Overview

Characterizing Galveston Bay: Connecting Science and Management at the Ecosystem Level

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> "Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise."
>
> --J. W. Tukey, 1962

As an Estuary of National Significance within the National Estuary Program (NEP), Galveston Bay is faced with diverse problems related to pollution, development, and overuse. These problems were broadly identified early in the five-year program, and are being characterized more completely by information gathering and scientific work. In translating scientific findings to management actions (by drafting a Comprehensive Conservation and Management Plan, CCMP), the Galveston Bay NEP has faced challenges common to estuary management in general. Galveston Bay therefore serves as a case history useful in considering the roles of managers and scientists in improving stewardship of the nation's estuaries.

Early in the five-year program, discussions by resource managers, scientists, and the bay user community resulted in consensus agreement on the Galveston Bay Priority Problems List (Table 1). This list, an approach suggested in EPA guidance to estuary programs (EPA, 1989), was used effectively for designing characterization work and for ranking and funding project proposals. However, the list was of little or no use in crafting future management strategies. One shortcoming was the lack of viability of one-dimensional (linear) logic inherent in the list, for dealing with multi-dimensional processes in a perturbed ecosystem context.

An impact matrix (Figure 1) utilizes two dimensions to increase the representation of dynamic processes in the estuary (National Research Council, 1990). Since one axis of the matrix represents perturbations, relational effects present in nature are incorporated. Within the matrix, individual cells nearly always suggest basic research or management possibilities, but rarely point to simple management solutions. Perhaps the greatest value of the matrix is in defining the universe of management alternatives, and identifying the gaps of knowledge within that universe (represented by "?" entries). A shortcoming of the matrix approach is the difficulty of describing the difference between direct and indirect relationships. One outgrowth of the matrix approach consists of conceptual (and perhaps eventually) numerical models coupling physical factors with chemical and biological processes. These may better account for natural complexity, but in doing so, may sacrifice management utility.

Initiating projects in this context to build a knowledge base for managers presents challenges. Our attempts are limited by the newness of ecosystem-level estuarine science as a discipline, in comparison to terrestrial and freshwater disciplines

Table 1. Galveston Bay Priority Problems List

Within the List, the four major problems (identified by letters A-D) are ranked in order of importance and are considered to be clearly independent. The second order problems within each major problem (identified by number) area are interdependent and may contribute or interact with problems of equal or higher category.

A. REDUCTION/ALTERATION OF LIVING RESOURCES

1. Loss of Physical Habit
   * wetlands and sea grasses
   * oyster reefs
   * shallow bay bottom (unvegetated)
2. Alteration of Salinity Gradients
   * impoundment, diversion, and interbasin transfer of fresh water inflow
   * bathymetric and circulatory changes (salinity intrusion)
   * ungaged inflows from rainfall in coastal watersheds
3. Alteration of Nutrient and Organic Loading
   * eutrophication and hypoxia
   * point and nonpoint sources
4. Bathymetric and Circulatory Changes
5. Land Subsidence and Sea Level Rise
6. Chemical and Pathogenic Contamination (biotic imparement)
   * point and nonpoint sources
7. Increased Turbidity and Sedimentation

B. PUBLIC HEALTH ISSUES

1. Discharge of Pathogens to Bay Waters
   * point and non-point sources
2. Chemical Contamination of Water, Sediments, and Living Organisms
   * point and nonpoint sources
3. Restriction of Contact Recreation
   * chemical and pathogenic contamination

C. RESOURCE MANAGEMENT ISSUES

1. Regulatory Problems
2. Fisheries Resource Depletion
3. Marine Debris

D. SHORELINE EROSION

1. Land Subsidence and Seal Level Rise
2. Bathymetric and Circulatory Change
3. Loss of Buffer Vegetation (Wetlands)
4. Use of Littoral Property

(shoreward) and to oceanographic science (seaward). Working in estuaries requires more than a single traditional discipline because estuaries are transitional, and lack the homogeneity of freshwater, terrestrial, and oceanic systems. Estuaries integrate decades or centuries of indirect upstream influences, and have become foci for human development and related direct impacts; yet organized scientific and management concern is only of recent vintage. Scientists have only recently recognized the need for multi-disciplinary, long-term efforts incorporating terrestrial ecology, soil science, hydrology, wetlands and river ecology, unrestricted by traditional artificial barriers (Joint Oceanographic Institutions, Inc., 1990). Only in this context can projects be conceived to reconcile our epistemology to the multi-dimensional, perturbed, but unified estuarine environment (see Table 2 for Galveston Bay NEP projects).

