Knowing the State of the Bay: The Need for a Continuing Process

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More than three years of sponsored scientific work has been conducted by the Galveston Bay National Estuary Program (GBNEP) to address estuarine problems identified by consensus at the outset of the program. The purpose of this sponsored science has been to support ecosystem-level management planning in the creation of a *Comprehensive Conservation and Management Plan* (CCMP). The purpose of this paper is to point out why this directed scientific program should continue indefinitely beyond the creation of the CCMP — and specifically, how future State of the Bay Symposia like this one can help put the results to work.

The findings of this symposium provide strong support for a continuing scientific program, in revealing how much of our conventional wisdom about the Bay is wrong. Even expert opinion — which guides management in the absence of data — shows itself to be inadequate: the ecosystem just goes on being what it is rather than what we imagine it to be. This point is illustrated by revisiting several fundamental topics in light of what the authors of this proceedings have presented. A less superficial synthesis of these findings will be published in the forthcoming *Galveston Bay Environmental Characterization Report.*

Salinity

Impoundments and diversions of fresh water for consumptive use, combined with salinity intrusions of Gulf Water landward through dredged channels are widely perceived to threaten the bay with a salinity increase. However, we know now that this has not yet occurred. Solis and Longley (page 289) indicate no significant trends (e.g., decreases) in inflow for both the Trinity River (the principle source of fresh water) and for the watershed as a whole. In contrast, four of the most urbanized bayous show *increasing* flow since the 1960s, perhaps related to increases in impervious cover (development) and increased return flows of wastewater, including groundwater.

Browning (page 299) emphasizes how increasing return flows to the Trinity River have elevated base flow during critical low-flow periods. Recent analyses conducted under the Clean Rivers Act show that low flows along the main stem of the Trinity and in some tributaries (e.g., during droughts) are now several times what they would naturally have been in the absence of return flows. Net additions from proposed inter-basin transfers could, of course, continue to increase return flows and thereby further elevate critical low flows in the future, dampening the seasonal flow signature. Diversions and low flow augmentation have apparently already flattened seasonal inflow extremes, but Solis and Longley indicate a lack of statistical significance for this trend.

Ward and Armstrong (page 19) elaborate these findings in revealing a three-decade general *decline* in Bay salinity totaling more than 4%. Specifics of this decline are revealed in their full report (Ward and Armstrong, in press). Spatially, salinity decreases are prominent in the lower Bay (especially East Bay) and in areas influenced by intrusion, particularly west of the Houston Ship Channel. Seasonally, the decline has been especially noticeable for late summer. An unexpected lack of direct linkage between freshwater inflow and Bay salinity suggests the dynamics of Gulf interchange, return flows, and localized runoff may be much more important (and more complex) than previously suspected.

Even though salinity is the most frequently measured and conservative estuarine property respecting hydrodynamics, Ward (page 315) points out in a separate paper why the prediction of salinity based on inflow remains so elusive. None of eleven Galveston Bay hydrodynamic models described previously by Ward (1991) have completely overcome problems of dimensional scaling (features like channels and dikes have hydrodynamic influence far out of proportion to their size) and lack of independence between salinity (as an independent variable) and model terms that spatially distribute salinity. For example, salinity, in part, determines its own distribution by creating density currents and by creating vertical density gradients that, in turn, influence tidal and wind-driven currents.

Nutrients

The nutrient literature abounds with East Coast studies identifying eutrophication and hypoxia among the dominant estuarine changes caused by human development. Indeed, broad-brush estimates of potential watershed nutrient sources (e.g., inter-bay comparisons of NOAA, 1989) suggest intermediate to high potential for nutrient over-enrichment in Galveston Bay. Sixty percent of the wastewater in Texas (by volume) flows to Galveston Bay, and much of the upper watershed consists of cultivated and urban lands with high nutrient runoff potential. Parts of the upper watershed have upward-curving load vs. flow correlations, showing that runoff elevates, rather than dilutes loading. Combined with the nutrient loading estimated by Newell, et al. (1992) for non-point sources in the lower watershed and estimates being developed by Armstrong (page 53) for point sources, the emerging pattern is typical of watersheds with over-enrichment problems that create widespread hypoxia and eutrophication.

However, the over-enrichment suggested by the source approach to nutrients contrasts with what occurs once they are dissolved in surface waters, adsorbed to sediments, and influenced by watershed quirks like impoundments. Unpublished data being compiled for the Trinity River (see Land, page 47) indicate a striking reduction in nitrogen, and particularly phosphorus, downstream of Lake

Livingston. This finding was also noted by Jensen, et al. (1991) in the first State of the Bay Proceedings. Ward and Armstrong (in press) point out a clear trend in increased nitrification of ammonia in such receiving waters as the Houston Ship Channel, combined with an overall reduced loading resulting from improved treatment. Crocker (page 27) shows decreasing nutrients in the Ship Channel, excepting nitrates and nitrites, the end products of nitrification during treatment.

