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Economic Impact of Gulf of Mexico Ecosystem Goods and Services and Integration Into Restoration Decision-Making

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Sustainability of natural resources requires balancing exploitation and conservation, enabled by management based on the best available scientific and economic information. Valuation of ecosystem goods and services is an important tool for prioritizing restoration efforts, recognizing the economic importance of conserving natural capital, and raising public awareness about the contribution of healthy ecosystems to social welfare, now and for future generations. The Deepwater Horizon oil spill (DHOS) in 2010 was a Gulf of Mexico ecological and economic disaster adding to decades-long degradation of the region's coastal and marine environment. In 2010, revenues from provisioning ecosystem goods and services generated by the five U.S. states bordering the Gulf of Mexico contributed over \$2 trillion per year to the nation's gross domestic product, including \$660 billion from the coastal county revenues and \$110 billion from ocean revenues. Mexico and Cuba contribute at least another \$40 billion per year from their Gulf coastal and ocean economies. Total economic value of Gulf ecosystem goods and services also requires valuation of nonmarket regulating, cultural, and supporting services, which are far more difficult to assess, but add billions more dollars per year. In light of this total economic value and trends in ecosystem stressors, new investment is necessary to ensure completeness, accuracy, and availability of Gulf economic impact data. Civil and criminal settlements related to the DHOS provide unprecedented opportunities for improving integration of ecosystem goods and services into decisions that affect Gulf restoration and sustainability. This paper highlights the economic contributions of Gulf ecosystem goods and services to the nation's welfare, and recommends actions and investments required to ensure that they are valued, and integrated into decision-making.

INTRODUCTION

A succession of natural and technological disasters in the last decade has focused international attention on the Gulf of Mexico and the five bordering U.S. states. Assessing the damages, ecological and economic restoration, and sustainability requires baseline information and understanding of the values of ecosystem goods and services (NRC, 2012). By traditional market-based economic measures, the Gulf of Mexico, bordering states, and international neighbors contribute vitally important revenue from ecosystem goods that support the nation's economy and social welfare. Analysis of nonmarket Gulf ecosystem services adds considerably more value, especially in the face of natural and human-induced disasters. As such, it seems likely that the Gulf's economic contributions to the nation's economy are much greater than generally appreciated.

Ecosystem and economic sustainability.—Daily et al. (1997) define ecosystem services as “a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life.” These services support the production of

ecosystem goods, “such as seafood, wild game, forage, timber, biomass fuels, natural fibers, and many pharmaceuticals, industrial products, and their precursors.” Taylor (1986) suggested that sustainability of these goods and services can be viewed in two ways: (1) an anthropocentric approach that assumes natural capital has value only on the basis of its benefits to human welfare; or (2) a biocentric approach that assumes natural capital also has intrinsic value, which may not be easily priced or traded on commercial markets, but should be considered in policy decisions (also see Goulder and Kennedy, 1997). The Brundtland Commission's report to the United Nations (WCED, 1987) defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Neumayer (2010) defined two varieties of sustainability analogous to Taylor's biocentric and anthropocentric views: “strong sustainability” maintains both animate and inanimate natural capital intact, whereas “weak sustainability” maintains humans' living standards (essentially the Brundtland definition of sustainability).

Heal (2012) suggests that identification of the portfolio of capital stocks has been shifting away

from natural capital and toward other forms of capital, including built capital (e.g., freeways, airports, buildings, and infrastructure) and intellectual capital (e.g., cures for diseases, new products). The crux of the sustainability issue, as Heal observed, is how long will the trade-off between capital services and natural services continue to work? Stiglitz et al. (2009) also recognized this dilemma, noting that present trends in the growth of the world economy are not sustainable and any measures and actions to sustain human well-being must promote a healthy sustainable environment that continues to provide an abundance of natural capital to national economies.

Developments in the field of ecological economics suggest that the next generation of economists must take into account the limits of natural capital (Daly and Farley, 2011). Hall and Day (2009) observed that, in recent decades, ecological economists questioned the foundations of mainstream (or neoclassical) economics, including “its dissociation from the biosphere necessary to support it and, especially, its focus on growth and infinite substitutability—the idea that something will always come along to replace a scarce resource.” Mainstream economists maintain that unrestricted market forces seek the lowest prices at each juncture, resulting in the lowest possible prices, and optimal deployment of all productive forces. Gowdy et al. (2010) labeled neoclassical economics as “faith-based economics,” concluding that this theory of production “is not a model of production at all, but rather a model of the distribution of productive inputs and the goods they had produced previously. No specific primary inputs from nature are essential in this model.” Neoclassical economists dismiss the notion of absolute scarcity of resources, arguing that economies have built-in, market-related mechanisms to deal with scarcities. They contend that technical innovations and resource substitutions, driven by market incentives, indefinitely solve the longer-term issues. “It was as if the market could increase the quantity of physical resources in the Earth” (Hall and Day, 2009).

Some forms of living natural capital do generate revenue and can be assigned market prices; however, “there are certainly other types of natural capital for which there are no prices. In a case like this we need to calculate *shadow prices*, reflecting the value of the resources concerned to society” (Heal, 2011). The United Nations Development Program’s Biodiversity and Ecosystems Framework (UNDP, 2012) concludes that to reverse trends of global biodiversity loss, and degradation of ecosystems, society must

intensify efforts and find new ways of financing biodiversity and ecosystem management, and undertake a shift in focus toward “the positive opportunities provided by biodiversity and natural ecosystems, in terms of harnessing their potential for sustainable development.” This framework calls for a new global emphasis on valuing biodiversity and ecosystem goods and services, integrating their value into decision-making, and working toward influencing markets and resource management to reflect that value.

Deepwater Horizon oil spill (DHOS) settlement: opportunity for sustainable development of Gulf of Mexico ecosystem goods and services.—The National Commission on the DHOS and Offshore Drilling called the assessment of the environmental, economic, and human health damages resulting from the DHOS a threshold challenge, “the spill itself is a regional issue, but the slow-motion decimation of the Gulf of Mexico’s coastal and marine environment—created by federal and state policies, and exacerbated by energy infrastructure and pollution—is an unmet national challenge” (Oil Spill Commission, 2011). Although the environmental, economic, and human well-being impacts are yet to be fully determined, one positive outcome from high-visibility disasters such as the DHOS and recent hurricanes may be an increased public awareness of the value of Gulf ecosystem goods and services to the nation’s environmental and economic vitality.

A historical lack of funding has limited ecosystem restoration activities in the Gulf (Oil Spill Commission, 2011). The DHOS settlements, which may approach \$30 billion for ecosystem restoration, not including mitigation and recovery expenditures by BP or other responsible parties immediately after the spill, represent an unprecedented opportunity to address this historical shortcoming. Since the spill, almost \$13 billion had been committed by responsible parties for claims and restoration, including: \$1 billion by BP for early restoration to Gulf state and federal agencies; \$500 million from BP for the Gulf of Mexico Research Initiative (DWH Natural Resource Trustees, 2011; GOMRI, 2012); \$90 million by Mitsui Oil Exploration (MOEX) for criminal settlement; \$7.8 billion from BP for Gulf Coast Claims Center claims; \$2.5 billion for BP’s criminal plea agreement in November 2012; and \$1 billion for Transocean civil settlement in January 2013. Future claims, including Natural Resource Damage Assessment (NRDA) penalties and Clean Water Act (CWA) fines, may yet add another \$20 billion to this total (Oil Spill Commission, 2011).

