C. Target Organisms

1. SPECIES OF CONCERN

Table Of Contents

1. SPECIES OF CONCERN

1.0 Introduction

Of the thirteen counties which make up the CCBNEP study area, only seven counties interface with the estuarine and marine system. Several of the listed species are not estuarine dependent (Table IV.C.1.1) and not addressed in detail in this report. Their importance to the management of the CCBNEP study area should noted, however, as any actions taken to protect or enhance habitat within the area watershed may affect the downstream estuarine-dependent flora and fauna.

Several listed species that directly depend on estuarine and adjacent marine habitats have been selected for further discussion in this section. Those species listed in Table IV.C.1.1, but which there is insufficient information to discuss status and trends were not included. In addition, the status of the exotic brown mussel *Perna perna* will be discussed.

Table.IV.C.1.1. Listed endangered, threatened and candidate species within the CCBNEP study area. USFWS[1] = US Fish and Wildlife Service; TPWD[2]=Texas Parks and Wildlife Department; TNHP[3]=Texas Natural Heritage Program; TOES[4]=Texas Organization of Endangered Species.

Scientific Name	Common Name	USFWS	TPWD	TNHP	TOES
PLANTS					
Eleocharis brachycarpa	Short-fruited Spikerush	C2		G1SH	
Anthericum chandleri	Lila de los Llanos	C2		G3S3	
Grindelia oolepis	Plains Gumweed	3C		G2S2	WL
Ambrosia cheiranthifolia	South Texas Ragweed	C1		G1S1	
Echinocereus rechenbachii albertii	Black Lace Cactus	E	E	G4T1S1	E
Allium elmendorfii	Elmendorf's Onion			G2S2	
Chloris texensis	Texas Windmill Grass	C2		G2S2	
Hoffmannesggia tenella	Slender Rush-pea	E	E	G1S1	E
Sesuvium trianthemoides	Roughseed Sea-purslane	C2		G1S1	E
SENSITIVE PLANT COMMUNITIES					
	Blackbrush Series			G5S5	
	Cane Bluestem-False Rhodesgrass Series			G3S3	
	Coastal Live Oak-Redbay Series			G3S3	
	Glasswort-Saltwort Series			G4S4	
	Gulf Cordgrass Series			G4S4	
	Mesquite-Granjeno Series			G5S5	
	Mesquite-Huisache Series			G5S5	
	Seacoast Bluestem-Gulfdune Paspalum Series			G4S3	

Table IV.C.1.1. Continued.

Scientific Name	Common Name	USFWS	TPWD	TNHP	TOES
	Sea Oats-Bitter Panicum Series			G4S3	
FISH					
Oostethus brachyurus	Opossum Pipe Fish		T	G5S1	
Syngnathus affinis	Texas Pipe Fish			G5S1	
AMPHIBIANS					
Hypopachus variolosus	Sheep Frog		T	G5S2	T
Notophthalmus meridionalis	Black-spotted Newt	C2	E	G1S1	E
Siren intermedia texana	Rio Grande Lesser Siren	C2	E	G5T2S2	E
REPTILES					
Lepidochelys kempii	Kemp’s Ridley Sea Turtle	E	E	G1S1	E
Caretta caretta	Loggerhead Sea Turtle	T	E	G3S2	T
Chelonia mydas	Green Sea Turtle	T	T	G3S1	T
Dermochelys coriacea	Leatherback Sea Turtle	E	E	G3S1	E
Eretmochelys imbricata	Hawksbill Sea Turtle	E/CH		G3S1	E
Gopherus berlandieri	Texas Tortoise		T	G4S3	T
Alligator mississippiensis	American Alligator	T/SA			WL
Holbrookia lacerata subcaudalis	Southern Earless Lizard			G3S3	
Holbrookia p. propinqua	Keeled Earless Lizard			G3S3	
Phrynosoma cornutum	Texas Horned Lizard	C2	T	G5S4	T
Cemophora coccinea lineri	Texas Scarlet Snake		T	G5S4	T
Drymarchon corais erebennus	Texas Indigo Snake		T	G5T2S2	WL
Drymobius margaritiferus	Speckled Racer		E	G5S1	WL
Lampropeltis triangulum	Mexican Milk Snake				WL
Leptodeira septentrionalis	Northern Cat-eyed Snake		E	G5T5S2	T
Nerodia clarki	Gulf Saltmarsh Snake	C2		G4QS4	
BIRDS					
Pelecanus occidentalis	Brown Pelican	E	E	G5S1	E
Egretta rufescens	Reddish Egret	C2	T	G4S22	T
Plegadis chihi	White-faced Ibis	C2	T	G5S2	T
Mycteria americana	Wood Stork		T	G5S3N	T
Grus americana	Whooping Crane	E	E	G1S1	E
Dendrocygna bicolor	Fulvous Whistling Duck	C2		G5S4	T
Oxyura dominica	Masked Duck			G5S4	WL
Elanoides forficatus	American Swallow-tailed Kite	3C	T	G5S2	T
Haliaeetus leucocephalus	Bald Eagle	E	E	G3S2	E
Buteo albicaudatua	White-tailed Kite		T	G5S2	T
Buteo albonotatus	Zone-tailed Hawk		T	G5S3	T
Falco femoralis septentrionalis	Aplomado Falcon	E	E	G4T2S1	E
Falco peregrinus anatum	American Peregrine Falcon	E	E	G3T2S1	E
Falco peregrinus tundrius	Arctic Peregrine Falcon	T	T	G3T1S1	T
Jacana spinosa	Northern Jacana				T
Charadrius melodus	Piping Plover	T	T	G2S2	T
Charadrius montanus	Mountain Plover	C2		G3S2	

Table IV.C.1.1. Continued.

Scientific Name	Common Name	USFWS	TPWD	TNHP	TOES
Charadrius alexandrinus nivosus	Western Snowy Plover	C2		G4TU	
Numenius borealis	Eskimo Curlew	E	E	G1S1	E
Numenius americanus	Long-billed Curlew	C2		G5S5	
Sterna antillarum antillarum	Coastal Least Tern				T
Sterna antillarum athalassos	Interior Least Tern	E	E	G4T2S1	E
Sterna fuscata	Sooty Tern		T	G5S2	WL
Rhynchops niger	Black Skimmer				T
Ceryle torquata	Ringed Kingfisher				WL
Camptostoma imberbe	Northern Beardless-tyrannulet		T	G5S3	WL
Pachyramphus aglaiae	Rose-throated Becard		T	G4G5S2	WL
Lanius ludovicianus migrans	Loggerhead Shrike	C2		G5T2?	
Aimophila botteri texana	Texas Botteri's Sparrow	C2	T	G4TUS3	T
MAMMALS					
Felis pardalis	Ocelot	E	E	G2?S1	E
Felis yagouaroundi	Jaguarundi	E	E	G4S1	E
Conepatus leuconotus texensis	Gulf Coast Hog-nosed Skunk	C1		G5T?S?	
Tursiops truncatus	Bottle-nosed Dolphin			G?S2	
Stenella plagiodon	Atlantic Spotted Dolphin		T	G?S1	T
Steno bredanensis	Rough-toothed Dolphin		T	G?S1	