The nutrient analyses of Ward and Armstrong (page 19) based on a compilation of 26 extant data sets has for the first time revealed a comprehensive picture of nutrient concentrations in the Bay itself. Phosphates, ammonia, and nitrates all show a substantial general *decline* bay-wide, with some localized exceptions. Their analysis also reveals an unexpected glimpse of the possible effects of this decline on Bay productivity. A general decline in Chlorophyll *a* and a halving of total suspended solids over the last two decades is noted, with commensurate reductions in total organic carbon and turbidity. Although cause and effect have yet to be linked, the Bay apparently grows less algae and, therefore, has clearer water than it did 20 years ago, due to reduced available nutrients. Ward and Armstrong point out that declines in primary productivity have definite food web implications. The root meaning of "eutrophication" is simply "the process of becoming well fed." What is a well-fed estuary, and when is it under- or over-fed? At what point does primary productivity reduction affect higher trophic levels, and, hence, the Bay's economy?

Wildlife

White, et al. (page 201) reveal a 19% loss in emergent wetlands since the 1950s. The leading single cause of loss (> 26,000 acres) is conversion to open water/barren flats (e.g., from subsidence), but conversion to several categories of upland (primarily rangeland) totals 35,600 acres. Urban development, perhaps unexpectedly, accounts for less than 10% of the wetland loss. Simultaneously, White et al. report only 700 acres of remaining submerged aquatic vegetation (including seagrasses) — representing a loss of 70 to 86% of this habitat present in the mid-1950s.

Habitat losses have amplified the concern for potential species declines cited as a priority problem by the GBNEP in 1990. However, the living resources trend studies of Green et al. (page 175) reveal chronic declines for just two of 14 finfish and shellfish species analyzed: blue crabs and white shrimp. Green et al. note the difficulty of separating anthropogenic effects on estuarine species from climatic and other naturally-induced cycles (for example, white shrimp have rebounded in 1991, a year of high inflow). Harvest (as opposed to habitat declines) may be a factor, particularly in light of a downward age-class shift for the Blue Crab. However, Zimmerman et al. (page 223) point out that habitat losses cannot continue without affecting an important suite of marine species. They show higher numbers of these species in marsh than in open water habitats, implying that a net gain in secondary productivity could be achieved from marsh creation.

The picture revealed by Green et al. for birds is more troubling. Being mobile and visually oriented, birds may constitute a more sensitive indicator of habitat trends than either finfish or shellfish. Declining populations in colonial waterbird species that feed at the marsh-bay interface (tricolored herons, snowy egrets, black skimmers, roseate spoon bills, and great egrets) may result from declines in habitat or habitat-dependent prey species.

Powell (page 207) indicates substantially more oyster reefs in Galveston Bay than were previously known. His sonar/Global Positioning System study of reef distribution was coupled with a geographic information system approach to mapping—all tools unavailable during previous mapping by the Texas Parks and Wildlife Department. Reefs originating from human influences like creation of spoil banks and oil and gas structures now account for a substantial portion of the reefs in the Bay. An atlas of Powell's detailed reef maps for the Bay will be published by the GBNEP.

For the macrobenthic community, substantial human impacts can be attributed to oilfield-produced water discharges in the study of Green et al., in the Bay bottom characterization of Carr et al. (page 83), and in a recent project sponsored by the USFWS (Roach et al., page 135). Toxic effects, which result in depauperate benthic communities extending hundreds of meters down-current (and substantially beyond the regulatory mixing zone), affect a relatively small proportion of the total bay bottom, but a substantial number of scattered locations. These findings were more confirming than they were surprising, and agree with literature from both Texas (Shipley, 1991) and Louisiana (Boesch and Rabalais, 1989). EPA's recent proposal of a general National Pollutant Discharge Elimination System (NPDES) permit prohibiting coastal produced water discharges is in agreement with recommendations made by the Point Source Task Force of the GBNEP (GBNEP, 1992).

Toxicants

The first GBNEP toxicity study (Brooks et al., 1992) tested seafood organisms from four locations not associated with known potential contaminant sources. This study determined that seafood is generally safe to eat, with the caveat that higher levels of contaminants in the upper Bay can pose some risk to individual consumers, depending on the frequency and amount of seafood consumed and the biological characteristics of the consumer doing the eating. For individuals consuming large quantities of seafood from Galveston Bay, risk levels were calculated to exceed an EPA benchmark level of concern for all four locations in the study.