Estuarine science, then, is seen as fragmented. But traditional management may be in even worse shape. For example, oyster (*Crassostrea virginica*) populations in Galveston Bay are influenced by water quality, hydrodynamic alterations, predation, disease, and harvest. Yet these elements are under separate agency jurisdictions with little institutionalized coordination. Management of natural resources in Texas has traditionally been accomplished

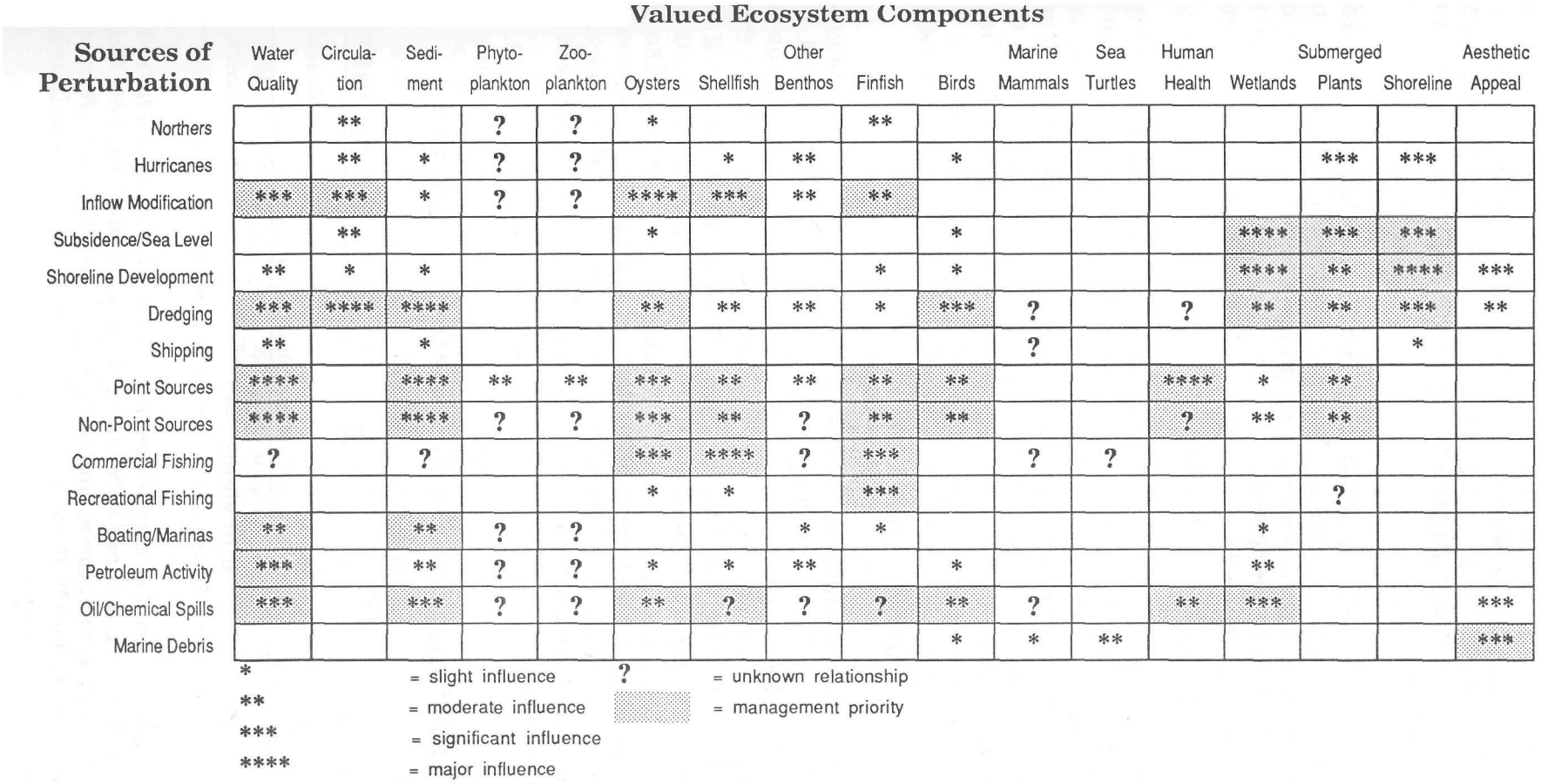

Figure 1. Galveston Bay ecosystem impact matrix. The matrix relates valued components of the ecosystem to natural and anthropogenic sources of perturbation. The matrix is based on a subjective determination, and therefore may be subject varying interpretations. Further, it was conceived from an environmental management perspective, and therefore is not necessarily exhaustive (e.g., the effect of hurricanes on human health may be great, although not as an element of environmental management).

by up to a dozen separate state agencies, as framed by the Texas Constitution. The multiple jurisdictions follow boundaries which, for Galveston Bay and most other estuaries, are not ecological boundaries. Effective management would therefore require, as a minimum, a new infrastructure that fundamentally corresponds to the problems (King and Kendall, 1987).