1 US Fish and Wildlife Service: E-Endangered; T-Threatened; T/SA- Threatened due to similarity of appearance. Because of the similarity of appearance of the Texas American Alligator hides and parts of other protected crocodilians, it is necessary to restrict commercial activities involving alligator specimens taken in Texas to ensure the conservation of other alligator populations, as well as other crocodilians that are threatened or endangered. USFWS, 12 October 1983. Fed. Reg. 48 (198):46332-46337. C1 - Candidate, category 1. USFWS has substantial information on biological vulnerability threats to support proposing to list as endangered or threatened. Data are being gathered on habitat needs and for critical designations. C2 - Candidate, category 2. Information indicates that proposing to list as endangered or threatened is possibly appropriate; substantial data on biological vulnerability and threats are not currently known to support the immediate preparation of rules. Further biological research field study will be necessary to ascertain the status and/or taxonomic validity of the taxa in category 2. 3A - Former Candidate, rejected because presumed extinct and/or habitats destroyed. 3B - Former Candidate, rejected because not a recognized taxon; i.e. synonym or hybrid. 3C - Former Candidate, rejected because more common, widespread, or adequately protected.

2 Texas Parks and Wildlife Department, Endangered/Threatened Species Data File: (TNHP, 1994). E - Endangered; T - Threatened.

3 Texas Natural Heritage Program, Special Species and Natural Community Status (1994). G1 - Critically imperiled globally, extremely rare, 5 or fewer occurrences. G2 - Imperiled globally, very rare, 6 to 20 occurrences. G3 - Very rare and local throughout range or found locally in restricted range, 21 to 100 occurrences. G4 - Apparently secure globally. G5 - Demonstrably secure, globally S1-5 state ranking of the same categories as those listed globally. GX - Believed to be extinct throughout range. U - denotes uncertain rank (G2?), or range (G1G2). Q - designates questionable rank or taxonomic assignment. H - denotes historical occurrence. T- subrank of subspecies or variety.

4 Texas Organization for Endangered Species; Endangered, Threatened and watch lists of Plants and Vertebrates of Texas (March, 1987 - plants and January, 1988 - vertebrates). E - State endangered species - any species which is in danger of extinction in Texas or in addition to list federal status. T - State threatened species - any species which is likely to become a state endangered species within the foreseeable further. WL - TOES Watch List - any species which at present has either low population or restricted range in Texas and is not declining or being restricted in its range but requires attention to insure that the species does not become endangered or threatened (State of Texas).

1.1 Whooping Crane (*Grus americana*)

1.1.1 Introduction

The Whooping Crane is one of the most well-known endangered species in North America due, in part, to its large size, low numbers, and continental migratory path. Whooping Cranes are the tallest bird species in North America, standing approximately 1.5 m (5 ft) tall, with a wingspan of 2.3 m (7.5 ft). Whooping Crane numbers decreased to 15 or 16 in 1941 in one remaining natural population. This group, known as the AWP population, breeds only in Wood Buffalo National Park in Canada and winters only along the central Texas coast at Aransas National Wildlife Refuge (ANWR). Much effort has been made to preserve crucial breeding, migratory, and wintering habitats to help increase population numbers and reintroduce new populations.

1.1.2 Status and Trends

Historical distribution of Whooping Cranes has been related to selective habitats utilized by this species. Winter range along the Gulf Coast extended from Louisiana to Mexico and concentrated in salt, brackish and fresh marshes, coastal lagoons, maritime beaches, and tallgrass prairie habitats (Allen, 1952). The first documentions of the winter distribution in the CCBNEP area were reported by J. A. Brundrett in 1885 and T. Webb in 1886 in the vicinity of ANWR, by J. J. Carroll in Refugio County from 1896 to 1900, and by H. C. Oberholser on Matagorda Island in 1900 (Stevenson and Griffith, 1946; Allen, 1952). Winter counts were initiated in 1937 and continue up to the present (Table IV.C.1.1.1) and illustrate the extremely low population numbers in the late 1930's through 1950's. The increase in the AWP population has been related to several factors that will be addressed below (Management and Conservation).

The interpretations of population data trends over time is often difficult due to factors that may influence population numbers. If natural fluctuations in population cycles are not addressed in time-series analysis, erroneous predictions may be calculated. Trends must be identified prior to the analyses in order to address any periodicity in data set. The first time-series analysis performed on the ANWR winter population data identified a general decrease in total number occurring at 10-year intervals but was not interpreted as significant periodic events (Miller et al., 1974). These results may have been affected by neglecting to perform a transformation procedure on the data prior to the time-series analysis (Boyce, 1985). Re-analyses of the same dataset resulted in pronounced periodicity and was reconfirmed when additional 10-year data points were added to the dataset (Boyce and Miller, 1985). Additional attention was employed on the actual data counts and evaluation of possible errors in missing part of the population due to utilization of other wintering ranges, uncounted birds, and birds counted more than once (Boyce, 1985). Predictions of population growth for AWP population were calculated by accounting for the 10-year periodicity and the influence the periodicity would have on variance (Table IV.C.1.1.1). Confidence intervals (95%) are narrower for the ARIMA model (Boyce, 1985) than for those calculated by Miller et al. (1974). Boyce cautioned that although predictions do account for periodicity, these values are invalidated by any change in management and conservation efforts or in the environment critical to the whooping cranes' survival.

Criteria for downlisting the endangered Whooping Crane to threatened in the United States are based on population numbers for nesting pairs (USFWS, 1994). Ninety nesting pairs in three separate, wild populations must be established by the year 2020 to satisfy the first recovery goal within the recovery plan. The AWP population must be maintained at the current 40 nesting pairs and two additional populations must each support 25 nesting pairs. A sustained population number of 1000 migratory and nonmigratory individuals for ten consecutive years must be attained before downlisting the species to threatened status. These numbers and time frame would ensure continued survival and potential for recovery through any future catastrophic events.

1.1.3 Conservation and Management

The decline of Whooping Cranes in the late 1800s resulted in only two known populations in North America: a non-migratory flock in southwestern Louisiana and a migratory population that wintered on the Gulf coast of Texas (Allen, 1952). The Louisiana population declined following a severe storm in 1940, and the last wild bird was taken into captivity in 1948. The ANWR was established in 1937 to provide habitat and protection for the remaining migratory population. The refuge encompassed 22,148 ha of Blackjack Peninsula and adjacent areas of coastal marsh and upland habitats. Protection of the breeding range of this population was afforded by the establishment of the Wood Buffalo National Park in 1922, although the Whooping Crane was not discovered to use this area for breeding until 1954 (Kuyt, 1987.). An additional 7700 ha were purchased by the federal government on Matagorda Island in 1942 and leased 2400 ha from the State of Texas for an airbase and bombing range. In 1975 a portion of the land on Matagorda Island was transferred to US Fish and Wildlife Service (USFWS) to be managed under refuge guidelines. In 1988 USFWS purchased an additional 2232 ha on south Matagorda Island, and an agreement for joint management of the island between USFWS and Texas Parks and Wildlife Department (TPWD) is being prepared. Currently, 44,606 ha are in federal and state ownership and are managed for critical Whooping Crane habitat. An additional 5,236 ha of adjacent coastal marshes are closed to hunting in accordance to the Proclamation Boundary (USFWS, 1994).

