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How can the earth sciences (e.g., geology, hydrology, the perspective of deep time) inform our perceptions about the future of this region?

I have taken the question of "how earth sciences inform our perceptions about the future of this region" in a slightly different light. The real question of how earth sciences influence our perceptions needs to be posed more in a manner of asking how do we reconnect people (their perceptions, thinking and actions, for everyone is connected) with their local, regional and global environmental support systems. The future of the Gulf Coast region will be very much influenced by natural events including hurricanes, tornadoes, river flooding, and anthropocentric activities, such as "development" of barrier islands and continued elimination of wetlands and coastal wetland forests. All of these factors need to be placed in the context of rising sea levels, changing temperatures, and modified weather patterns resulting from global climate change. Even though the public focus and news presently follows the New Orleans reconstruction, it is urgent that the circumstances leading to the hurricane disaster be placed into a broader context of changes in the river systems within the US and much of the world. Postel and Richter (2003) summarize findings of an National Research Council committee on the status of aquatic ecosystems in the U.S. The report finds that the U.S. has lost nearly 117 million acres of wetlands since the 1800's, representing a 30% loss of presettlement wetland area. In addition, 85% of the inland surface waters are artificially controlled and greater than 50% of the perennial rivers have fish populations disturbed by turbidity, high temperatures, toxins, or low dissolved oxygen. Forty percent of the rivers are affected by low flows and 41% affected by siltation, bank erosion and channelization. These factors also influence the response of the gulf coast biotic communities, as the Mississippi River drains much of the Midwest into the Gulf.

Earth sciences can only inform our perceptions if we, as a society, begin to understand our position and responsibilities in the wider realms of "place," locally, regionally and globally. The earth sciences must be taught as an integrated whole in courses. Researchers must be willing to express ideas to the public and not be limited to imparting their knowledge in academic journals or college lecture halls. Today's students are largely shut off from the world having spent much time indoors, with electronic input from cell phones, radios, and video games (Orr 1992, p 134). Orr notes that, overall, knowledge of nature has declined noticeably in the last few decades. He states that, "now, Americans possess an extremely limited understanding of animals, natural systems, and major conservation issues". Orr sees ecology as a science lending itself to coordinating or at least linking the earth sciences together. In many Biology Departments, Ecology as a field of study has often been isolated from the social sciences, humanities and professions.

The critical issues facing the reconstruction of New Orleans, as a specific example, are part of the broader issue of human development along coastal waters and the localized, unlinked management of resources such as water and wetlands. By unlinked I mean that we need a new management paradigm, one that calls for management of land and water resources on a watershed-scale basis. What can earth sciences do to best guide human activities towards this end? The answer, I think, can focus on two issues: biotic integrity of rivers and wetlands and sustainable use of water resources.

Ecology and the Gulf Coast ecosystem: Understanding the interdependence of rivers, bays and estuaries.

There are three sources of risk that New Orleans faces in rebuilding (Sparks 2006): The first source includes the winds, rain torrents, and storm surges from hurricanes that arise from the Atlantic Ocean. The second is water vapor and higher temperatures in the Gulf of Mexico, which combined induce heavy rainfall in the area. The third source of risk is the water of the Mississippi River when it overflows its banks.

The Mississippi River has had a long history of meanders across the alluvial plain at its mouth at the Gulf of Mexico (Sparks 2006). Throughout its history, it has brought down sediment from the Midwestern states and deposited its load as "lobes" that constitute the alluvial plain (the Delta). Sparks describes he Delta as roughly a triangle, with the upstream Atchafalaya River at the apex of the triangle. If New Orleans were not maintained as a deepwater port, the Atchafalaya River would be carrying most of the Mississippi River flow. It is a much shorter distance to Atchafalaya Bay (112 miles) from the Delta apex than the present course of the Mississippi River (from apex of the Delta to the mouth is 225 miles) (Sparks 2006). Because of dams on the Mississippi River, it now carries 50% less sediments than in the 1950s. (Baron, Poff et al. 2002) estimate that 1.2×10^9 m^3 of sediment is accruing yearly in river reservoirs throughout the world and is not consequently being deposited in coastal marshes or bays. This contributes to loss of sand on beaches in the Gulf coast.

