

# Biological Components of Galveston Bay

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## Distribution and Abundance

### Estuarine Vegetation

**PETER F. SHERIDAN**—The plant life of Galveston Bay includes phytoplankton in the water column, benthic microflora, macroalgae, submerged aquatic vegetation and emergent vascular plants. Some groups are so dense that they are major sources of physical structure for other estuarine organisms, while some groups are major producers of organic materials for assimilation by consumers. Other functions of vegetation include refuge from predators, maintenance of water quality by filtering runoff and tidal inputs, and shoreline stabilization.

**Phytoplankton**—The phytoplankton of upper Galveston and Trinity Bays is composed of at least 132 species, including diatoms (54 taxa), green algae (45 taxa), blue-green algae (14 taxa), dinoflagellates (9 taxa), euglenoids (7 taxa), cryptophytes (2 taxa), and golden-brown algae (1 taxon) (1). Many of these species, particularly the green algae, are freshwater forms entering via river discharge. Over an annual cycle (September 1975–August 1976), the mean percentage of the standing crop for each division was found to be diatoms (41.6 percent), green algae (24.2 percent), blue-green algae (23.0 percent), dinoflagellates (5.9 percent), euglenoids (2.6 percent), and others (2.7 percent). Major peaks in phytoplankton density occurred in late winter and mid-summer. The winter peak was due to the diatoms *Skletonema costatum* and *Cyclotella meneghiniana*, while the summer peak in densities was due to a bloom of the blue-green *Oscillatoria* sp. As a group, diatoms were the dominant phytoplankters in November, December and February–June (*Skletonema* and *Cyclotella* in cold months, *Nitzschia closterium*, *Navicula abunda* and *Thalassionema nitzschoides* in warmer months). Green algae were a consistent 20 to 30 percent of the monthly standing crops, and *Ankistrodesmus* sp. bloomed in September–October. Blue-green algae were relatively abundant July to October, and a bloom of *Oscillatoria* in July represented 70 percent of the standing crop. The dinoflagellate *Prorocentrum* sp. comprised 45 percent of the total density in January. Euglenoids such as *Euglena* spp. and *Eutreptia* spp. were relatively abundant in May and August. Lower salinity stations were dominated by blue-green and green algae while high salinity sites were dominated by diatoms.

Similar studies on phytoplankton distribution and abundance have not been conducted in lower Galveston, East or West Bays.

**Benthic Microflora**—Components of the benthic microflora have been examined in a descriptive sense (2-4), but little information on temporal or spatial distribution is available. Thirty-three genera

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Table 2.1. Benthic Algae Collected from Bay Sediments (2) and Beach Sands (4) in the Galveston Bay System.

<u>Green Algae</u>	<u>Blue-green Algae</u>	<u>Diatoms</u>
Bracteacoccus	Anabaena	Achnanthes (2)
Characium	Anacystis	Actinoptychus (3)
Chlamydomonas	Aphanocapsa	Amphora (3)
Chlorosarcina	Aphanothece	*Coscinodiscus (10)
Chlorosarcinopsis	Calothrix	*Cyclotella (3)
Chlorococcum	Gloeocapsa	Diatoma (1)
Cylindrocystis	Lyngbya	*Diploneis (4)
Eremosphaera	Myxosarcina	Epithemia (1)
Gloeocystis	Nostoc	Eunotogramma (1)
Hormidium	Oscillatoria	Mastogloia (1)
Oedocladium	Schizothrix	Melosira (2)
Pleurastrum	Spirulina	Navicula (4)
Radiosphaera	Synechococcus	Nitzschia (9)
Stichococcus	Synechocystis	Opephora (1)
Tetracystis	Xenococcus	Pinnularia (1)
Tetraedon		Pleurosigma (4)
		Rhopalodia (2)
		*Skeletonema (1)
		Stenopterobia (1)
<u>Cryptophytes</u>	<u>Euglenophytes</u>	Stephanodiscus (1)
Cryptomonas	Euglena	Surirella (1)
		Synedra (1)

(n) = number of species in genus, if given  
 \* = most abundant

of algae were identified from Galveston Island beach sands, and 22 genera (56 species) of diatoms were identified from bay sediments (Table 2.1). The diatoms *Coscinodiscus*, *Diploneis*, *Cyclotella* and *Skeletonema* were noted as being very abundant (2), the latter two genera also dominating the phytoplankton as noted previously. Diatoms were the main component of the benthic microflora in waters deeper than 0.5 m, while blue-green algae dominated the shallow water and tidal flats (3). Algal densities could not be related to depth, sediment type, Eh, pH or salinity.

**Macroalgae**—There has been no survey of macroalgal types over the whole bay system. Several faunal surveys (9, 13, 24) noted that, where present, the macroalgae is represented by *Enteromorpha*, *Ectocarpus*, *Dictyota*, *Sargassum*, *Polysiphonia* and *Gracilaria*. The major study of macroalgae was limited to Galveston Island proper (46), finding 19 genera and 28 species over a two-year period (Table 2.2). The gulf shore community is composed of *Cladophora*, *Bryocladia* and *Ceramium* in summer and shifts to *Enteromorpha*, *Bangia* and *Gelidium* in winter. The bay shore community is barren in the summer and is primarily *Enteromorpha* and *Ectocarpus* during winter. The flora is considered depauperate relative to other Gulf estuaries.

**Submerged aquatic vegetation**—Submerged aquatic vegetation is limited in areal extent. On the Trinity River delta, the submerged freshwater plants *Vallisneria americana* (tapegrass) and *Sagit-*

**Marshes, woodlands and swamps**—Emergent vegetation can be classified as salt, brackish or freshwater marshes, fluvial woodlands and swamps. These wetlands are large-scale contributors to estuarine productivity in terms of particulate matter, nutrients, structure, protection and substrate. Salt marshes cover an estimated 140 km<sup>2</sup> (12). Species such as *Spartina alterniflora*, *Batis maritima*, *Salicornia* spp. and *Juncus roemerianus* are most common in the more frequently flooded areas, while *Borrichia frutescens*, *Monanthochloa littoralis*, *Distichlis spicata*, *Suaeda* spp., *Iva* spp. and *Aster* spp. are less common (Table 2.3). *Spartina alterniflora* is the dominant plant in subsiding salt marshes due to almost constant flooding. Brackish marshes (230 km<sup>2</sup>; 12) are of moderate salinity regimes (1 to 18 ppt) but are flooded by storm tides from the bay and by freshwater inundation from rainfall and runoff, thus they have a mixture of vegetation types (Table 2.3). Plants frequently occurring in fresher areas include *Scirpus maritimus*, *S. californicus* and *S. americanus*, *Alternanthera philoxeroides*, *Bacopa monnieri*, *Typha* spp., *Paspalum lividum* and *Phragmites australis*, while plants in the more saline brackish marshes include *Spartina patens* and *Scirpus* spp. *Scirpus olneyi* and *S. maritimus*, *Paspalum vaginatum*, *Juncus roemerianus* and species from higher salt marshes. Lower elevation brackish marshes are dominated by *Scirpus*, *Typha*, *Eleocharis* and *Bacopa*. Fresh marshes are generally beyond all salt water intrusion except during hurricane surges. There are approximately 40 km<sup>2</sup> of fresh marshes, primarily in the Trinity and San Jacinto River systems (12). Low fresh marshes are characterized by *Typha* spp., *Scirpus americanus* and *S.*

*tartaria kurziana* (strap-leaf) are currently found in mixed stands (5). *Vallisneria* has also been found in the Chocolate Bay area off West Bay (24). Extensive *Kuppia maritima* (widgeon grass) beds were once located in shallow marginal waters of Trinity Bay and upper Galveston Bay (6-8). East Bay was found to be devoid of submerged vegetation (9). *Kuppia* was also scattered in various embayments along lower Galveston Bay and West Bay (10-13). Western West Bay, Christmas Bay and Bastrop Bay harbored seagrass beds dominated by *Halodule wrightii* (shoal grass) and lesser amounts of *Thalassia testudinum* (turtle grass) and *Halophila engelmannii* (13, 14). The areal extent of submerged vegetation has apparently declined from approximately 21 km<sup>2</sup> around 1960 (6-8, 12) to <1 km<sup>2</sup> by 1979 (15). There have been no studies of seasonal growth or distribution of submerged vegetation in the Galveston Bay system, and no actual bay-wide site surveys for species composition and distribution.

Indeterminant (not enough data)	Winter-Spring	Summer-Fall
<i>Dicotyola dichotoma</i>	<i>Ectocarpus siliculosus</i>	<i>Bryocladia cuspidata</i>
<i>Gracilaria foliifera</i>	<i>Petalonia fascia</i>	<i>Ceramium strictum</i>
<i>Sargassum fluitans</i>	<i>Enteromorpha clathrata</i>	<i>Cladophora dalmatica</i>
<i>Sargassum natans</i>	<i>Enteromorpha flexuosa</i>	<i>Cladophora linum</i>
<i>Vaucheria</i> sp.	<i>Enteromorpha linguata</i>	<i>Polysiphonia gorgoniae</i>
	<i>Enteromorpha prolifera</i>	<i>Polysiphonia denudata</i>
	<i>Uva lactuca</i>	<i>Polysiphonia tepida</i>
	<i>Gelidium crinale</i>	<i>Spyridia filamentosa</i>
	<i>Bangia fuscopurpurea</i>	<i>Chaetomorpha linum</i>
	<i>Polysiphonia subtilissima</i>	<i>Erythrocladia subintegra</i>
		<i>Erythrotrichia carnea</i>
		<i>Goniotrichum alsidii</i>
		<i>Achrochaetium</i> sp.

Table 2.2. Benthic Macroalgae of Galveston Island Grouped by Maximum Growth Periods (46).

Table 2.3. Typical Plants Found in Galveston Bay Wetland Environments (15).

<u>Salt Marsh</u>			
<i>Spartina alterniflora</i>	smooth cordgrass	<i>Typha latifolia</i>	common cattail
<i>Batis maritima</i>	saltwort	<i>Spartina cynosuroides</i>	big cordgrass
<i>Salicornia virginica</i>	glasswort	<i>Phragmites australis</i>	common reed
<i>Salicornia bigelovii</i>	glasswort	<i>Eleocharis parvula</i>	dwarf spikerush
<i>Distichlis spicata</i>	seashore saltgrass	<i>Cyperus</i> spp.	flatsedge
<i>Borrichia frutescens</i>	sea-oxeye	<i>Enchinochloa crusgalli</i>	barnyard grass
<i>Monanthochloe littoralis</i>	shoregrass	<i>Leptochloa</i> spp.	sprangletop
<i>Juncus roemerianus</i>	needle rush	<i>Bacopa monnieri</i>	coastal waterhyssop
<i>Suaeda</i> sp.	seablite or seepweed	<i>Aster tenuifolius</i>	saline aster
<i>Lycium carolinianum</i>	Carolina wolfberry	<i>Aster subulatus</i>	saltmarsh aster
<i>Spartina spartinae</i>	gulf cordgrass	<i>Aster spinosus</i>	spiny aster
<i>Spartina patens</i>	marshhay cordgrass	<i>Paspalum lividum</i>	longtom
<i>Iva frutescens</i>	bigleaf sumpweed	<i>Paspalum vaginatum</i>	seashore paspalum
<i>Iva angustifolia</i>	narrowleaf sumpweed	<i>Setaria geniculata</i>	knotroot bristlegass
<i>Limonium nashii</i>	sea-lavender	<i>Zizaniopsis miliacea</i>	giant cutgrass
<i>Scirpus maritimus</i>	salt-marsh bulrush	<i>Solidago sempervirens</i>	seaside goldenrod
<i>Sporobolus</i> spp.	dropseed	<i>Baccharis halimifolia</i>	groundsel bush
<i>Sesuvium portulacastrum</i>	sea purslane	<i>Iva frutescens</i>	bigleaf sumpweed
<i>Heliotropium curassavicum</i>	salt heliotrope	<i>Iva angustifolia</i>	narrowleaf sumpweed
		<i>Iva annua</i>	seacoast sumpweed
<u>Brackish Marsh</u>		<i>Sesuvium portulacastrum</i>	sea purslane
<i>Spartina spartinae</i>	gulf cordgrass	<i>Salicornia</i> spp.	glasswort
<i>Spartina patens</i>	marshhay cordgrass	<i>Limonium nashii</i>	sea-lavender
<i>Borrichia frutescens</i>	sea-oxeye	<i>Juncus roemerianus</i>	needle rush
<i>Distichlis spicata</i>	seashore saltgrass	<i>Lycium carolinianum</i>	Carolina wolfberry
<i>Monanthochloe littoralis</i>	shoregrass	<i>Sporobolus</i> spp.	dropseed
<i>Scirpus maritimus</i>	salt-marsh bulrush	<i>Fimbristylis castanea</i>	fimbry
<i>Scirpus americanus</i>	three-square bulrush	<i>Hydrocotyle</i> spp.	pennywort
<i>Scirpus californicus</i>	California bulrush	<u>Fresh Marsh</u>	
<i>Scirpus olneyi</i>	Olney bulrush	<i>Spartina spartinae</i>	gulf cordgrass
<i>Alternanthera philoxeroides</i>	alligatorweed	<i>Typha latifolia</i>	common cattail
<i>Typha domingensis</i>	narrowleaf cattail	<i>Typha domingensis</i>	narrowleaf cattail
		<i>Scirpus americanus</i>	three-square bulrush