The Whooping Crane was first protected under the Migratory Bird Treaty Act (US and Canada) in 1916. The Whooping Crane was officially listed as threatened with extinction in 1967 (Federal Register, Vol. 32, Number 48, March) and listed as endangered in 1970 (Federal Register, Vol. 43, Number 94, May 15). Coordination efforts between US and Canada continued with the initiation of a migration-monitoring program in 1975 where data are collected along the migration corridor. Information from these data have been used to determine key habitats and potential hazards to the Whooping Cranes. A Memorandum of Understanding (MOU) in 1985 between the USFWS and Canadian Wildlife Service (CWS) formalized much of the efforts between the two agencies for management and research program implementation. Also in 1985, USFWS approved a plan for Federal-State Cooperative Protection of Whooping Cranes in the thirteen states that are within the migration corridor. The plan included response strategies for potential hazards and for location information to recover sick or injured birds during migration; a similar plan was adopted in Canada in 1987. The 1985 MOU between USFWS and CWS was

Table IV.C.1.1.1. Forecasts of AWP Whooping Crane population based on a birth-death process model (Miller et al., 1974) and a multiplicative ARIMA model (Boyce, 1985). Observed population numbers from 1973-74 to 1993-1994 were reported by US Fish and Wildlife Service (1994) and for 1994-95 by USFWS-ANWR (T. V. Stehn, pers. comm.).

Winter	Observed	Miller et al. (1974)			Boyce (1985) ARIMA Model		
			95% C.I.			95% C.I.	
		Forecast	Lower	Upper	Forecast	Lower	Upper
1973-74	49	53	44	62	-	-	-
1974-75	49	55	42	68	-	-	-
1975-76	57	58	41	74	-	-	-
1976-77	69	60	41	78	-	-	-
1977-78	70	62	40	84	-	-	-
1978-79	74	65	40	90	-	-	-
1979-80	76	68	40	96	-	-	-
1980-81	78	70	39	100	-	-	-
1981-82	73	73	39	107	-	-	-
1982-83	73	76	39	113	-	-	-
1983-84	75	79	39	119	-	-	-
1984-85	86	82	39	125	-	-	-
1985-86	97	85	39	130	88	77	98
1986-87	110	89	39	138	90	79	102
1987-88	134	93	40	145	97	85	109
1988-89	138	97	41	153	100	88	113
1989-90	146	100	41	159	107	93	121
1990-91	146	104	41	167	109	96	124
1991-92	132	109	42	176	105	91	120
1992-93	136	114	43	185	100	86	115
1993-94	143				102	88	118
1994-95					108	93	125
1995-96					116	99	134
1996-97					119	101	138
1997-98					127	108	147
1998-99					131	111	152
1999-00					138	118	160
2000-01					141	120	164

renewed for another five years in 1990. Critical habitat at ANWR includes estuarine marshes, shallow bays, tidal flats and upland rangeland (Allen, 1952; Blankinship, 1976). A few key plant species predominate in different zones within the marshes: *Spartina alterniflora* (smooth cordgrass) in the intertidal zone; and *Distichlis spicata* (saltgrass), *Batis maritima* (glasswort), *Salicornia* spp. (saltwort), and *Borrichia frutescens* (sea-oxeye daisy) in the high marsh zone. Submergent vegetation (e.g., seagrasses) fringe the shallow bay margins and tidal flats are typically barren of vascular plant species. Upland vegetation is predominately grasses interspersed with oak mottes, swales and ponds (Stevenson and Griffith, 1946; Allen, 1952; Labuda and Butts, 1979).

Territory delineation and evaluation form a critical component in understanding wintering ecology of the Whooping Crane. Systematic aerial and ground censuses have been undertaken since the 1950s to define territory boundaries and changes over time. Size of territory has been related to neighbor effects; where several crane pairs are adjacent to one another, territory size decreases and overlaps are more common (Stehn and Johnson, 1987). Unused areas within the critical habitat at ANWR in 1982-83 were occupied and defended by newly mated pairs in 1983-84. However, crowding into established areas was reported in earlier years when crane numbers were lower and have been related to intraspecific relationships within family units. The use of leg bands has further defined relationships between current family groups, pairs and single birds (Stehn and Johnson, 1987). Each family unit of cranes defends an extensive territory while wintering at ANWR, and often subadults will winter near their parent's territory (Blankinship, 1976; Bishop and Blankinship, 1982; Stehn and Johnson, 1987).

The increase in Whooping Crane numbers raised some questions about the possible expansion into new areas to accommodate new territories. Cranes have occupied and defended territories on Matagorda Island, Lamar Peninsula, and Welder Point beginning in the 1970s. Prime marsh habitat is still available on Matagorda Island and adjacent areas, however, expansion may be contingent upon pairs which bring young into the new area and those young establishing territories close to the parents (Stehn and Johnson, 1987). Unpaired subadults have often been observed moving about other pairs' territories or in areas which have no defending pairs. Although habitat suitable for Whooping Cranes has been defined at marshes near Mission Bay and within the Guadalupe Delta, few birds have wintered in areas outside the ANWR area. Two subadults were observed south of El Campo (approx. 150 km northeast of ANWR) during the winter months 1984-85 feeding in harvested corn fields and feeding and roosting in a coastal marsh (Lange, 1992). A subadult left Matagorda Island in mid-January 1987 and wintered with Sandhill Cranes for two months 72 km northeast of the wintering area (Stehn, 1992). Movements by other subadults have been documented, making census data difficult to collect. In addition, territorial pairs will also move into adjacent territories when the defending pair is not occupying the area or not able to see the intruders or even move around the refuge during the winter.

Whooping Crane movements within and between territories are related to foraging, resting, comfort, walking, and alert behavior. In an activity budget analysis on three consecutive seasons (1978-79 through 1980-81), cranes spent 56% of their time foraging with most of that time spent during early morning hours (Bishop and Blankenship, 1985). However, this time varied in relation to habitat type; Whooping Cranes spent more time foraging in marsh (>70%), than upland or bay (about 50%). Additional differences were determined in time spent in exhibiting alert behavior. The highest percentage of alert behavior occurred in the upland habitat type, with lower percentages in marsh and open bays. Similar findings were reported by Hunt (1987) as cranes spent 33% of time in alert behavior in the uplands as compared to 6% in the wetland habitats. Bishop and Blankinship (1982) interpreted these differences in regards to predator detection and avoidance, as patches of thick vegetation in the uplands limited visual range.

The amount of time foraging may also be dependent upon the varying abundance of prey items in different habitat types. Allen (1952) reviewed the available literature and accounts of food items to that date from Louisiana and Texas. Louisiana locals believed that the Whooping Cranes fed on crayfish to a large extent, and also consumed small fish and insects in the coastal marshes. Various plants were also consumed, including the white roots of *Crinum americanum* (locally referred to as "marsh onion" or "glaïeul") and basal portions of *Nothoscordium bivalve* ("prairie lily"), sweet potatoes, sprouting corn, roots of *Scirpus olneyi* (Olney's three-square) and *Spartina alterniflora* (smooth cordgrass) (as related to John Lynch, USFWS, in Allen, 1952). *Callinectes sapidus* (blue crab) were reported in various accounts (in Allen, 1952) as were other shellfish and mullet in the coastal marshes on Blackjack Peninsula, the principal part of ANWR. The Whooping Cranes' preference for coastal marshes was further illustrated by the Mexican cowhand name for this species "viejo del agua" or "old man of the water". Unpublished, written observations of John Lynch on ANWR in December 1939 discussed the availability of *Ensis* spp. clams; the species had to be extracted with a spade once the burrow was disturbed, so Lynch believed that crane could only successfully capture the clam at the opening of the burrow. Early accounts of food resource studies at ANWR also related the importance of fish as a prey item (O.S. Pettingill, in Allen, 1952).