Clearly, both science and management must each become better integrated internally to address the estuarine ecosystem. But furthermore, they must then be linked to each other--perhaps a more challenging goal. The NEP is conceived to be a force to connect science and management at this broad systems level. But this goal is much easier to state than to accomplish. How, indeed, can science and management be connected to solve problems?

Frustrated managers may believe scientists *know* lots of things that don't help solve problems, while scientists may believe managers *do* lots of things that don't help solve problems. The two groups operate on different scales of resolution, on different time schedules; they ask different questions because they have differing ultimate goals. Managers may be forced into, and therefore become used to, operating in a knowledge vacuum. Estuary science simply lacks funding continuity, an interdisciplinary systems approach, and seemingly any ability to cast results in a synoptic form that is useful. Conversely, scientists may view managers as unresponsive, unrigorous, and hurried.

As an alternative, we can seek a continuum between science and management, that benefits both (Figure 2). The knowledge spectrum can be envisioned as extending from testing of risky hypotheses with low *a priori* plausibility (basic research, on the left), through assembling of useful "facts" describing ecosystems (applied/descriptive science, in the middle), to application of understanding to solve problems (management, on the right). In this idealized paradigm, there is organic continuity between scientists and managers. There is also a fundamental tension that pushes science to the left (in search of the unknown) and managers to the right (away from the unknown). In this respect coordination of science and management requires conscious effort to balance speculation with pragmatism.

The Science/Management Knowledge Spectrum

Science **Management**

Low Plausibility	Moderate Plausibility	High Plausibility	Problem-Solving
Hypothesis Testing (deductive)	Descriptive Science (inductive)	Applied Science	

knowledge

Unknown >> **Known**

Figure 2. Idealized science/management knowledge spectrum. Estuarine activities take place along a knowledge plausibility gradient. Data may enter the system at any point (as tests of hypothesis predictions on the left; as monitoring on the right). The integrity of information transfer from left to right determines the effectiveness of problem-solving. A conceptually related diagram is given by O'Connor and Flemmer (1987).

Table 2. Galveston Bay National Estuary Program Scientific/Technical Projects.

Project	Purpose	Pitfalls
Priority Problems List	Integrate scientific/management perceptions with societal estuary values	Linear format does not correspond to ecosystem
Ecosystem Impact Matrix	Define estuary in context of human and natural perturbations; identify knowledge gaps	Suggests"what" to manage but not "how" or "where"
Conceptual Model	Promote common understanding of ecosystem structure and function	Level of complexity modeled is arbitrary; requires "tiers" for various uses; not useful without human impacts
Numerical Model	Simulate ecosystem; predict outcome of human impacts and management actions	Expensive and time-consuming; biological components extremely problematic
Characterization Projects:	Determine status and trends for estuarine resources; probable causes for priority problems	Are short, schedule-driven in NEP programs; must be linked in ecosystem context
Status and Trends for Point Source Loadings	Cumulative assessment of permitted wastewater discharges	Relies on permit and self-reported values
Shoreline Survey for Unauthorized Point Sources	Determine scope of unauthorized discharges	Requires elaborate surface and aerial field logistics
Status and Trends for Non-Point Source Loadings	Estimate overall NPS impact by parameter and subwatershed	Utilizes "ballpark" quantification of loadings; field data verification expensive
Status and Trends for Ambient Water and Sediment Quality	Determine physico-chemical trends and human activity correlates	Data limited in time, space; some historical protocols are now determined erroneous
Status and Trends for Living Resources	Determine biological trends and human activity correlates	Data rare for non-consumed species; catch rates have obscure relationship to population regulation
Status of Trawling Bycatch in Galveston Bay	Estimate magnitude of estuarine bycatch; relate mortality to fishery stocks	Lack of data on portion of bycatch mortality that is compensatory with natural mortality; public controversy
Status of Human-Induced Incidental Fish Mortality	Estimate magnitude of mortality from intake structures, dredging, oil and gas activity, recreation	Lack of data for some sources; public controversy

Table 2, Cont.