California	bulrush	<i>Scirpus californicus</i>
bulrush	longtom	<i>Paspalum lividum</i>
spikesedge	spikesedge	<i>Eleocharis</i> spp.
flatsedge	flatsedge	<i>Cyperus</i> spp.
partidge pea	partidge pea	<i>Cassia fasciculata</i>
groundsel bush	groundsel bush	<i>Baccharis halimifolia</i>
cordgrass	cordgrass	<i>Sesbania drummondii</i>
marshhay	marshhay	<i>Spartina patens</i>
doveweed	doveweed	<i>Croton</i> spp.
bulrush	bulrush	<i>Scirpus</i> spp.
spikesedge	spikesedge	<i>Eleocharis</i> spp.
flatsedge	flatsedge	<i>Cyperus</i> spp.
black willow	black willow	<i>Salix nigra</i>
hackberry /	hackberry /	<i>Celtis</i> spp.
sugarberry	sugarberry	<i>Fraxinus</i> spp.
ash	ash	<i>Ulmus crassifolia</i>
cedar elm	cedar elm	<i>Ulmus americana</i>
American elm	American elm	<i>Quercus aquatica</i>
water oak	water oak	<i>Quercus lyrata</i>
overcup oak	overcup oak	<i>Quercus phellos</i>
willow oak	willow oak	<i>Quercus stellata</i>
post oak	post oak	<i>Quercus virginiana</i>
live oak	live oak	<i>Liquidambar styraciflua</i>
sweetgum	sweetgum	<i>Ilex vomitoria</i>
yaupon	yaupon	<i>Cephalanthus occidentalis</i>
buttonbush	buttonbush	<i>Sapum sebiferum</i>
Chinese tallow	Chinese tallow	<i>Pinus taeda</i>
loblolly pine	loblolly pine	<i>Carya aquatica</i>
water hickory	water hickory	<i>Carya illinoensis</i>
pecan	pecan	<i>Populus deltoides</i>
cottonwood	cottonwood	<i>Plantanus occidentalis</i>
American	American	<i>Planera aquatica</i>
sycamore	sycamore	<i>Acacia farnesiana</i>
water elm	water elm	<i>Parkinsonia aculeata</i>
huisache	huisache	<i>Tamarix gallica</i>
retama	retama	<i>Sabal minor</i>
salt cedar	salt cedar	<i>Taxodium distichum</i>
boxelder	boxelder	<i>Acer negundo</i>
Swamp	Swamp	<i>Taxodium distichum</i>
bald cypress	bald cypress	<i>Planera aquatica</i>
water elm	water elm	<i>Carya aquatica</i>
water hickory	water hickory	<i>Helianthus</i> spp.
buttonbush	buttonbush	<i>Sorghum halepense</i>
California	bulrush	<i>Scirpus californicus</i>
bulrush	longtom	<i>Paspalum lividum</i>
spikesedge	spikesedge	<i>Eleocharis</i> spp.
flatsedge	flatsedge	<i>Cyperus</i> spp.
alligatorweed	alligatorweed	<i>Alternanthera philoxeroides</i>
rush	rush	<i>Juncus</i> spp.
seedbox	seedbox	<i>Ludwigia</i> spp.
arrowhead	arrowhead	<i>Sagittaria</i> spp.
pickereelweed	pickereelweed	<i>Pontederia</i> sp.
knotweed	knotweed	<i>Polygonum</i> spp.
common reed	common reed	<i>Phragmites australis</i>
waterhyssop	waterhyssop	<i>Bacopa monnieri</i>
burthead	burthead	<i>Echinodorus</i> spp.
water hyacinth	water hyacinth	<i>Eichhornia crassipes</i>
beakrush	beakrush	<i>Rhynchospora</i> sp.
fimbry	fimbry	<i>Fimbristylis</i> spp.
barnyard grass	barnyard grass	<i>Echinochloa crusgalli</i>
sprangletop	sprangletop	<i>Lepochloa</i> spp.
marshhay	marshhay	<i>Spartina patens</i>
cordgrass	cordgrass	<i>Lemma</i> spp.
duckweed	duckweed	<i>Hydrocotyle</i> spp.
marsh penny-	marsh penny-	<i>Zizaniopsis miliacea</i>
southern	southern	<i>Sesbania drummondii</i>
wildrice	wildrice	<i>Baccharis halimifolia</i>
rattlebush	rattlebush	<i>Salix nigra</i>
groundsel bush	groundsel bush	<i>Cephalanthus occidentalis</i>
black willow	black willow	<i>Transitional Areas</i>
gulf cordgrass	gulf cordgrass	<i>Spartina spartinae</i>
bermudagrass	bermudagrass	<i>Cynodon dactylon</i>
sea-oxeye	sea-oxeye	<i>Borrichia frutescens</i>
spiny aster	spiny aster	<i>Aster spinosus</i>
gulfdune	gulfdune	<i>Paspalum monostachyum</i>
paspalum	paspalum	<i>Paspalum lividum</i>
longtom	longtom	<i>Panicum</i> spp.
panicum	panicum	<i>Rhynchospora</i> spp.
beakrush	beakrush	<i>Andropogon virginicus</i>
broomsedge	broomsedge	<i>Andropogon glomeratus</i>
bluestem	bluestem	<i>Iva annua</i>
bushy bluestem	bushy bluestem	<i>Andropogon glomeratus</i>
seacoast	seacoast	<i>Artisida</i> spp.
sumpweed	sumpweed	<i>Setaria</i> spp.
threawn	threawn	<i>Helianthus</i> spp.
bristleglass	bristleglass	<i>Sorghum halepense</i>
sunflower	sunflower	<i>Johnsongrass</i>

*californicus*, *Phragmites australis*, *Eleocharis* spp., *Cyperus* spp., *Juncus* spp., *Ludwigia* sp., *Sagittaria* spp. and *Paspalum lividum* (Table 2.3) (1, 15). Higher fresh marshes are typified by *Spartina spartinae*, *Paspalum* spp., *Polygonum* spp., *Panicum* spp., *Borrchia*, *Rhynchospora macrostachya*, *Fimbristylis* sp., *Aster* spp. and *Sesbania drummondii*. Many species of *Spartina* exhibit broad salinity tolerances and are found in several categories of marsh. Fluvial woodlands along floodplains cover 450 km<sup>2</sup> (12) and support a variety of water-tolerant trees and shrubs (Table 2.3), including *Fraxinus* spp., *Salix nigra*, *Ulmus* spp., *Celtis* spp., *Carya* spp. and *Quercus* spp. Swamps containing saturated soils or nearly permanent standing water comprise 50 km<sup>2</sup> (12) and are dominated by *Taxodium distichum* (Table 2.3). Additional information on wetland plants is also available (16).

Between wetland surveys of 1956 and 1979, several changes were noted in vegetation patterns in the estuary: (1) expansion of open water into former marshes and woodlands; (2) expansion of marshes along the bay side of barrier islands into prior tidal flats; (3) formation of wetlands farther up creek valleys; (4) landward expansion of existing marshes; (5) reduction of submerged vegetation; and (6) reduction or modification of wetlands by human activities (15). Of primary concern are the losses of 63 km<sup>2</sup> of fresh marsh and 42 km<sup>2</sup> of salt and brackish marshes during this period. These losses are ascribed to such activities as channelization, impoundments, filling and subsidence associated with subsurface petroleum or water extraction.

### Invertebrates

Invertebrates within the Galveston Bay system are discussed by component groups such as zooplankton, benthos, and mobile and sessile macrofauna. While there have been a number of studies of invertebrates in this area, there are no synoptic zooplankton or macrofaunal surveys on a bay-wide basis.

**Zooplankton**—A 12-month study of zooplankton in the upper Galveston and Trinity Bay areas (1) revealed 70 species representing nine phyla. The most abundant plankters included copepods (primarily *Acartia tonsa*, followed by *Labidocera*, *Cyclops* and *Oithona*) and barnacle nauplii (*Balanus* spp.); in fact, these two phyla plus a mixed assemblage of copepod nauplii and copepodites represented >70 percent of the zooplankton in 11 of 12 months. Other phyla included rotifers (*Asplancha*, *Brachionus*, *Keratella*), dinoflagellates (*Noctiluca scintillans*) and larvaceans (*Oikopleura*). Zooplankton densities peaked in April (dominated by copepod nauplii and *Noctiluca*) and August (*Acartia* and copepod nauplii). Barnacle nauplii were most dense in late winter-early spring. Fluctuations in zooplankton densities were not linked to variations in river flow, but salinity regimes regulated species composition and seasonal distribution.

A three-and-a-half-year study (17) of the larger zooplankters in the same region (mouth of the San Jacinto River and southern Trinity Bay) identified 94 taxa dominated by crustaceans and fishes. Crab larvae, tentatively identified as *Rhithropanopeus harrisi*, were the most abundant group followed by other crustaceans such as *Petrolisthes armatus*, *Pinnixa* sp., *Palaemonetes* spp. and *Callinectes* spp., and by the fishes *Brevoortia patronus* and *Anchoa mitchilli*. Two broad seasonal groups were detected relating to abundance of organisms, with a "warm" season characterized by many larval crustaceans and few fishes and a "cool" season where the reverse trend was found.

A 16-month study of the zooplankton of Christmas Bay (18) indicated that this high salinity embayment hosted a permanent zooplankton assemblage of three species (*Mnemiopsis mccradyi*, a ctenophore, and *Acartia tonsa* and *Oithona colcarva*, copepods) apparently unaffected by temperature and salinity fluctuations. Other taxa such as larval crustaceans, other copepods, and the ctenophore *Beroë ovata* exhibited summer peaks in abundance.

No zooplankton studies have been conducted in West Bay or East Bay.

**Benthos**—Six benthic macroinvertebrate assemblages occur in the Galveston Bay complex, including open bay center, oyster reef, grassflat, bay margin, inlet-influenced and river-influenced assemblages (Table 2.4). The river-influenced assemblage covers the greatest area, including all of Trinity Bay, upper Galveston Bay, and part of East Bay. Oyster reef assemblages occur primarily in central Galveston Bay and divide Galveston Bay into upper and lower sections. Lower Galveston Bay contains primarily inlet-influenced and open bay center assemblages. The bay margin assemblage occurs on the bay side of Bolivar Peninsula and near Texas City. All six assemblages are found in West Bay.

The river-influenced assemblage contains a small group of common bay species, including the bivalve *Mulinia lateralis*, the polychaetes *Capitella capitata*, *Streblospio benedicti* and *Mediomastus ssp.*, and brackish-water mollusks such as *Macoma mitchelli*, *Texadina sphinctostoma* and *Rangia flexuosa*. These species occur in parts of estuaries where salinities vary from fresh to brackish over long periods of time. Average salinities in Trinity Bay range from less than 5 ppt to about 10 ppt (15). However, over relatively short periods of time, the river-influenced assemblage is subjected to greater natural salinity fluctuations (0-33 ppt) than are other bay assemblages.

In contrast to the river-influenced assemblage, the inlet-influenced assemblage contains the highest number of species, partly because of more stable salinities. This assemblage, composed primarily of mollusks, contains some species that are restricted to the area of Galveston and East Bays near Bolivar Roads and Rollover Pass and to West Bay near San Luis Pass. Common species include mollusks such as *Mulinia lateralis*, *Lyonsia hyalina*, *Mysella planulata*, *Turbonilla* sp., *Acteocina canaliculata* and *Nassarius acutus* and polychaetes such as *Owenia fusiformis*, *Paraprionospio pinnata*, *Clymenella torquata* and *Mediomastus californiensis*.

The oyster reef assemblage is found primarily on or near reefs and is dominated by the American oyster *Crassostrea virginica* and the mollusks *Ischadium recurvum*, *Brachidontes exustus* and *Mulinia lateralis*. The common polychaetes *Mediomastus californiensis* and *Streblospio benedicti* are also abundant.

The bay margin assemblage is limited to shallow, sandy stations in East and West Bays and lower Galveston Bay. Most stations are less than 2 km from shore and less than 1 meter deep. Crustaceans such as *Ampelisca* spp., *Cerapus tubularis* and *Oxyurostylis salmoi* are more abundant in the bay margin assemblage than in any other assemblage except the grassflat assemblage.

Crustaceans are dominant in the grassflat assemblage and include such species as *Ampelisca abdita*, *Acanthohausorius* sp. and *Cymadusa compta*. Bivalves such as *Amygdalum papyrium*, *Lyonsia hyalina* and *Laevicardium mortoni* and polychaetes such as *Articida fragilis* and *Scoloplos fragilis* are common. Grassflats are of limited distribution in the Galveston Bay system and occur principally in patches along the margin of the Trinity River delta and Christmas Bay.

The open bay center assemblage occurs in lower Galveston Bay and East and West Bays in muddy sediments and in relatively deep water. Polychaetes are the predominant group and are characterized by *Paraprionospio pinnata*, *Parandalia fauvelii* and *Podarkeopsis levinscua*.