The interest in prey preference and availability has been approached in three methods of analysis: analysis of droppings, observations of feeding birds, and inspection of feeding ponds and other habitats. Analysis of droppings is difficult when fecal matter is dropped into water or heavy vegetation (Allen, 1952). A pinkish cast is evident in the droppings when crustaceans have been ingested. While only indigestible parts of the prey item remain in the fecal material, early examinations revealed *C. sapidus*, *Quercus* spp. acorns, *Tagellus gibbus* and *Solen* spp. (razor clams) and *Cambarus* spp. (crayfish) as predominant prey items, as were fish and *Lycium carolinianum* (wolfberry) berries. Determination of prey items from visual observations is difficult unless the prey is large. Increasing success is possible when knowledge of foraging strategies is also evaluated. Quantitative analyses of prey items in feeding areas can produce a list of items available and abundance of those items, but may not necessarily reflect the crane's preference.

Additional prey items are identified from visual observations of foraging Whooping Cranes that may not be discernible in fecal droppings. Allen (1952) reviewed the early literature and personal observations of several verbal accounts (e.g., Beaty, Keefer, Pettingill, Tisdale) from ANWR. All animal food items generated from visual observations were: *Alpheus* spp. (pistol shrimp), *Calianassa* spp. (mud shrimp), *C. sapidus*, *Littorina irrorata* ("common periwinkle"), grasshoppers, *Mugil* spp.(mullet), other fish, *Agkistrodon piscivorous* (cottonmouth moccasin), and *Nerodia* spp. (water snake, possibly identified as Clark' water snake). Whooping Cranes were observed to feed on various vegetation: *Batis maritima* (glasswort); *Salicornia* spp. (saltwort); cultivated oat, corn, wheat, and sorghum sprouts; potatoes, *Paspalum* spp.; *Andropogon* spp.; other grass species; and, acorns of several *Quercus* spp.

Inspection of feeding ponds and other habitat types after visual observations were complete offered more ecological clues (Allen, 1952). Pieces of *Callinectes sapidus* were often left after a Whooping Crane had fed on the edible portions of this prey items. Large burrows of marine worms, along the edges of ponds were quantified as an estimated 200 worms/ft^3 of mud. Although this prey item is quite small, the abundance of the worms, visual observations of the cranes in the vicinity of the worms, and the indigestible mandibles in fecal droppings illustrate the potential importance of this group as a prey item.

A summarization of the animal and plant prey items revealed that 28 animal groups and 17 plant groups were determined to be eaten by Whooping Cranes according to studies up to the early 1950's (Table IV.C.1.1.2) (Allen, 1952). Seven species were highlighted as important prey items based on relative abundance, knowledge of foraging strategies, and habitat utilizations: *Laeonereis culveri* (polychaete worm), *Crangon heterochaelis* (pistol shrimp), *Calianassa jamaicense* var. *louisianensis* (mud shrimp), *Callinectes sapidus* (blue crab), *Cambarus hedgpethi* (Hedgpeth's crayfish), *Tagellus gibbus* (short razor clam), and *Solen viridus* (?) (green razor clam).

Additional efforts to determine food prey availability were undertaken at ANWR during the mid 1960s. Several factors, including a two-fold Whooping Crane population increase, and increased human activity within and around the refuge boundaries, could have an effect on prey availability. A fecal dropping and visual observation study was initiated in fall 1970 and several weather events were related to prey selection (Blankinship, 1976). Low rainfall and low tides from November 1970 to September 1971 increased bay salinities and dried up shallow ponds. *Callinectes sapidus* populations declined and crane diet shifted to clams (species not given). Heavy rainfall and flooding associated with Hurricane Fern in September 1971 lowered bay salinities and increased water levels in inland ponds and tidal inlets. *Callinectes sapidus* populations increased throughout a mild winter and were predominant part of the cranes' diet. Low salinities and flooded marshes and ponds with associated high rainfall continued throughout the following two years (1973-74), and crab populations continued to maintain high levels. Lower water levels occurred during late December or January of these years, and crane diet shifted to at least five species of clams (species not given). *Callinectes sapidus* was postulated to be the preferred food items when both crabs and clams were available. Foraging efficiency observations revealed 32 clams captured by an adult female and eaten by herself and an immature crane in a 30 minute period. Blankinship listed the following items as additional prey taken by cranes during this study: *Lycium carolinianum* fruits, *Quercus* spp. acorns, *Uca pugilator*, *Calianassa jamaicense*, *Penaeus* spp., eels (unknown species), *Natrix sipedon clarki* (snake), *Thamnophis souritus* (sic) *proximus*, and *Cambarus* spp.

Shifts in prey selection have been documented and have been partially explained by either alterations to habitats, environmental conditions, and seasonal abundance of prey items. While the two species of razor clams were abundant in fecal material in 1940 and 1941, no specimens were collected in 1946 (Hedgpeth studies) or in winters of 1946-47 and 1947-48 (Allen studies). Allen (1952) attributed possible alterations to the coastal marsh environment including dredging Gulf Intracoastal Waterway (GIWW) across key areas of the marsh and oil explorations and drilling activities as negatively affecting the razor clam populations at ANWR. Hunt (1987)

Table IV.C.1.1.2. Prey items for the Whooping Crane as reported by Allen (1952); taxonomic and common names are listed as in original document (* denotes important prey groups).

Taxonomic Group	Common Name
Animal Foods	
Annelida	
Polychaeta	
Neanthes succinea	
**Laeonereis culveri*	
Notomastus spp.	
Arthropoda	
Crustacea	
Amphipoda (?)[a]	
**Crangon heterochaelis*	pistol shrimp
**Callianassa jamaicense* var. *louisianensis*	mud shrimp
**Callinectes sapidus*	blue crab
Uca pugilator	common fiddler crab
**Cambarus hedgpethi*	Hedgpeth's crayfish
Cambarus spp.	
Insecta	
Odonata	unidentified dragonflies
Phasmomantis carolina	praying mantis
Locustidae	unidentified grasshoppers
Hemiptera	
Notonectidae	back swimmers
Belostomatidae	giant water bugs
Corixidae	water boatmen
Diptera	larval and nymph forms of flies, midges, etc.
Coleoptera	aquatic beetles
Hydrophilidae	water scavenger beetle
Mollusca	
Pelecypoda	
**Tagellus gibbus*	short razor clam
**Solen (viridis?)*	green razor clam
Gastropoda	
Littorina irrorata	common periwinkle
Melampus coffeus	ear snail
Cerithidea spp.	
Chordata	
Pisces	
Fundulus spp. (possibly *F. similis*)	black chub
Cyprinodon variegatus	sheepshead minnow

Table IV.C.1.1.2. Continued.

