Artificial modifications of the coast in response to the *Deepwater Horizon* oil spill: quick solutions or long-term liabilities?

M Luisa Martínez[1*], Rusty A Feagin[2], Kevin M Yeager[3], John Day[4], Robert Costanza[5], Jim A Harris[6], Richard J Hobbs[7], Jorge López-Portillo[1], Ian J Walker[8], Eric Higgs[9], Patricia Moreno-Casasola[1], Julio Sheinbaum[10], and Alejandro Yáñez-Arancibia[11]

The *Deepwater Horizon* oil spill threatened many coastal ecosystems in the Gulf of Mexico during the spring and summer of 2010. Mitigation strategies included the construction of barrier sand berms, the restriction or blocking of inlets, and the diversion of freshwater from rivers to the coastal marshes and into the ocean, in order to flush away the oil, on the premise that these measures could reduce the quantity of oil reaching sensitive coastal environments such as wetlands or estuaries. These projects result in changes to the ecosystems that they were intended to protect. Long-term effects include alterations of the hydrological and ecological characteristics of estuaries, changes in sediment transport along the coastal barrier islands, the loss of sand resources, and adverse impacts to benthic and pelagic organisms. Although there are no easy solutions for minimizing the impacts of the *Deepwater Horizon* disaster on coastal ecosystems, we recommend that federal, state, and local agencies return to the strategic use of long-term restoration plans for this region.

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On 20 April 2010, the drilling rig *Deepwater Horizon* exploded over the Macondo Prospect oil field and subsequently sank, initiating the release of huge amounts of petroleum and natural gas into the Gulf of Mexico. Almost 3 months later, on 15 July 2010, the corporation responsible for the accident reported that the leak had been stopped by placing a cap on the wellhead.

Dimensions of the problem

Considerable uncertainty remains regarding the actual oil-flow rate and the total amount of oil spilled because of the difficulty of installing accurate measurement devices at the depth at which the well was situated (~1500 m). The best estimate of the spill rate was 60 thousand barrels (~2.5 million gallons) of crude oil per day, which represents a total of about 5.2 million barrels (~216 million gallons) during the 86 days that the well was leaking (Kerr 2010). This was the second largest oceanic oil spill in history, topped only by the combined output of the Arabian Gulf spills that occurred in 1991 (~336 million gallons; NOAA 2010). By comparison, the *Exxon Valdez* oil spill in Alaska in 1989, which generated considerable national and international attention, was much smaller (10.8 million gallons; NOAA 2010).

Because the *Deepwater Horizon* spill originated deep underwater, its effects were "three-dimensional", contaminating a large volume of the ocean water column, millions of hectares of the ocean surface, and probably large areas of the seafloor as well. Residual oil plumes and tar balls are still impacting more than 100 km of the southern US coastline, and a full cleanup is expected to take years. Estimates vary considerably regarding how much of the oil was removed by the initial attempts at skimming and burning. It has been estimated that perhaps 23% of the oil released from the well was dissolved or evaporated, approximately 13% was dispersed naturally and, as a result of the widespread application of the chemical dispersant COREXIT® 9500, around 16% remains as microscopic droplets suspended in Gulf waters (Lehr *et al.* 2010). The residual amount (~38%) was thought to have been either washed ashore or buried in seafloor sediments. These estimates should be considered with

In a nutshell:

- The *Deepwater Horizon* oil spill seriously impacted coastal ecosystems
- Sand berms were built, inlets were restricted or blocked, and freshwater was diverted from upstream to protect coastal ecosystems from oil exposure
- These projects are likely to compound rather than limit ecological damage
- Financial and other resources would be better used by following established, long-term restoration plans

[1]*Red de Ecología Funcional, Instituto de Ecología, Xalapa, Veracruz, México* *(marisa.martinez@inecol.edu.mx); [2]*Department of Ecosystem Science and Management, Texas A&M University, College Station, TX;* [3]*Department of Marine Science, University of Southern Mississippi, Stennis Space Center, MS;* *(continued on p49)*

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caution, however, because accurate measurements were difficult to make.

Ecosystems at risk

Many ecosystems – including deep-sea benthic environments, the pelagic ocean, beaches and dunes, estuaries, and tidal brackish and freshwater wetlands – and numerous species were, and remain, at risk of long-term detrimental effects as a result of the oil spill. These ecosystems provide valuable ecosystem services to society, including fisheries, recreation, habitat refugia, water purification, climate regulation, carbon sequestration, hurricane protection, and nutrient cycling (Batker *et al.* 2010).