A study of benthic communities and sediments by Carr et al. (page 83) reports on a limited number of sites specifically known or suspected to be contaminated, revealing a complex picture for toxicity. Findings are highly method-dependent: no sites were shown toxic based on American Standard Testing Methodology (ASTM) standardized solid-phase sediment toxicity tests on the living amphipod *Grandidierella japonica,* while approximately half of all sites revealed toxicity to developing sea urchin (*Arbacia punctulata*) embryos exposed to extracted pore water. Toxicity under the latter procedure was clearly associated with oilfield produced water outfalls and dredged material disposal sites. The results highlight the continuing dilemma that choice of methods imposes both for contaminants management (which requires regulatory standardization) and fate and effects research that can define ecological implications (which requires sensitivity). Clearly, portions of the Bay are influenced by toxic contaminants to a degree that requires a methodological tool to overcome the traditional problem of proliferating "non-detectable" level of data.

Phillips (page 165) notes that current procedures for both contaminant monitoring and assessment, and communication of human health risks are currently inadequate. In particular, the Texas Department of Health has no funding for routine fish tissue sampling, even though a majority of citizens recently polled either believe such monitoring occurs, or are not sure. Because most fish and shellfish studies show some level of tissue contamination, and because contaminant-caused changes in the estuarine community structure are also well documented, expanded use of sentinel organism monitoring may be desirable (see Wade, et al., page 109) for discussion of the NOAA Mussel Watch program).

The Need for a Continuing Process

Few of the findings summarized above enjoyed the reassurance of widespread expert consensus prior to conducting the studies. Fortunately, science thrives on the failure of expectations through its tenet of testing *falsifiable* hypotheses. The more well-accepted the hypotheses that are rejected (or more usually, modified), the greater the leaps of knowledge. As a list of hypotheses, the Priority Problems List of the GBNEP has served well to guide our choice of issues, but it is in discovering where we are wrong that best serves management and science. This is, of course, a never-ending process.

Compared to the degree of knowledge we need to adequately manage the Bay, how much have we acquired? Recent deliberations by 16 task forces convened to draft action plans for the CCMP reveal continuing and substantial knowledge limitations. During the drafting of about 100 preliminary management initiatives, about 130 research needs were directly identified. For example, Ward (page 19) points out that in spite of the quintessential role of sediments in a shallow, wind-driven system like Galveston Bay, every step in the sediment dynamics process is inadequately understood. Many planning initiatives have been excluded from the developing the management plan solely on the basis of a lack of underlying knowledge. Many of these knowledge gaps cannot be filled in just three years of sponsored science, reflecting our continuing (but decreasing) basic ignorance of key aspects of the estuary.

The need for a continuing scientific program directly linked to estuarine management is easy to evoke but more difficult to accomplish. Five needs identified in the first State of the Bay Symposium (Shipley, 1991) remain valid:

- Science must address the right questions, requiring that managers have a role in identifying and ranking project topics;

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

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

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

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

But how do we fulfill these needs as management initiatives are implemented over the next decade and beyond? Some elements of such a process have already been identified by the Research and Public Participation Task Forces of the GBNEP. In somewhat preliminary and incomplete form, these include:

- Continue the State of the Bay Symposium as a periodic gathering of managers, scientists, policy-makers, and the public — perhaps on a schedule of once every two years;

- Continue to publish proceedings of research summaries (separate from full reports) in a format useful beyond the scientific community;

- Link the Symposium to a continuation of the Priority Problems approach — using improving knowledge of the Bay to continually improve a consensus list of estuarine concerns;

- Link the Symposium to a periodic redirection of the CCMP itself — whereby future revision of the CCMP conforms to findings related to the identified estuarine problems;

- Link the Symposium to a Bay research program with comprehensive funding support and an institutional sponsor — one which utilizes the continuing Priority Problems approach for project awards; and

- Involve the public and public policy makers in the State of the Bay process by convening the Symposium as a forum for citizen monitoring, public communication, and agency involvement.

Federal support of the GBNEP is currently scheduled to throttle back beginning in 1995. However, the commitment of Galveston Bay user groups, agencies, the scientific community, and the public to wise stewardship appears to be at an all time high and steadily increasing. That this commitment can translate to research funding and an ongoing State of the Bay program remains among the best hopes for the continued vitality of the Galveston Bay ecosystem.

Bibliography

Brooks, J. M., T.L. Wade, M.L. Kennicut, D. Wiesenberg, D. Wilkenson, T.J. McDonald, S.J. McDonald. 1992. Toxic characterization of aquatic organisms in Galveston Bay: a pilot study. Galveston Bay National Estuary Program Publication GBNEP-20. 341 pp.

Boesch, D. F., and N. N. Rabalais (eds.). 1989. Produced waters in sensitive coastal habitats. U. S. Department of the Interior Minerals Management Service OCS Study MMS 89-0031. 157. pp.

Carr, R. S. In press. Survey of Galveston Bay bottom sediments and benthic communities. Galveston Bay National Estuary Program Publication.

Galveston Bay National Estuary Program. 1992. Managing Galveston Bay: issues and alternatives. Draft discussion items and possible management strategies. 86 pp.

