IV. INTERCONNECTEDNESS OF THE ECOSYSTEM

Section II described the seven distinct components, or habitats, that comprise the bay ecosystem; how the bay ecosystem is influenced by, and dependent upon, its watershed; and how the bay ecosystem is connected to its adjacent ecosystems, the riverine/floodplain and nearshore gulf, and distant ecosystems on the continent. Section III outlined the elements and connectivity within each of the habitat components. While the biotic elements of each habitat were emphasized, the abiotic constituents are equally important. The populations of organisms are responding to the availability of chemical materials, physical substrates, and other elements.

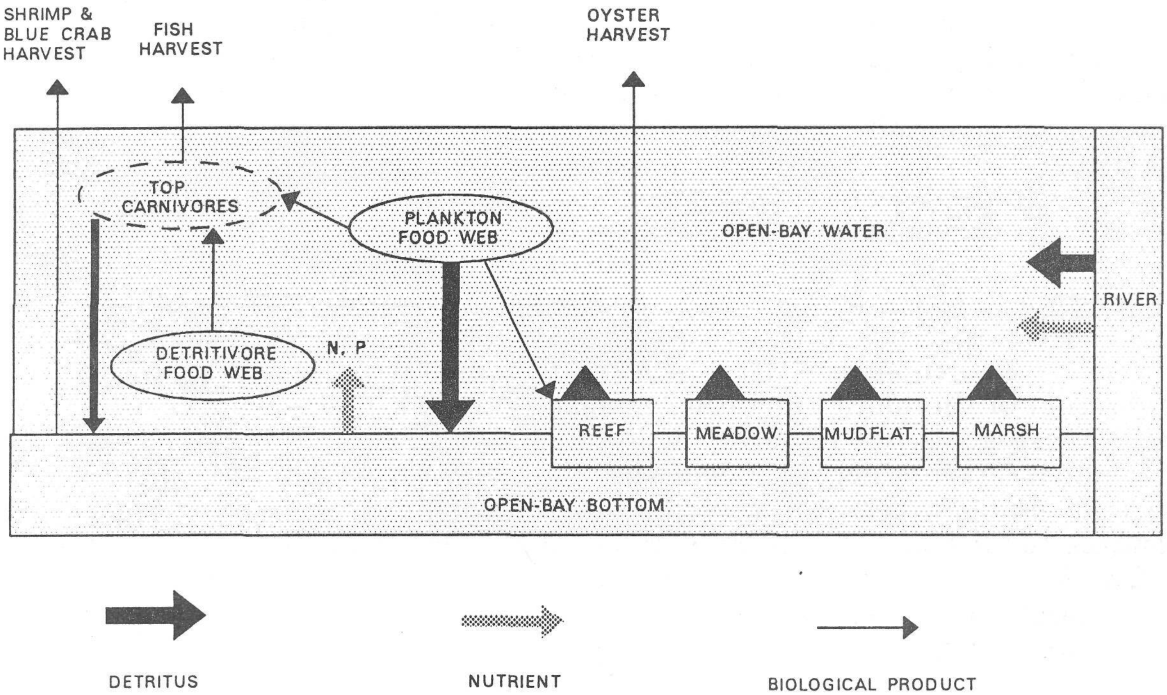
Each system exhibits not only the characteristics of its components, but also characteristics of its own which arise from combinations and interactions of the components (TGLO, 1976). Humans are most concerned with the exploitation and preservation of the biotic constituents for commercial harvest and recreation. To achieve these goals, we must be aware of the interconnectedness of the system. The common link which connects the biological and nonbiological entities is energy. Energy acquisition and use is basic to every organism. There is a network of connections between the populations of the different species which inhabit the bay. The food web is the most conspicuous connection but more complicated and subtle linkages with heat, salinity, nutrients, sediment and other components are equally important.

The bay ecosystem has been defined as an interacting, interdependent group of components, functioning as a whole. Each component has characteristics, but is linked to, may influence the control of, or be controlled by, other components (TGLO, 1976). Recognition of these control mechanisms is vital to our management of the bay.

The basis for organization within any ecosystem is the food web. Physical energy, in the form of sunlight, is captured by **primary producers** or plants that transform the physical energy into chemical energy by the process of photosynthesis. The primary producers vary in each habitat. It is terrestrial vegetation in the watershed, emergent plants and both benthic and epiphytic algae in marshes, phytoplankton in the open-bay and nearshore gulf, submergent plants and epiphytic and benthic algae in seagrass meadows, benthic algae on shallow open-bay bottoms and mudflats, and crustal algae on shallow oyster reefs. The chemical energy is stored as organic compounds in all of these primary producers.