Taxonomic Group	Common Name
Mugil cephalus	striped mullet
Amphibia	
Rana pipiens	leopard frog
Reptilia	
Agkistrodon piscivorous	cottonmouth moccasin
Natrix sipendon clarkii	Clark's water snake
Aves	
Anatidae[b]	ducklings
Vegetable Foods	
Halodule wrightii	shoalgrass
Paspalum spp.	jointgrass
Andropogon spp.	broomgrass
Spartina alterniflora	popping cane
Distichlis spicata	saltgrass
Gramineae spp.	manna-grass
Cyperus spp.	galingale
Scirpus olneyi	three-square rush
Rynchospora (sic) spp.	beakrush
Nothoscordum bivalve	prairie lily
Crinum americanum	marsh onion
Quercus virginiana	live-oak
Q. myrtifolia	pin oak
Q. marilandica	blackjack oak
Salicornia (bigelowii?)	glasswort
Batis maritima	saltwort
Lycium carolinianum	salt flat cranberry/wolfberry

[a] Traces of amphipod (?) in droppings
[b] stomach contents from Whooping Crane killed in Manitoba

found variability of food habits both between and within 1983-1984 and 1984-1985 winters. Although *C. sapidus*, clams, and *L. carolinianum* were primarily eaten in both winters, *C. sapidus*, *Quercus* spp. acorns, and *L. carolinianum* were also utilized during early and mid-winter and clams were more predominant during late winters. *Lycium carolinianum* berry production occurs around the first two weeks of December, and availability is limited to the next six weeks. Production was quite variable between the two winter seasons; in 1983-84 densities were 3.88 berries m^{-2}, while in 1984-85, densities were 20.37 berries m^{-2}. In a recent study, foraging strategies of cranes were related to changes in crab abundance and temperature over two winters (Fall 1992 through Spring 1994) (Chavez-Ramirez et al., in review). Visual foraging predominated even when crab abundances were low, and the cranes only switched to tactile foraging at low temperatures. This shift in foraging techniques was interpreted as the effect temperature had on prey availability.

Management of *Callinectes sapidus* for the benefit of the Whooping Crane was first discussed in the early 1950's (Hedgepeth, 1950). The abundance of *C. sapidus* under variable salinity conditions is evidence of the species adaptability to coastal Texas marshes. The availability of *C. sapidus* to the Whooping Crane during winter months is an important consideration. Hedgpeth reported a general decrease in the percentage of female crabs during March and continuing through September. Movements and arrival of juvenile blue crabs are irregular, and some small individuals may begin entering the salt flat areas in early summer through mid-winter. Young crabs disperse via currents from high tides or predominant winds, and typical fall high tides may increase small crab abundance in coastal marshes. Availability can be further affected by low temperatures and low water levels following winter northers. Motile organisms typically migrate to deeper waters, however, many may be stranded and die from cold exposure within shallow, semi-isolated ponds and swales. Allen (1952) suggested supplying deeper ponds with crabs procured from commercial fisherman during the winter to offset natural losses of this important prey item.

1.1.4 Probable Causes and Future Threats

1.1.4.1 Grazing

Indirect effects of grazing upland areas were identified as trampling by livestock in the upland areas reduces the abundance of *Lycium carolinianum* berries, arthropods and freshwater aquatic organisms important to Whooping Cranes (Hunt, 1987). In addition, barbed-wire fences may also increase potential for entanglement, and subsequent injury and/or death. Human disturbances related to maintenance and management of livestock also negatively affect Whooping Cranes.

1.1.4.2 Disturbance

Human-induced disturbances occur through oil and gas operations through road construction and traffic within and adjacent to crane habitat. Recommendations have been proposed including rerouting of traffic and restricted oil and gas drilling during winter months (Hunt, 1987). Although planes do not seem to disturb Whooping Cranes, low-flying helicopters appear to disrupt normal feeding activities (Hunt, 1987). Degree of disturbance by hunting and boating activities has been evaluated via several staged scenarios: hunter in outboard, hunter in airboat, airboat harassment (Mabie et al., 1989). Bird activity was analyzed with regard to cessation of current activity (e.g., feeding, resting) and initiation of avoidance behavior (e.g., alert, walking or flying away from disturbance). Airboat harassment appeared to have the greatest effect in disrupting normal activities, but depended on family group. Most normal activity resumed within two hours after disturbance ended. Other boat and barge traffic effects on crane activity appeared to be negligible when adequate distance was maintained; in fact, there is evidence that some birds have habituated to GIWW boat activity (Stalmaster and Newman, 1978; Knight and Knight, 1984). Other impacts to crane habitat by boating activity include damage to submergent vegetation from propellers in shallow water (Irby, 1990).

Construction of the GIWW has altered coastal marsh habitat within the wintering range of the Whooping Crane. Negative impacts were first documented by Allen (1952) during his prey abundance study. Prior to original dredging, Allen reported firm substrate within Mustang Lake and high abundances of *Calianassa* spp. (mud shrimp), *Tagelus* spp., and *Solen* spp. Two families occupied the north and south end of Mustang Lake when the refuge was established in 1937. Following dredging of the GIWW, few *Calianassa* were located and no clams were found in the lake area.

Habitat losses and gains attributable to GIWW construction and maintenance was estimated from 1930 to 1986 using aerial photography. Aerial-coverage changes occurred within several habitat types: deep water, shallow water, submerged vegetation, and upland grassland habitats. Deep water and upland grassland habitats increased from dredging activity and disposal of dredge material, respectively. Shallow water and submergent vegetation habitats exhibited significant losses; tidal flats, tidal ponds, and high marsh all showed lower, yet significant losses over time. All losses could not be completely attributable to GIWW activities, as other processes (e.g. natural erosion and accretion, subsidence, reef building or decline, natural marsh evolution and succession, fire, influence of cattle grazing and range management and other human activities) could not be quantified within the analysis. Some increase in crane habitat occurred in the transition from deep water to shallow water and submergent vegetation habitats. Overall, net loss to gain ratio was calculated as 2:1, which represented a net loss of 10.4 ha of crane habitat per year for the past 45 years and a total habitat loss of 11%. Most of this loss occurred early during the time frame examined (Sherrod and Medina, 1992). Fewer dredging impacts have occurred since the 1970's, as dredge material has been placed in upland or contained-disposal areas, and used in beneficial-use projects.

1.1.4.3 Mortality

An estimated 19% crane mortality occurred on the wintering grounds, primarily at ANWR, from 1950-1987 while 60-80% occurred during migration. Analysis of eight recovered individuals for cause of death revealed that two or three died from shooting incidents, one by an avian predator, and three were unresolved (Lewis et al., 1992). Migrating Whooping Cranes may fly through areas open to Sandhill Crane hunting, which increases potential for accidental shootings. Archibale et al. (1976) suggest immediately closing a hunting area if Whooping Cranes were sighted in the vicinity and limiting hunting to daylight hours to insure proper bird identification. In addition, efforts to educate the hunting public about field identification should be continued. Coastal waterfowl hunting is prohibited within the ANWR boundaries, however, cranes do utilize public areas adjacent to the refuge during season. Only one accidental shooting has been reported (Thompson and George, 1987).