Project	Purpose	Pitfalls
Status and Trends for Oysters	Determine trends for key estuarine indicator species	Population survey requires elaborate field logistics
Status and Trends for Shellfishing Closures / Pathogenic Contamination	Determine history of bacterial pollution, shellfishing closures, and human pathology related to bay	General lack of public health reporting
Survey of Toxics in Seafood Organisms	Determine tissue toxic burden for five commercial species from four locations; conduct risk analysis	Low risk findings from extensive sampling regime do not address toxic "hotspots"
Status and Trends for Wetland and Aquatic Habitats	Utilize remote imagery and ground truth to digitize 1989 maps to compare to 1956 and 1979 for trends	Not cheap enough or quick enough to use same approach for long term monitoring
Status of Resident and Migratory Bird Habitat	Compile and synthesize existing information on habitats associated with bay; describe bird utilization	Portions of bird habitat outside scope of NEP guidance
Status of Marina Impacts	Determine impacts of Marinas on water and sediment quality	Estimates must be extrapolated from selected cases
Status of Dredge and Fill Impacts	Compile and synthesize existing information on dredging impacts	Lack of information on impacts, beyond project descriptions
Economic Resource Inventory	Estimate reserve quantities of mineral resources; determine possible future related impacts to bay	Economic uncertainty
Data Base Inventory	Identify and describe available data sets; determine completeness; provide information in usable, synoptic form	Requires extensive effort by senior staff members; some institutions uncooperative; high proportion data is lost
Bay Bibliography	Compile all known citations for Galveston Bay; create friendly on-line searchable file	More time-consuming than expected
Coastal Ocean, Mapping, Planning, and Assessment System (COMPAS)	Make synoptic information compiled from critical bay data avialable to managers and public	Requires custom module programing with elaborate interagency coordination
Information Center	Permanently house key information resources for scientists, managers, and public	Requires funding outside NEP into future

Table 2, Cont.

Project	Purpose	Pitfalls
Symposia	Identify researchers; promote peer interaction at ecosystem level; reach consensus on probable causes	Requires independent scientists to contribute findings for benefit of managers and bay
Publication Series	Publish project reports for all characterization projects	Review and publishing time-consuming
Environmental Characterization Report	Draft final synthetic report on the "State of the Bay;" establish factual foundation for CCMP	Must be drafted prior to final results becoming available

This view of stewardship also reveals the indirect dependence of management on basic science (for some, this revelation may not require a diagram). The left end is inherently part of all science; given a choice, the scientist will choose pursuit of the unknown over dealing with the known, every time. That is to say, if we limit the full spectrum of science, we ultimately eliminate a sound basis for management. This relationship is obscured by cases in which human impacts are obvious and soluble without scientists--or example, local impacts resulting from a single point source. However, the lack of even fundamental scientific principles applied to ecosystem-level management is widespread (e.g., for estuary monitoring, National Research Council, 1990).

The NEP was not conceived to supply the commitment to science that is necessary for long-term progress. Rather, estuary programs follow the dictum that: "we need to do something about our estuaries, and it better be sooner, rather than later," or perhaps: "we can be effective by just reducing the data we already know about and applying the results to management." This emphasis on immediate action is rightly placed: "doing" is at least as important as "knowing." Since estuaries have been neglected so long, we can make rapid progress for the first few years without a commitment to long-term research. However, efficient as this strategy is in the short term, it casts managers in the role of "skimming" research results and expert opinion from scientists without supplying anything substantial in return. In doing so we have relied on the generally high personal commitment of scientists to conserving estuaries.

Fortunately, solutions to the lack of a national scientific strategy for the land-sea interface are beginning to emerge outside the NEP (Joint Oceanographic Institutions, Inc., 1990). While not making a direct contribution to this effort, the 17 estuary programs are, none-the-less, cast as testing grounds for a new continuity of estuary science and management. As individual programs shift from short term to long-term perspectives, this continuity can result not only in a gain in critical new understanding of estuaries, but also in improved opportunity to be responsible for (that is, consistently act on) what we know.

How do we implement the science/management continuum? Work over the last

three years in Galveston Bay suggests at least five general needs for scientists to effectively contribute to estuary management. Similar needs have been identified by other coastal management programs. These are:

1. Science must address the right questions, requiring that managers have a role in identifying and ranking project topics (see opening quote);

2. Science must be undertaken in the context of a perturbed ecosystem, requiring that projects focus on impact dynamics rather than traditional ecology alone;

3. Science must provide data at a scale of resolution applicable to management, requiring generalized geographic ordering of projects and sampling within projects;

4. Results must be available to managers in an accessible, useful format; requiring that data be converted to synoptic information; and

5. Science must provide to management an ongoing sensory component, requiring a monitoring program with a direct link to management objectives and managers themselves.

The commitments of scientists and managers in facing these challenges will necessarily differ, if each group is to remain effective. However, each of these groups brings fundamental strength to an "uneasy alliance" (Flemer, *et al.*, 1986), which provides maximal attainable resolving power for the problems facing Galveston Bay.

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