The size range of primary producers is very broad, from microscopic single-cell phytoplankton to large multi-celled macrophytes in seagrass meadows and marshes. Following death, the primary producer plants attract **decomposer** organisms such as microscopic bacteria and fungi. This is a vital stage in the food web for many of the larger consumers cannot digest the energy-containing chemical compounds found in plants until they have been processed by microorganisms that have the requisite digestive enzymes. The mixture of dead

Figure 19. Detrital transport in the Galveston Bay ecosystem. Detritus is generated in the open-bay water habitat and imported from the reef, meadow, marsh, and mudflat habitats and the riverine/floodplain ecosystem.



plant material covered with decomposer organisms is called **detritus** and it is an important energy storage mechanism in the ecosystem.

Both pelagic grazing and detrital food webs are prominent in the ecosystem. The importance of detritus to the ecosystem is shown in Figure 19. Nutrients enter from the riverine connections, are regenerated by the benthic microbial community, and are extracted from the atmosphere (as carbon dioxide). The plankton-grazing food web supports the oyster harvest and contributes, via intermediaries, to the fish harvest. Detritus input comes from the rivers and all other habitats. The detritivore food web supports the shrimp and blue crab harvest and contributes to the fish harvest.

The next level of the food web is composed of **primary consumers**, organisms which eat the primary producers. Since the primary producers are either macrophytes (such as submerged aquatic vegetation) or microphytes (such as phytoplankton), primary consumers are herbivores. In one sense, the decomposers which feed on primary producers are also primary consumers, as are detritivores. Some primary consumers also feed on other primary consumers and thus become omnivores. The third trophic level includes the **secondary consumers**, or carnivores, animals that only eat other animals. Primary and secondary consumers, and their egested material, are linked to the decomposers as well. Often it is difficult to designate a given species to a single consumer level. For the purposes of this discussion, all consumers will be aggregated into a single consumer category.

The inputs for any trophic structure are energy and materials. The dominant source of energy is sunlight, either direct or indirect. Sunlight reaches the terrestrial landscape and the subaerial portion of the marshes unimpeded. It is rapidly attenuated in the subaqueous habitats, and functional only at relatively shallow depths in the estuary. Materials can be generally categorized as freshwater, inorganic nutrients, organic matter, and sediment.

Figure 20 illustrates the flow of energy and materials in the estuary and its adjacent ecosystems, the riverine floodplain and nearshore gulf. Freshwater arrives as precipitation and surface runoff. Its quantity, seasonality, and point of entry establish the salinity gradient in the estuary. In addition to this critical role, it also transports inorganic nutrients, organic matter, and sediment. Thus freshwater inflow directly regulates the transport of the other material to the estuary. If inflow is inadequate, or inappropriately timed, it acts as a **constraint** on other material inflow. These constraining mechanisms have been described as "work gates", for a small amount of expended energy in the water movement controls a great deal of potential energy in the organic chemical bonds (TGLO, 1976). Note that the riverine inflow also regulates the input of inorganic nutrients and organic matter from the delta marsh, via the flooding regime.

Similarly, wind or tidal action can exert widespread effects. Tides carry inorganic nutrients to marshes and remove organic matter and waste products. Winds can resuspend bottom sediments that reduce water transparency and affect photosynthesis in seagrass meadows, by benthic algae, and in open-bay waters (Figure 20). The equilibrium between suspended sediments and bottom sediments is bidirectional. The combination of high tides and winds can push sediment into marsh areas where it is entrapped. Because sediments often have inorganic nutrients (and pollutants) adsorbed to them, this can result in nutrient storage (TGLO, 1976). Suspended sediments can affect the biota as well, clogging the feeding mechanisms of various filter feeders (such as oysters or clams), or burying smaller benthic infauna. In either case, the energy flow from producer to consumer, or primary to secondary consumer, can be interrupted.