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1.2 Piping Plover (*Charadrius melodus*)

1.2.1 Introduction

The Piping Plover is one of six North American belted plovers. Piping Plovers attain a body length of 17 cm and weigh 46-64 g (Wilcox, 1959; Palmer, 1967; USFWS, 1988). Adults in breeding plumage are characterized by orange bills, black foreheads and a single black breast band. After breeding, the orange bill coloration, as well as the black forehead and breast band are lost. Nonbreeding Piping Plovers are relatively easy to distinguish from Snowy Plovers (*Charadrius alexandrinus*) by their orange legs and slightly larger size (Haig and Oring, 1987; USFWS, 1988). The individual contribution of Piping Plovers to ecotourism in our area has not been determined, but birdwatching generated $4-6 million for communities within the CCBNEP study area during 1994 (Sansom and Kastrin, 1995).

There are three breeding populations of Piping Plovers: northern Great Plains, Atlantic Coast, and Great Lakes. Typical habitats in the northern Great Plains include lake shores and alkali wetlands in southeastern Alberta, southern Saskatchewan, southern Manitoba, and North Dakota, and gravel bars in rivers of Montana, North Dakota, south Dakota, Iowa, and Nebraska. The Great Lakes population nests at Lake of the Woods in Minnesota and Ontario, as well as along lower Lake Michigan shorelines. The Atlantic Coast populations breeds on Atlantic coastal beaches from Canada to North Carolina (Haig and Oring, 1987; USFWS, 1988). Piping Plovers arrive in their breeding range in late March and remain until July (Haig and Oring, 1985; 1987; Prindiville, 1986; Wiens, 1986). Although clutch size ranges from 3-5 eggs, fledging success is low (0.3-2.1 chicks/year) (Haig and Oring, 1985; USFWS, 1988).

1.2.2 Status and Trends

Intense hunting pressure along the Atlantic Coast caused serious declines in Piping Plover populations early this century (Bent, 1929). Piping Plover numbers rebounded in the 1920's following passage of the Migratory Bird Treaty Act. However, post-depression home construction along Atlantic Coast and Great Lake beaches, as well as water management on lakes and rivers throughout the species' range again caused major declines (Haig and Oring, 1987). In 1985, the Piping Plover was listed as Endangered (Sidle, 1985). A total of 5,482 breeding adults were counted during the last comprehensive census (1991). Most breeding pairs were found in the northern Great Plains (63.2%), followed by the Atlantic Coast (36%). Only 0.2% remained at Great Lakes sites (Haig and Plissner, 1993). A 7% annual population decline was found using demographic simulation modeling of the Great Plains population. Extinction is predicted in approximately 80 years if declines continue unchecked (Ryan et al., 1993).

1.2.3 Conservation and Management

Piping Plovers breeding on the Atlantic coast winter farther south on that coast, while birds breeding on the Great Lakes and northern Great Plains winter primarily along the Gulf coast (Haig and Oring, 1987; USFWS, 1988; Haig and Plissner, 1993). Nearly 48% of birds censused during winter were found in Texas; about 19% were found within the boundaries of the

CCBNEP study area (Haig and Plissner, 1993). Both Great Lakes and northern Great Plains recovery plans acknowledged the lack of information concerning winter habitat requirements of Piping Plovers and recognized the need to fill this knowledge gap before proper conservation measures could be undertaken (USFWS, 1988). These observations prompted a flurry of studies on Piping Plover winter ecology.

Piping Plovers frequent a variety of habitats including sandy beaches, sandflats adjacent to beaches, coastal inlets, washover passes, mudflats, and blue-green algal flats (Haig and Oring, 1985; Johnson and Baldassarre, 1988; Nicholls, 1989; Chaney et al., 1993a, 1993b; Withers, 1994; Lee; 1995). Although the habitat types used by Piping Plovers are fairly well known, causes of interhabitat movements are poorly understood. Recent studies suggested tide height, wind speed, and wind direction may play important roles in diurnal movement patterns (Chaney et al., 1993a; Lee, 1995). Plovers normally forage in damp sediment between the water line and dry, higher elevations (Chapman, 1984; Nicholls and Baldassarre, 1990a; Withers, 1994).

While wintering, Piping Plovers shift from open, sandy Gulf beaches to adjacent protected mud, sand, or algal flats. These habitat shifts may be caused by daily or seasonal tidal fluctuations and/or prey availability. Shifts from Gulf beach habitats to blue-green algal flats corresponded with mid-winter low tides (Chaney et al., 1993a; Lee, 1995). Between-habitat shifts may also be due to greater prey availability as substrate is exposed by receding tides. A sand flat adjacent to the beach on Mustang Island appeared to be marginal habitat because it was rarely used except during peak migration when beach space was limited (Lee, 1995). The benthic community of the sandflat was depauperate. Piping Plovers and benthic infauna were abundant on two blue-green algal flats in the upper Laguna Madre, indicating the potentially high value of those habitats when exposed (Withers, 1994).

Piping Plovers are visual surface feeders who, on occasion, have been observed vibrating one foot on the damp sand, apparently causing prey items to surface (Chapman, 1984; Lee, 1995). Prey items (from gut content analysis) include marine worms, insects (fly larvae and beetles), crustaceans, molluscs, and other small marine animals (Bent, 1929). Piping Plovers usually feed during the day, with peak foraging in the early morning and late afternoon (Chaney et al., 1993a; Lee, 1995); they occasionally feed at night (Chapman, 1984). In a recent study of wintering shorebird use of blue-green algal flats in the upper Laguna Madre, Piping Plovers were significantly ($P < 0.01$) associated with polychaetes ($\chi^2 = 9.63$), tanaids ($\chi^2 = 7.20$) and insect biomass ($\chi^2 = 8.68$). Regression models of Piping Plover abundance and prey density or biomass at several spatial and temporal scales revealed significant ($P < 0.05$) positive relationships with polychaete density, insect larvae density, amphipod density and/or polychaete biomass. R^2 ranged from 0.30 to 0.69 (Withers, 1994).

Little is known about roosting sites of Piping Plovers in the CCBNEP study area. They generally roost among wrack material located above beach berms, in tire tracks, behind dried, curled sections of blue-green algal flats, or in washover passes, all which provide wind protection. Newport Pass is one of the few sites known to be an important roost site within the CCBNEP study area (C. Zonick, pers. comm.). Piping Plovers are sensitive to disturbance by humans (e.g., vehicle traffic, air traffic, pets, construction) and habitat degradation (e.g., floods, eroded shorelines, oil spills) (USFWS, 1988). Disturbance of roosting birds is of particular concern because of the energetic expenditure caused when birds are flushed (R. Cobb, pers. comm.).

Present and potential threats to Piping Plover populations in the CCBNEP study area include habitat loss as a result of recreational and commercial development of beaches and flats, habitat degradation due to dredge and fill activities, contamination, wetland drainage, water level manipulation on rivers, and increased predation (USFWS, 1988). The impact of environmental contaminants such as agriculture runoff or oil spills has received little attention in the CCBNEP study, but both have the potential to cause serious problems for wintering Piping Plovers. Chapman (1984) found that they were little affected by the *Ixtoc I* oil spill, but theorized that a more severe or extended oil spill occurring from early August to mid-December could cause severe declines in wintering Piping Plover populations.

