000 gal/yr of diesel fuel saved	1484	Metric tons of carbon dioxide equivalent (MTCO2e)
Navigation support and maintenance	$22.9M–$10M over 3 yr	$12.9M/3 yr	$4.3M	2015 USD

Table 2. Value comparison of Horseshoe Bend Island to 2 other dredged-material placement site alternatives[a]

Service	Horseshoe Bend	Island E	Shell Island Pass
Carbon sequestration estimate	5220 kg C/yr	2645 kg C/yr	2871 kg C/yr
Hypoxia reduction in the Gulf	0.00028%	0.00019%	—
Nitrogen removal (annual)	1645.5 kg/yr	1577.2 kg/yr	2404.0 kg/yr
Emission reductions	1484 MTCO2e	—	—
Navigation support and maintenance	$4.3M	—	—

[a]Dashes indicate insufficient data.

perspective reflected little value added in the service provided to support navigation (7%). Nutrient sequestration, the reduction in potential hypoxia in the Gulf of Mexico, received 16% of the weight. Improvement in the environment received 12%.

RESULTS

Ecosystem service identification and quantification

The services of environmental and habitat improvement, climate regulation, nutrient sequestration, and navigation support were assessed through consideration of a suite of measurements. The creation and development of Horseshoe Bend Island has resulted in the realization of several benefits, and some costs, ranging from the existence of additional emergent wildlife habitat and enhanced recreational opportunities to navigational enhancements. One way to account for the benefits associated with this placement is to catalog the change in ESs since the initial placement.

Based on the island survey compiled by Berkowitz et al. (2017), specific measures of changes in habitat and