Green, A., M. Osborn, P. Chai, J. Lin, C. Loeffler, A. Morgan, P. Rubec, S. Spanyers, A. Walton, R. D. Slack, D. Gawlik, D. Harpole, J. Thomas, E. Buskey, K. Schmidt, R. Zimmerman, D. Harper, D. Hinkley, T. Sager, and A. Walton. 1992. Status and trends of selected living resources in the Galveston Bay system. Galveston Bay National Estuary Program Publication GBNEP-19. 452 pp.

Jensen, P., S. Valentine, M. T. Garrett, and Z Ahmad. 1991. Nitrogen loads to Galveston Bay. Pages 99-104 *in* Shipley, F. S. and R. W. Kiesling (eds.). 1991. Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6. 220 pp.

Newell, C. J., H. S. Rifai, and P. B. Bedient. 1992. Characterization of non-point sources and loadings to Galveston Bay. Volume I, Technical Report. Galveston Bay National Estuary Program Publication GBNEP-15. 221 pp.

NOAA. 1989. Susceptibility and status of Gulf of Mexico estuaries to nutrient discharges. National Oceanic and Atmospheric Administration Strategic Assessment of Near Coastal Waters. 37 pp.

Shipley, F.S. and R. W. Kiesling (eds.). 1991. Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6. 220 pp.

Shipley, F.S. 1991a. Characterizing Galveston Bay: connecting science and management at the ecosystem level. In Shipley, F. S. and R. W. Kiesling (*eds.*). 1991. Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6. 220 pp.

Shipley, F.S. 1991b. Oil field-produced brines in a coastal stream: water quality and fish community recovery following long term impacts. Texas J. Sci. 43:51-64.

Ward, G. H. 1991. Modeling options for Galveston Bay. Pages 191-196 *in* Shipley, F. S. and R. W. Kiesling (*eds.*). 1991. Proceedings. Galveston Bay Characterization Workshop, February 21-23, 1991. Galveston Bay National Estuary Program Publication GBNEP-6. 220 pp.

Ward, G. H. and N. E. Armstrong. In press. Ambient water and sediment quality of Galveston Bay: present status and historical trends. Galveston Bay National Estuary Program Publication.

Conceptual Models of the Galveston Bay Ecosystem

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A series of hierarchical conceptual models of the Galveston Bay ecosystem are being developed to facilitate understanding of the bay and optimize management of anthropogenic factors that affect the ecosystem. These models are habitat-based and problem-oriented. It is desirable that these models be understandable by the general public, useful to managers and decision-makers, and retain sufficient detail to be meaningful to scientists.

The model for the general public (Tier I) will be landscape-based and incorporate the entire watershed. It will focus on the role of freshwater inflow, dissolved and suspended substance transport, and estuarine hydrography to demonstrate that distant events in the watershed and Gulf of Mexico influence subsequent events in the bay.

The model for managers and decision-makers (Tier II) will focus on disturbances and perturbations and how they affect valued ecosystem components. The Galveston Bay National Estuary Program (GBNEP) Galveston Bay Impact Matrix has identified the valued ecosystem components and sources of perturbation. Scientific consensus has determined the specific factors that are altered by a given disturbance. The model will trace the pathways by which a disturbance factor will affect an ecosystem component.

Scientific consensus has been achieved regarding the important generalized components of bay habitats (Tier III). The estuarine ecosystem is a composite of strikingly different habitats. The largest is the three-dimensional (length, breadth, and depth) *open-bay water* component (Figure 1) to which all other habitats are linked. Equally large in areal extent but virtually two-dimensional (length and breadth) is the underlying *open-bay bottom* component (Figure 2). The bottom functions as a matrix in which two different types of habitat patches can be found. On hard bottom with strong currents, patches of *oyster reef* (Figure 3) rise up to provide the only hard substrate and elevated surface above the bottom. On softer sediment in shallow water, patches of submerged aquatic vegetation, the subtidal *seagrass meadows* (Figure 4), can be found near the periphery of the bay. As the bay bottom slopes upward at the edge of the bay, meadows of emergent intertidal vegetation, the *peripheral marshes* (Figure 5), punctuate the shoreline. Some low-sloping shore zones do not support emergent vegetation but form the intertidal *peripheral mud flats* (Figure 6). Patches of very soft, unconsolidated subtidal bottom are scattered within the various shoreline wetlands to create the *peripheral marsh embayments*. These poorly known habitats support a visibly rich biota. This conglomerate of habitats is connected upstream to the freshwater *riverine/flood-*

plain habitat (Figure 7), downstream to the *near-shore gulf,* and via migratory birds, to the interior of the continent.