One connection rarely understood or appreciated by the public is that floodplain ecosystems (including downstream estuaries and marshes) are dependent on naturally dynamic river-flow patterns (Rood, et al. 2005). Dams induce physical changes on river flow with biological consequences (Ward and Stanford 1987). The physical components include river and floodplain hydrology, sediment movement, and channel structure. The biological components are, simply, all the flora and fauna. The consequences of dam building are changes in community structure (e.g., species composition and number) and function (nutrient cycling, energy flow). Flood pulses (re-set mechanisms) rejuvenate riparian forests and can be thought of as equivalent to fires in upland forests. Sediment deposition in upstream reservoirs increases erosion downstream from the release because the released water has higher "competence," implying it can (and will) carry more sediments (Leopold 1997). In short, the river's erosional power is greater.

A truism is that all rivers are connected to their floodplains, if only by the fact that the rivers are responsible for having created the valleys they drain. However, there is a stronger connection between the river and its valley: terrestrial organic matter (leaves, sticks, dead organisms, etc.) are critical for aquatic ecosystem function (Baron, et al. 2002); (Vannote, et al. 1980). The organic matter is seasonal, and of all sizes. Many aquatic and amphibious species feed at various trophic levels and form functional feeding groups (detritivores, burrowers, scrapers, etc). The invertebrates, algae, bryophytes, vascular plants, and bacteria of the benthos are responsible for much of the water purification that goes on in aquatic ecosystems (Baron, et al. 2002).

Loss of Mississippi River delta wetland and coastal sediments.

Several reports have documented the fact that the Delta has been increasing losing wetlands. The net loss of wetlands is greater than 4,000 km^2 from the Louisiana coastal zone. In 1930, there was 22,000 km^2 of extant wetlands, whereas in 1990 there was only 18,000 km^2 (Cardoch, et al. 2002). This loss of wetlands and the ecosystem services they provide is serious, as approx 50% of the population of Louisiana live in coastal parishes. In fact, the population increased from 500,000 in 1890 to greater than 2 million in 1990 (Cardoch, et al. 2002). Those authors note that, as a result of sediment loss and canal dredging, there has been subsidence in the marshes and a net loss of 1.23 cm/ year (a value 10 times the average world-wide eustatic sea-level rise). Interestingly, the total costs of flood control, navigation, oil and gas extraction in the Mississippi exceeds $12 billion (Cardoch, et al. 2002). Annual maintenance is also expensive and placed at $ 461 million. However, those authors estimate the non-market value of the lost marshes to be $29.4 billion. The 1993 flood in the upper Mississippi River, with $16 billion losses, might not have been so dramatic if 53,000 km^2 of wetlands had been available to capture and store the water (Mitsch, et al. 2001).

Deltas are maintained by riverine inputs. They are dynamic systems with flow regimes that range from daily tides to switching of river channels occurring over hundreds or thousands of years. Infrequent events, such as channel switching, great river floods, and strong storms (hurricanes) result in major spatial changes in geomorphology (Leopold 1997). More frequent events (annual floods, frontal passages, daily tides) maintain salinity gradients, deliver and re-distribute nutrients, transport organisms and sediments and organic materials, and enhance ecosystem productivity (Rood, et al. 2005). Deltas are in danger from human activities, as sediment and nutrient inputs are reduced. Deterioration of the barrier islands results in increased wave energy that erodes coastal marshes. Sediment reworking is part of the dynamic nature of delta evolution. Several papers cited herein note that dams, diversions for irrigation, municipal and industrial withdrawals, channelizations, dike construction are not methods for sustaining wetlands or other aquatic ecosystems. Day, et al. (1997) note, “environmental management of deltas requires managing a wide array of fluxes.” Sustainability in a marsh or wetland is attained if the rate of elevation gain is equal to the rate of sea level rise (Day, et al. 1997).

Another example of forming human perceptions, ideas and actions as a consequence of understanding the broader ecological issues concerns the runoff from the Mississippi and hypoxia in the Gulf of Mexico. A major issue is reducing nitrogen loadings (Mitsch, et al. 2001). Hypoxia develops when the oxygen levels in the water are less than 2 ppm. Between 1999 and 2003, the size of the “dead zone” downstream from the mouth of the Mississippi has been between 13,000 to 20,000 km^2 (Rabalais, et al. 1996). This comprehensively shows the need to place “local” gulf issues into the broader context: The Mississippi River total watershed is 3 million km^2. It represents about 40% of the territory of the lower 48 states and is 90% of the freshwater flow into the gulf (Mitsch, et al. 2001). The total amount of nitrogen carried into the Gulf yearly is1,567 X 10^3 tons. Controlling nitrogen flux into the Mississippi River will require management at the basin scale to change cropping systems, reduce agricultural fertilizer additions, manage manure spreading, increase earlier uptake with wetlands and riparian zones, and changing tillage practices (Mitsch, et al. 2001).