A 12-month study of the benthos of Trinity Bay (1) indicated that polychaetes were the most speciose group collected (35 species), followed by crustaceans (18 species), mollusks (14 species), and bryozoans, rhyzochocoids and chordates (5 species). Seventy-four percent of all individuals collected were polychaetes, primarily *Mediomastus californiensis* and other capitellids. Other abundant species were the mollusks *Macoma* sp., *Ammicola* sp. and *Texadina sphinctostoma*. Densities of benthic organisms exhibited spring and late summer peaks.

Macroinvertebrates—These mobile and sessile species are rarely encountered using the plankton or benthic sampling methods involved in prior sections except as larval or early juvenile forms. No synoptic surveys of macroinvertebrates in the Galveston Bay system (other than oysters, *Crassostrea virginica*) have been conducted. The public oyster reefs within the estuary have been described (19, 20). The reefs are typically long and narrow, are oriented perpendicular to water currents, and are densest in the mid-bay region and across the mouth of East Bay. Settlement of spat (free-swimming larvae) generally occurs during April to November, primarily in the summer months. Oysters reach market size in 13 to 18 months. The distribution of oyster reefs depends on the interactions of temperature, salinity, predation and disease (19). High salinities allow an increased predation by oyster drills (*Thais haemastoma*) and increased infection by *Perkinsus marinus* ("dermo"). Extensive periods of low salinity can also kill oysters, so most of the viable reefs are located in areas characterized by 10 to 20 ppt mean annual salinity. Since 1975, the areal distribution of oyster reefs has been stable.

Although not well documented, there are numerous species of mobile macroinvertebrates in the estuary (13, 21-24) (Table 2.5). All of these species were collected in western West Bay (but are found elsewhere) and many of these species are probably limited to submerged vegetation or oyster reef habitats, rarely caught elsewhere. In shallow, fringing habitats *Palaemonetes* spp. (grass shrimp) are most common and reach maximum abundance in March through July. *Macrobrachium ohione*

Table. 2.4. Characteristic Species in Macroinvertebrate Assemblages (15).

Galveston-Trinity-East Bays

River-Influenced

Bivalves

*Mulinia lateralis*  
*Macoma mitchelli*  
*Rangia flexuosa*

Gastropods

*Texadina sphinctostoma*  
*Vioscalba louisianae*  
*Texadina barretti*

Polychaetes

*Parandalia fauveli*  
*Streblospio benedicti*  
*Capitella capitata*  
*Mediomastus californiensis*  
*Polydora ligni*

Crustaceans

*Corophium louisianum*

Inlet-Influenced

Bivalves

*Mulinia lateralis*  
*Lyonsia hyalina floridana*  
*Tellina texana*

Gastropods

*Turbonilla* cf. *T. interrupta*  
*Nassarius acutus*

Polychaetes

*Owenia fusiformis*  
*Apoprionospio pygmaea*  
*Onuphis eremita oculata*

Bay Margin

Bivalves

*Amygdalum papyrium*

Polychaetes

*Streblospio benedicti*  
*Paraprionospio pinnata*

*Tharyx marioni*

*Owenia fusiformis*

Crustaceans

*Oxyurostylis salinoi*  
*Monoculodes nyei*  
*Cerapus tubularis*  
*Hargeria rapax*

Open Bay Center

Bivalves

*Mulinia lateralis*

Polychaetes

*Paraprionospio pinnata*  
*Pseudeurythoe ambigua*  
*Parandalia fauveli*  
*Sigambra* spp.

Crustaceans

*Acetes americanus*

Oyster Reef

Gastropods

*Boonea impressa*  
*Texadina sphinctostoma*

Bivalves

*Crassostrea virginica*  
*Ischadium recurvum*  
*Brachidontes exustus*  
*Mulinia lateralis*

Polychaetes

*Nereis succinea*  
*Polydora ligni*  
*Mediomastus californiensis*  
*Streblospio benedicti*  
*Parandalia fauveli*

Crustaceans

*Melita nitida*  
*Rhithropanopeus harrisi*  
*Cassidinidea lunifrons*



West Bay (including Chocolate, Christmas and Bastrop Bays)

<p><b>Crassiflat</b></p> <p>Bivalves Amygdalum papyrium Laevicardium mortoni Polychaetes Chone duneri Nereis succinea Streblospio benedicti Crustaceans Ampelisca abdita Edotea montosa Cerapus tubularis Listriella sp.</p> <p><b>Oyster Reef</b></p> <p>Bivalves Crassostrea virginica Ischadium recurvum Polychaetes Nereis succinea Crustaceans Grandidierella bonnieroides Oxyrostylis salinot Rhithropanopeus harrisi</p> <p><b>River-Influenced</b></p> <p>Gastropods Texadina barretti Bivalves Macoma mitcheilli Mulinia lateralis Polychaetes Parandalia fauveli Scoloplos fragilis Paraprionospio pinnata Glycinde solitaria</p> <p><b>Open Bay Center</b></p> <p>Bivalves Mulinia lateralis</p>	<p><b>Crassiflat</b></p> <p>Bivalves Mysella planulata Lyonsia hyalina floridana Polychaetes Paraprionospio pinnata Podarkeopsis leviscina Cossura delta Mediomastus californiensis Melinna maculata</p> <p><b>Inlet-Influenced</b></p> <p>Gastropods Turbonilla cf. T. interrupta Acteocina canaliculata Bivalves Mulinia lateralis Periploma margaritaceum Mysella planulata Lyonsia hyalina floridana Polychaetes Paraprionospio pinnata Clymenella torquata Owenia fusiformis Mediomastus californiensis Crustaceans Ampelisca brevisimulata</p> <p><b>Bay Margin</b></p> <p>Gastropods Acteocina canaliculata Bivalves Mulinia lateralis Ensis minor Lyonsia hyalina floridana Polychaetes Mediomastus californiensis Crustaceans Ampelisca abdita Ampelisca brevisimulata Oxyrostylis salinot</p>
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Table 2.5. Macrocrustaceans Collected in Trawl Surveys of the Galveston Bay System (13, 21-23).

<u>Stomatopods</u>	<u>Crabs</u>
Squilla empusa	Petrolisthes armatus
	Clibanarius vittatus
<u>Shrimp</u>	Pagurus longicarpus
Penaeus setiferus	Pagurus pollicaris
Penaeus aztecus	Ovalipes stephensoni
Penaeus duorarum	Callinectes sapidus
Trachypenaeus similis	Callinectes similis
Xiphopenaeus kroyeri	Menippe mercenaria
Alpheus heterochaelis	Rhithropanopeus harrisi
Palaemonetes pugio	Hexapanopeus angustifrons
Palaemonetes vulgaris	Neopanope texana
Palaemonetes intermedius	Eurypanopeus depressus
Macrobrachium ohione	Panopeus herbstii
Periclimenes longicaudatus	Pachygrapsus transversus
Hippolyte zostericola	Uca spp.
Tozeuma carolinense	Libinia dubia
	Heterocrypta granulata

Table 2.6. Comparison of the Most Numerous Fishes Collected During a Two-Year Period in Various Galveston Bay Habitats (Rank Order) (27).

<u>Channels</u>	<u>Open Bay</u>
Stellifer lanceolatus	Micropogonias undulatus
Micropogonias undulatus	Anchoa mitchilli
Symphurus plagiusa	Cynoscion arenarius
Anchoa mitchilli	Stellifer lanceolatus
Polydactylus octonemus	Arius felis
Arius felis	Sphoeroides parvus
Menticirrhus americanus	Citharichthys spilopterus
Brevoortia patronus	Leiostomus xanthurus
Citharichthys spilopterus	Symphurus plagiusa
Leiostomus xanthurus	Polydactylus octonemus
<u>Nearshore Flats</u>	<u>Peripheral Lagoons and Bayous</u>
Micropogonias undulatus	Micropogonias undulatus
Anchoa mitchilli	Anchoa mitchilli
Leiostomus xanthurus	Leiostomus xanthurus
Arius felis	Cynoscion arenarius
Sphoeroides parvus	Mugil cephalus
Brevoortia patronus	Citharichthys spilopterus
Cynoscion arenarius	Brevoortia patronus
Citharichthys spilopterus	Arius felis
Menticirrhus americanus	Symphurus plagiusa
Stellifer lanceolatus	Sphoeroides parvus

(river shrimp) is found in low salinity areas during April and May. Postlarval *Penaes aztecus* (brown shrimp) enter the estuary in February through April, move into shallow nurseries, and then reappear in large numbers in open bay waters during March through July. *Penaes setiferus* (white shrimp) postlarvae begin entering the estuary in April and juveniles become most numerous in open waters during July through November. A small population of *Penaes duorarum* (pink shrimp) enters as larvae to shallow estuarine nurseries in the fall and juveniles are recaptured in March through May in open bay waters. *Callinectes sapidus* (blue crab) is most susceptible to sampling gear in October through April but may recruit almost all year. One species not included in Table 2.5 but quite important to the system is *Loliginella brevis* (brie squid). It is a summer inhabitant of higher salinity waters (9) and may be an important determinant of community composition as a predator (25).

#### Vertebrates

This section encompasses fishes, birds, amphibians, reptiles and mammals, but only fishes have been the object of synoptic surveys.

**Fishes**—A comprehensive list of the ichthyofauna of the Galveston Bay system encompassed 66 families, 122 genera and 162 species (26). Freshwater fishes (9 families, 19 species) rarely found in the bay were included. Results of a two-year, synoptic trawl survey (27) indicated that, of 96 species recorded, six species accounted for 91 percent of the total number of fishes collected: *Micropogonias undulatus* (Atlantic croaker, 51 percent); *Anchoa mitchilli* (bay anchovy, 22 percent); *Stellifer lanceolatus* (star drum, 8 percent); *Leiostomus xanthurus* (spot, 4 percent); *Cynoscion arenarius* (sand seatrout, 3 percent); and *Arius felis* (hardhead catfish, 3 percent). These six species plus Mugil cephalus (striped mullet) were responsible for 74 percent of the biomass collected, dominated by *Micropogonias* (37 percent of the weight) over all others (>10 percent each). In general, the same small group of 13 species dominated catches in various bay habitats (Table 2.6). The total fish fauna was most numerous in April and May (dominated by *Micropogonias*) and least dense in December and January (dominated by *Anchoa*). Biomass peaks generally occurred May through August (*Micropogonias*, *Stellifer*), while the biomass of a mixed assemblage was lowest in November. Although no surveys have addressed West Bay proper, surveys of Chocolate Bayou (24) and Christmas Bay (13) revealed 72 and 83 species of fishes, respectively, with similar dominant species. Larval and postlarval fishes often numerically dominate zooplankton collections. The same species that later comprise the bulk of the trawl catches are usually the most abundant as plankters (17, 18, 28).

**Birds**—Although no comprehensive study of the avifauna of the Galveston Bay system has been conducted, observers and checklists have recorded 139 bird species associated with wetlands and bay habitats (29, 30). This group of species accounts for 25 percent of the 565 bird species recorded for Texas (31). Further, these wetland-related forms do not include the large number of terrestrial resident or migratory birds. Three large groups of birds have a significant representation in the Galveston Bay system—waterfowl, shorebirds and colonial nesting waterbirds.

Waterfowl are censused each January during the Mid-winter Waterfowl Survey, a cooperative effort between the Texas Parks and Wildlife Department and the U.S. Fish and Wildlife Service. These surveys have shown that 60 percent of Texas' wintering waterfowl are found on the upper Texas coast, including large populations of *Chen caerulescens* (snow goose), associated with rice-growing regions of the coastal prairies (32). Aerial surveys of the Galveston Bay system for the years 1978 and 1984 through 1987 have recorded an average of 11,500 waterfowl annually. The five most common species observed during these surveys were *Anas crecca* (green-winged teal), *Aythya collaris* (ring-necked duck), *Aythya affinis* (lesser scaup), *Mergus serrator* (red-breasted merganser), and *Oxyura jamaicensis* (ruddy duck). Although a total of 32 species of waterfowl has been observed in the bay system (Table 2.7), only *Dendrocygna bicolor* (fulvous whistling duck), *Anas fulvigula* (mottled duck), *Aix sponsa* (wood duck), and *Anas discors* (blue-winged teal) are regular breeders in the area. The remaining species of waterfowl use the estuary during migration or while overwintering.