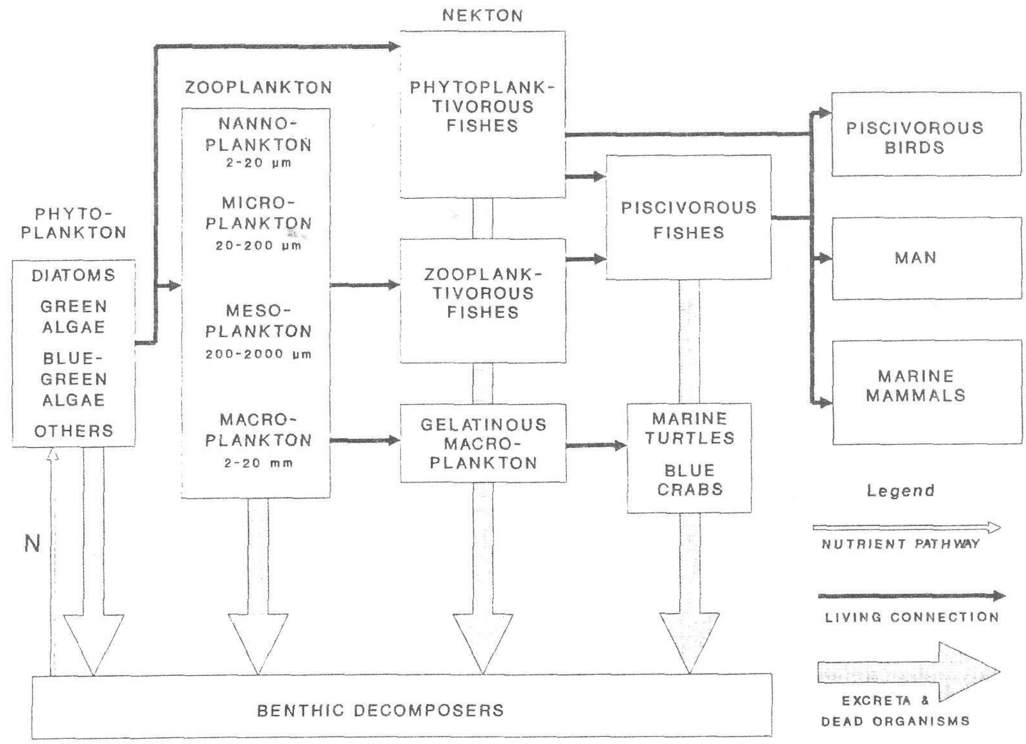

Figure 1. Connectivity of the open-bay water habitat.

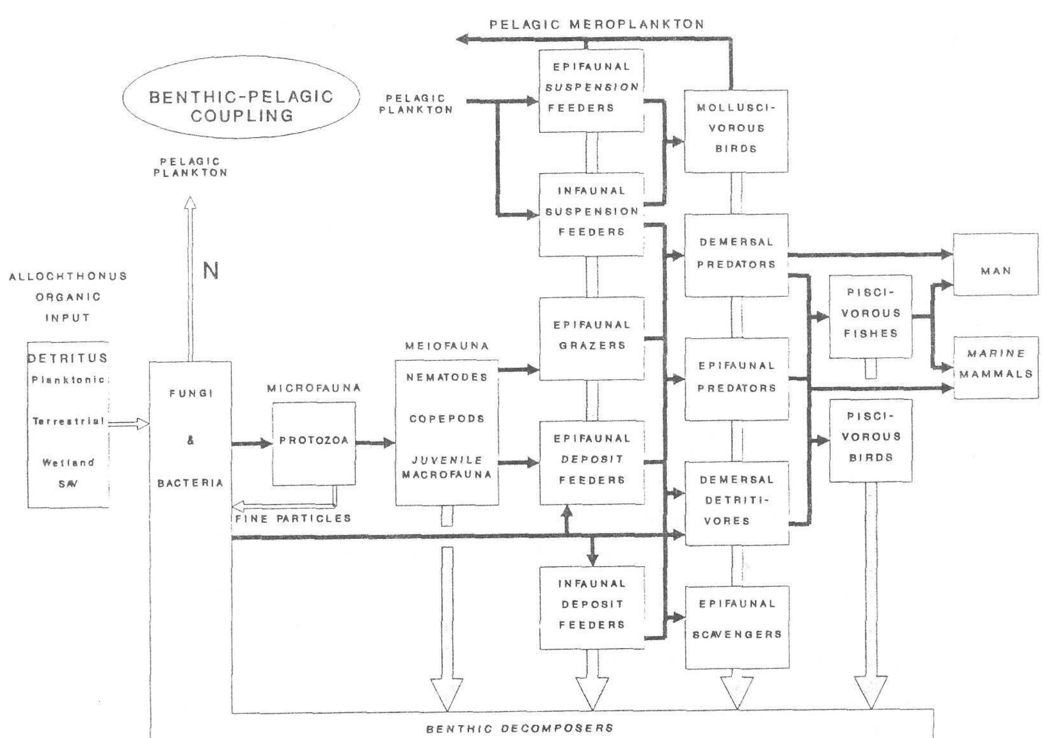

Figure 2. Connectivity of the open-bay bottom habitat.