Using nature's services: Linking upstream mitigation to downstream benefits.

Cardoch, et al (2002) (and others) found that net primary production (NPP) is a good aggregate measure of energy available to support ecosystem structure and function. Those authors state that deltas are ecologically sustainable if change in net primary production, defined as the amount of energy fixed by primary producers that is available to higher trophic levels, over the long term is greater than or equal to zero (0). (Cardoch, John W. Day et al. 2002) conclude that average NPP for a freshwater marsh with no input is 2015 g/m^2/yr. For a freshwater marsh with riverine input, NPP averages 3000 g/m^2/yr. For comparison, brackish water marshes have a higher overall productivity, and average NPP of 3375 g/m^2/yr and 2459 for salt marshes (compared to 478 for water). Their study shows that, for the Mississippi Delta, NPP has dropped from 2500 to 2000. With no action and higher sea levels, NPP is expected to drop to 1400 g/m^2/yr by 2050. They recommend employing river diversions to enhance sedimentation in the Delta marshes and use of secondarily treated wastewater to increase biotic productivity. In the context of understanding local biotic responses in a regional context (Mississippi watershed), it is important to understand that humans are increasingly co-opting larger amounts of net primary productivity. In global marine environments, fisheries harvest and bycatch is using 8% of the global primary aquatic primary production (Vitousek, et al. 1986); for shelf and upwelling areas, the amount co-opted by humans increases to 24% and 25%, respectively.

Maintaining the marshes should be a regional high priority. Marshes and estuaries in the Gulf are absolutely critical for productive commercial and sport fisheries. As an example (Minello and Rozas 2002), in a 437 hectare marsh near Galveston, TX, a functioning marsh produces commercially valuable species, including brown shrimp (16.2 million), white shrimp (15.5 million), and blue crab (11.3 million). This shows the importance of estuarine marshes as nurseries. Those authors find these numbers to be representative of marshes in the Gulf Coast. However, an important component of the productivity is the connectivity of the marsh. Young shrimp and crabs are recruited into the marshes if the tidal connectivity is sufficient. Marsh connectivity is the degree of distance from an edge of marsh and freshwater (Minello and Rozas 2002). Tidal rivers create more edges, thus more habitat heterogeneity, as they flow through the marshes. Minello and Rozas measured maximum marsh use by species occurs when they are at maximum edge of 50% water (highly fragmented marshes with large amount of edge). This enhances food resources and reduces predation pressure. The authors conclude that tidal creek construction (or addition of edge) should be a high priority along the Gulf coast.

Using an ecological basis for estoring aquatic ecosystems.

Aquatic ecosystems can be protected or restored by recognizing the following (Sweeney, et al. 2004): (1) Aquatic ecosystems are connected strongly to terrestrial ecosystems, rather than isolated bodies or conduits. (2) Dynamic patterns for flow that are maintained within the historical range of variation will promote the integrity and sustainability of downstream aquatic systems. (3) Aquatic ecosystems need sediments, thermal and light properties, chemical and nutrient inputs, and an allowance for biotic populations to fluctuate within natural ranges. Sweeny, et al. (2004) note the need to develop quantitative measures of ecosystem response to justify the restoration projects and recover ecosystems services.

Writing specifically for the Mississippi River delta, Sparks (2006) states that the focus of human construction should be on the original high-elevation New Orleans to keep the cultural and national historic areas of the old city. The U.S. Corps of Engineers should consult with other state and federal agencies to find ways to enhance the buildup of the sediments in the Atchafalaya lobe of the Delta. This requires not maintaining the Port of New Orleans as a deepwater port. This is a dramatic conclusion. However, given the long-term options for sea level rise, continued land subsidence, and the potential expense following another hurricane, it is an idea that should be thought out and strongly considered. Sparks considers “two New Orleans,” one on either side of the Atchafalaya River. In any case, Sparks recommends the Corps of Engineers look at the 9,000 years of geological and archaeological data of large flood recurrence (Sparks 2006) and re-think its focus on enhancing the flood control structures.

Sparks also recommends that the Corps of Engineers should re-examine the gradual loss of storage capacity in present flood control reservoirs in the upstream reaches of the Mississippi River. Sediments should be allowed to flow downstream to rebuild and enhance delta-building and maintenance. This concurs with earlier studies (Leopold 1997) concerning the possible use of floodplain land now in agriculture for channel storage. Purchasing easements from floodplain owners would allow flooding of that land. Payment of easements would take place of disaster relief. A benefit of allowing sediment to move downstream would be to enhance beach nourishment along the Gulf Coast. Presently, constructed beaches have a 50 year life span and are very expensive (Leatherman 2006). With integrated planning, if sediments from the upper Mississippi drainage were “allowed” downstream, the sediments would provide an ecosystem service by enhancing beach buildup less expensively and with longer duration.