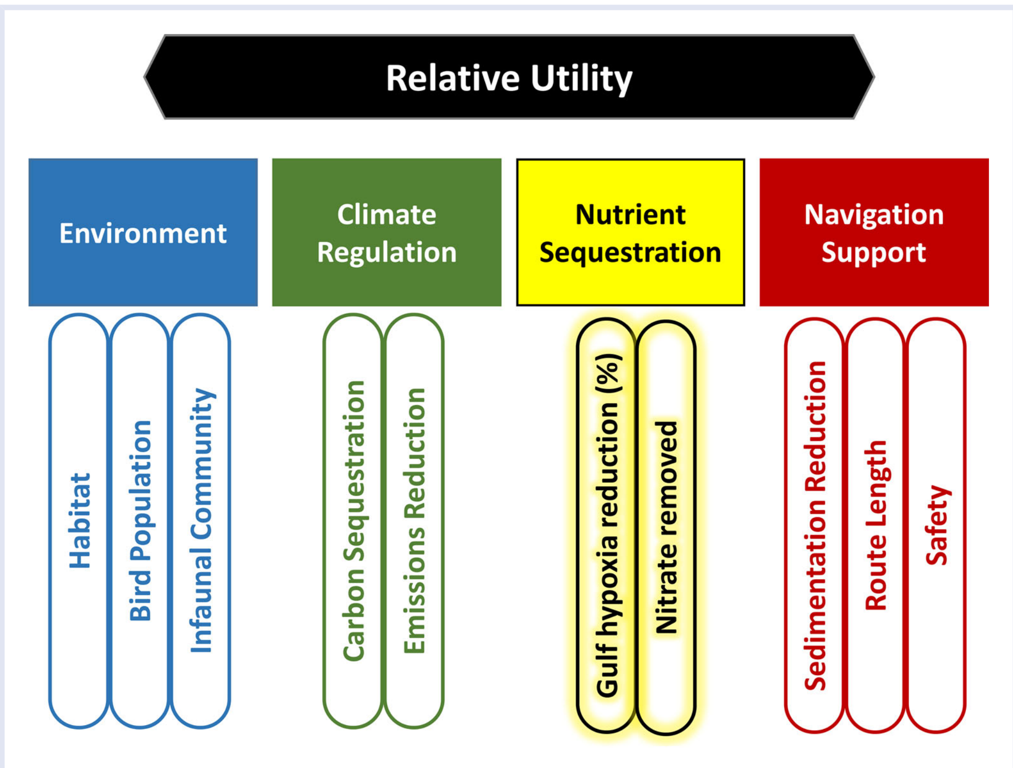

Figure 3. The decision tree used to calculate relative utility. The value for relative utility is given by the weighted sum across 4 ecosystem services (colored boxes). Included in the utility for the Environmental ESs are performance metrics for habitat (created habitat size for essential fish, aquatic bed, emergent aquatic, forested categories, and plant and animal species richness measures), bird population (total species, wading species, density and proportion of juveniles), and infaunal communities (species abundance, richness, percent not dominated and percent nonchironomids). The utility for Climate Regulation included performance metrics for C sequestration (estimated kg C/yr) and emissions reduction ($MTCO_2e$). Nutrient Regulation ESs comprised metrics for the estimated reduction in Gulf hypoxia due to the retention of N-laden sediments (percent of N retained) and the reduction of nitrates by inundated sediments (nitrate removed). Navigational Support utility includes sedimentation reduction (change in the anticipated volume and frequency of maintenance dredging), route length reduction (distance change in the navigational channel, loss of native river bank with channel straightening), and safety (elimination of turns and the risk of barges not knowing about the new channel route). The value for each box is given by the normalized weighted sum of metrics shown in each oval. The colors of the boxes here correspond to the stacked bar graphs in Figure 4.

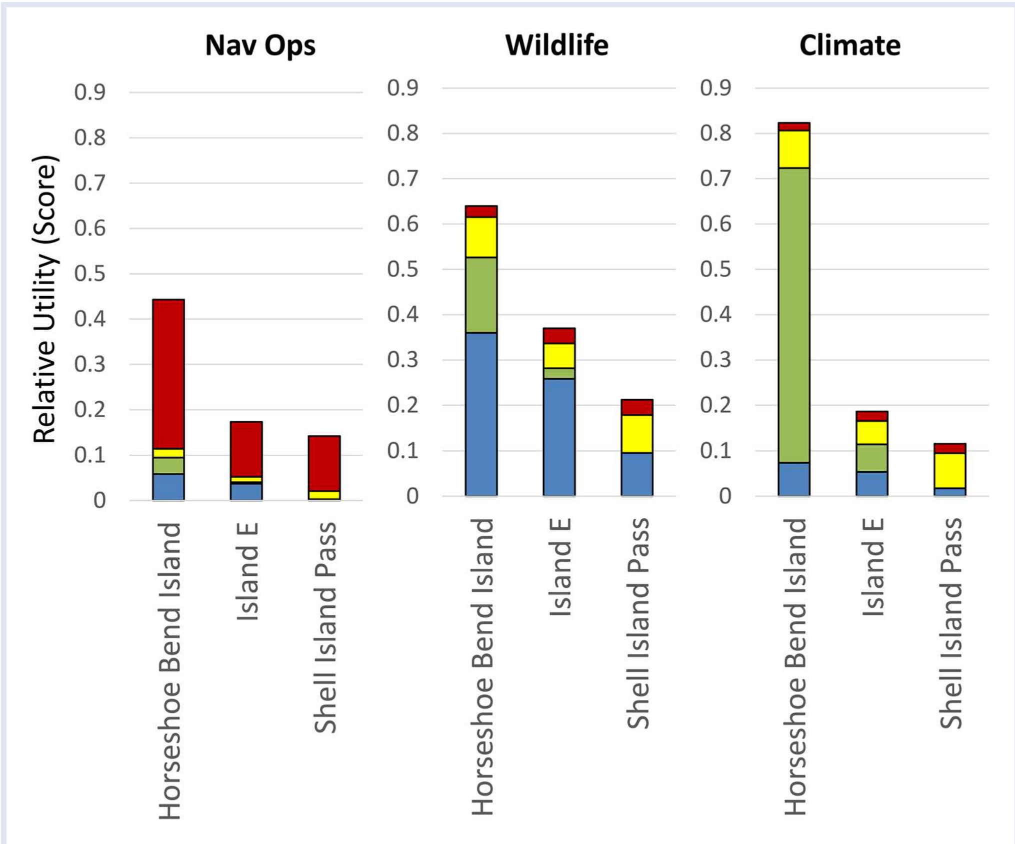

Figure 4. Demonstration of the relative utility given by the island for each type of service, considered from different perspectives. The value for relative utility is given by the weighted sum across 4 ecosystem services. Ecosystem services included here are performance metrics falling into the categories of Environment (habitat, bird population, and infaunal communities), Climate Regulation (C sequestration and emissions reduction), Nutrient Sequestration (N retained and nitrates removed), and Navigational Support (sedimentation reduction, route length, safety). The colors correspond to the different services: Environment, **blue**; Climate regulation, **green**; Nutrient Sequestration, **yellow**; Navigation Support, **red**. The difference between the plots are due to different weights placed on each service, which correspond to the potential perspectives of decision makers with varying focus on navigational operations (Nav Ops), wildlife management (Wildlife), and climate regulation (Climate).