Haig (1987) likened Texas Gulf beaches to vehicular highways for plover migration. She noted that south Texas beaches and flats were the most productive areas for wintering Piping Plovers, as well as most threatened. Filling of back-beach lagoons and flats during maintenance dredging and construction, particularly from Port Aransas to Mustang Island, was identified as a major threat in the CCBNEP study area. Withers (1994) addressed the question of habitat conservation in the following statement:

> *"Any tidal flat with a well-developed macrobenthic community is likely to be used by shorebirds. Since the conservation and management of shorebirds requires adequate habitats for both present and future populations, any tidal flat which hosts a persistent macrobenthic community during the late fall, winter and spring, regardless of the presence or absence of shorebirds, is potentially important, and should be preserved."*

1.2.4 Current Research

Tamara Teas (TAMU-CC) and Lee Elliot (TPWD) have recently completed the fieldwork for a study of effects of human disturbance on nonbreeding Piping Plovers. Curt Zonick (University of Missouri, Columbia) is currently completing his doctoral dissertation on ecology and conservation of nonbreeding Piping Plovers using the Texas Gulf coast.

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1.3 Brown Pelican (*Pelecanus occidentalis carolinensis*)

1.3.1 Introduction

The Eastern Brown Pelican (*Pelecanus occidentalis carolinensis*) is one of two subspecies (*Pelecanus occidentalis californicus* is the other) and one of two species found in North America (the White Pelican *Pelecanus erythrorhynchos* is the other). The Brown Pelican weighs up to 4 kg and can have a wing span over 2 m (Williams et al., 1980). Brown Pelicans, for the most part, are restricted to coastal habitats and are rarely found inland, or more than 32 km offshore. Brown Pelicans feed almost entirely on small fish usually less than 15 cm in length (Schreiber et al., 1975).

Brown Pelicans nest exclusively in colonies on small coastal islands in early spring and summer. The historical nesting range of the Eastern Brown Pelican included the east coast of Mexico, Texas, Louisiana, Florida, South Carolina and North Carolina (Williams et al., 1980). Normal clutch size is three eggs with nesting success varying from 0.5 to 2.0 young fledged per adult pair (King et al., 1985). Variation in nesting success has been attributed to age of adults, availability of food, loss of habitat, parasite infestation, and egg shell thinning caused by pesticides (King et al., 1977; Blus and Keahey, 1978; King et al., 1985).

1.3.2 Status and Trends

King et al. (1977) thoroughly reviewed the decline of Brown Pelicans on the Louisiana and Texas coast and found populations were declining prior to 1930's, but between 1952 and 1957, numbers of birds dramatically decreased. By 1963, Brown Pelicans, as a breeding population, had completely disappeared from the Louisiana coast (James, 1963). King et al. (1977) believed that less than 100 Brown Pelicans per year were present on the Texas Coast from 1967 to 1974. The dramatic decline from thousands prior to 1930 to less than 100 in the 1960's resulted in the placement of this species on the Endangered Species List of the US Department of the Interior in 1971 (US Code of Federal Regulations, Title 50, Part 17). Declines prior to the 1930's were attributed to shootings by fisherman and hunters.

The major decline in the 1950's may have been caused by hurricanes, disease, or pesticides. The pesticide DDT and residue compounds (DDE, DDD, and DDT) causes egg shell thinning (Schreiber and Risebrough, 1972), while extreme sensitivity to the insecticides Endrin and Dieldrin can result in mass mortality (Blus et al., 1974). Eggs with thin shells often are crushed under the weight of the adults. Evidence of pesticide-induced eggshell thinning and mortality was found following the dramatic decline of the 1950's (King et al., 1977). King et al. (1977) compared eggs collected in the early 1970's to those collected by Anderson and Hickey (1970) in the 1950's and before 1943 (pre-DDT), and found that eggs from the early 1970's were 10% thinner than pre-1943 eggs while eggshells in the 1950's averaged 20% thinner than pre-1943 eggs. Eggshell thinning of less than 10 % usually does not lead to structural failure, but serious breakage often occurs when eggshell thinning exceeds 15% (Hickey and Anderson, 1968; Anderson et al., 1969; Blus 1970; Risebrough et al., 1970; Anderson and Hickey, 1972; Coulter and Risebrough, 1973. The dramatic decline in the number of Brown Pelicans in the 1950's coincided with the initiation of the use of Endrin, an insecticide used to control cotton boll weevils and sugarcane borers (King et al., 1977). Throughout the 1950's and 1960's, fish kills were reported along the lower reaches of the Mississippi and Atchafalaya rivers whenever heavy rains produced runoff from crop fields. In April and May 1975, Endrin caused the death of 300 transplanted pelicans, more than half of the original 500 birds brought to Louisiana to restock populations thus demonstrating the possible role of pesticides in the observed decline in the 1950's (Winn, 1975). King et al., (1977) found a heavy infestation of ticks *Ornithodoros capensis* associated with nest abandonment on a small island near the Aransas National Wildlife Refuge in April 1975.

The largest nesting colony of Brown Pelicans on the Texas coast is located on Pelican Island, a spoil island in Corpus Christi Bay (within the boundaries of the CCBNEP). The number of Breeding pairs on Pelican Island has varied from 0 to 100 % of the birds nesting on the Texas coast, but averaged 69.33 % SE = 6.56, from 1973-1993 (data provided by Lee Elliott TPWD from Texas Colonial Waterbird Census summarization). Brown Pelican populations in Texas have been on the increase since approximately 1973 (Fig. IV.C.1.3.1). This increase in the number of nesting pairs coincides with the discontinued use of DDT in 1972, as well as an effort to protect rookery islands during the breeding season from human intrusion and disturbance. At the present time in Texas, Brown Pelicans nest primarily at two sites: Sundown Island in Galveston Bay, and Pelican Island in Corpus Christi Bay.

The colonial nesting habit of the species and concentration of breeding birds in these two areas may be negatively impacted by disease, predator pressure, and adverse weather conditions. One of the most recent and potentially devastating threats to Texas Brown Pelicans comes from the