In July 2012, the *Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012* (RESTORE Act) was enacted into law as part of the omnibus transportation bill (PL 112-141, 2012); subtitle f of the bill entitled Gulf Coast Restoration legislates how CWA civil penalties (still to be litigated as of December 2012) are to be allocated and spent. Whereas NRDA funding is limited to restoration, rehabilitation, replacement, or acquisition of the equivalent of natural resources injured by the spill, CWA funds may support a wider range of activities of long-term benefit to the health of the Gulf Coast and ocean ecosystem and economy. Various programs prescribed by PL 112-141 require socioeconomic science and data; for example, a comprehensive plan to restore and protect Gulf ecosystems, must be developed in 2013 (initial plan is GRC, 2013). Like the Gulf Coast Ecosystem Task Force's *Gulf of Mexico Regional Ecosystem Restoration Strategy* (GCERTF, 2011), the plan calls for supporting science-based adaptive management, and ecosystem observations and monitoring required for successful restoration. Among the priority objectives identified by the Task Force to achieve this strategic goal is "Expanding ecosystem services and benefits analysis tools and capabilities to determine the socioeconomic benefits that ecosystems provide throughout the Gulf region" (GCERTF, 2011).

Ecosystem services approach to damage assessment and valuation.—The National Research Council's 2012 report, "Approaches for Ecosystem Services Valuation for the Gulf of Mexico after the Deepwater Horizon Oil Spill" (NRC, 2012) observed that, "The magnitude and depth of the DWH event, in concert with the complexity of the GoM ecosystem and the difficulties in establishing baseline values, pose serious challenges to the trustees charged with carrying out the NRDA process, which has historically been applied to shallow-water events of much more limited extent and scale. Recent studies suggest that an 'ecosystem services approach' may expand the potential to capture, value, and restore the full breadth of impacts to the ecosystem and the public."

An ecosystem services approach to valuation of the Gulf considers "the benefits people receive from a multitude of resources and processes provided by ecosystems, produced as a consequence of the functioning of the ecosystem" (NRC, 2012), including: provisioning services or the material goods provided by ecosystems (i.e., food, feed, fuel, and fiber); regulating services (e.g., climate regulation, flood control, water purification); cultural services (e.g., recreational,

spiritual, aesthetic); and supporting services (e.g., nutrient cycling, primary production, soil formation) (MEA, 2005; NRC, 2012).

Pendleton (2008) defines the economic concepts needed to quantify the total economic value of ecosystem goods and services, which includes the value we place on goods we can use directly (use value), the value we place on services we use only indirectly (indirect use value), or the value we place on resources we may never use (nonuse value). Use values include revenues generated by quantities sold, jobs, taxes, and businesses lost or created. These are the provisioning services or goods produced by ecosystems. Regulating, cultural, and supporting services provide nonmarket or noncommercial, indirect, passive-use values that are "the difference between the maximum that people would be willing to pay for something and the cost of providing that thing." Estimation is less precise and requires the use of a diverse array of valuation techniques that vary by type of service (e.g., see Bakter et al., 2010). The NRDA process requires assessment of both provisioning service revenues and nonmarket values of regulating, cultural, and supporting services.

A continuing challenge in operationalizing ecosystem services is accounting for its value in a comparable manner with other traditional goods and services. The Environmental Protection Agency (EPA) has initiated an effort to develop a framework for identifying final ecosystem goods and services that would avoid double-counting of some benefits and the exclusion of others (Ringold et al., 2010). Barbier et al. (2013) provide a general review of the state of valuing estuarine and coastal ecosystem services on a global basis and find that although quite a bit of work has been conducted on valuing the more charismatic services (recreation, aesthetic, and cultural) in the most recognized habitats (marsh, mangrove, and coral reefs), there still remains a lack of work focusing on seagrass and oyster reefs, two critically important habitats in the Gulf (Yoskowitz et al., 2012a). This is primarily driven by a lack of resources to conduct primary research. However, this has begun to change recently with valuation studies in the Gulf taking place for storm protection by marsh (Barbier et al., 2013; Petrolia et al., 2011) and nitrogen regulation by oyster reefs (Beseres Pollack et al., 2013).

In addition to lessons learned from the Exxon Valdez oil spill (EVOS) related to clean-up, assessment, and restoration science (e.g., Paine et al., 1996; Peterson et al., 2003), the DHOS response effort should learn from the socioeconomic science derived from the EVOS response.

The U.S. Oil Pollution Control Act of 1990 (OPA 1990), passed in response to EVOS, mandates including passive use in assessing damages. Methods for nonmarket valuation of ecosystem services such as contingent valuation were rigorously developed and utilized to estimate penalties and litigate claims (Carson et al., 2003); however, there was minimal success for plaintiffs (Duffield, 1997). For example, in prosecuting civil claims, market valuation procedures (“diminution in market price”) used by commercial fish experts were admissible, whereas nonmarket valuation procedures applied to subsistence uses (hedonic price model) were not. Recommended actions to improve successful application of nonmarket values into DHOS decision-making have included calls for more and better socioeconomic data on ecosystem services (Lubchenco et al., 2012), and incorporating the concepts of ecosystem services, in practice and in law, to oil spill damage assessment and recovery strategies (NRC, 2013).

Gulf ecosystem revenues.—The National Ocean Economics Program (NOEP) maintains a comprehensive national information system that contains market values for coastal and ocean ecosystem goods and services, searchable by year, state, and industry sector for U.S. states that can be used to estimate of the value of ecosystems services provided by the Gulf (CBE, 2012). The NOEP online database (NOEP, 2012a) is divided into ocean economy (economic activities that indirectly or directly use the ocean as an input) and coastal economy (economic activities that take place in coastal areas). Both include values for establishments, wage and salary employment, and gross domestic product (GDP). Data for establishments and employment are taken from the Quarterly Census of Employment and Wages, and GDP data are from the Bureau of Economic Analysis, which develops the estimates of GDP from several sources. Value estimates are provided for the sectors and industries.

Gross domestic product is the value added to production by the labor and property located in a state, derived as the sum of the gross state product originating in all industries in a state (NOEP, 2012a). U.S. Gulf states, if considered an individual country, would rank 7th in GDP in the world (BEA, 2011; NOS, 2011). On the basis of the NOEP’s combined ocean and coastal economy data, the GDP of the five Gulf states’ provisioning services reached over \$2 trillion annually in 2010, including \$660 billion from revenues generated by the counties bordering the Gulf, and \$110 billion from ocean industries in coastal counties (Figs. 1, 2; tables with complete breakdown of both economies by state,

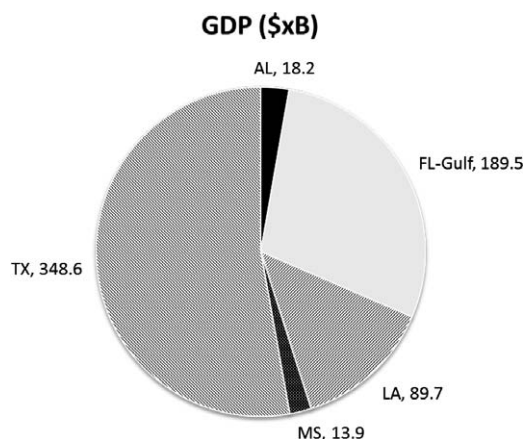


Fig. 1. Coastal economy GDP in 2010 for Gulf coastal counties only: less than 1% of the United States by area, these counties produced \$660 billion in GDP, or 5% of U.S. GDP (source: NOEP, 2012a).

sector, and industry are posted online at http://www.marine.usf.edu/gomurc/docs/gulf_value_paper-supplemental_tables.xls). The estimated revenues for the Florida ocean economy include both the Atlantic and Gulf coasts. The NOEP does allow queries of the ocean economy data by county, but these data are far less complete than the statewide data, as explained in the NOEP User’s Guide (Colgan, 2007). The estimated revenues from the 42 Florida Gulf counties in 2010 was \$8.2 billion, with no data from 13 of 42 counties, and no data for 185 of 252 industry sectors (42 counties times 6 sectors).