The movement of surface waters is unpredictable beyond a few days; ocean currents in the Gulf of Mexico are highly variable and are dominated by the presence of an intense eddy field in the open Gulf, seasonal changes in continental shelf currents, tides, winds, hurricanes, and waves. The lingering effects of the oil spill and oil-dispersant mixtures residing in the ocean are currently unknown and subject to intensive research. However, the risk of damage to neighboring states and other countries is by no means over. The potential impacts on coastal communities and the geopolitical consequences of the spill could be extensive; more than 15 million people from three nations (11 states in the US and Mexico, combined, plus Cuba) live in the coastal areas bordering the Gulf of Mexico. Protection of these coastal ecosystems is therefore an international necessity. In particular, the marshes on the Alabama, Florida, Louisiana, and Mississippi coasts are in special need of attention because their proximity to the oil well increased their exposure and because large and economically important fisheries are located in these ecosystems.

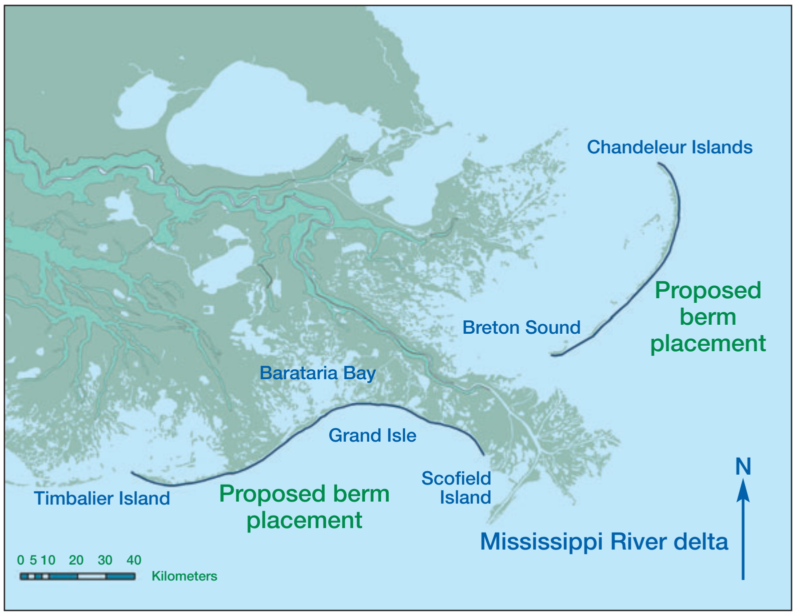

Figure 1. *Location of the proposed sand berms along the Louisiana coast. Adapted from Lavoie* et al. *(2010).*

Analysis of oil-spill mitigation efforts

The *Gulf Coast Restoration Plan,* pledged by President Obama on 16 June 2010 and subsequently expanded (The White House 2010), was aimed at mitigating the ecological, economic, and social damage due to the oil-spill's impacts, as well as recovering the thousands of square kilometers of wetlands that have vanished over the past century due to poor watershed management, stream diversion, levee construction, hydrological alteration, and diminished sediment supply (Day *et al.* 2007). However, the details of how, or even if, this restoration is to be carried out are incomplete, and it is unclear how this effort relates to the long-term restoration plan already in place for Louisiana (ie the Coastal Protection and Restoration Authority's master plan; CPRA 2010).

On 11 May 2010, in direct response to threats to coastal ecosystems, the State of Louisiana requested emergency authorization from the US Army Corps of Engineers to perform spill mitigation work on all barrier islands, from Grand Isle and areas west, and from Grand Terre Island eastward to Sandy Point, as well as around the Chandeleur Islands. This request had no overt links to the Coastal Protection and Restoration Authority's master plan, nor was it connected with President Obama's *Gulf Coast Restoration Plan*. Furthermore, the request was made without consulting the regional scientific community. Its stated purpose was to enhance the capability of the barrier islands to reduce the amount of oil reaching coastal marshes. The proposal included the following actions: (1) building a barrier sand berm on the seaward side of existing barrier islands, and (2) closing some inlets between barrier islands and reducing the cross section of some inlets by partially filling them with large rocks (Lavoie *et al.* 2010).