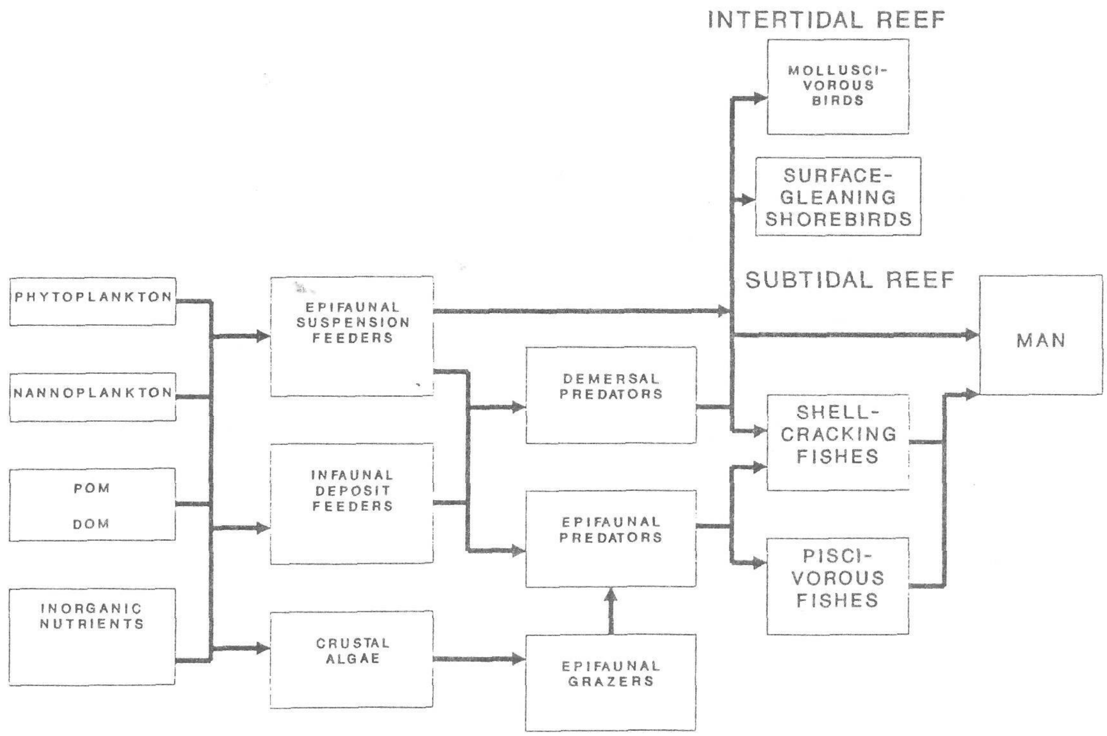

Figure 3. Connectivity of oyster reef habitat.