Even with all of Florida included, the estimated total GDP contribution of \$109.9 billion per year by the Gulf states’ ocean economy (Figs. 2, 3) is conservative as many of the NOEP values are underestimated due to lack of data. NOEP’s ocean economy data, for example, did not have data for minerals (including oil and gas) or boat- and shipbuilding in Mississippi for any year. An American Petroleum Institute report estimated the 2007 market value of oil and gas industries in Mississippi to be over \$7.2 billion, with labor income adding another \$3.6 billion, comparable in magnitude with 2010 ocean economy data for the state of Louisiana (PricewaterhouseCoopers, 2009). In 2007, Mississippi shipbuilding led all other Gulf states in sales (\$1.2 billion), with 10 businesses employing over 10,000 workers (Mississippi Gulf Coast Alliance for Economic Development, 2007).

These values also do not include the contributions in ecosystem goods and services of other international communities around the

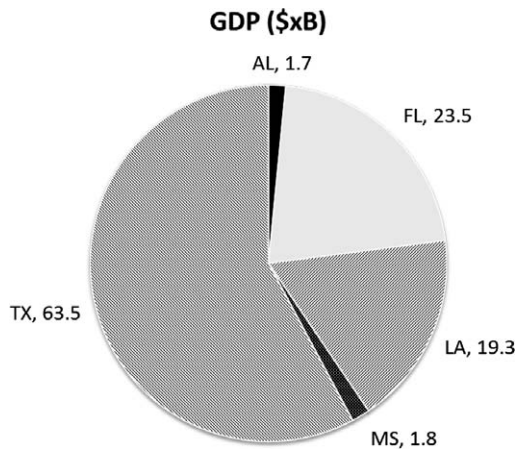


Fig. 2. Ocean economy GDP in 2010 by Gulf state: Gulf states contribute \$109.8 billion, or 40% of GDP, from all U.S. coastal states (source: NOEP, 2012a). Florida includes both Atlantic and Gulf coasts. County data is too sketchy to derive Gulf coast estimate.

Gulf (Mexico and Cuba). Total annual value for Mexico’s ocean economy derived from the Gulf of Mexico region includes: \$39.8 billion from oil and gas revenues, \$9.2 billion from tourism, \$0.38 billion from fisheries, and \$0.05 billion from transportation (UNIDO Project Coordination Unit, 2011). These sources raise the value of the Gulf ocean economy to over \$160 billion per year. Cuba’s GDP (official exchange rate) in 2010 totaled \$57 billion (CIA, 2012). Cuba hosts 2.5 million foreign tourists per year, mostly visiting coastal regions, and tourism is the nation’s largest source of foreign exchange

earnings (Institute for Cuban and Cuban-American Studies, 2007).

Over 70% of the Gulf ocean economy comes from mineral industries (Fig. 3), with 75% of these from oil and gas industries and the rest from sand and gravel. Energy revenues change routinely and dramatically due to market fluctuations. Yoskowitz (2009) estimated the annual value of the Gulf ocean economy on the basis of 2003 data to total \$124 billion, including \$77 billion from oil and gas activities, and noted that this was based on oil prices of \$28 per barrel in 2003, which rose to over \$100 in 2012, tripling oil and gas revenues to over \$230 billion per year. On the basis of the 3-yr average from 2008 to 2010, Gulf states (land and ocean) provide 54% of nation’s crude oil production, 52% of natural gas production, and 47% of crude oil refinery capacity (NOS, 2011). U.S. demand for energy resources is predicted to increase at an average annual rate of 0.3% from 2010 through 2035, although the nation will not likely return to the levels of energy demand growth experienced in the 20 yr before the 2008–2009 recession, due to moderate projected economic growth and population growth, coupled with increasing levels of energy efficiency (EIA, 2012). Domestic production will meet an increasing proportion of this demand in the increasing effort to reduce reliance on imported fossil fuels (Fig. 4). The U.S. Energy Information Administration predicts that U.S. production of domestic crude oil will increase from 5.5 million barrels per day in 2010 to 6.7 million barrels per day in 2020, and U.S. natural gas production will

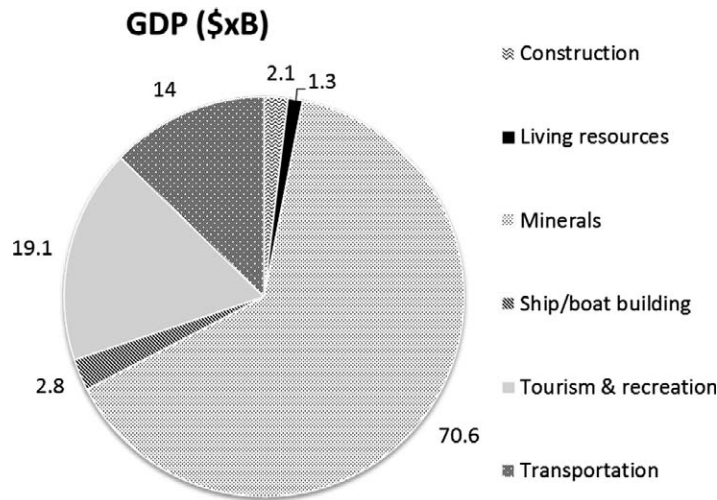


Fig. 3. Gulf ocean economy GDP contribution of \$109.9 billion in 2010 from all five Gulf states, combined by industry sector (source: NOEP, 2012a). Data include both coasts of Florida, and do not include state of Mississippi mining or ship-/boat-building GDP estimates, which are unavailable in the NOEP database.

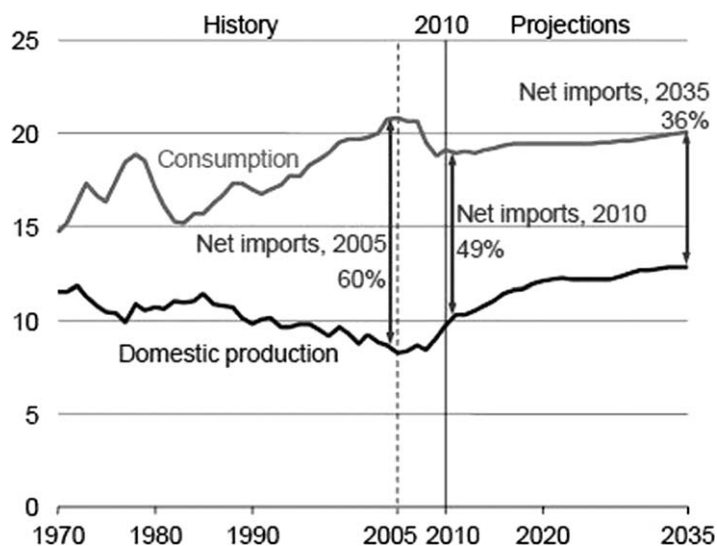


Fig. 4. Total U.S. petroleum and other liquids production, consumption, and net imports, 1970–2035 (million barrels per day) (from EIA, 2012).

grow by 1.0% per year, from 20 to 27.9 trillion cubic feet in 2035 (EIA, 2012). Lee and Garza-Gomez (2012) estimate the loss in market capitalization due to the DHOS to be from \$252 billion to \$562 billion as of September 19, 2010 when the Macondo well was permanently sealed, including: \$68.2–98.9 billion to BP; \$23.8–64.6 billion to eight Deepwater Horizon partners; and \$183.7–463.1 billion to other firms in the oil and gas industry.