The Galveston Bay system has been identified by the Western Hemisphere Shorebird Reserve Network as a regionally significant reserve site (34), denoting support of >5 percent of all mid-continental shorebird populations during migration. Large populations of migrating or overwinter-

**Table 2.7. Waterfowl Observed in the Galveston Bay System (32, 33).**

<u>Common Name</u>	<u>Scientific Name</u>	<u>Common Name</u>	<u>Scientific Name</u>
Fulvous whistling duck	<i>Dendrocygna bicolor</i>	American wigeon	<i>Anas americana</i>
Black-bellied whistling duck	<i>Dendrocygna autumnalis</i>	Canvasback	<i>Aythya valisineria</i>
Greater white-fronted goose	<i>Anser albifrons</i>	Redhead	<i>Aythya americana</i>
Snow goose	<i>Chen caerulescens</i>	Ring-necked duck	<i>Aythya collaris</i>
Ross' goose	<i>Chen rossii</i>	Greater scaup	<i>Aythya marila</i>
Canada goose	<i>Branta canadensis</i>	Lesser scaup	<i>Aythya affinis</i>
Wood duck	<i>Aix sponsa</i>	Old squaw	<i>Clangula hyemalis</i>
Green-winged teal	<i>Anas crecca</i>	Black scoter	<i>Melanitta nigra</i>
Mottled duck	<i>Anas fulvigula</i>	Surf scoter	<i>Melanitta perspicillata</i>
Mallard	<i>Anas platyrhynchos</i>	White-winged scoter	<i>Melanitta fusca</i>
Northern pintail	<i>Anas acuta</i>	Common goldeneye	<i>Bucephala clangula</i>
Blue-winged teal	<i>Anas discors</i>	Bufflehead	<i>Bucephala albeola</i>
Cinnamon teal	<i>Anas cyanoptera</i>	Hooded merganser	<i>Lophodytes cucullatus</i>
Northern shoveler	<i>Anas clypeata</i>	Red-breasted merganser	<i>Mergus serrator</i>
Gadwall	<i>Anas strepera</i>	Ruddy duck	<i>Oxyura jamaicensis</i>
		Masked duck	<i>Oxyura dominica</i>

**Table 2.8. Shorebirds Recorded for the Galveston Bay System (33, 34).**

<u>Common Name</u>	<u>Scientific Name</u>	<u>Common Name</u>	<u>Scientific Name</u>
Black-bellied plover	<i>Pluvialis squatarola</i>	Long-billed curlew	<i>Numenius americanus</i>
Lesser golden-plover	<i>Pluvialis dominica</i>	Marbled godwit	<i>Limosa fedoa</i>
Snowy plover	<i>Charadrius alexandrinus</i>	Hudsonian godwit	<i>Limosa haemastica</i>
Wilson's plover	<i>Charadrius wilsonia</i>	Ruddy turnstone	<i>Arenaria interpres</i>
Semipalmated plover	<i>Charadrius semipalmatus</i>	Red knot	<i>Calidris canutus</i>
Piping plover	<i>Charadrius melodus</i>	Sanderling	<i>Calidris alba</i>
Killdeer	<i>Charadrius vociferus</i>	Semipalmated sandpiper	<i>Calidris pusilla</i>
American oyster-catcher	<i>Haematopus palliatus</i>	Western sandpiper	<i>Calidris mauri</i>
Black-necked stilt	<i>Himantopus mexicanus</i>	Least sandpiper	<i>Calidris minutilla</i>
American avocet	<i>Recurvirostra americana</i>	White-rumped sandpiper	<i>Calidris fuscicollis</i>
Greater yellowlegs	<i>Tringa melanoleuca</i>	Baird's sandpiper	<i>Calidris bairdii</i>
Lesser yellowlegs	<i>Tringa flavipes</i>	Pectoral sandpiper	<i>Calidris melanotos</i>
Solitary sandpiper	<i>Tringa solitaria</i>	Dunlin	<i>Calidris alpina</i>
Willet	<i>Catoptrophorus semipalmatus</i>	Stilt sandpiper	<i>Calidris himantopus</i>
Spotted sandpiper	<i>Actitis macularia</i>	Buff-breasted sandpiper	<i>Tryngitis subruficollis</i>
Upland sandpiper	<i>Bartramia longicauda</i>	Short-billed dowitcher	<i>Limnodromus griseus</i>
Eskimo curlew	<i>Numenius borealis</i>	Long-billed dowitcher	<i>Limnodromus scolopaceus</i>
Whimbrel	<i>Numenius phaeopus</i>	Common snipe	<i>Gallinago gallinago</i>
		American woodcock	<i>Scolopax minor</i>
		Wilson's phalarope	<i>Phalaropus tricolor</i>
		Red-necked phalarope	<i>Phalaropus lobatus</i>
		Red phalarope	<i>Phalaropus fulicaria</i>



**Table 2.9. Colonial Nesting Waterbirds of the Galveston Bay System (36).**

<u>Common Name</u>	<u>Scientific Name</u>	<u>Common Name</u>	<u>Scientific Name</u>
Olivaceous cormorant	<i>Phalacrocorax olivaceus</i>	White ibis	<i>Eudocimus albus</i>
Anhinga	<i>Anhinga anhinga</i>	White-faced ibis	<i>Plegadis chihi</i>
Great blue heron	<i>Ardea herodias</i>	Roseate spoonbill	<i>Ajaia ajaja</i>
Great egret	<i>Casmerodias albus</i>	Laughing gull	<i>Larus atricilla</i>
Snowy egret	<i>Egretta thula</i>	Gull-billed tern	<i>Sterna nilotica</i>
Little blue heron	<i>Egretta caerulea</i>	Caspian tern	<i>Sterna caspia</i>
Tricolored heron	<i>Egretta tricolor</i>	Royal tern	<i>Sterna maxima</i>
Reddish egret	<i>Egretta rufescens</i>	Sandwich tern	<i>Sterna sandvicensis</i>
Cattle egret	<i>Bubulcus ibis</i>	Forster's tern	<i>Sterna forsteri</i>
Black-crowned night-heron	<i>Nycticorax nycticorax</i>	Least tern	<i>Sterna antillarum</i>
Yellow-crowned night-heron	<i>Nycticorax violaceus</i>	Black skimmer	<i>Rynchops niger</i>

**Table 2.10. Game and Furbearing Mammals of the Four Counties Surrounding Galveston Bay (41, 42).**

<u>Common Name</u>	<u>Scientific Name</u>	<u>Common Name</u>	<u>Scientific Name</u>
White-tailed deer	<i>Odocoileus virginianus</i>	Red fox	<i>Vulpes vulpes</i>
Virginia opossum	<i>Didelphis virginiana</i>	Gray fox	<i>Urocyon cinereoargenteus</i>
Beaver	<i>Castor canadensis</i>	Long-tailed weasel	<i>Mustela frenata</i>
Muskrat	<i>Ondatra zibethicus</i>	Mink	<i>Mustela vison</i>
Nutria	<i>Myocaster coypus</i>	Eastern spotted skunk	<i>Spilogale putorius</i>
Raccoon	<i>Procyon lotor</i>	Striped skunk	<i>Mephitis mephitis</i>
Ringtail	<i>Bassariscus astutus</i>	River otter	<i>Lutra canadensis</i>
Coyote	<i>Canis latrans</i>	Bobcat	<i>Felis rufus</i>

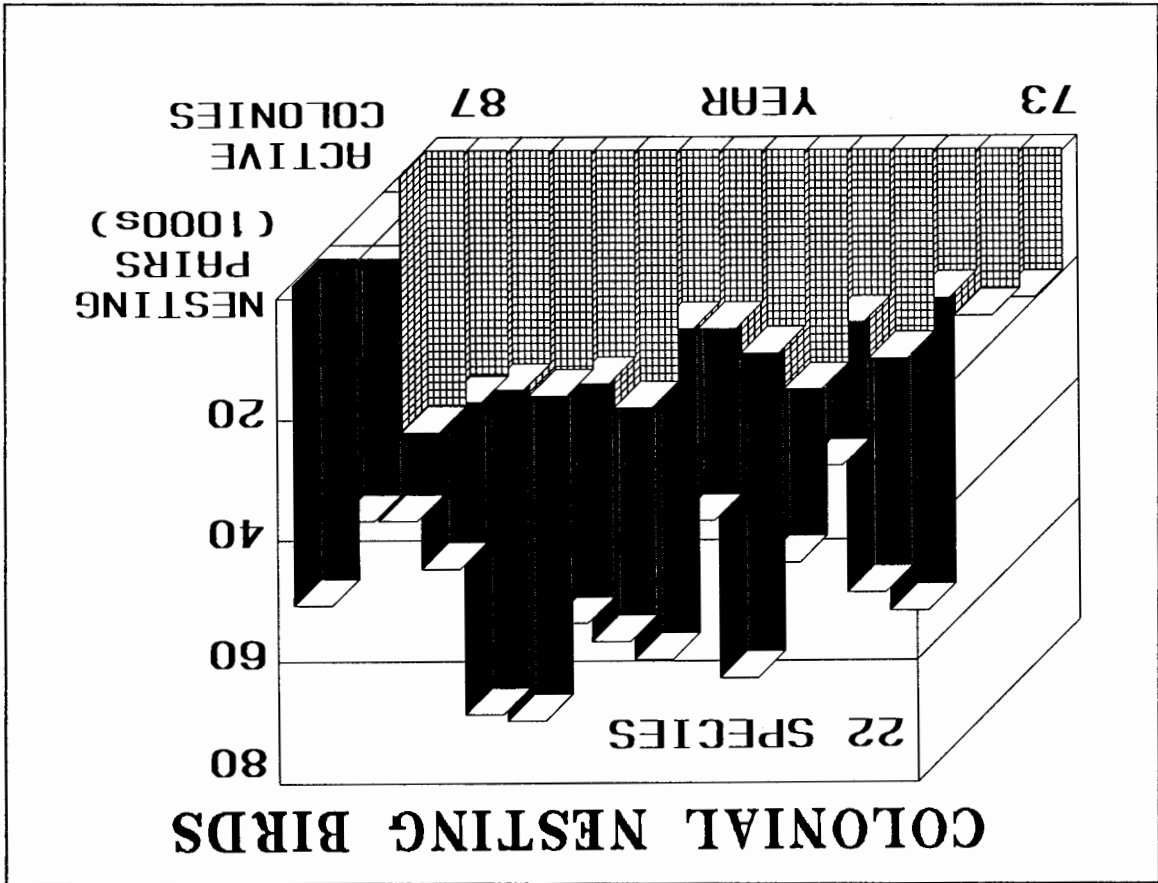
The relative contribution of each floral component to total system primary production has been Primary Productivity

Some of the relationships of organisms to their physical environments were considered previously, but the interactions of groups of organisms with extrinsic factors such as temperature, salinity, substrate and habitat availability need to be emphasized. This section will generally follow the trophic structure of the estuary.

Dynamics and Interactions

alligator (*Alligator mississippiensis*) has recently become a harvestable animal under state statutes (39). During 1984-1986, a total of 655 alligators were harvested from the counties surrounding the estuary, with 384 (59 percent) taken in freshwater marshes of Chambers County. Reptiles that frequent the system and have been identified as threatened or endangered by the U.S. Fish and Wildlife Service (33) include: *Dermochelys coriacea* (leatherback sea turtle), *Lepidochelys kempi* (Kemp's ridley sea turtle), *Caretta caretta* (loggerhead sea turtle) and *Chelonia mydas* (green sea turtle). Sea turtles were once an important component of the bay system, so much so that there was a commercial sea turtle fishery in Galveston Bay during the 1890's (40). Mammals—Schmidly (41, 42) documents 54 species of mammals for the counties surrounding Galveston Bay. Of these, 15 are furbearers and one is a game species (Table 2.10). The mammals most dependent upon wetlands environments include *Sylvilagus aquaticus* (swamp rabbit), *Scturus carolinensis* (gray squirrel), *Castor canadensis* (beaver), *Ondatra zibethicus* (muskrat), *Rattus rattus* (roof rat), *Oryzomys palustris* (northern rice rat), *Myocastor coypus* (nutria), *Procyon lotor* (raccoon), *Mustela vison* (mink), *Lutra canadensis* (river otter), and *Turlops truncatus* (bottlenosed dolphin).

Figure 2.2. Abundance of colonial nesting birds during 1973-1987 (33, 35).



**Table 2.11. Primary Productivity in the Galveston Bay System (Data Sources in Parentheses).**

<b>Flora</b>	<b>Average Estimated Primary Productivity (g dry/m<sup>2</sup>/yr)</b>	<b>Areal Coverage (km<sup>2</sup>)</b>	<b>Estimated Annual Production (metric tons)</b>
Phytoplankton (44,45,47)	350	1,425	498,750
Benthic microflora (44,47)	500	1,425	712,500
Submerged vegetation (1,15,48)	2,600	1	2,600
Freshwater marsh (1,12)	820	40	32,800
Salt-Brackish Marsh (12,43)	1,100	370	407,000
Woodlands/swamps (12,47)	700	500	350,000

roughly estimated in Table 2.11. Phytoplankton, benthic microflora, salt and brackish marshes, and woodlands and swamps each contribute roughly the same order of magnitude of organic materials to annual production. Fresh marshes produce an order of magnitude less, while seagrasses contribute two orders of magnitude less production than the four main components. Some of the assumptions made in constructing Table 2.11 need testing, such as productivity of phytoplankton and benthic microflora within Galveston Bay and presumption that such productivity occurs under the total bay surface of 1,425 km<sup>2</sup> (550 mi<sup>2</sup>). Within the various habitats, the variation in productivity can be dramatic. For example, in the fresh marsh *Sagittaria graminea* produces 215 g dry/m<sup>2</sup>/year while *Phragmites australis* produces 2,984 g dry/m<sup>2</sup>/year (1), and in the salt marsh *Batis maritima* produces 425 g dry/m<sup>2</sup>/year while *Spartina* spp. produce 1,100 g dry/m<sup>2</sup>/year (43). The most productive component, the seagrasses, are the least abundant in this estuary.