environmental conditions can be developed. Horseshoe Bend Island provides approximately 6.0 ha of emergent habitat and 7.7 ha of aquatic bed habitat. The island now supports 81 plant species and 23 animal species, including 9 species of wading birds. It supports both a healthy invertebrate community (i.e., not *Chironomid*-dominated) and a microbial community that promotes nutrient sequestration in island soils. By comparison, Island E is measured at 23.1 ha. It consists of approximately 2.0 ha of emergent habitat and 13.5 ha of aquatic bed habitat. Island E supports 50 plant species and 20 animal species, one of which is a wading bird. Had dredged material been placed in Shell Island Pass, it is estimated that an area approximately the size of Horseshoe Bend Island (35 ha) in the Atchafalaya Bay would have been elevated to aquatic bed habitat. Placement at Shell Island Pass was not expected to result in the formation of emergent lands because the controlling elevation would be governed by water levels in the bay. Horseshoe Bend Island and Island E creation eliminated aquatic bed, essential fish habitat approximately the size of the emergent part of the island. Placement at Shell Island Pass, in limiting the depth of the pass and the receiving bay, would have created essential fish habitat approximately the size of Horseshoe Bend Island.

The sediments and plants of the emergent habitat sequester C and remove N. Although wetlands sequester C and emit methane, recent studies indicate that temperate riverine wetlands are a net C sink if they exist for several decades (Mitsch et al. 2013). In 2013, Horseshoe Bend Island was estimated to remove 1645 kg of N and Island E removed 1577.2 kg (Berkowitz et al. 2016). With these measurements, an estimate for nitrate removal can be made for Shell Island Pass, assuming that the disposal area would be the same size as Horseshoe Bend Island but that all that area would be aquatic bed habitat. By this estimation, the Shell Island Pass would remove 2404.0 kg of nitrate annually.

Establishment of the island resulted in the development of a more efficient river channel that has been designated as the new federal navigation channel. The new channel is shorter in length and has lower rates of shoaling. The rerouted navigational channel is now 1.13 km (0.7 nautical miles) shorter and has fewer turns. On the basis of data from the port of Morgan City, Louisiana, it was estimated from a review of marine traffic transiting the lower reach of the Atchafalaya River in 2015 that 4096 vessel trips were made along the new route, including more than 1407 trips by cargo ships and tug boats. A tug traveling at 7.4 km/hour (4 knots) and consuming 300 L (80 gal) of fuel per hour (typical for a commercial vessel, per the USACE New Orleans District) would have a transit time that is 10 minutes shorter and would consume 49 L (13 gal) less fuel. The shorter transit time for 1400 trips would reduce the annual fuel consumption by more than 68 000 L (18 000 gal). The straighter route, with reduced shoaling rates, is resulting in a safer and more reliable navigation channel, although no data on accidents in the area are available since the rerouting. Development of Island E with dredged material did not alter the navigation channel. Neither would placement of material at Shell Island Pass be expected to alter the route of size of the navigation channel. Development of Horseshoe Bend Island has resulted in a straighter navigational channel. However, any change in the navigation channel brings some risk in terms of alerting vessels and ensuring they are aware of the new route. No such risk would be incurred with placement of material at each Island E or Shell Island Pass.

The necessary annual dredging to maintain barge traffic has been reduced to channel maintenance dredging required every 3 years, according to the USACE New Orleans District. Annual maintenance dredging removed on average 841 010 cubic meters (1.1 million cubic yards) of sediment; the maintenance dredging required postconstruction removes 573 410 cubic meters (750 000 cubic yards) of sediment. Based on 27- to 30-inch cutter head dredges that have been used to dredge this navigation channel in the past, and assuming the same type of material is removed, the maintenance dredging now required has saved approximately 4 807 470 L (1.27 million gal) of diesel fuel over 10 years (prior dredging consumption estimated at 605 600 L annually, postconstruction estimated at 412 610 L every 3 years). Development of Island E from dredged material did not change the need for maintenance dredging of the channel. The placement of material at Shell Island Pass also would not be expected to alter the frequency or amount of maintenance dredging. Emergence of Horseshoe Bend Island has resulted in a straighter navigational channel and reduced shoaling of the channel, thus reducing dredging requirements.