The premise was essentially twofold: (1) sand berms can function as a geomorphic obstruction to, and an ecological filter for, oil spills, thereby protecting coastal marsh and estuarine ecosystems; and (2) spill cleanup is easier on sandy (dredged) substrate than in marshes and wetlands. In spite of intense controversy surrounding this project, it was partially authorized on 27 May 2010 (*Deepwater Horizon* Response 2010). The US Army Corps of Engineers approved a permit for 46 miles of sand berms to be constructed on the Chandeleur Islands (on the eastern side of the Mississippi River's outlet to the Gulf) and from Scofield Island to Timbalier Island (on the western side) (Figure 1; USACE 2010). As of 22 November 2010, 12.5 miles of berms had been completed (Figure 2; USACE 2010). Subsequently, authorities from the state and coastal counties presented a plan to use rock

Figure 2. *Building sand berms (with dredged sand) along the Louisiana coast.*

barriers to close some inlets into Barataria Bay to prevent oil intrusion into the estuary. This permit request was denied (USACE 2010).

A similar situation occurred on Dauphin Island, Alabama, where berms were constructed in May 2010. During Hurricane Katrina, a large gap was created as the island was cut in half by the storm surge (Feagin and Williams 2008) and the "Katrina Cut" project was subsequently initiated to block a major inlet (Figure 3). The aim of the approximately $13 million Katrina Cut project was to fill and armor the gap with a combination of geo-textile tubes and riprap (a barrier consisting of large rocks or lumps of concrete). Initially, the plan was to re-open the inlet once the oil risk abated, although this has since changed; the intention now is to leave the barrier in place.

Freshwater diversions were also used in an effort to mitigate the impacts of the spilled oil. In late April 2010, the State of Louisiana opened floodgates into the Barataria Bay and Breton Sound basins, the premise being that by increasing the quantity of water flowing down the basins, oil could be prevented from approaching coastal marshes and penetrating inland. The initiated flow rate was much greater than that recommended in long-term planning documents describing the purpose of these diversion structures, which was to maintain salinities appropriate for fish and oyster production and to allow sedimentation into submerging wetlands (CPRA 2010).

Decisions to construct sand berms, fill inlets, or divert freshwater as protective measures against encroaching oil should be based on scientific knowledge and experience, and should take into account long-term restoration and management plans. To the best of our knowledge, there are no documented examples in the peer-reviewed literature of the effectiveness of these methods in mitigating oil-spill impacts on coastal ecosystems. The role played by natural barrier islands in reducing erosion rates of inland coastal margins has been extensively investigated in this region (eg Stone and McBride 1998); however, there is little evidence of the successful use of constructed sand berms for oil protection in the literature (Froede 2007). The absence of evidence to support or refute the effectiveness of these methods in mitigating coastal ecosystem oil impacts underscores the importance of involving the scientific community in decision making and the integration of any coastal oil-spill mitigation strategies into existing coastal restoration plans. Below, we outline scientific and technical considerations that bear directly on the *Deepwater Horizon* accident and the subsequent remediation efforts.

Mitigation strategies

Sand berms

The amount of sediment needed to build the proposed sand berms in Louisiana alone is substantial. Estimates show that building a 2-m-high, 130-km-long barrier requires 2 million cubic meters of sand (Bahr 2010). The Northern Gulf region no longer features a continuous chain of islands for a variety of reasons, including human perturbations in sediment supply, sea-level rise, subsidence, and periodic hurricane damage (eg Otvos and Carter 2008). In this context, any sedimentary modification will be relatively short-lived. There is also the question of where the sediment for the berms comes from. Offshore sandy sediment resources are limited in extent and volume (Kulp *et al.* 2005), and the transport of suitable sediment from farther afield (Finkl *et al.* 2006) can be prohibitively expensive in terms of both time and resources. Sediment is precious in this region and should be used strategically (Kulp *et al.* 2005; Finkl *et al.* 2006). Moreover, when planning any large-scale dredging operation (Figure 2), serious consideration must be given to the potential impacts on in situ benthic organisms and habitat, and the potential for increasing turbidity and its effects on pelagic flora and fauna (Wilber and Clarke 2001; Erftemeijer and Lewis 2006).