Most of the plant production is separated in space and time from the consumer community. In fact, some of that production may never reach the consumers due to inundated regimes and tissue storage. It has been estimated that woodlands, swamps and freshwater marshes export only 8 to 10 percent of the annual aboveground production whereas the frequently inundation low salt marshes may export 30 to 45 percent annually (1, 47). The low nutritional quality, refractory nature of much of the biomass, and resistance to direct grazing all increase from phytoplankton and algae through submerged aquatic vegetation to emergent vascular plants of the salt marsh and woodlands. Thus, the primary consumption of most of the plant biomass is only available along the detritus pathway. Although many organisms play major roles in breaking down this refractory material, they rarely directly assimilate the organic plant matter and, instead, utilize the surface microbial decomposers (47).

#### **Primary Consumption**

Less than 10 percent of emergent vegetation of these wetlands is consumed directly, and most of the grazers are insects (47). *Ondatra zibethicus* (muskrat) and *Myocastor coypus* (nutria) are other direct consumers. Submerged vegetation may be directly consumed by a small number of aquatic organisms (snails, fishes such as *Lagodon rhomboides* [pinfish]) as well as certain species of ducks. Phytoplankton are directly grazed by many zooplankters and planktivorous fishes, while benthic algae and epiphytes are utilized by snails, fiddler crabs and other organisms (47). The vast majority of primary consumers in the system are detritivores, species that directly or indirectly consume detrital particles and, lacking the necessary digestive enzymes, in reality utilize only the surface bacteria and fungi. This group includes many benthic organisms (bivalves, gastropods, crustaceans) and bottom feeding fishes and macroinvertebrates (47).

The available evidence suggests that the phytoplankton-based branch of the food web may not be as important to the Galveston Bay system as is the emergent marsh-detritus branch, even though annual primary production may be similar for both groups. First, average phytoplankton densities



A synopsis of commercial and recreational fisheries (Figure 2.6) indicates that landings are generally highest in summer and fall months, with the exception of oysters that are a winter-spring harvest with public reefs closed during the warm months. The blue crab fishery reaches a maximum in early summer. The bait shrimp fishery is most productive in summer and fall, coincidentally when both demand and supply are highest. The bay commercial shrimp fishery has two seasons separated by closures: a June and July fishery for brown shrimp (*Penaeus aztecus*) and an August through

Atlantic croaker. Commercial and recreational landings of spotted seatrout followed by sand seatrout, redfish, flounders and stabilized and is led by landings of spotted seatrout followed by sand seatrout, redfish, flounders and importation. Recreational fishing, now controlled by size and bag limits on certain species, has flounders the dominant species and mullets, Atlantic croaker, black drum and sheepshead next in were banned, thus the decline seen around 1980. The commercial fishery is now increasing, with redfish (*Sciaenops ocellatus*) in the late 1970's. Commercial landings of spotted seatrout and redfish commercial and recreational fishing pressure on spotted seatrout (*Cynoscion nebulosus*) and since 1975 (Figure 2.5) (54, 55) were primarily due to regulatory actions in the face of heavy effort but may also indicate increasing marsh access (discussed later). Fluctuations in fish landings loading. An apparent upward trend in shrimp landings is in part due to increasing inshore fishing regulatory actions such as closing of days to oyster harvesting after heavy rainfall and pollutant some degree of annual fluctuation (Figure 2.4) (54, 56). Some abrupt changes have been due to Since 1960, landings of penaeid shrimp, oysters and blue crabs have been relatively stable given as spotted seatrout, sand seatrout, southern and gulf flounders, Atlantic croaker and redfish (55).

The Galveston Bay system supports a wide variety of species in its bay and nearshore commercial and recreational fisheries (Table 2.12). In 1986, commercial fisheries landed more than 10,000 metric tons of seafood with a dockside value exceeding \$26 million for the top 10 species alone (Table 2.13). The commercial catches were dominated by invertebrates such as brown shrimp, pink shrimp and white shrimp (totaling 6.8 million kilograms), blue crabs (1.4 million kilograms) and oysters (1.6 million kilograms, whole) (54). Southern and gulf flounders and Atlantic croaker were the dominant fishes. The 1986 recreational fisheries landed in excess of 280 tons, primarily of sportfishes such as spotted seatrout, sand seatrout, southern and gulf flounders, Atlantic croaker and redfish (55).

#### Fisheries

Vegetated habitats serve other functions than providing direct or indirect sources of food. Aside from these, wetlands function as natural water treatment plants for nutrients and wastes, provide aesthetic value, control biogeochemical cycles of elements such as nitrogen and sulphur, buffer inlands from storms and reduce flooding, and provide useful products such as lumber. Perhaps the most significant functions of wetlands for estuarine organisms are provision of nursery areas for feeding, refuge and substrate utilization by other organisms. In a *Spartina alterniflora* marsh, densities of crustaceans such as *Palaeomonetes pugio*, *Callinectes sapidus* and *Penaeus aztecus* and fishes such as *Lagodon rhomboides*, *Fundulus* spp., *Sciaenops ocellatus* and *Cynoscion nebulosus* were all significantly higher in flooded marsh areas than in adjacent non-vegetated waters (23, 49). During most seasons, densities of juveniles of many commercially, recreationally and ecologically important fishes and crustaceans are higher in vegetated habitats such as salt marshes, fresh marshes and seagrasses around Galveston Bay than in adjacent open waters (Figure 2.3, from 50). There are indications that the vegetative structure provides refuge from predators and foods (such as epiphytic algae and high densities of infauna) not found in open waters (50-52). The connection between amounts of vegetated habitats and fisheries productivity in adjacent waters has been demonstrated worldwide. For example, landings of brown shrimp in nearshore Louisiana waters have been directly linked to the amount of salt marsh vegetation present (53). Thus, wetlands habitats are quite valuable in many aspects.

#### Habitat Utilization

are on the low end of the scale for Texas estuaries (1), which are, in turn, on the low end of the range of estuarine production in general (44). Second, zooplankton densities (the main consumers of phytoplankton) are also on the low end of the ranges seen in other Texas estuaries (1). Third, salt marsh productivity is higher in Texas than in most other Atlantic and Gulf coast states (63). Finally, the macrobenthic and fish faunas are omnivores or carnivores except in their earliest larval stages (47).

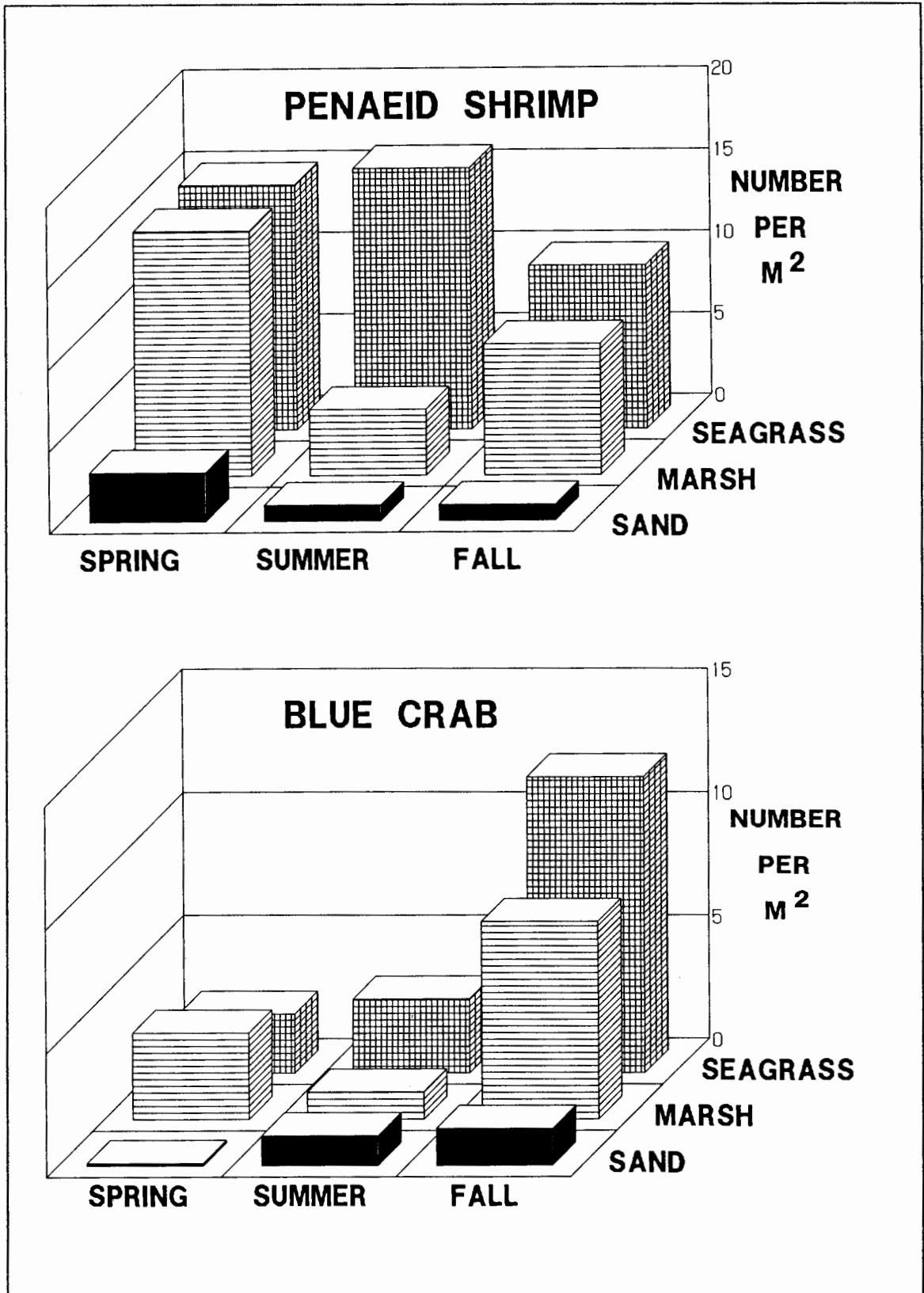


Figure 2.3. Habitat selection by penaeid shrimp (*Penaeus* spp.) and blue crabs (*Callinectes sapidus*) in various aquatic habitats of the Galveston Bay estuary (50).

Scientific Name	Common Name	Finfish
Alectis alais	African pompano	
Lepisosteus spatula	Alligator gar	
Micropogonias undulatus	Atlantic croaker	
Trichinurus lepturus	Atlantic cutlassfish	
Selene setapinnis	Atlantic moonfish	
Strongylura marina	Atlantic needlefish	
Chaetodipterus faber	Atlantic spadefish	
Dasyatis sabina	Atlantic stingray	
Pogonias cromis	Black drum	
Pomatomus saltatrix	Bluefish	
Ictalurus furcatus	Blue catfish	
Ictalurus punctatus	Channel catfish	
Rachycentron canadum	Cobia	
Family Gadidae	Codfish	
Coryphaena hippurus	Dolphin	
Paralichthys albigutta	Flounder	
Paralichthys lethostigma	Gulf flounder	
Trachinotus carolinus	Southern flounder	
Aplodinotus grunniens	Florida pompano	
Bagre marinus	Freshwater drum	
Seriola dumerilii	Gafftopsail catfish	
Mycteroperca bonaci	Greater amberjack	
Epinephelus itajara	Groupers	
Epinephelus striatus	Black grouper	
Epinephelus phoenax	Jewish fish	
Mycteroperca nigrilus	Nassau grouper	
Epinephelus flavolimbatus	Scamp	
Epinephelus nigritus	Warsaw grouper	
Mycteroperca venenosa	Yellowedge grouper	
Mycteroperca interstitialis	Yellowfin grouper	
Peprilus burti	Yellowmouth grouper	
Artus felis	Gulf butterfish	
Menticirrhus littoralis	Hardhead catfish	
Menticirrhus americanus	Kingfish	
Elops saurus	Gulf kingfish	
Micropterus salmoides	Southern kingfish	
Euthynnus alletteratus	Ladyfish	
Scomberomorus cavalla	Largemouth bass	
Scomberomorus maculatus	Little tunny	
Brevoortia patronus	Mackerel	
Mugil cephalus	King mackerel	
Mugil curema	Spanish mackerel	
Anchylopeseta quadrocellata	Menhaden	
Trachinotus falcatus	Mullet	
	Striped mullet	
	White mullet	
	Ocellated flounder	
	Permit	

Table 2.12. List of Common and Scientific Names of Commercial and Recreational Finfish and Shellfish Caught or Landed in Texas (54, 55).