Valuation and relative utility

Certain services produced through the creation of Horseshoe Bend Island, specifically C sequestration, nutrient sequestration, emissions reductions, and navigation, produce benefits that can be valued in different tradable or economic units (Table 1). Although this emergent riverine habitat is known to both sequester C and emit methane, recent modeling suggests that similar habitats (natural, flow-through wetland in Ohio) sequester an average of 86 g of C per square meter each year, when averaged over 100 years (Mitsch et al. 2013). The Ohio study was used as a benchmark and assumed that the island will remain relatively stable 100 years into the future. When averaged over those 100 years, it was estimated that Horseshoe Bend Island will sequester 5220 kg of C each year. It is worth noting, however, that as the island is developed it will take many years (>30 years) before the sequestration gains overtake the effects of methane emission. By the same conversion and with the same caveats, the smaller Island E is estimated to be able to sequester 2645 kg of C per year. Without the emergent vegetation, the larger area of sediment disposal in Shell Island Pass is estimated to retain 55% of the C relative to Horseshoe Bend Island, or 2871 kg annually.

Emissions reduction was another service that was realized as a result of the island's creation. Given the amount of fuel saved per trip and the number of trips made each year by tugs and ships, 1484 metric tons of carbon dioxide equivalent (MTCO2e; US Environmental Protection Agency's conversion of a gallon of diesel fuel to MTCO2e, 0.010217) are being realized each year. Disposal at either Island E or Shell Island Pass would not alter the navigation channel or reduce the length of passage in this way. Therefore, these alternative disposal site cannot be attributed with analogous reductions in fuel use of commercial vessels.

The sediments reduce the load of N delivered to the northern Gulf of Mexico, with the potential to reduce the annual hypoxic zone. Turner et al. (2007) calculated that creation of an additional 1 009 300 ha (10 093 km^2) of wetland in this region will reduce the delivery of N to the Gulf by less than 8%. Therefore, the contribution of the 35 ha of Horseshoe Bend Island to this reduction is a modest 0.00028%. The smaller Island E could be considered to reduce the sediment load to the Gulf and therefore be considered to reduce the N load there by 0.00019%. Disposal in Shell Island Pass, however, will continue to distribute N-laden sediment into the Gulf and cannot be considered as an asset to hypoxia reduction. This reduction has an economic value in proportion to the cost of the hypoxic zone. Reduction in the extent of the hypoxic zone in the Gulf of Mexico has been associated with measurable economic effects (Rabotyagov et al. 2014; Smith et al. 2017) and therefore considered a monetized or tradable service. An associated measure, denitrification in sediments, can be quantified but is difficult to convert to a market value.

A readily quantifiable economic value realized as a result of the island's creation is navigational service and maintenance expressed as the reduction in dredging requirements. The 3-year cost of dredging prior to island creation is valued at \$22.9M, and the 3-year estimated cost of dredging after island creation is \$9.9M (USACE New Orleans District). The estimated \$12.9M savings to the USACE translates into \$4.3M per year. The navigation channel and the need for maintenance dredging would not have been altered by material disposal at either Island E or Shell Island Pass. Therefore, these alternative disposal sites cannot be attributed with analogous reductions in the costs or frequency of maintenance dredging. Scouring and maintaining that route requires some initial loss of native river bank, which is more likely to be clay or other dense material. Initial dredging of any new route, therefore, has the potential to require different equipment and more energy. No such costs would be incurred with placement of material at either Island E or Shell Island Pass.