The Oil Spill Commission (2011) observed, “The Deepwater Horizon oil spill put at risk two enormous economic engines ... *Tourism and fishing*, the industries affected as collateral damage, were highly sensitive to both direct ecosystem harm and, indirectly, public perceptions and fears of tainted seafood and soiled beaches.” These impacts continue for years after the spill (Lubchenco et al., 2012). In 2009, U.S. Gulf tourism and recreation industries generated over 16% of the Gulf’s GDP (Fig. 4), and supported over 620,000 jobs and \$10 billion in wages (NOS, 2011). Butler and Sayre (2010) estimated that just three coastal counties in Mississippi lost \$11 million in tax dollars from tourism (gaming, restaurants, hotels) alone between May and August, 2010. Addy and Ijaz (2010) estimated that Alabama may make DHOS claims for lost 2010 tax revenue due to tourism totaling \$149 million.

Gulf fisheries are some of the most productive in the world and yield more finfish, shrimp, and shellfish annually than the South and mid-Atlantic, Chesapeake, and New England areas combined. Gulf states are home to four

of the top seven fishing ports in the nation by weight, and eight of the top 20 fishing ports in the nation by dollar value (NOS, 2011). In 2008, the commercial fishing industry employed over 200,000 people in the region (NMFS, 2008). In 2009, commercial harvest from the five U.S. Gulf states was 1.4 billion pounds valued at \$661 million, about 16% of U.S. landings (Fig. 5; NOS, 2011). In 2009, marine recreational participants took more than 23 million trips, catching 173 million fish from the Gulf of Mexico and surrounding water, representing 31% of total U.S. marine recreational fishing trips and 44% of all U.S. marine recreational fishing catch (NOS, 2011). Impacts of the DHOS on Louisiana commercial fishing alone may exceed \$143 million in 2011–2013 (IEM, 2010). McCrea-Strub et al. (2011) estimated an annual loss of \$247 million in commercial fisheries landings due to DHOS. Sumaila et al. (2012) estimate that potential economic impacts in the decade following the DHOS on Gulf commercial and recreational fisheries and mariculture may result in lost revenue, profit, wages, and total economic impact with a present value of \$3.7, \$1.9, \$1.2, and \$8.7 billion, respectively, and the loss of over 22,000 jobs.

The Gulf is a critical national transportation region, generating 11.6% of Gulf GDP (Fig. 3). Seven of the top 10 busiest ports in the United States and 13 of the top 20 ports by tonnage were located in the Gulf of Mexico in 2009 (NOS, 2011). The Port of South Louisiana, located between Baton Rouge and New Orleans, handles the largest amount of shipping, in terms of

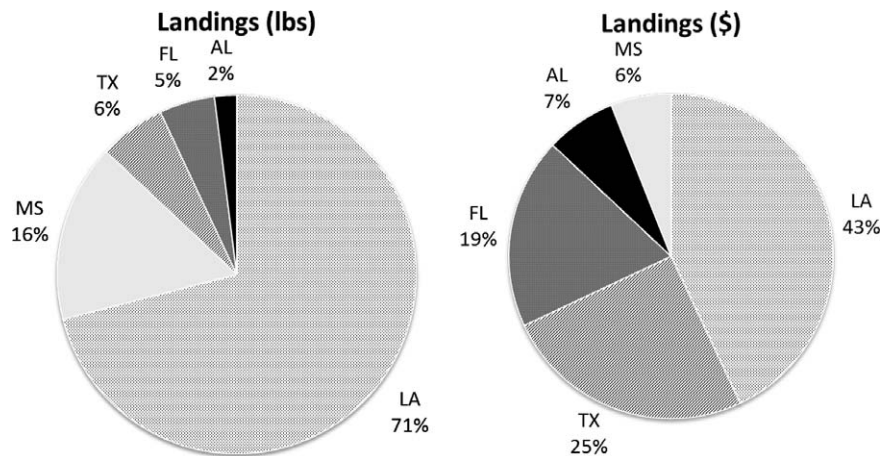


Fig. 5. Left, distribution of 1.4 billion pounds of commercial fish landings by state, average annual from 2007 to 2009; right, distribution of \$660 million of commercial fish landing value by state, annual average from 2007 to 2009 (from NOS, 2011).

tonnage, of all U.S. ports, is the largest volume shipping port in the Western Hemisphere and ninth largest in the world, largest bulk cargo port in the world, and is a critical transit point for the export of grain shipments from the Midwest, handling some 60% of all U.S. raw grain exports. Ports of New Orleans, South Louisiana, and Baton Rouge extend along the banks of some 172 miles (277 km) of the Mississippi River. These ports allow cargo to move to and from 33 states found along the river and its tributaries. The Mississippi River and its tributaries dwarf all other inland waterways in terms of tonnage of freight each year (Fig. 6).

Nonmarket value of Gulf ecosystem services.—Estimating a total economic value for Gulf ecosystem services that includes nonmarket values (from cultural, regulating, and supporting services) remains problematic. Yoskowitz et al. (2012a) pointed out that although some nonmarket ecosystem services may be considered “priceless,” this conclusion hinders our ability to integrate estimates of ecosystem services into complex decision-making processes. Although the field of ecosystem valuation has advanced significantly in recent decades, data and studies on nonmarket values (in the strict economic definition) are diffuse and complex due to the lack of standardized methodological approaches conducted at differing spatial and temporal scales, large variability due to lack of scientific data or missing values, and qualitative assessments and interpretations (Wilson and Farber, 2008; Yoskowitz et al., 2012a).

The NOEP does not provide a database of nonmarket values or shadow prices by services or states that can be used to estimate the regional

value of these services. Both the Harte Research Institute (HRI; Santos and Yoskowitz, 2013) and NOEP (2012b), however, do maintain online databases of nonmarket valuation studies from around the nation. NOEP (2012c) summarizes recreational nonmarket values (including beaches, recreational fishing, coastal and marine wildlife viewing, scuba diving, and snorkeling) from these references, including explanations of valuation methods. Kildow et al. (2009) used these studies and other resources to estimate nonmarket values for cultural services associated with ocean and coastal recreation in the Gulf of Mexico, ranging from \$19.5 billion to \$51.5 billion per year (Table 1; Kildow et al., 2009), not including tax revenues.