**Table 2.12. (Continued)**

<b>Common Name</b>	<b>Scientific Name</b>
Pigfish	<i>Orthopristis chrysoptera</i>
Pinfish	<i>Lagodon rhomboides</i>
Red drum	<i>Sciaenops ocellatus</i>
Seatrout	
Sand seatrout	<i>Cynoscion arenarius</i>
Silver seatrout	<i>Cynoscion nothus</i>
Spotted seatrout	<i>Cynoscion nebulosus</i>
Shark	
Atlantic sharpnose	<i>Rhizoprionodon terraenovae</i>
Blacktip	<i>Carcharhinus limbatus</i>
Bull	<i>Carcharhinus leucas</i>
Great hammerhead	<i>Sphyrna mokarran</i>
Scalloped hammerhead	<i>Sphyrna lewini</i>
Shortfin mako	<i>Isurus oxyrinchus</i>
Smooth dogfish	<i>Mustelis canis</i>
Sheepshead	<i>Archosargus probatocephalus</i>
Silver perch	<i>Bairdiella chrysoura</i>
Smallmouth buffalo	<i>Ictiobus bubalus</i>
Smooth puffer	<i>Lagocephalus laevigatus</i>
Snapper	
Lane snapper	<i>Lutjanus synagris</i>
Red snapper	<i>Lutjanus campechanus</i>
Vermilion snapper	<i>Rhomboplites aurorubens</i>
Southern stingray	<i>Dasyatis americana</i>
Spot	<i>Leiostomus xanthurus</i>
Striped burrfish	<i>Chilomycterus schoepfi</i>
Swordfish	<i>Xiphias gladius</i>
Tilefish	<i>Lopholatilus chamaeleonticeps</i>
Triggerfish, gray	<i>Balistes capriscus</i>
Tripletail	<i>Lobotes surinamensis</i>
Tuna	
Blackfin tuna	<i>Thunnus atlanticus</i>
Bluefin tuna	<i>Thunnus thynnus</i>
Yellowfin tuna	<i>Thunnus albacares</i>
Wahoo	<i>Acanthocybium solanderi</i>
Shellfish	
Atlantic bay scallop	<i>Argopecten irradians</i>
Crab	
Blue crab	<i>Callinectes sapidus</i>
Stone crab	<i>Menippe mercenaria</i>
American oyster	<i>Crassostrea virginica</i>
Shrimp	
Brown shrimp	<i>Penaeus aztecus</i>
White shrimp	<i>Penaeus setiferus</i>
Pink shrimp	<i>Penaeus duorarum</i>
Rock shrimp	<i>Sicyonia brevirostris</i>
Royal red shrimp	<i>Hymenopenaeus robustus</i>
Seabob	<i>Xiphopenaeus kroyeri</i>
Squid	
Brief squid	<i>Lolliguncula brevis</i>
Long-finned squid	<i>Loligo pealei</i>

Figure 2.4. Annual landings (1960-1986) of blue crabs, oysters and three species of penaeid shrimp from Galveston Bay and nearshore waters (54, 56).

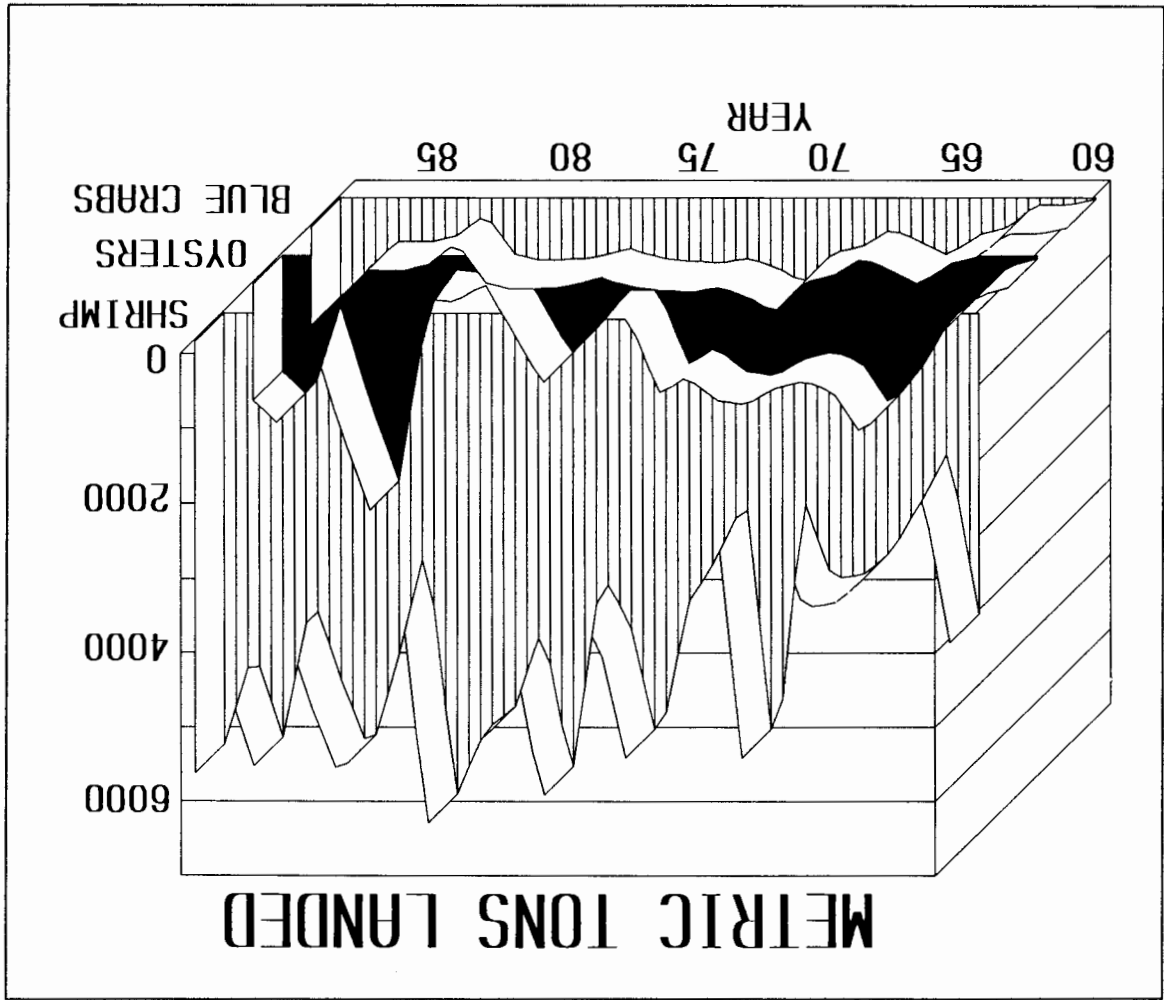


Table 2.13. Landings by Galveston Bay Fisheries During 1986, Including Bay and Nearshore Waters (NMFS Statistical Subarea 18). Landings (Kilograms, kg) and Ex-vessel Value (\$) Are in Thousands. ? = Ex-vessel Value Not Available (54, 56).

Species	Commercial	Recreational
Shrimp (3 species)	6,820 Kg	18,135 \$
Blue crabs	1,375 Kg	1,043 \$
Oysters	1,610 Kg	6,950 \$
Redfish	-	43 \$
Sand seatout	-	57 \$
Spotted seatout	-	102 \$
Atlantic croaker	18 Kg	37 \$
Flounder	73 Kg	39 \$

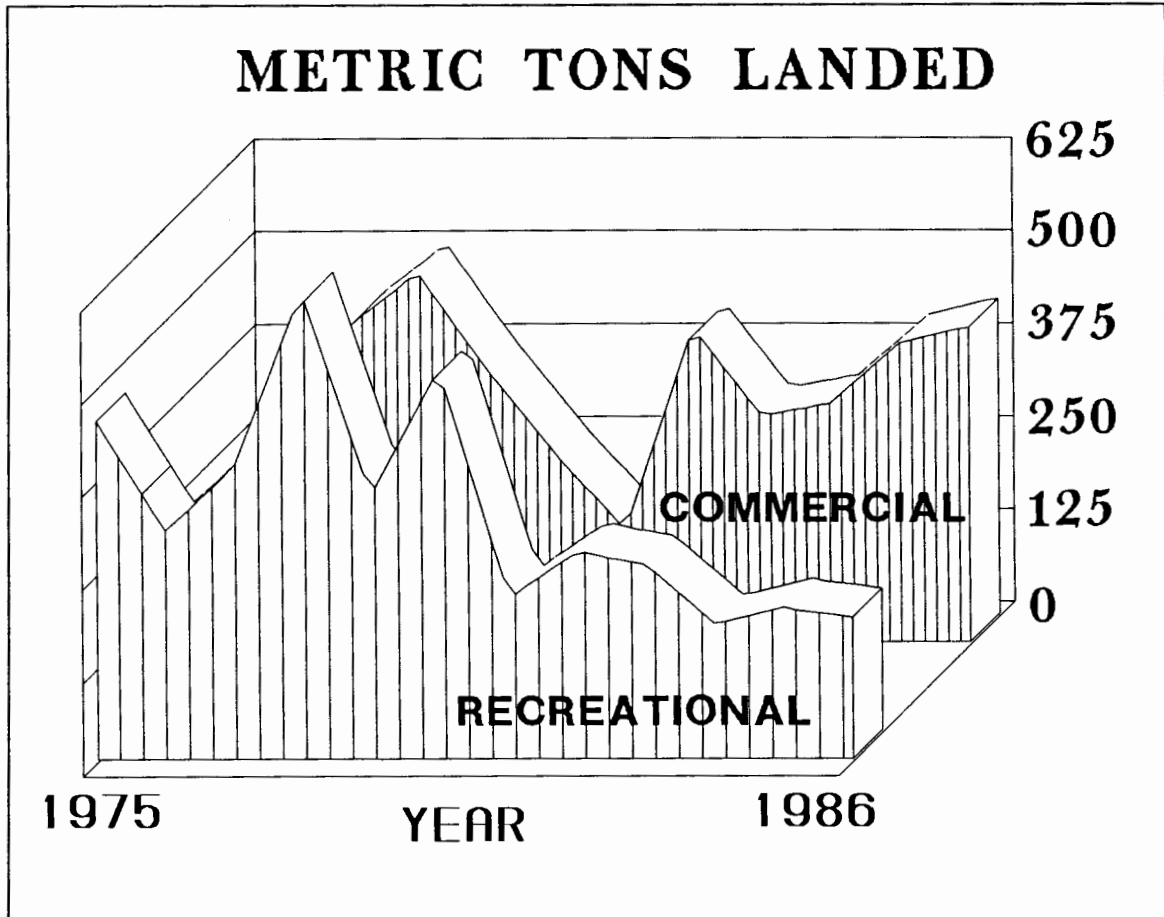


Figure 2.5. Annual landings (1975-1986) of commercial and recreational finfishes from Galveston Bay and nearshore waters (54, 56).

October fishery for white shrimp (*P. setiferus*). Recreational finfish fisheries are most productive in summer (spotted seatrout, redfish) and fall (flounder). Commercial finfish harvests are highest in the fall, concentrating on flounder, mullet and Atlantic croaker.

### Ecological Interactions and Problems

The greatest problems involved in the maintenance of the Galveston Bay biota are related to human utilization of estuarine resources such as wetlands, fresh water and coastal habitats. Each of these areas presents its own unique interactions and prospects for various scenarios of the future status of the bay.

#### Sea Level Rise and Wetlands Loss

One of the critical problems facing the Galveston Bay estuary is apparent sea level rise (a combination of rapid, local subsidence of land due to groundwater and petroleum withdrawal (15) and slow, oceanic water rise from glacial melting) and associated wetlands loss. As pointed out in previous sections, many estuarine inhabitants depend on wetlands for food, refuge or living space. In 1979, the area containing the estuary's wetlands had elevations of 0 to 1.6 meters above mean sea level and encompassed some 740 square kilometers (Figure 2.7) (15).

The result of the combined forces of subsidence and glacial melting has led to a moderate projection of a 1.0- to 1.6-meter sea level rise by the year 2100 (57). If a 1.6-meter rise were experienced, the new wetlands area (0- to 1.6-meter elevations) would decrease in size by more than 50 percent to 360 square kilometers (Figure 2.8), assuming inland migration of the vegetation. The old 0- to 1.6-meter elevations would be converted to open bay water. However, this new wetlands area is



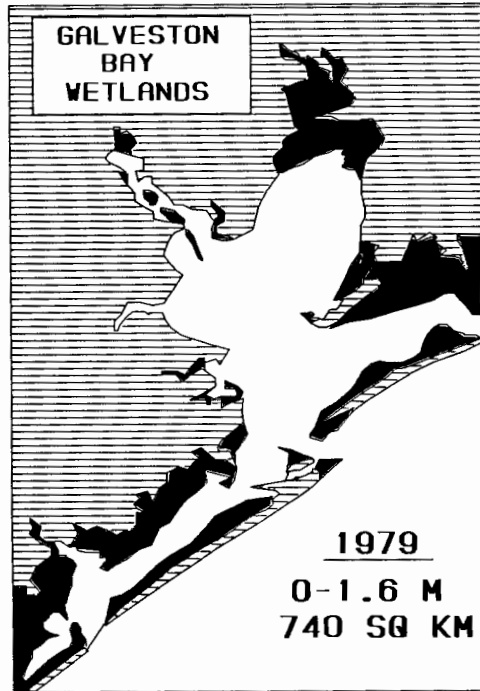


Figure 2.7. Low elevation areas (0-1.6 meters, shaded) where Galveston Bay wetlands were located in 1979, barring development (15).