Some constraints can be long-lasting. As sediment is trapped in a salt marsh, the level of the marsh gradually rises. The vegetation may shift from smooth cordgrass (*Spartina alterniflora*) at a lower level to gulf cordgrass (*Spartina patens*) on higher ground. Not only is gulf cordgrass less productive (fewer pounds per acre of grass produced) than smooth cordgrass, but it will be flooded less frequently (requiring higher tides) which reduces tidal transport of nutrients and detritus back into the estuary (TGLO, 1976). Some marshes may become totally drained at low tide, causing motile species to seek refuge on featureless bottoms where they are vulnerable to predators. Thus shrimp or small forage fishes may be eaten when they are very small, reducing the transfer of biomass between trophic levels.

The transfer of biomass varies between habitats (Figure 20). In the autotrophic nearshore gulf, seagrass meadow, and peripheral marsh habitats producers (P) are eaten by consumers (C) or contribute to detritus (D) reserves; detritivores (primary consumers) are also eaten by other (secondary) consumers. The

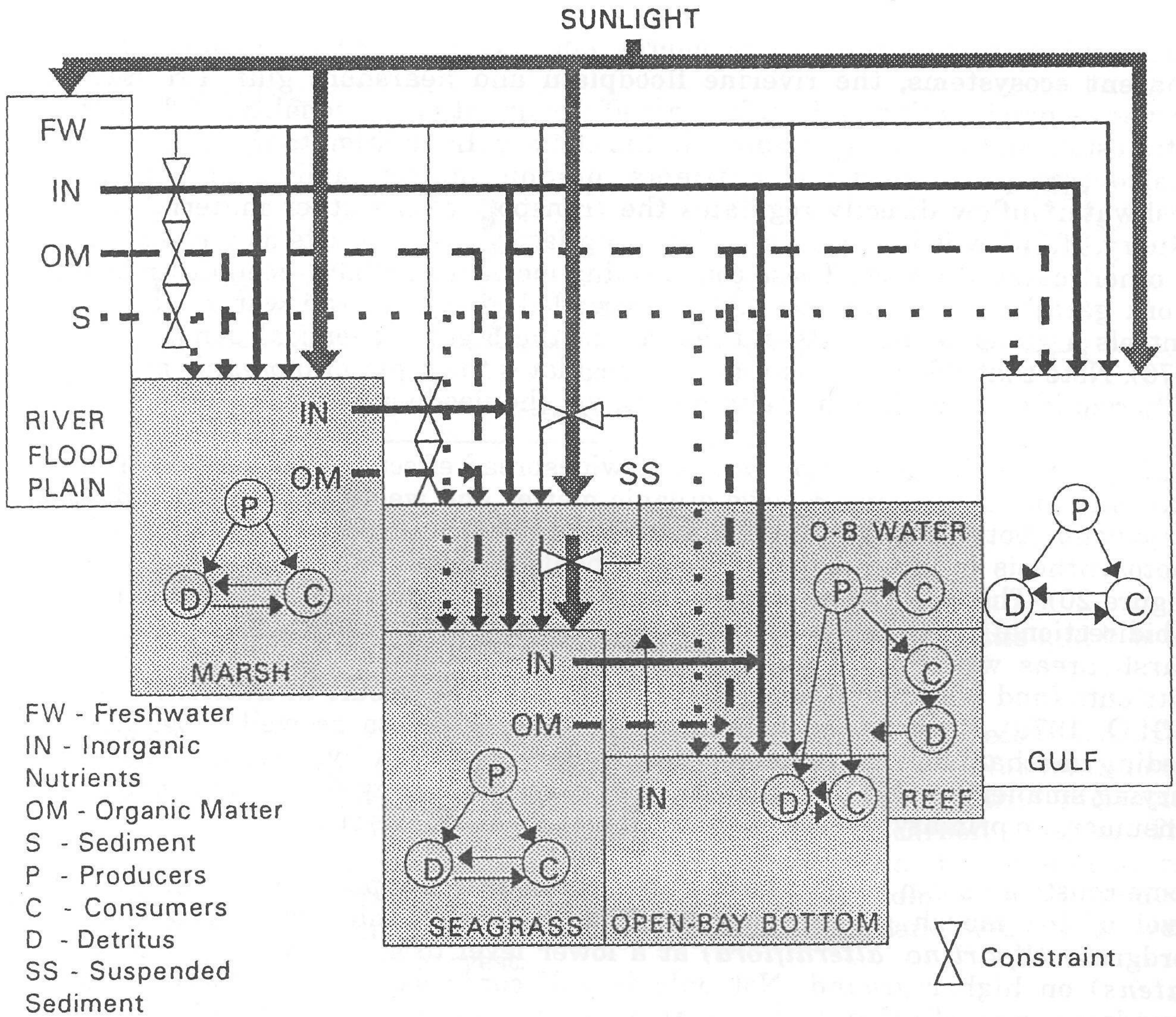


Figure 20. Ecosystem constraints. The movement of freshwater, inorganic nutrients, organic material and sediment to various ecosystem habitats passes through various physical workgates which regulate flow.