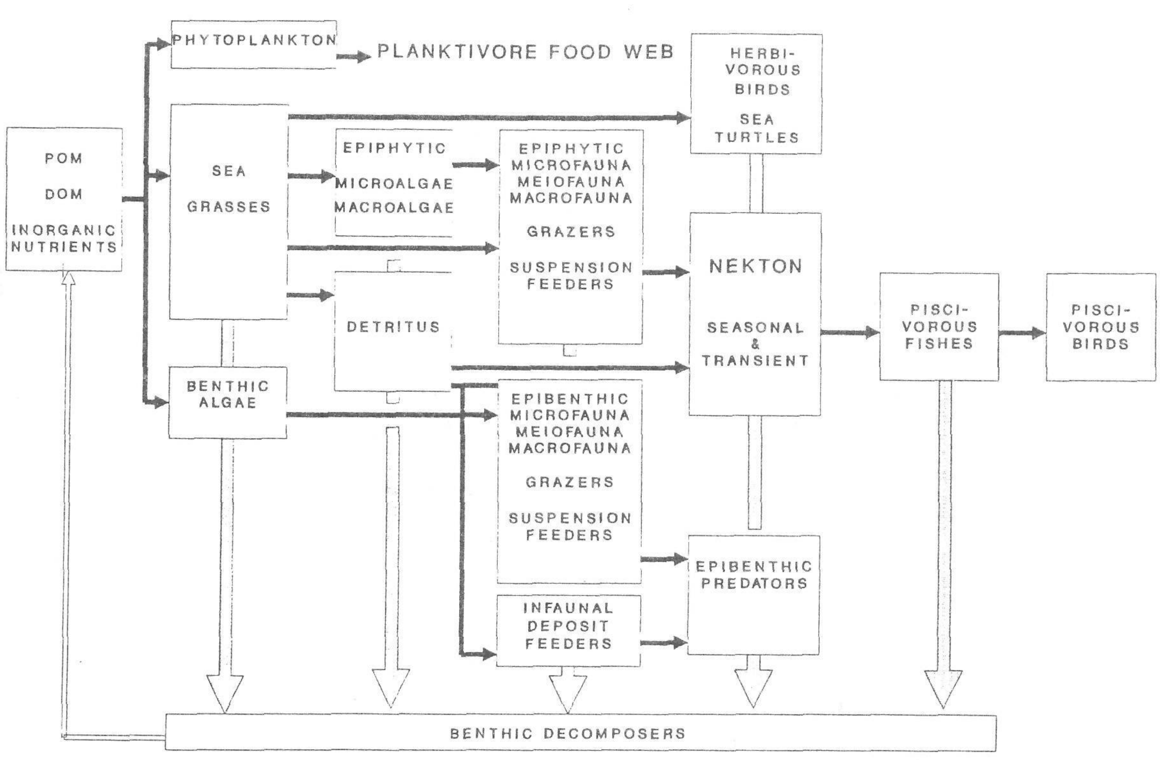

Figure 4. Connectivity of seagrass meadow habitat.

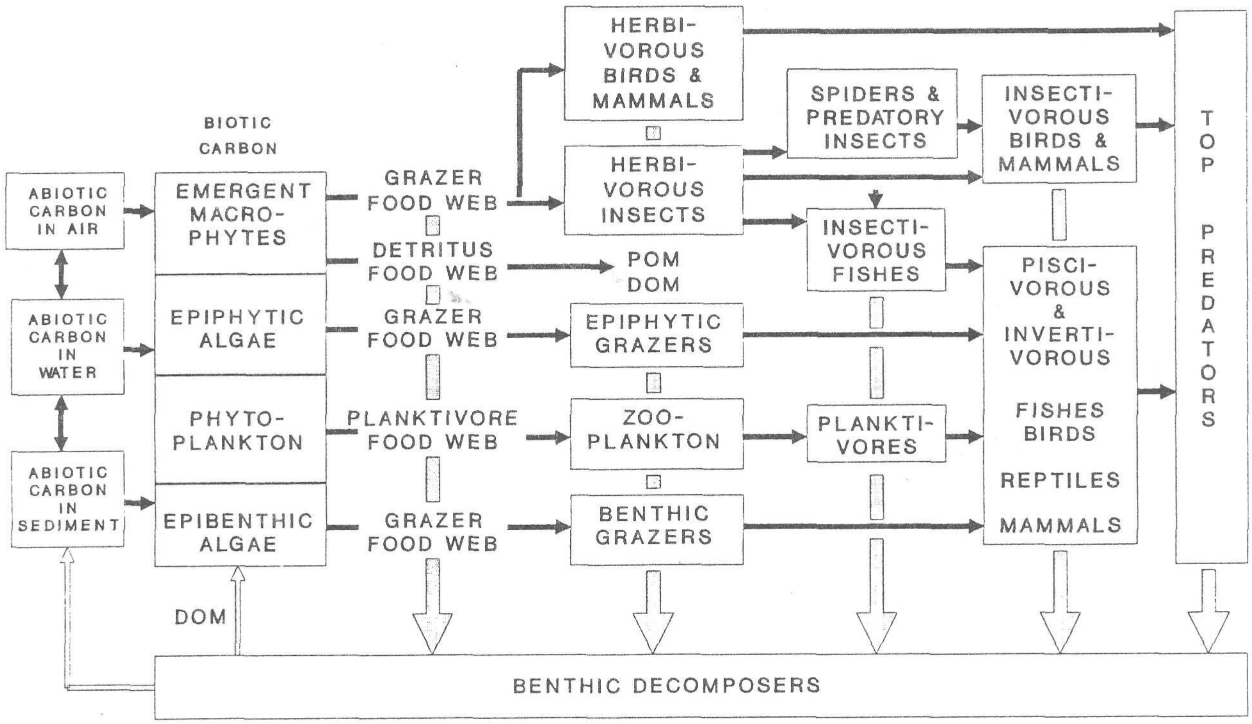

Figure 5. Connectivity of marsh habitat.