Inlet restrictions

Inlets, particularly their geographical positions, are critical to the hydrological and ecological function of bays and estuaries. Geomorphic and ecological changes are likely to occur in locations where sand berms or other oil-spill mitigation operations block or restrict inlets. Profound alterations to sediment and biological transport routes are possible whenever local hydrology is manipulated (Chaibi and Sedrati 2009). The reduction of inlet volume decreases the exchange of water and sediments during tides (Kraus and Militello 1999). This, in turn, affects flow velocities, typically resulting in scouring along bank margins, while near-shore wave dynamics often change as well (Komar 1996). The closing of inlets can modify the salinity, oxygen level, and turbidity of back bays. Associated ecosystems often experience large fish kills or other radical shifts toward new ecological states, as physical and chemical parameters adjust to a decrease in mixing throughout the water column (Goodwin 1996). If inlet restriction is absolutely necessary, it should aim to minimize the impacts on local hydrology and ecosystem function.

Figure 3. *Crews blockade the inlet with riprap at Katrina Cut on Dauphin Island, Alabama. This view is from the uninhabited west end of the island, looking across the inlet toward the heavily developed east end.*

Long-term barrier dynamics

Barrier islands, inlets, and sand resources are dynamic features of regressing coastlines. They change shape and move in response to ocean currents, winds, hurricanes, and storm surges (Grasso *et al.* 2009). All barrier islands are subject to, and impacted by, sand supply and mean sea level, but the details of how they form differ. Barrier islands along the southeastern US coastline are formed by natural wave, tidal, and aeolian processes. In contrast, the barrier islands of the Mississippi Delta were formed by the deposition of silt-laden sands arriving from upstream, and have a relatively short life cycle as compared with coastal barrier islands elsewhere. Additionally, the other Gulf barrier islands differ from those in North Carolina, for example, by being more sand starved and by being exposed to higher rates of relative sea-level rise due to high local subsidence rates.

Construction of sand berms and inlet restrictions should be based on knowledge of consolidation loading to the underlying sediment (eg compaction of sediments relative to sea level), overwash processes, and other features associated with long-term barrier island migration (Rosati and Stone 2009) or broad-spatial-scale littoral processes (Kraus and Militello 1999). In this sense, berms will be easily eroded, overtopped, and assimilated into the littoral budget of the islands. For example, Sallenger *et al.* (2009) observed exceptionally large geomorphic changes in the Chandeleur Islands as a result of several storms. In the broader context of the loss of these islands, relatively small waves from Hurricane Alex (2010) breached and eroded 2-m-high berms in southwest Louisiana and the Chandeleur Islands. Although provision of sand to the adjacent islands could be a positive outcome of rapid erosion, this would still represent a relatively expensive, non-strategic use of sediment resources.

In contrast, wherever inlets are blocked or restricted, the sedimentary and biological responses will be long-lasting and far-reaching. Inlet restriction projects, while initially driven by a sense of urgency to prevent oil from reaching estuaries, may turn out to have the most detrimental effects on estuarine ecosystems. The current trends in coastal science and engineering research lead in the opposite direction, toward a measured and strategic use of human engineering in the context of overwhelmingly large, powerful, and long-term natural processes (Feagin *et al.* 2010).

Freshwater diversions

Earlier studies that tested the effectiveness of river diversions in removing nutrients and organic loads draining into adjacent streams and rivers concluded that such strategies are useful. Mitsch and Day (2006) found that the use of these large freshwater diversions (maximum discharge 150–200 $m^3 s^{-1}$) was sufficient to remove from rivers and streams a substantial percentage (> 60%) of the nitrate–nitrogen supplied to these fluvial systems by farmland runoff. At the same time, the diversions increased the supply of sediments and nutrients to coastal areas, where they are needed to rebuild eroding marshes.

Because these studies have shown that freshwater diversions can flush contaminants downstream and potentially away from the coast, the State of Louisiana opened diversion structures in the Barataria Bay and Breton Sound basins, in an attempt to prevent oil from flowing into coastal marshes. The general consensus among researchers and fishermen has been that this action devastated oyster recruitment, and is projected to wreck the oyster harvest for approximately 3 years (Greater New Orleans Inc Regional Economic Alliance 2010). In terms of reducing oiling, there has been no scientific evidence to support or refute that the use of freshwater diversions was effective in the Gulf. As with any environmental manipulation, there is a need for formal and rigorous research to reduce uncertainties and to ensure that the benefits are likely to be greater than potentially negative side effects.