Localized, published valuations of regulating and supporting services provide insight into the magnitude of Gulf-wide value and may be applied to other areas by value transfer approaches (Wilson and Farber, 2008; Yoskowitz et al., 2012b). Bakter et al. (2010), for example, did a comprehensive valuation of Mississippi River delta regulating and supporting services and natural capital, as well as analysis of the value of restoration options in the wake of hurricanes, which indicated that Mississippi River delta ecosystem services alone are valued at \$12–47 billion annually. Further, this natural capital has a minimum asset value of \$330 billion to \$1.3 trillion (based on 3.5% discount rate). Yoskowitz et al. (2012b) identified expected changes in ecosystem services values provided by wetland habitats in the Galveston Bay region (99,000 acres), due to projected sea-level rise (SLR) from 2009 to 2100, utilizing value transfer and transferring metaregression analysis functions

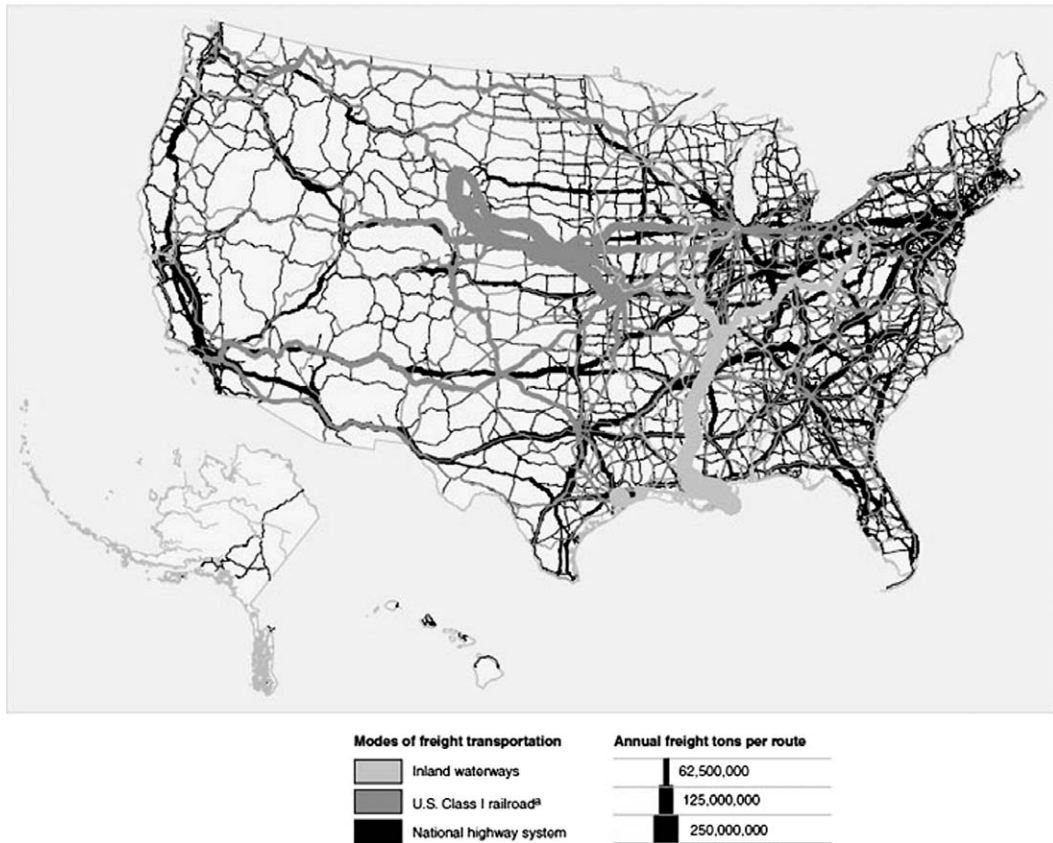


Fig. 6. Tonnage of freight on highways, railroads, and inland waterways based on 2007 data (from GAO, 2011).

to combine value estimates from multiple original studies and apply them to the policy site. A simple least-squares regression model was used to calculate the monetary value of selected ecosystem services provided by each chosen habitat in 2009 (initial condition) and 2100 under a conservative 0.69-m SLR scenario. The value for lost fresh marsh, salt marsh, and swamp, including all ecosystem services (nutrient cycling, disturbance regulation, food, aesthetics, recreation, and water regulation) totaled over \$100 million per year from 2009 to 2100. U.S.

Gulf coastal counties include 44 million ha (18.2 million acres) of wetlands, almost 17% of all the wetlands (land and coast) in the conterminous United States (NOS, 2011; Dahl, 2006). Recognizing that the transfer of Galveston Bay results across the Gulf may be problematic, for example, as SLR is not the same across the Gulf region and habitats vary in ecosystem function and service values, scaling up from Galveston Bay (99,000 acres) to the Gulf region (18.2 million acres) would result in a regional loss due to SLR and lost wetlands of \$18.4 billion per year.

TABLE 1. Estimated annual nonmarket values for selected recreational activities (nearest million \$) that generate up to another \$52 billion per year in nonmarket value of Gulf states' ecosystem services (from Kildow et al., 2009).

Activities	Alabama	Louisiana	Mississippi	Texas	Florida ^a
Beach	237–592	81–202	174–434	705–1,762	3,543–8,858
Swimming	164–410	92–230	135–337	592–1,480	3,222–8,055
Bird watching	118–472	228–911	181–725	401–1,605	1,949–7,795
Other wildlife	161–644	264–1,056	60–238	315–1,260	1,257–5,026
Fishing	253–422	749–1,249	280–466	986–1,643	3,377–5,629
Total—max. estimates	933–2,540	1,414–3,648	830–2,200	2,999–7,750	13,348–35,363

^a Includes Gulf and Atlantic coasts of Florida.

Studies from land and coastal habitats around the world demonstrate that the nonmarket value of an ecosystem is consistently two to five times greater economically when managed to sustain biodiversity and productivity vs conversion to farmland (MEA, 2005). Moreover, natural systems function better than human-altered systems as ecosystem service providers. Bakter et al. (2010) observed that “ecosystem functions, and the services they produce, result from broad interactions across large landscapes (e.g., storm buffering) or, in some cases, the whole planet (e.g., climate and carbon sequestration)...This interdependence and tremendous scale of operation makes nature the best producer of these life-sustaining goods and services. It would be scientifically impossible, and economically undesirable, to attempt to set up parallel human institutions, markets, and factories that could provide for global climate regulation, oxygen production, and provision of water.” MEA (2005) noted that “the loss of species and genetic diversity decreases the resilience of ecosystems, which is the level of disturbance that an ecosystem can undergo without crossing a threshold to a different structure or functioning. Growing pressures from additional drivers such as overharvesting, climate change, invasive species, and excessive nutrient loading push ecosystems toward thresholds that they might otherwise not encounter.” Once pushed to altered, less desirable states, nonresilient ecosystems may never return to predisturbance levels of ecosystem function (e.g., productivity, diversity) (Beisner et al., 2003; Folke et al., 2004). Functional diversity, trophic linkages, and connectivity between habitats affect ecological resilience, recovery of disturbed ecosystems, and sustained value of ecosystem services (Polis et al., 1997; Peterson et al., 1998; Valentine and Heck, 2005; Valentine et al., 2013). Declines of healthy coral reefs in the Atlantic after global bleaching in the late 1990s, for example, demonstrate the ecosystem-wide impacts of decline in a small suite of foundational keystone species and the dynamic complexity of recovery after major disturbances (Jackson et al., 2001; Baker et al., 2003).