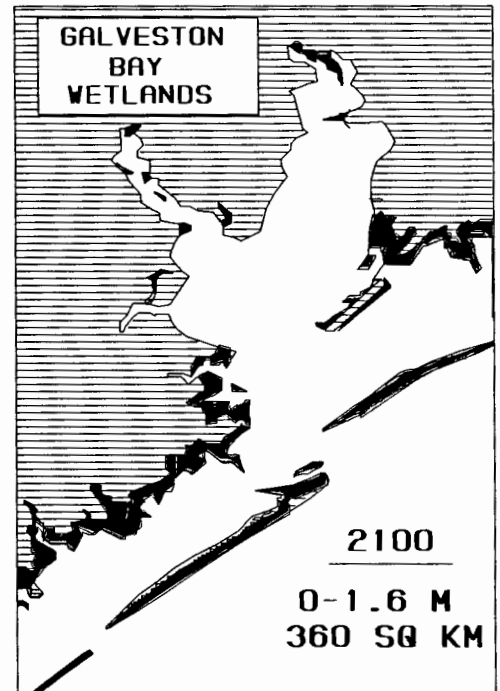


Figure 2.8. Low elevation areas (0-1/6 meters, shaded) where future Galveston Bay wetlands could exist, barring development, after a 1.6-meter rise in sea level by the year 2100 (15).

Oyster survival and production are excellent indicators of the natural patterns of mixing of fresh and salt waters (19, 20). Under ideal situations oysters survive and grow well at salinities of 10 to 35 ppt. However, salinities of more than 20 ppt bring predators (such as oyster drills) and disease (such as "dermo") that decrease survival and production. Fresh water kills are also incurred if salinities drop below 10 ppt for extended periods or at the wrong time of year. The net result is the typical pattern of oyster reef formation primarily where waters are consistently 10 to 20 ppt. Major shifts in the seasonal timing or amounts of discharge from river systems could cause long-term changes in oyster reef distribution and production.

To a constricted arm of the Galveston Bay system, such as West Bay, a freshet of unrestricted flow can be quite beneficial for oysters. West Bay had been a high salinity-low production bay until a July 1979 tropical storm dropped 110 cm of rain in 24 hours (59). Salinities were dramatically lowered and, combined with subsequent high settlement of oyster spat, reported oyster harvest jumped from zero to 1,225 metric tons in the November 1982 through April 1983 season and 907 metric tons the following season (Figure 2.10) (60). Since then, salinities have increased and reported oyster harvest has tapered off.

When fresh water inflow patterns are artificially altered, the results may not be so beneficial to white shrimp productivity. Sabine Lake is located between Galveston Bay and Lake Calcasieu, Louisiana. Dams were built on the Sabine and Neches Rivers in 1965-1966 that contained the natural peak river flows of January through May for later release in generating electricity in the normally low flow period of June through October (61). Portions of the surrounding marshes were also leveed off at the same time. These summer flood conditions negated recruitment of white shrimp to nursery areas by artificially lowering salinities to unacceptable levels. The Sabine Lake white shrimp fishery collapsed, while fisheries in Galveston Bay and Lake Calcasieu continue (Figure 2.11) (56).



Figure 2.10. Oyster production from West Bay (1975-1986) following an unusual rainfall during a tropical storm that lowered bay salinities for an extended period (60).

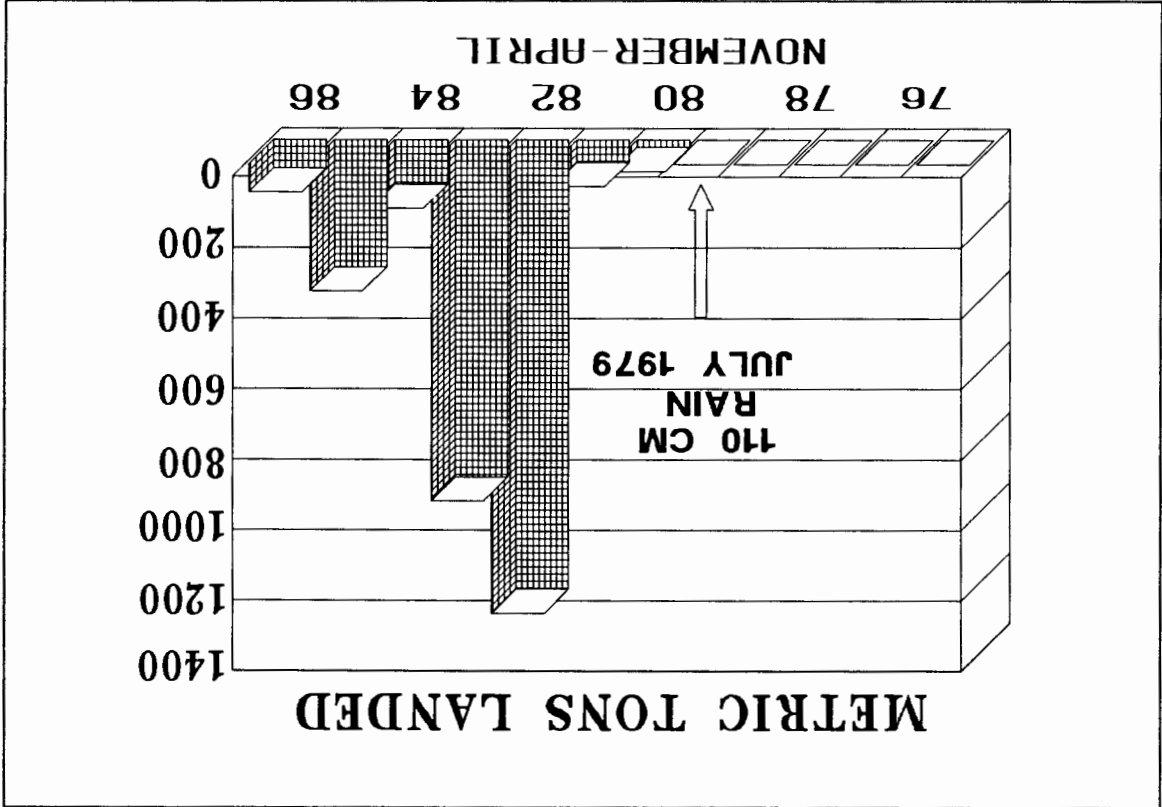
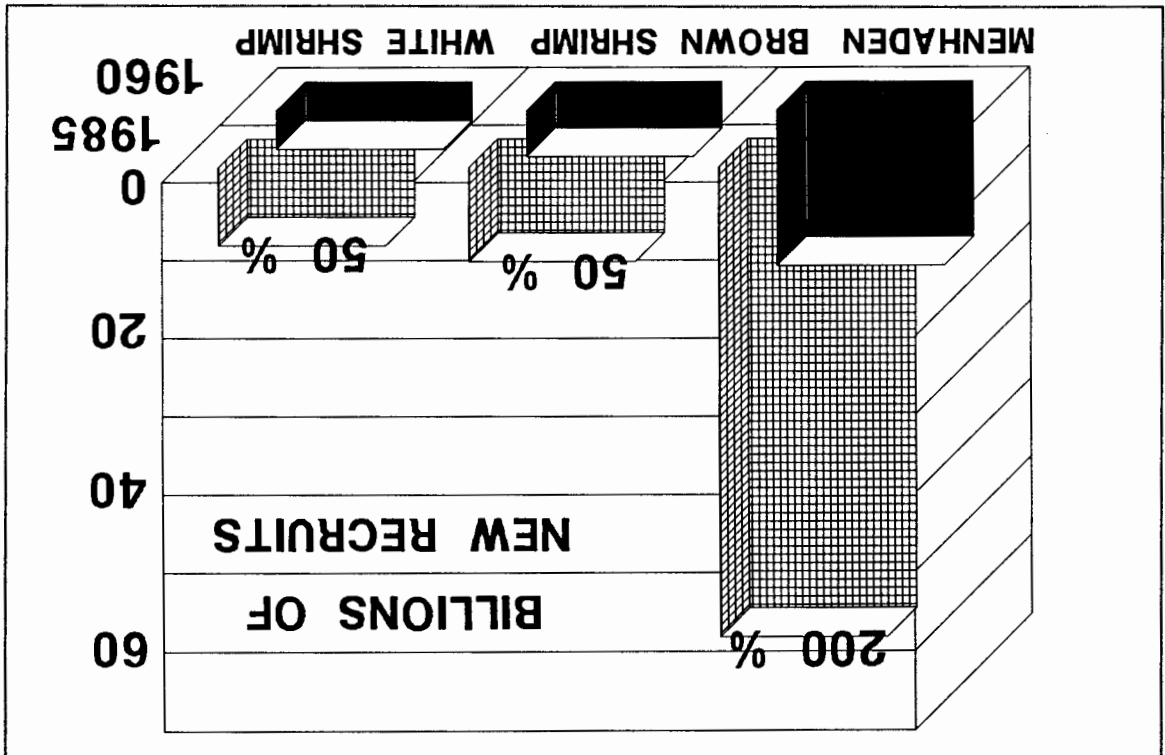


Figure 2.9. Increases in recruitment of menhaden, brown shrimp and white shrimp to U.S. Gulf of Mexico fisheries between 1960 and 1985 (58).



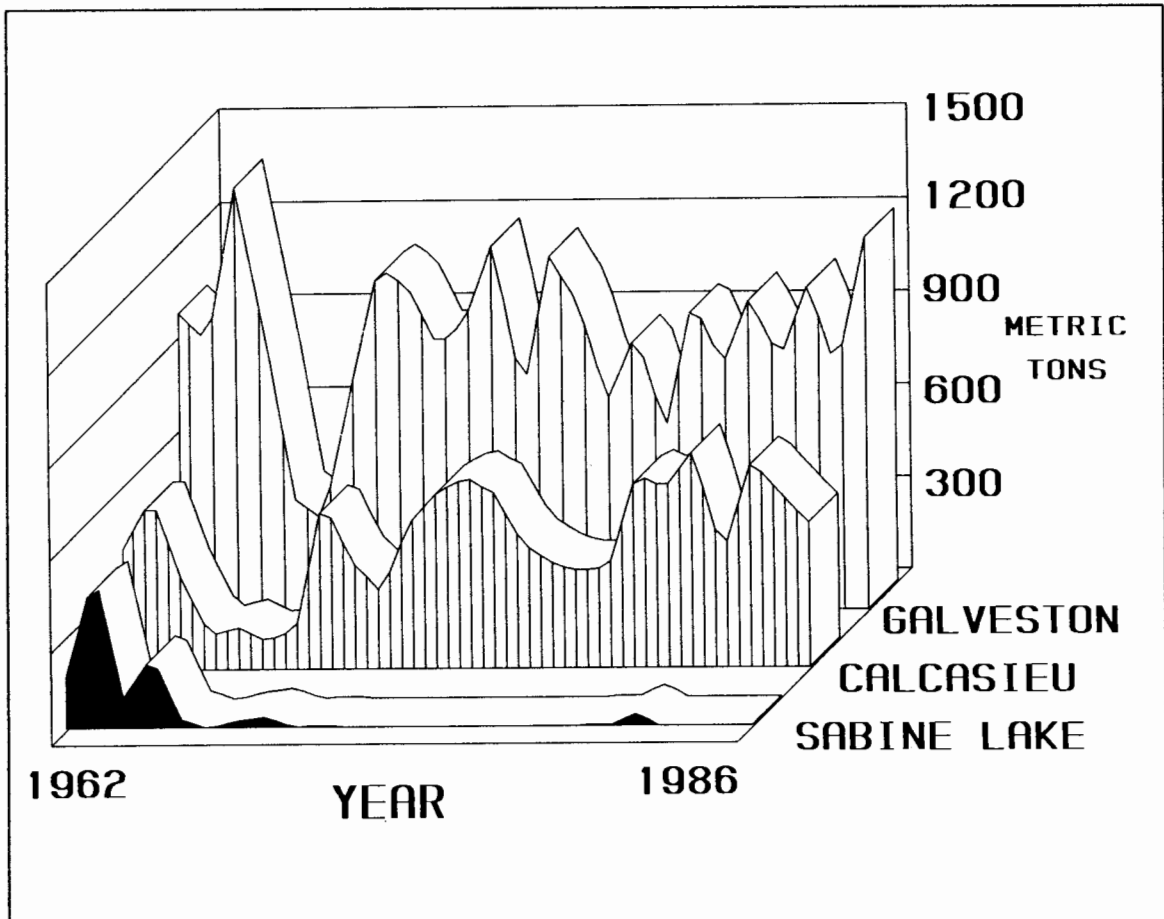


Figure 2.11. White shrimp production in Sabine Lake, Texas (1962-1986) before and after the Sabine and Neches Rivers were dammed in 1966 compared with landings in Galveston Bay and Lake Calcasieu, Louisiana (56).