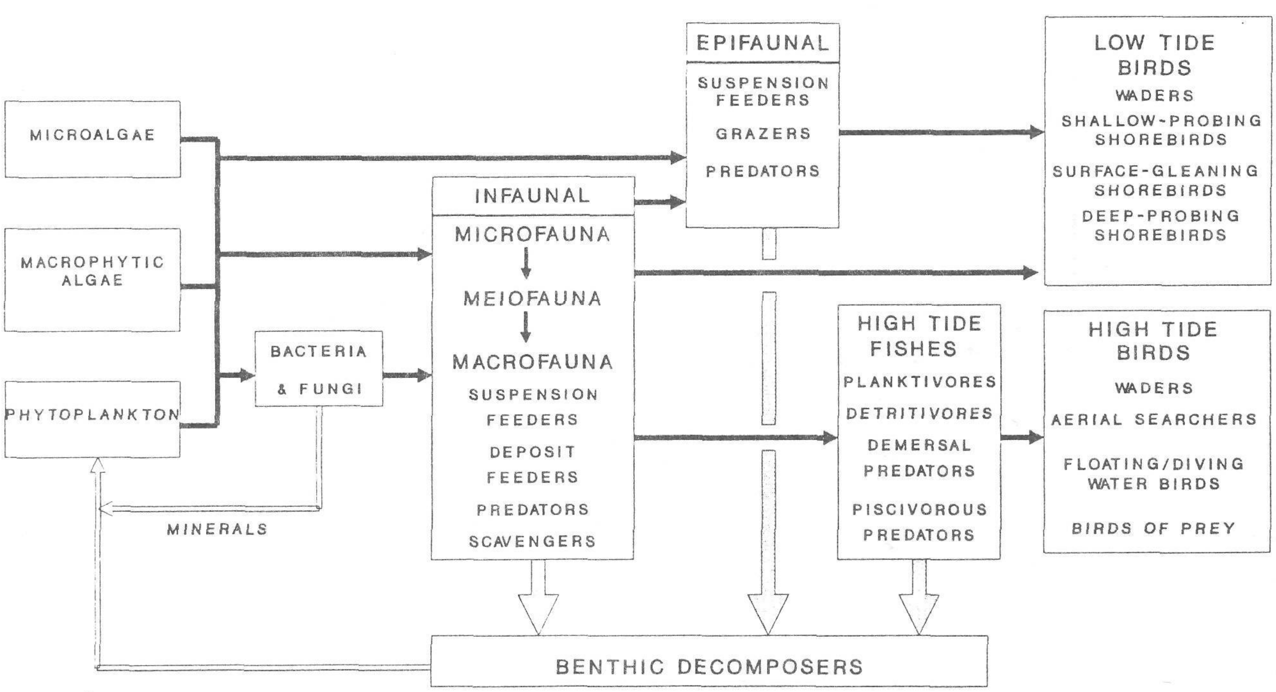

Figure 6. Connectivity of intertidal mud flat habitat.

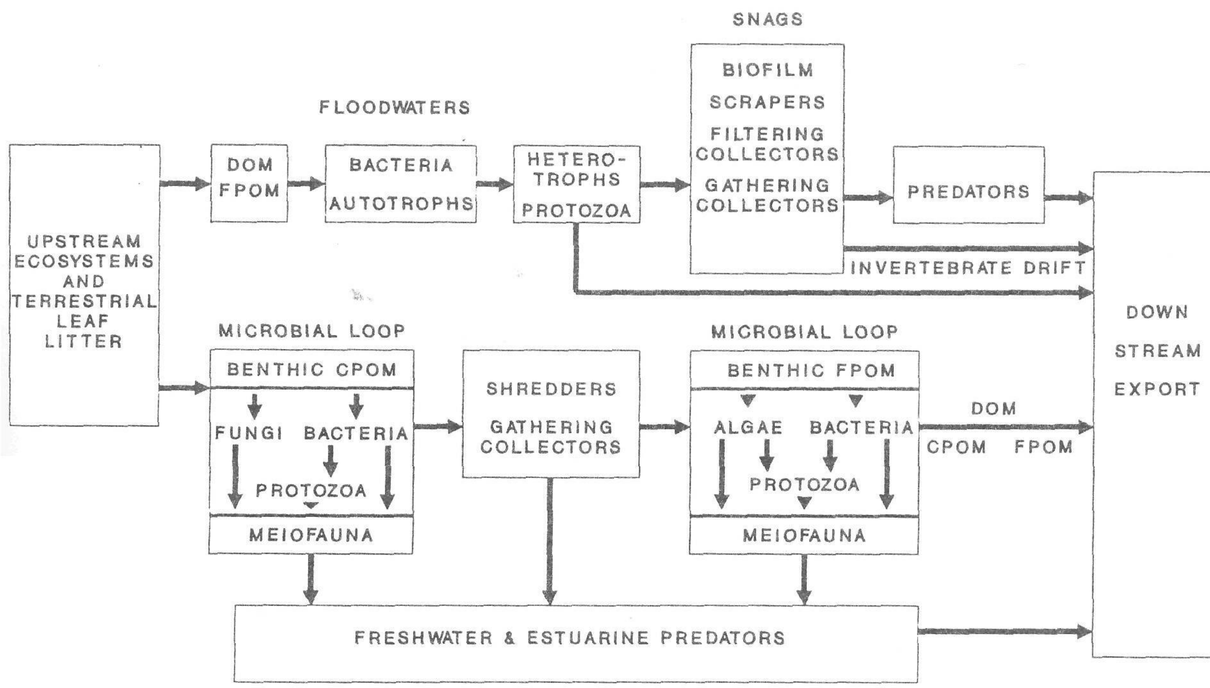

Figure 7. Connectivity of the riverine/floodplain habitat.