Over 2 million ha (5 million acres) of wetlands found along the Gulf Coast represent half of the U.S. total (Turner, 2009). The most heavily oiled areas affected by the DHOS slicks were the beaches and wetlands of the Mississippi River delta. An estimated 593,400 ha (2,300 square miles) of historic Louisiana coastal marsh and cypress forest (out of 7,000 square miles) has been heavily affected by oil and gas industry activities (NOS, 2011). In the past decade, coastal Louisiana lost more than 0.3 ha of wetlands per hour and is facing

the highest rates of relative SLR in the nation, approximately 8 mm (0.3 inch) per year (Couvillion et al., 2011). Over one-third of Louisiana’s currently affected coastal wetlands will be lost by the year 2050 at current rates of loss (NOS, 2011). About 0.4 ha (1 acre) of wetland alone can store 5.7 million liters (1.5 million gallons) of floodwater, and wetlands in only 15% of a watershed can reduce flooding, risk of costly property damage, and loss of life by as much as 6% (NOS, 2011). Attempts to restore and mitigate the losses have been going on for decades in Louisiana (Turner, 2009). As Turner notes, a lack of precautionary science-based approaches to these projects, including in administration, management, and implementation phases, has resulted in negative consequences ranging from expensive failed restoration efforts, or worse, enhanced loss rates.

The oceans’ role as a carbon source and sink depends in part on the “biological carbon pump,” including photosynthetic uptake of carbon dioxide, biosynthesis of reduced carbon compounds, natural iron fertilization, grazing, sinking (and swimming) of organic matter into the deep ocean, and respiratory consumption of fixed carbon and remineralization into simpler inorganic forms—processes fostered by diverse, productive ocean ecosystems (Herr and Galland, 2009; Pollard et al., 2009). Globally between 1980 and 2000, productive coastal habitats including mangroves, tidal marshes, and seagrass meadows declined at an areal loss rate of 1–2% due to many human-induced impacts that can be controlled, such as aqua- and agriculture, forestry, coastal development, and mechanical damage due to vessels, dredging, and trawling (Murray et al., 2010). Carbon stored in these habitats, or “blue carbon,” includes carbon captured and stored by coastal wetlands or avoided emissions from conversion activities that enable release of greenhouse gases (Murray et al., 2010). Investing in protection of coastal habitats may be economically reasonable on the basis of carbon offset assessments. Mangroves, for example, cover only around 0.7% (around 140,000 km²) of global tropical forests and store up to 20 Pg of CO₂, (1 petagram is 1 billion metric tons), equivalent to roughly 2.5 times the annual global CO₂ emissions (e). Seagrasses, salt marsh, and mangroves store up to 5,500 tCO₂e/ha, sequester 18.7 tCO₂e/ha (several times more than forests), and may release up to 1 Pg annually due to land-use conversion (Laffoley and Grimsditch, 2009). Sequestration rate for seagrass habitats is a function of net community production (production vs respiration), which can vary widely (factor of four) among geographic regions and grass species (Duarte et al., 2010). Siikimaki et al.

(2012) suggest that preventing mangrove loss has the potential of reducing global emissions for a cost of roughly \$4 to \$10 t⁻¹ CO₂, compared with recent European Union Emission Trading Scheme carbon offset credit prices, which have remained between roughly \$10 and \$20 t⁻¹ CO₂. Although the U.S. market remains primarily a voluntary market, regional cap and trade regimes are either implemented or on the horizon (e.g., West Coast Climate Initiative Agreement signed by West Coast state governors in 2007).

Recommendations for integrating ecosystem service values in Gulf restoration decision-making.—NRC (2004), in its report, *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*, observed that “despite growing recognition of the importance of ecosystem functions and services, they are often taken for granted and overlooked in environmental decision-making. Thus, choices between the conservation and restoration of some ecosystems and the continuation and expansion of human activities in others have to be made with an enhanced recognition of this potential for conflict and of the value of ecosystem services. In making these choices, the economic values of the ecosystem goods and services must be known so that they can be compared with the economic values of activities that may compromise them and so that improvements to one ecosystem can be compared to those in another.” Their key recommendations for integrating ecosystem services valuation in restoration decision-making processes included:

- Economic valuation of changes in ecosystem services should be based on the comprehensive definition of total economic value, including both market-use and passive-use values.
- Concerted efforts should be made to overcome existing institutional barriers that prevent ready and effective collaboration among ecologists and economists regarding the valuation of ecosystem services.
- Existing and future interdisciplinary programs aimed at integrated environmental analysis should be encouraged and supported.
- Ecosystem valuation is most useful as an input into environmental decision-making when the valuation exercise is framed in the context of the specific policy question or decision under consideration.
- Valuation analysis should have the following components: a way of estimating the changes in ecosystem structure and functions that would result from implementation of the policy; a way of estimating the changes in

ecosystem services that result from the changes in structure and function; a way of estimating the value of these changes in ecosystem services, which involves integration of ecological and economic methods and models.

Our recommendations for new actions and investments address these NRC report priorities, the call of Lubchenco et al. (2012) for actions to improve successful application of nonmarket values into DHOS decision-making, and the recent NRC (2013) recommendations for incorporating the concepts of ecosystem services, in practice and in law, to oil spill damage assessment and recovery strategies. Objectives intended to improve understanding required to value and sustain Gulf of Mexico ecosystem goods and services include:

1. Establish Gulf of Mexico permanent funds to support strong sustainability using oil and gas revenues and DHOS settlement funds;
2. Develop national protocol for bringing ocean and coastal ecosystem services into carbon markets;
3. Support and establish new regional capabilities that integrate market and nonmarket values of priority Gulf ecosystem goods and services into ocean and coastal decision-making.
4. Support primary valuation studies of nonmarket ecosystem goods and services for the Gulf of Mexico.

Rationale and actions for these objectives follow.

1. Establish Gulf of Mexico permanent funds to support strong sustainability using oil and gas revenues and DHOS settlement funds: Heal (2012) highlighted regions running their oil-producing economies sustainably by conversion of natural capital (oil and gas) into financial capital. The financial capital yields dividends after the natural capital is fully depleted, compensating for the loss of natural capital by the accumulation of another form of capital. The Alaska Permanent Fund, for example, receives 25% of oil and gas royalties, accumulating \$28 billion since 1976, and pays an annual dividend to all Alaska residents, averaging over \$1,000 per year per person (<http://www.apfc.org/home/Content/aboutFund/aboutPermFund.cfm>). Since 1954, OCS oil and gas companies have paid over \$156 billion to lease offshore blocks, 80% from the Gulf region or an average of \$2.7 billion per year (BOEM, 2012a). Bureau of Ocean Energy Management (BOEM) awarded 181 leases on tracts cover-

ing 1,036,205 acres, netting \$325 million, in the western Gulf of Mexico Sale 218 of 2012 (BOEM, 2012b). As of 2011, 46% of this revenue goes to the U.S. Treasury General Fund, most used to support the BOEM and Bureau of Safety and Environmental Enforcement (formerly Minerals Management Service). The Outer Continental Shelf Lands Act mandates that 27% go to all oil-producing states located in the federal 8(g) zone (3 miles from state's seaward boundary). The Gulf of Mexico Energy Security Act of 2006 requires that Alabama, Louisiana, Mississippi, and Texas, and their qualified coastal political subdivisions receive 37.5% of the oil and gas revenues generated from leases issued in the Gulf of Mexico. Beginning in fiscal year 2017, the four states will annually share 37.5% of all qualified OCS revenues from all Gulf of Mexico leases issued after 20 Dec. 2006, in areas available for leasing at the time of enactment (BOEMRE, 2011).