### Habitat Alteration

The linkage between abundance of (and access to) wetlands and system productivity has been discussed. Just where does Galveston Bay fall when habitat protection is mentioned? In 1979, the estuary was surrounded by approximately 715 square kilometers of wetlands (determined from maps in 15). Wetlands losses between surveys in 1956 and 1979, whether natural or due to human activities, have been severe (15). In the Marsh Point area of East Bay, subsidence and petroleum exploration canals led to a 26 percent loss of salt and brackish marsh to open water. Jones Bay, at the northeast end of West Bay, suffered a 37 percent loss of marsh area due to housing development and its location on the edge of one of the two major subsidence cones in the Houston area. At the mouth of the San Jacinto River, subsidence has caused a 42 percent reduction of fresh marshes and swamps. Seagrasses and other submerged vegetation, primarily found in West Bay but never very extensive, have declined precipitously by 95 percent on a baywide basis. Galveston Island itself has lost 37 percent of its wetlands due to housing projects and industrialization (62). For the entire estuary, a net loss of 16 percent of the vegetated wetlands occurred during the period 1956 through 1979. A complete system inventory is needed to determine what has transpired in the last eight years, a period during which Houston experienced a rapid population growth.

### Conclusion

Given all the above information, a distillation of the material leads to three important facts to remember concerning the health of the Galveston Bay biota:

1. Texas Department of Water Resources. 1981. Trinity-San Jacinto estuary: a study of the influence of freshwater inflows. TDWR Report LP-113, Austin, TX, 386 p.
2. Wood, E.J.F. 1963. A study of the diatom flora of fresh sediments of the south Texas bays and adjacent waters. Publ. Inst. Mar. Sci. Univ. Texas 9:237-310.
3. Oppenheimer, C.H. and E.J.F. Wood. 1965. Quantitative aspects of the unicellular algal population of the Texas bay systems. Bull. Mar. Sci. 15:571-588.
4. Dykstra, R.F., F.J. MacIntee, and H.C. Bold. 1975. Some edaphic algae of the Texas coast. Tex. J. Sci. 26(1/2):171-177.
5. Zimmerman, R.J., National Marine Fisheries Service, Galveston, TX, unpublished data.
6. Renfro, W.C. 1959. Basic ecological survey of Area M-2. Texas Game and Fish Comm., Mar. Fish. Proj. Rep., Project No. M-2-R-1. 5 p.
7. Pullen, E.J. 1960. Ecological survey of area M-2. Texas Game and Fish Comm., Mar. Fish. Proj. Rep., Project No. M-2-R-2. 5 p.
8. Pullen, E.J. 1962. An ecological survey of upper Galveston and Trinity Bays. Texas Game and Fish Comm., Mar. Fish. Proj. Rep., Project No. M-2-R-3. 5 p.
9. Reid, G.K., Jr. 1955. A summer study of the biology and ecology of East Bay, Texas. I. Introduction, description of the area, some aspects of the fish community, the invertebrate community. Texas J. Sci. 7(3):316-343.
10. Johnson, R.B. 1966. The effects of engineering projects on the ecology of Jones Bay, p. 148-157. In Texas Parks Wildl. Dep., Coastal Fisheries Project Reports, Austin, TX.
11. Johnson, R.B. 1966. The effects of engineering projects on Moses Lake, p. 159-168. In Texas Parks Wildl. Dep., Coastal Fisheries Project Reports, Austin, TX.
12. Fisher, W.L., J.H. McGowen, L.F. Brown, Jr., and C.G. Groat. 1972. Environmental geologic atlas of the Texas coastal zone—Galveston-Houston area. Bureau of Economic Geology, Univ. of Texas, Austin, TX, 91 p.
13. McEachron, L.W., C.R. Shaw, and A.W. Moffett. 1977. A fishery survey of Christmas, Drum and Bastrop Bays, Brazoria County, Texas. Texas Parks Wildl. Dep., Tech. Ser. No. 20. 83 p.
14. West, R.L. 1972. Inventory of aquatic vegetation. Texas Parks Wildl. Dep., Coastal Waterfowl Project No. W-29-R-25, Job No. 20. 6 p.
15. White, W.A., T.R. Calman, R.A. Morton, R.S. Kimble, T.C. Littleton, J.H. McGowen, H.S. Nance, and K.E. Schmides. 1985. Submerged lands of Texas, Galveston-Houston area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bureau of Economic Geology, Univ. of Texas, Austin, TX, 145 p.
16. Lazarine, P. undated. Common wetland plants of southeast Texas. U.S. Army Corps of Engineers, Galveston District, Galveston, TX, 135 p.
17. Holt, G.J.D. 1976. Community structure of macrozooplankton in Trinity and upper Galveston Bays, with special reference to the cooling water system of Cedar Bayou Electric Generating Station. Ph.D. Dissertation, Texas A&M University, College Station, TX, 96 p.
18. Bagnall, R.A. 1976. Definition and persistence of an estuarine zooplankton assemblage. Ph.D. Dissertation, Univ. of Houston, Houston, TX, 137 p.
19. Hofstetter, R.P. 1977. Trends in population levels of the American oyster *Crassostrea virginica* Gmelin on public reefs in Galveston Bay, Texas. Texas Parks and Wildl. Dep., Tech. Ser. No. 24. 90 p.
20. Hofstetter, R.P. 1983. Oyster population trends in Galveston Bay 1973-1978. Texas Parks and Wildl. Dep., Manag. Data Ser. No. 51. 33 p.

### References

- There is a critical dependence of fish and wildlife on wetlands;
- A continued decline in wetlands acreage is foreseen; and
- The timing and amount of fresh water inflow are critical to the biota as we now know it.

21. Johnson, R.B., Jr. 1974. Ecological changes associated with the industrialization of Cedar Bayou and Trinity Bay, Texas. Texas Parks Wildl. Dep., Tech. Ser. No. 16, 79 p.
22. Trent, L., E.J. Pullen and R. Proctor. 1976. Abundance of macrocrustaceans in a natural marsh altered by dredging, bulkheading and filling. Fishery Bull. (U.S.) 74:195-200.
23. Zimmerman, R.J. and T.J. Minello. 1984. Densities of *Penaeus aztecus*, *Penaeus setiferus*, and other natant macrofauna in a Texas salt marsh. Estuaries 7(4A):421-433.
24. Moffett, A.W. 1975. The hydrography and macro-biota of the Chocolate Bayou estuary, Brazoria County, Texas (1969-1971). Texas Parks Wildl. Dep., Tech. Ser. No. 14, 72 p.
25. Hargis, V.A. and R.T. Hanlon. University of Texas Medical Branch, Marine Biomedical Institute, Galveston, TX, unpublished data.
26. Parker, J.C. 1965. An annotated checklist of the fishes of the Galveston Bay system, Texas. Publ. Inst. Mar. Sci. Univ. Texas 10:201-220.
27. Sheridan, P.F. 1983. Abundance and distribution of fishes in the Galveston Bay system, 1963-1964. Contrib. Mar. Sci. 26:143-163.
28. Arnold, E.L., Jr., R.S. Wheeler, and K.N. Baxter. 1960. Observations on fishes and other biota of East Lagoon, Galveston Island. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 344, 30 p.
29. Feltner, T.B. and A.N. Pettingell. 1980. A birder's checklist of the upper Texas coast, 6th edition. Ornithology Group, Houston Outdoor Nature Club, Houston, TX.
30. Arnold, K.A. 1984. Checklist of the birds of Texas. Texas Ornithological Society, Austin, TX. 147 p.
31. Arnold, K.A., Department of Wildlife and Fisheries, Texas A&M University, College Station, TX, unpublished data.
32. Texas Parks and Wildlife Department. 1986. Waterfowl harvest recommendations. Texas Parks Wildl. Dep., Job Performance Rep., Project No. W-106-R-12. 122 p.
33. Mueller, A.J., U.S. Fish and Wildlife Service, Houston, TX, unpublished data.
34. Myers, J.P., R.I.G. Morrison, P.Z. Antas, B.A. Harrington, T.E. Lovejoy, M. Sallaberry, S.E. Senner, and A. Tarak. 1987. Conservation strategy for migrating species. Amer. Scientist 75:19-26.
35. Blacklock, G.W., R.D. Slack, D.B. Blankinship, S. Kennedy, K.A. King, R.T. Paul, J. Smith, and R.C. Telfair, III. 1978. The Texas colonial waterfowl census, 1973-1976. Proc. 1978 Conf. Colonial Waterfowl Group, pp. 99-104.
36. Texas Parks and Wildlife Department. 1987. Texas colonial waterbird census summary - 1986. Texas Parks Wildl. Dep. and Texas Colonial Waterbird Soc., Spec. Admin. Rep., Austin, TX.
37. Dixon, J.R. 1987. Amphibians and reptiles of Texas. Texas A&M University Press, College Station, TX, 434 p.
38. Mueller, A.J. 1985. Vertebrate use of nontidal wetlands on Galveston Island, Texas. Texas J. Sci. 37:215-225.
39. Johnson, L., C. Martin, and B. Thompson. 1987. Texas alligator survey, harvest, and nuisance summary, 1986. Texas Parks Wildl. Dep., Annual Rep., Austin, TX, 18 p.
40. Doughty, R.W. 1984. Sea turtles in Texas: a forgotten commerce. Southwest. Historical Quart. 88:43-70.
41. Schmidly, D.J. 1983. Texas mammals east of the Balcones fault zone. Texas A&M University Press, College Station, TX, 400 p.
42. Schmidly, D.J. 1984. The furbearers of Texas. Texas Parks Wildl. Dep., Bull. No. 111, 55 p.
43. Ward, G.H. and N.E. Armstrong. 1980. Matagorda Bay, Texas: its hydrography, ecology, and fishery resources. U.S. Fish Wildl. Serv., Biological Services Program, Washington, DC, FWS/OBS-81/52. 230 p.
44. Flint, R.W. 1984. Phytoplankton production in the Corpus Christi Bay estuary. Contrib. Mar. Sci. 27:65-83.
45. Corliss, J. and L. Trent. 1971. Comparison of phytoplankton production between natural and altered areas in West Bay, Texas. Fishery Bull. (U.S.) 69:829-832.

46. Lowe, G.C., Jr. and E.R. Cox. 1978. Species composition and seasonal periodicity of the marine benthic algae of Galveston Island, Texas. *Contrib. Texas. Mar. Sci.* 21:9-24.
47. Gosselink, J.G., C.L. Cordes, and J.W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. Vols. I-III. U.S. Fish Wildl. Serv., Office of Biological Services, Washington, D.C., FWS/OBS-78/9-11.
48. McKay, C.P. and C. McMillan. 1977. Production ecology and physiology of seagrasses, p. 53-87. In C.P. McKay and C. Helfferich (eds.), *Seagrass Ecosystems*. Marcel Dekker, Inc., New York.
49. Zimmerman, R.J., T.J. Minello, and G. Zamora. 1984. Selection of vegetated habitat by *Penaeus aztecus* in a Galveston Bay salt marsh. *Fishery Bull.* (U.S.) 82:325-336.
50. Zimmerman, R.J., National Marine Fisheries Service, Galveston, TX, unpublished data.
51. Minello, T.J. and R.J. Zimmerman. 1983. Fish predation on juvenile brown shrimp, *Penaeus aztecus* Ives: the effect of simulated *Spartina* structure on predation rates. *J. Exp. Mar. Biol. Ecol.* 72:211-231.
52. Gleason, D.F. 1986. Utilization of salt marsh plants by postlarval brown shrimp: carbon assimilation rates and food preferences. *Mar. Ecol. Prog. Ser.* 31:151-158.
53. Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. *Trans. Amer. Fish. Soc.* 106:411-416.
54. Osburn, H.R., W.D. Quast, and C.L. Hamilton. 1987. Trends in Texas commercial fishery landings, 1977-1986. Texas Parks Wildl. Dep., Manage. Data Ser. No. 131. 108 p.
55. Osburn, H.R., and M.O. Ferguson. 1987. Trends in finfish landings by sport-boat fishermen in Texas marine waters, May 1974-May 1986. Texas Parks Wildl. Dep., Manage. Data Ser. No. 119. 464 p.
56. Baxter, K.N. and Hightower, M., National Marine Fisheries Service, Galveston, TX, unpublished data.
57. Titus, J.G. 1986. The causes and effects of sea level rise, p. 219-248. In J.G. Titus (ed.), *Effects of Changes in Stratospheric Ozone and Global Climate*. Vol. I. Overview. U.S. Environmental Protection Agency, Washington, D.C.
58. Klima, E.F., R.J. Zimmerman, T.J. Minello, and J.N. Nance. (in prep.). Wetland losses and fisheries production gains: a paradox in the northwestern Gulf of Mexico. National Marine Fisheries Service, Galveston, TX.
59. National Weather Service, Galveston, TX.
60. Texas Parks and Wildlife Department, Austin, TX, unpublished data.
61. Texas Department of Water Resources. 1981. Sabine-Neches estuary: a study of the influence of freshwater inflows. Texas Dep. Water Res., Austin, TX, Publ. LP-116.
62. Mueller, A.J., U.S. Fish and Wildlife Service, Houston, TX, unpublished data.
63. Turner, R.E. 1976. Geographic variations in salt marsh macrophyte production: a review. *Contrib. Mar. Sci.* 20:47-68.
64. Eubanks, T., Jr., Ornithology Group, Houston Outdoor Nature Club, Houston, TX, unpublished data.