Conclusions: Why has the perception and use of earth sciences not occurred?

Karr (1991) answers this question by referring to the dominance of reductionist viewpoints. He describes state and federal water management as a major impediment to a holistic approach to healthy aquatic ecosystems. Few ecologists have participated in the development of standards or policies. Engineers have failed to incorporate concern for biotic impairment. Politicians implement programs based on local interests and short time scales. Finally, engineers attack problems as if whole-scale ecological problems could be fixed without an understanding of whole ecosystems. Management of natural resources suffers from a lack of interdisciplinary breadth and lack of grounding in ecological theory. This is why an overall, integrated approach to watershed education and development of an ecological perception should be a high priority. Water law is a complex mix of federal and state policies and shows an alarming lack of appreciation of the relatedness between ground and surface water. Responsibility is vested in patchwork of local, state, national laws. Regulators stress measuring effluent toxicity because biological integrity is difficult to measure (La Point and Waller, 2004). Whereas the Clean Water Act goals of "fishable and swimmable" are laudable, there is a societal unwillingness to limit private land rights for the public good. Karr (1991) states, "although chemical and physical approaches are legally defensible, they cannot measure complex attributes such as ecological health or "biotic integrity." Biotic integrity is the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitat of the region.

A consequence of the reductionist approach to modern science is that many scientists have "lost sight of the significance of nature and the nature of significance." (Orr 2004) Other authors have commented on the arrogance of thinking we can control forces of nature. One such, J. McPhee (McPhee 1990) titled his book, "The Control of Nature," and discusses at length how efforts to control flooding by using dams and river control structures ultimately must fail (the example of the Atchafalaya control is a terrific chapter). Orr notes that "making life simpler, ecologically sustainable, more friendly, and more conducive to human growth requires only a fraction of the technology now available (pg 15). He also proposes that education needs an almost-complete revamping to assure that students and the public learn to place human needs, desires, and life into an ecological context (Orr 2004). He promotes six recommendations: (1) All education should be environmental education. (2) The goal of education is not mastery of a subject matter, but master of one's person. (3) Knowledge carries with it the responsibility to see that it is well used in the world. (4) We cannot say we know something until we understand the effects of this knowledge on real people and their communities. Understanding the bottom line of unemployment, crime, divorce rates, alcoholism, child abuse, lost savings, etc. (5) Faculty and administrators that provide a role model of integrity, care, and thoughtfulness and institutions capable of embodying ideals wholly and completely in all their operations. And (6) process is important for learning. How learning occurs is as important as the content. I think there is much in this for leading to formulating perceptions – and learning - about earth sciences and *Homo sapiens*.

Orr (1992) cites the 1981 issue of Coevolutionary Quarterly, which asks 11 questions as a test of bioregional knowledge. These certainly would test the perceptions of the local, state and federal people working on the aftermath of the Katrina hurricane. However, the questions go more to the understanding of the general population affected. How would their actions change and how would they view the reconstruction of New Orleans if they could answer the following questions?

1. What soil series are you standing on?
2. When was the last time a fire burned in your area?
3. Name five edible plants in your region and their seasons of availability.
4. From what direction do winter storms generally come in your region?
5. Where does your garbage go?

6. How long is the growing season where you live?
7. Name five grasses in your area. Are any native?
8. Name five resident and five migratory birds in your area.
9. What primary geological event or processes influenced the land where you live?
10. What species have become extinct in your area?
11. What are the major plant associations in your area?

And using this knowledge, recommendations for maintaining the ecosystem services provided by rivers (Postel and Carpenter, 1997) can be applied to restoring the inter-connected Gulf Coast and Mississippi River ecosystems:

1. We need a regional (watershed scale) water (including wetlands) management policy, one that incorporates aquatic ecosystem needs, particularly variable flow regimes and sediment flows.
2. Watersheds should be the focus of coordination and policies. This may appear difficult, and very likely would be, but it is in everyone's self interest.
3. Increase communication and education across disciplines, and enhance public education in non-traditional ways by employing active educational programs.
4. Use ecological principles as guidelines for restoration efforts for aquatic ecosystems.
5. Protect and enhance the remaining intact freshwater and estuarine ecosystems.
6. Bring the ecosystem concept home!

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