Mabus (2010) observed, "While the full long-term effects of the [DHOS] spill will take time to determine, the negative environmental, economic, and social impact on the Gulf's habitats and communities may persist for years." Federal and non-governmental organization-led strategic plans produced in response to the DHOS event (e.g., Mabus, 2010; Brown et al., 2011; GCERTF, 2011; Ocean Conservancy, 2011; Oil Spill Commission, 2011; Peterson et al., 2011) call for support of a long-term monitoring program designed to assess and restore ecosystem services damaged by the spill, to monitor and improve the overall health of Gulf ecosystem goods and services degraded by many human and natural factors, and help prepare for future disasters. Two years after the DHOS, impacts of the spill were evident in a range of ecosystem components including coastal habitats and biota (Lubchenco et al., 2012; Mishra et al., 2012; Silliman et al., 2012; Dubansky et al., 2013), deep sea corals (White et al., 2012), and marine mammals (NMFS, 2012). Twenty years after the EVOS on Alaska's coast, ecosystem goods and services are still recovering (Exxon Valdez Oil Spill Trustee Council, 2010); the continuing EVOS restoration plan still includes research, monitoring, and habitat protection efforts.

New ecological data from a comprehensive Gulf-wide monitoring and observing system are required to provide a stronger foundation on ecosystem functioning and more robust economic values. NRC (2012) noted, "To assess the value of changes in ecosystem services from environmental impacts such as an oil spill, economic valuation methods need to be combined with

ecological assessments of impacts. Analysis of impacts on the supply of services combined with economic valuation methods can generate estimates of the value of changes in ecosystem services as a result of environmental changes." NRC (2004) recommended the required components of a comprehensive ecosystem valuation, which begins with science-based understanding of ecosystem structure and functions (Fig. 7).

In 2007, the Gulf of Mexico Coastal Ocean Observing System (GCOOS) developed strategic and build-out plans for a Gulf-wide Regional Coastal Ocean Observing System, estimated to cost \$130 million over 10 yr, including capitalization and annual operating costs required for the various subsystems (GCOOS, 2007). Considering a total value of the Gulf region to the nation of over \$2 trillion per year in GDP, and a likely minimal 1:1 return on ocean observing system investment (Kaiser and Pulsipher, 2004), DHOS settlement funds should be used to support the build-out of a Gulf-wide ecosystem monitoring program.

2. Develop national protocol for bringing ocean and coastal ecosystem services into carbon markets: Stern (2006) reported on an independent review to assess evidence and promote understanding of the economics of climate change. On the basis of review of scientific evidence and modeling analyses, they conclude that climate change is global in its causes and consequences. International collective action must drive an effective, efficient, and equitable global response, including co-operation in many areas such as creating price signals and markets for carbon, spurring technology research, development and deployment, and promoting adaptation. Unlike studies that only forecast impacts, the review identifies elements of a long-term pro-growth strategy. Their model analyses use the basic economics of risk and suggest that business-as-usual climate-change policies will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%, and an average 5–10% loss of GDP by 2050. Costs of mitigation through deep cuts in emissions to achieve stabilization at 500–550 parts per million CO₂e are estimated to be 1% of GDP by 2050.

The Stern Review further noted that ecosystems are particularly vulnerable to climate change, with up to 40% of species potentially facing extinction after 2°C of warming, and ocean acidification due to rising carbon dioxide levels. Establishing a carbon price for these resources, through tax, trading, or regulation, is viewed as an essential foundation

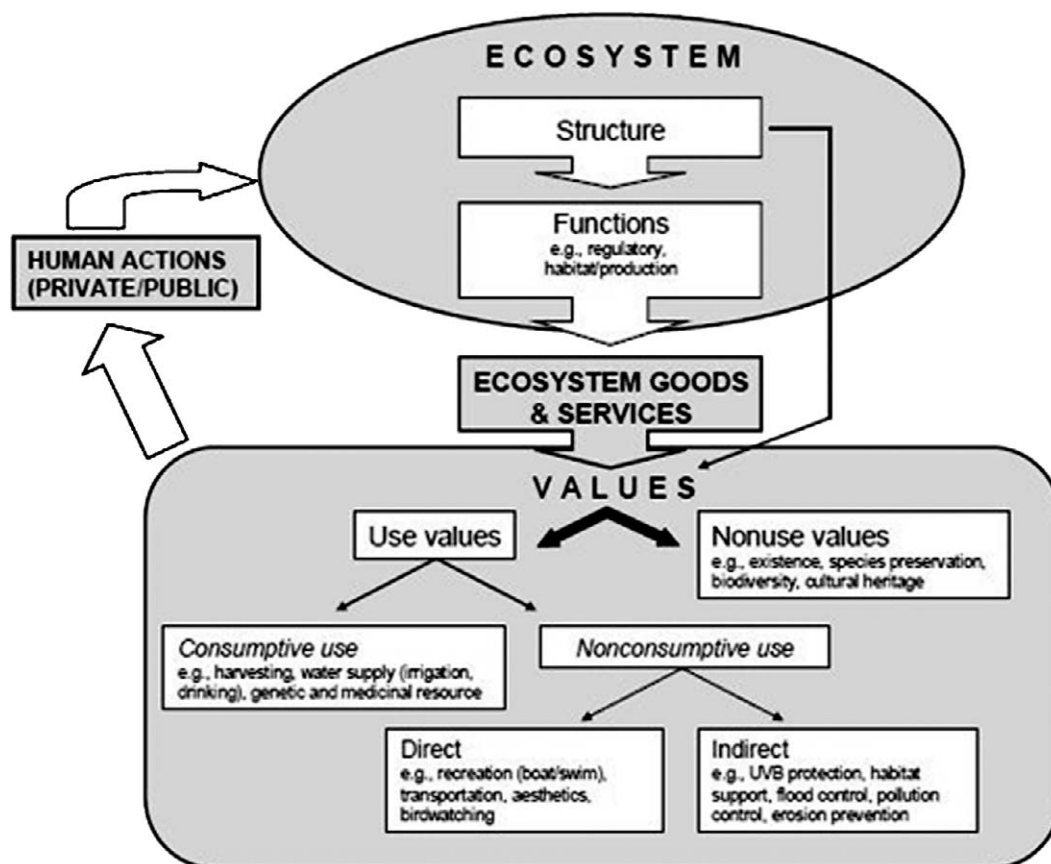


Fig. 7. Connections between ecosystem structure and function, services, policies, and values (from NRC, 2004).

for climate-change policy. Those who produce greenhouse-gas emissions and cause climate change, thereby imposing costs on the world and on future generations, must face the consequences of their actions. Carbon pricing also provides incentive to invest in new mitigation technologies and economic opportunities. Public spending on research, development, and demonstration must reverse declines over the last two decades, doubling of investments in this area to around \$20 billion per annum globally, to support the development of a diverse portfolio of these technologies.

The Stern Review concludes that in addition to mitigation, adaptation policy and actions are also crucial for dealing with the unavoidable impacts of climate change, and the only response available for the impacts that will occur over the next several decades before mitigation measures can have an effect. Governments must provide policy frameworks that include, for example, long-term policies for valuing, restoring, and conserving climate-sensitive public goods and services, including natural resources protection, coastal protection, and emergency preparedness.

Emmett-Mattox et al. (2011) identify developing a national protocol for carbon pricing as a critical next step in integrating coastal ecosystem services into decision-making and policy frameworks. Essentially, this protocol ensures that offset projects are suitable for receiving credits before credits are issued, and includes requirements and procedures adopted by registries and markets that enable creation of and accounting for project offset credits. Greenhouse gas offset registries and markets have varying protocol standards and required elements, but share commonalities. For tidal wetlands, for example, protocol may require that projects be ecologically appropriate, additional, permanent, and verified by an independent third party. A national tidal wetlands protocol would provide standardized criteria, methodologies, and tests that remove the burden from each individual project for having to prove that a restoration project merits offset credits. Critical to any successful blue carbon market is strong understanding of the biophysical and ecological functioning of habitat type in sequestering carbon (McLeod et al., 2011). Not

accurately accounting for carbon sequestration would damage the reputation of any market that was established or trying to establish itself.