autotrophic open-bay water habitat supports pelagic consumers and the heterotrophic open-bay bottom and oyster reefs. On healthy reefs with strong currents, oyster-generated detritus is swept away to bottom habitat. Everywhere one chooses to look, a physical factor can be found that constrains another physical or some biotic factor. Salinity and temperature are universally important in coastal waters.

Individual diagrams showing inputs, outputs, transformations of energy, storage of energy or materials, and controlling factors can be, and should be, constructed for each habitat and ecosystem. Two important observations can be made (TGLO, 1976). First, every ecosystem has a complicated network of pathways and controlling mechanisms which connect organisms and storage compartments. Changing the flow of energy or material in any one pathway will likely result in a change in storage or energy flow through the transforming organisms. Second, there are numerous interdependent connections between ecological systems. Flows of energy and material, as well as controlling factors within each ecosystem, are complex and the result of forces both within and without the system. These ramifications confound human attempts to manage ecosystems.

Spatial Variation of Bay Productivity

Bellis (1974), using data from Galveston Bay and three other estuaries, proposed that the middle reach of an estuary possesses an assemblage of interrelated characteristics such that the concept of a "middle estuary" as a subsystem is useful. He suggested that the middle estuary, with salinities of 5 to 18 ppt, provides the primary support for blue crab, oyster, and shrimp fisheries.

Zimmerman and others (1990) found that the highest numbers of penaeid shrimp, blue crab and commercial fishes were in marshes of the middle and lower bay. Benthic crustaceans which were the prey of these species were also at greatest abundance in these marshes. These authors described the bay interconnectedness as follows:

> "Low salinity (oligohaline) marshes in the upper bay (especially at the Trinity Delta) exported large amounts of organic material to the middle bay. The plants of the river delta defoliate each winter and the entire standing crop is exported downstream. Enriched plant detritus in the middle system increases the productivity of epibenthic detritus feeders (such as peracarid crustaceans) and these were foraged by juveniles of commercially valuable fishes, shrimps and crabs. Because both the marsh and the subtidal bottom in the middle bay had high abundances of forage organisms, the entire area was valuable nursery habitat. The moderate influence of mesohaline to polyhaline salinities in the middle bay also encouraged utilization by consumers. In the lower bay, algal carbon was another base for secondary productivity in marsh and seagrass habitats heavily epiphytized by algae. Finally, the interconnections between the different systems of the bay appeared to be critical to maintaining overall fishery productivity." (Zimmerman et al., 1990).

The mid-bay region was described as the frontal zone where nutrients from the upper bay mixed with immigrating recruits from the lower bay. Organic detritus from the upper bay was an apparent energy source for food chains in the middle bay. The middle bay also supports the greatest concentration of oyster reefs.

In essence, there is no part of the bay which can be "written off" as deserving less protection or vigilance. The upstream riverine ecosystems provide freshwater that maintains the salinity gradient, nutrients that support bay productivity, and sediments which maintain delta marshes. The freshwater marshes are unique habitats which seasonally defoliate completely and provide detritus and nutrients to the middle bay. The saltwater marshes provide detritus, nutrients, and perennial habitat structure which nurture juveniles of important commercial and recreational species. The oyster reefs support a unique community of significant commercial importance. The seagrass meadows, although nearly gone, provide an alternative plant community and sheltering habitat which annually defoliates. The mudflats provide unique access for upper level consumers. The open-bay bottom, although less productive, recycles important nutrients to overlying waters and, by sheer areal extent, supports important detritus-based food webs and commercial harvest, particularly the larger size classes of important organisms. The open-bay water is the only habitat to have significantly increased in size (by 30% in volume, due to subsidence and sea-level rise; Ward, 1993). The open-bay water habitat is the matrix for the grazing food web and connector to all other habitats. Finally, the nearshore gulf is the source of most larval organisms, as well as major predators, and habitat of the ultimate fishery.