The relative utility ranges of Horseshoe Bend Island are greater than both Island E and Shell Island Pass placement under all of the perspectives considered (Figure 4). However, the gain in utility from Horseshoe Bend over other placement options differs with the relative importance of different services provided with the island's creation. The difference between the utility of the outcomes are due to different weights placed on each service, which correspond to the potential perspectives of decision makers with varying focus on navigational operations (Nav Ops), wildlife management (Wildlife), and climate regulation (Climate). From the Nav Ops perspective, Horseshoe Bend is clearly the highest utility alternative, with nearly double the value of the other options. The island provides services in the form of navigational support that are absent in the other alternatives, specifically straightening and shortening the route as well reducing the need for maintenance dredging. Navigational support from the other options is limited to the safety in maintaining the known channel and preserving the native bank in the current channel. When considering the Wildlife perspective, Horseshoe Bend Island is still the highest utility alterative, with nearly 3 times the value of Shell Island Pass. Under this weighting scheme, the potential for nutrient sequestration of Shell Island Pass with higher nitrate removal is compensated by higher retention of sediments contributing to hypoxia in the Gulf by both Horseshoe Bend and Island E. The habitat value of emergent lands was higher because of the richness of plant and animal species as well as bird density and nesting populations. Horseshoe Bend Island has a higher habitat value because its size and location means that it has a higher diversity and density of nesting birds and more nesting activity. By contrast, the habitat value for Shell Island Pass was limited to increased essential fish habitat. Were this an elicited weight set from a decision maker, Shell Island Pass would have been reported to have 33% of the utility of Horseshoe Bend Island. Under the Climate perspective, the measurements of relative utility for Island E and Shell Island Pass are nearly equal (0.186 and 0.115) with Horseshoe Bend Island showing a large value advantage (0.823). The difference between the 2 islands under this perspective is due in large part to the weight placed on the climate service metrics of emissions reduction and C sequestration, which are provided by Horseshoe Bend Island solely or to a greater extent, respectively.

DISCUSSION

The benefits realized by the strategic placement of dredged material to support the development of an inchannel island were measured through a series of performance metrics and compared to 2 alternative placement sites. Those metrics can be given an estimated market value. The largest values gained from island creation was the reduced need for navigational dredging, which is valued at $4.3 million USD annually. Also notable is the reduced C emissions of more than 1000 MTCO2e from the reduced dredging frequency and the shortened channel length. These benefits, however, are not independent; therefore, it is not appropriate to add them to produce a total monetary value for ESs (Farber et al. 2002). Alternatively, the value of each benefit can be considered relative to the role that that benefit plays in the overall consideration of a decision maker. To this end, the performance metrics were also included in a decision model incorporating different hypothetical perspectives. The outcome of the model always indicated that the inchannel island development outperformed a constructed island and dispersion in a shallow pass. The differential, however, was based on different factors in each case. From a NavOps perspective, Horseshoe Bend Island adds value in that it supports navigation. This added value aligns with the reduction in federal spending for maintenance dredging. From the Wildlife perspective, its value comes from the environmental benefits, specifically the gains in habitat and bird populations. From the Climate perspective, its value comes mainly from the emissions reduction reflecting the quantified value for the reduced fuel use of commercial vessels using the channel but is bolstered by a larger potential for C sequestration with emergent vegetation. The decision model allows consideration of all the performance metrics, even those not readily monetized or supported by market value.

The use of ESs to evaluate project alternatives adds value to decision making in several ways. Evaluation of ESs forces a prediction of the outcomes at different sites. Ecosystems are inherently complex, and their components often interact in nonlinear ways across a range of temporal and spatial scales. This coupled with the effect of irregular events, such as storms, lead to considerable unpredictability in the quantification of ESs production (Chee 2004). Specifying the anticipated results of the action ensures we have a reasonable understanding of the system. Use of ESs may lend clarity or transparency to decisions made considering the relative cost of alternatives and development of specific services.

Two important concepts underlie the definition of ES. The first is the tie of ESs to human well-being, encompassing all its financial, health, and social components. The second idea is that EWN solutions produce both intermediate and final services. By definition, "intermediate" ESs are the ecological processes, functions, structures, characteristics, and interactions that are essential to the existence of final ESs but are not directly enjoyed, used, or consumed by beneficiaries (Landers and Nahlik 2013). Alternatively, "final" ESs are the components of nature directly enjoyed, consumed, or used to yield human well-being (Boyd and Banzhaf 2007). This distinction can help illustrate the benefits generated by engineering solutions in which ecosystem response models can be used to quantify changes in ecological function that support ESs. When benefits can be valued through monetization or in other markets, they are necessarily final ESs.