Conclusions

Coastal ecosystems are dynamic, which means there are inherent risks for their inhabitants; hurricanes, storm surges, tsunamis, and rainfall-induced flooding are natural hazards, some of which may increase in frequency and/or magnitude with climate change. Continued pressure to increase oil extraction from coastal zones may lead to further stress on coastal ecosystems and recurring contaminant spills, resulting in large-scale and temporally extended social and economic impacts. The coasts of the Gulf of Mexico have been exposed to two of the five largest oil spills in history, many minor oil spills, and ongoing natural leaks (Jernelöv 2010). This necessitates a carefully considered approach to any restoration efforts for the Gulf's ecosystems.

Sand-berm construction, inlet modification, and the use of freshwater diversions to reduce oil exposure are high-risk strategies with dubious short-term effectiveness and potentially long-term negative implications. They involve the expenditure of large amounts of finite material and fiscal resources. Responses to the *Deepwater Horizon* accident appear to have been largely politically motivated, with little input from the regional, national, or international scientific community. Why did this happen? Why did risky programs, based on little or no technical or scientific evidence, continue to move forward? Are we prepared to deal with the lasting side effects? Did these projects make any difference to oil-spill remediation? The answers to these questions are largely unknown.

Comprehensive coastal restoration plans, including the CPRA (2010), have been extensively developed, and there is broad support for them from scientists and stakeholders. The consideration and development of these restoration plans is in direct contrast to the poorly planned schemes aimed at limiting the impacts of the *Deepwater Horizon* oil spill. The scientific community is regularly portrayed as being internally conflicted on many environmental issues and consistently calling for more research; in this particular case, however, the existence of a comprehensive plan should have at least provided a secure platform for developing an effective, efficient, and engaged approach to ecological restoration. In this instance, the scientific community had delivered clear, comprehensive recommendations, but these were not adequately taken into account.

Were there other alternatives? Another option may have been to simply do nothing in direct response to the spill, and instead to redouble commitment to the CPRA. Some oil-spill damage may have been inevitable, yet the responses to it (eg artificial sand berms) may, in the end, cause even greater long-term harm to coastal ecosystems. In trying to reduce harm, we may have introduced more and longer-range impacts.

The challenges involved in designing mitigation and restoration plans are extensive and complex, and need to balance environmental and socioeconomic benefits. Ultimately, to prevent future disasters like the *Deepwater Horizon* spill, we need to shift the burden of risk (prior to the approval of drilling permits) more directly to the oil companies by improving and enforcing regulations, and requiring adequate insurance or assurance bonds to indemnify the public (Costanza *et al*. 2010). It is of particular concern that a Mexican oil company has begun the exploration and drilling of deep-water oil/gas wells, even though there is no regulation of these activities and no research regarding their safety and/or possible impacts in case of an accident. In addition to exploring for new wells, it is time to invest in research, development of safety procedures, accident prevention, long-term monitoring, and environmental conservation and restoration. We need to ensure that the shock of the oil spill does not distract us from the development of a viable, long-term plan for the restoration of the Gulf Coast. Elements of such a plan are already in place and judicious implementation needs to begin.

Finally, a year after the oil spill began, the results of studies to assess whether these artificial modifications of the coast actually worked, or if their impacts were worse than the spill itself, are beginning to trickle in. It is time to develop methods, policies, and institutions to act on that knowledge.

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[4]*Department of Oceanography and Coastal Sciences, School of the Coast and Environment, Louisiana State University, Baton Rouge, LA;* [5]*Institute for Sustainable Solutions, Portland State University, Portland, OR;* [6]*Department of Natural Resources, School of Applied Sciences, Cranfield University, Bedfordshire, Cranfield, UK;* [7]*School of Plant Biology, University of Western Australia, Crawley, Australia;* [8]*Department of Geography, University of Victoria, Victoria, British Columbia, Canada;* [9]*University of Victoria, Victoria, British Columbia, Canada;* [10]*Oceanografia Fisica, Ensenada, Baja California, Mexico;* [11]*Red de Ambiente y Sustentabilidad, Instituto de Ecología, El Haya, Xalapa, Veracruz, México*