3. Support and establish new regional capabilities that integrate market and nonmarket values of priority Gulf ecosystem goods and services into ocean and coastal decision-making: The Center for Blue Ocean initiated NOEP in 1999. Since 2004, data collection and database maintenance has been provided by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. The NOEP database is an invaluable valuation tool for market values (revenues), and not yet designed to quantify nonmarket values across U.S. regions (e.g., Kildow et al., 2009; Batker et al., 2010). Funding limits their ability to keep the database up to date and complete, and their ability to create useful derivatives such as the National Ocean Watch web site (NOEP, 2012a). Accurate and complete market revenues, and nonmarket valuation data, are critical to the renewed emphasis on ecosystem services valuation as a decision-support tool. This effort should be a national government priority and has begun to make its way into policy requirements such as the Principles and Requirements for Federal Investment in Water Resources (CEQ, 2013), where the evaluation framework requires that benefit/cost methods "...should apply an ecosystem services approach in order to appropriately capture all effects (economic, environmental, and social) associated with a potential Federal water resources investment." Additionally, the Sustaining Environmental Capital: Protecting Society and the Economy report (PCAST, 2011) also explicitly calls for the integration of ecosystem services into the decision-making process. As a result of these previous two efforts at the executive-branch level and the work of many groups in the Gulf region, the Draft Initial Comprehensive Plan from the Gulf Coast Ecosystem Restoration Council (GRC, 2013) has adopted five goals where ecosystem services are alluded to such as: "...ecosystem restoration activities that produce environmental benefits and reduce economic losses from storm surge flooding." The plan further requires that "...projects and programs that promote community resilience should be tied to ecosystem restoration or protection," thereby explicitly connecting the restored or protected habitats to the services that are potentially supplied from them. The National Research Council's report

on an ecosystem services and the DHOS (NRC, 2013) suggests three key research-related needs that should be supported to implement an ecosystem services approach for Gulf restoration decision-making:

1. There is a critical need for an overarching infrastructure for organizing and integrating the wealth of data that has been and will be collected in the Gulf of Mexico.
2. Although a substantial body of data exists to support a better understanding of ecosystem structure and function within the Gulf of Mexico, a comprehensive model that incorporates biophysical, social, and economic data for the Gulf of Mexico should be developed in the long term, whereas models for subcomponents of the Gulf of Mexico and its services are necessary in the short term.
3. Research and management focused on resilience, both in principle and in specific applications.

As Heal (2012) and Stiglitz et al. (2009) observed, the usual neoclassical measures of economic performance (e.g., GDP, unemployment, inflation) do not adequately cover the state of natural capital and may be misleading, suggesting the need for a continued search "for the data to produce a single number that can tell us convincingly whether we are sustainable." Adjusted net savings (ANS) is recommended as a better measure of sustainability that may provide warnings of impending environmental and economic crises, which conventional economic statistics fail to deliver. Calculating ANS includes a conventional measure of net investment in plant and equipment (investment net of depreciation), investment in human capital through education, investment in intellectual capital through research and development, and the degradation of natural capital (World Bank, 2011). Heal (2012) notes, however, that we are not yet able to construct this measure accurately because "we do not have good quantitative measures of some aspects of wealth, nor do we have measures of the economic values of several important types of wealth. Prominent among the categories of wealth that we cannot measure or value fully are some types of natural capital." Stiglitz et al. (2009) suggested that we measure ANS as best we can, continue to improve measures until we have good ones, and supplement the ANS with "additional data that indicate the physical state of some of the more important environmental threats that cannot be captured by a wealth measure, such as the concentration of

greenhouse gases in the atmosphere, the number of species close to extinction, and the acidity of the oceans.”

NOEP (2012a) and HRI (Santos and Yoskowitz, 2013) host bibliographies of value studies from around the world; values from existing Gulf studies and values from analogue ecosystems in other locations should be integrated in an online database and interactive mapping tool to enable a place-based, Gulf-wide (Large Marine Ecosystem scale) valuation of ocean and coastal ecosystems, with layers included for priority ecosystem elements (highest value and most sensitive habitats, living and nonliving resources) across the Gulf.

RESTORE Act includes funding for Centers of Excellence (section 1605), at least one in each Gulf state, devoted to science, technology, and monitoring, including the priority discipline of “sustainable and resilient growth, economic, and commercial development in the Gulf Coast Region.” In support of all the prescribed priority disciplines, one or more centers should address *Gulf Ecosystems Services Sustainability and Valuation*. Related justifications and tasks, based largely on NRC (2004), may include:

- Research at the “cutting edge” of the valuation field, such as dynamic production function approaches, general equilibrium modeling of integrated ecological–economic systems, conjoint analysis, and combined stated-preference and revealed-preference methods.
- Research on improved valuation study designs and validity tests for stated-preference methods applied, to determine the nonuse values associated with aquatic and related terrestrial ecosystem services.
- Development of a consistent process and guidelines for inclusion of ecosystem services into decision-making at all levels (e.g., local, state, and regional) regarding selection and evaluation of performance of DHOS restoration projects. Yoskowitz (2012a) observe that inclusion of ecosystem services may allow for a better selection among alternatives by showing which project provides the most benefits or targets the desired ecosystem services, leading to improved assessment and decision-making.
- External review by peers and stakeholders of ecosystem valuation studies early in their development when there remains a legitimate opportunity for revision of the study’s key judgments.
- Increased interdisciplinary training and collaborative interaction among economists and ecologists; we add the need to increase support for university-level education to train the next-generation workforce of ecological economists.

4. Support primary valuation studies of non-market ecosystem goods and services for the Gulf of Mexico: The DHOS settlement provides opportunities for initiating a permanent fund devoted to research and development to support decision-making related to both restoration and conservation of Gulf ecosystem goods and services. Yoskowitz et al. (2012a) concluded that strong understanding of an ecosystems’ structural (biophysical) and functional (ecological) elements is required to quantify ecosystem services. The quantification of ecosystem services is considered to be an ongoing challenge and more work in the natural and social sciences is needed to effectively measure them, in both monetary and non-monetary terms. At the same time, we must begin to integrate ecosystem services values into the decision making process where we do have enough information. Measuring changes from baseline conditions (as assessed using various indicators of ecosystem function) is required for quantifying changes in ecosystem services; however, baseline information often does not exist. More scientific knowledge about the natural processes behind the provision of services is needed to help economists value ecosystem services and improve current valuation methods.

New primary valuation studies for the Gulf of Mexico should be supported to fill in critical gaps. These may include revealed-preference, stated-preference, and cost-based valuation methods, as well as value transfer (single point/average or function) methods (NRC, 2012). The latter may be required, for example, for transferring results from studies far removed from the Gulf. The NOEP and GecoServ databases provide excellent starting points to initiate value transfer applications and identify the gaps. The Gulf of Mexico Sea Grant programs, NOAA, and EPA Gulf of Mexico Program recently invested \$1.3 million in primary valuation research for the Gulf focusing on marsh, oysters, and mangroves (NOAA, 2012). This is a strong start but there is still a need to value other critical habitat types such as seagrass, barrier islands, and pelagic ecosystems.

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