Had a purely economic approach been taken with no direct comparison between placement sites for Horseshoe Bend Island, the performance metrics in Table 1 would have been monetized and combined into a value in USD for placement creating the island. The price of C and nitrate would be multiplied by the net present value of the anticipated sequestration in the future. The cost of hypoxia in the Gulf would be multiplied by the fraction of reduction associated with the island. The value of emissions reduction in a relevant trading group would be calculated. Each of these figures would be added to the savings from reduced dredging associated with the placement. That total figure may be important for planning and justification of the project. However, it provides less opportunity for consideration of those ESs that are not easily monetized, such as environmental benefits.

Monetization, although providing a powerful perspective, has its limitations in development and interpretation. There are numerous difficulties surrounding the economics of ESs, including the fundamental issue that most services are not market-based commodities, and therefore their value is oftentimes unknown or unpriced. Renzetti (2005) succinctly describes problems encountered with monetization of water resource services (including issues of marginalization, distortions, and relativization), while Turner et al. (2016) consider the complications arising from issues of service bundling, including double counting, nonlinearities, and threshold effects. Despite these complexities, economists have devised several methodologies to estimate the value of ESs (Wainger and Boyd 2009).

An alternative to economic or social valuation of ESs is to develop a relative valuation of a project with decision analysis. The outcome with these approaches does not provide a dollar value or credit unit that can assessed according to a market. However, the results do provide a project utility score, which is meaningful relative to an appropriate comparison. This type of analysis can be used to determine the percent gain in utility from a specific project (i.e., Linkov and Moberg 2012). Further, a comparison of utility incorporates the decision makers' specific preferences for different services as weighted priorities. The results are specific to not only the project in the analysis but also the prioritization that is incorporated. The results presented are a normalized weighted sum of the ESs produced by Horseshoe Bend Island compared to the 2 reference locations: a more traditional island created from dredged material and a nearby disposal and dispersion area.

In the comparison of relative utility, those benefits that are difficult to value in a marketplace were also considered. A decision analytical approach was used to combine classes of performance metrics, allowing a direct comparison of the relative gains from different disposal options in the same area. The relativistic approach for measuring performance is useful in considering the utility, if not the dollar value, of a solution from different decision-maker perspectives. Using a decision model still requires that comprehensive ES performance metrics be identified and collected. Any decision model requires consideration of the perspectives of the decision makers in the form of weights on each objective (Edwards and von Winterfeldt 1986). This approach provides a means by which project managers could consider different ESs for different stakeholder groups. Project managers for different types of projects would need to consider how the decision model developed here may need to be modified to fit other dredging projects. However, modifying a decision model transparently would support the objective of fully capturing and measuring changes in ESs.

This research offers a straightforward means of quantifying the value of ESs associated with an innovative dredging project that supports the USACE navigation mission. It can be improved with additional information, including characterization of benefits from multiple temporal and spatial scales. The USACE is expanding the ESs benefit metrics to be collected by including services not captured at Horseshoe Bend Island, including natural hazard mitigation, human health support, raw goods and materials provisioning, and food provisioning. The goal is to integrate them into USACE business practices to develop a comprehensive picture of project value. The results of this research can be used to identify opportunities for novel solutions that are expected to enhance social, economic, and ecological capital.

CONCLUSIONS

Managers of dredging and navigation projects are challenged to streamline and improve upon their operations and management in the face of dwindling budgets, increasing regulatory restrictions, and demands for increasing stakeholder engagement necessitating solution transparency. These decisions reflect a complex set of trade-offs between project costs and different ecosystem goods and services. A need has therefore arisen to identify and, to the extent possible, quantify the broader array of environmental, economic, and societal benefits originating from individual projects. The process of quantifying and valuing ESs offers a mechanism to integrate the multi-objective interests of numerous stakeholders into the decision-making process. The purpose of this study was to quantify the ESs realized by a recently constructed project on the Atchafalaya River, not from a traditionally economic perspective typically used by the USACE to determine return on investment, but from a more comprehensive standpoint—one that captured a full array of benefits generated by the island. A series of monetized and nonmonetized factors were used to quantify the market value of these services. A multicriteria evaluation of these outputs was then conducted, performing trade-offs to generate outcomes based on the objectives of a variety of management perspectives. As the USACE increases its use of EWN principles and practices nationwide, capturing the full array of environmental, economic, and social benefits generated by these novel solutions becomes critical. The approach presented herein can be used to justify the application of this island-building approach at other riverine sites. Demonstration of this approach on the Atchafalaya River, Louisiana, fosters its integration into USACE business practices of project design, intending to both increase project value and more effectively manage waterways.

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