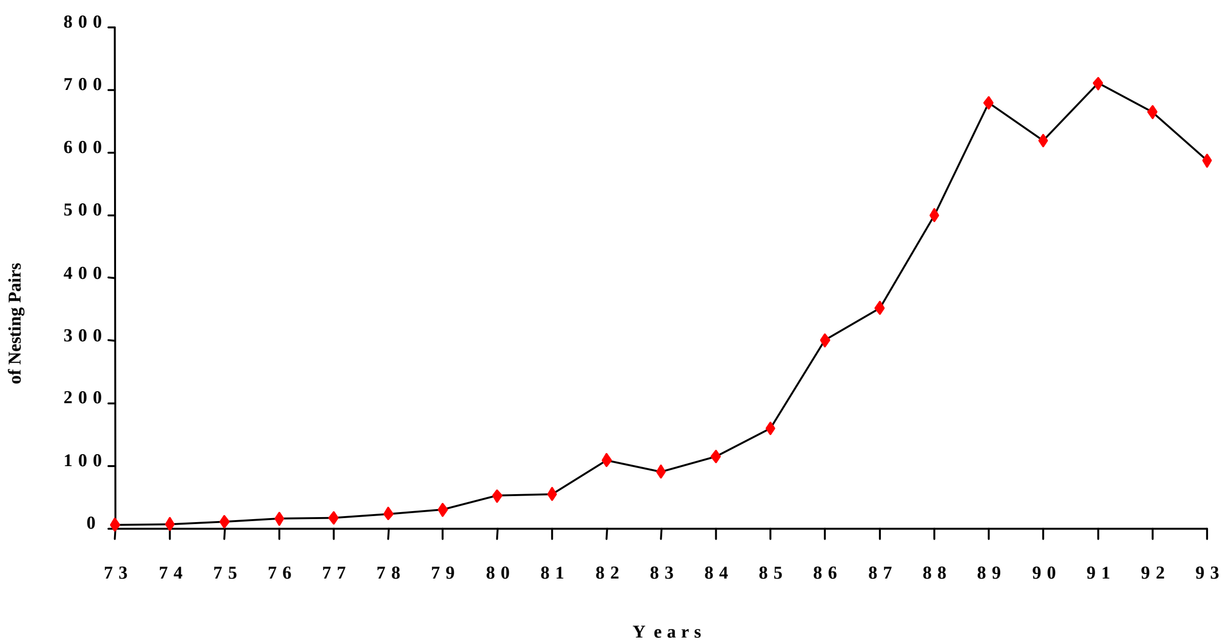

Fig. IV.C.1.3.1 Number of nesting pairs of Brown Pelicans located at Pelican Island in Corpus Christi Bay 1973-1993 (Lee Elliot, TPWD, unpubl. data, Texas Colonial Waterbird Survey).

introduced fire ant (*Solenopsis invicta*). Roper (1992) cites Allan Strand and Steve Robertson (USFWS) as observing near 100 % mortality associated with hatchlings in water bird colonies on some of the islands in the Second Chain of Islands group near San Antonio Bay in 1991.

Little is known about this species' migration patterns, but it is generally presumed that birds reside in the vicinity of their nesting grounds. Results of color banding studies indicate that many subadult Texas pelicans do not return to nesting sites until their second or third year after fledging (King et al., 1985). King et al. (1977) found in 1974, only three subadults out of 30 were banded. Because all Brown Pelicans fledged in Louisiana and Texas since 1971 were banded, he concluded the 27 unbanded young observed in 1974 probably came from Mexican colonies.

1.3.3 Current Research

Currently, we are unaware of any studies relating to Brown Pelicans within the CCBNEP boundaries, other than the Texas Colonial Water Bird Census conducted annually which is sponsored by the Texas Parks and Wildlife Department and the Texas Colonial Waterbird Society.

Pelicans are at the top of the food chain so some chemical pollutants tend to be biomagnified in their tissues. Because Brown Pelicans are particularly sensitive to pollutants, monitoring their population trends might aid in early detection of environmental pollutants.

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1.4 Interior Least Tern (*Sterna antillarum*)

1.4.1 Introduction

Least Terns (*Sterna antillarum*) measuring 21- 24 cm in length, are the smallest members of the subfamily Sterninae and family Laridae of the order Charadriiformes. They are characterized by a black-capped crown, white forehead, grayish back and upper wings, white under surface, orange legs, and a black-tipped bill (Boyd and Thompson, 1985). The historical breeding grounds of the Interior Least Tern are sand bars or gravel spits along the Red, Missouri, Arkansas, Mississippi, Ohio and Rio Grande river systems (Sidle and Harrison, 1990). Least Terns usually lay two or three eggs with clutch size averaging 2.4 eggs (Smith and Renken 1990). Because of the ephemeral nature of their nesting habitat, nesting success is usually low ranging from 0.20 to 1.09 fledglings per pair (Sidle and Harrison, 1990). Least Terns are piscivorous and believed to feed on any small sized fish (Moseley, 1976). Prey fish are captured by hovering and diving over standing or flowing water (Sidle and Harrison, 1990).

1.4.2 Status and Trends

Currently, in North America, three subspecies of Least Tern, (*Sterna antillarum antillarum*, the Coastal Least Tern, *S. a. athalassos* the Interior Least Tern, and *S. a. browni* the California Least Tern) are recognized by ornithologist. The validity of the subspecies designations has been questioned in recent years (Massey, 1976; Sidle and Harrison, 1990; Thompson et al., 1992). The most recent morphometric and genetic assessment of North American Least Terns could not distinguish between the subspecies (Sidle and Harrison, 1990). No consistent morphological, behavioral, or vocal differences were found by Massey (1976) while studying Coastal Least Terns and California Least Terns. Thompson et al. (1992), analyzed seven bill, leg, wing and plumage characters from 267 museum specimens of adult Least Terns and found no significant morphological differences among the three subspecies. A study of electrophoretic variation in proteins encoded by 50 loci revealed no genetic distinctions between Coastal Least Terns and Interior Least Terns for 22 specimens from breeding sites on the Texas coast, Rio Grande, and Texas panhandle rivers (Thompson et al., 1992). Although Interior Least Terns have been shown to demonstrate a high degree of nest site fidelity (Mayer and Dryer, 1990; Smith and Renken, 1990), occasionally Coastal Least Terns populate interior breeding sites (Boyd and Thompson, 1985). Boyd and Thompson (1985) reported that a Least Tern banded as a chick in Rockport Texas, was found nesting in Quivira National Wildlife Refuge, Kansas. Because of the difficulty in distinguishing subspecies of Least Terns by morphometric or genetic characters and the possibility of interbreeding populations, Thompson et al. (1992), recommend reassessment of the subspecies designation.

The California Least Tern was listed as Endangered in 1970. The Interior Least Tern was originally proposed for listing as Endangered, but due to the recent taxonomic uncertainty of subspecies designations the US Fish and Wildlife Service did not list the subspecies and instead designated as Endangered those Least Terns occurring in the interior North America (50 Federal Register 212,784-21,792) (Sidle and Harrison, 1990). The cause for perceived declines in

Interior Least Tern populations is attributed to habitat loss. Construction of dams, channelization, and other water conservation practices have reduced the number of suitable sand bars for nesting.

Least Terns nesting within the CCBNEP boundaries are not part of the Federally listed Endangered group; however, substantial declines in numbers along the Texas coast have been noted (Clapp et al., 1983). Blacklock et al. (1978) found Least Tern populations along the upper Texas coast had declined by 75 %, from a mean of 4,180 birds in 1973-1974 to 1,030 in 1975-76. An extensive dissertation by Thompson (1982), studying the distribution, colony characteristics, and population status of Least Terns Breeding on the Texas coast revealed no significant decline in Least Tern populations had occurred. Thompson (1982) estimated between 5,500 and 8,300 breeding pairs of Least Terns were present on the Texas coast from 1979-81. According to Thompson (1982) previous reported declines observed during the Texas Colonial Waterbird Census were artifacts of sampling and were not indicative of actual population levels for Least Terns on the Texas coast.

Little is known about the wintering grounds of the Interior Least Tern but it is generally believed that they may migrate as far south as coastal Brazil. The closest breeding sites of Interior Least Terns to the CCBNEP area are small populations at Falcon Lake in Starr and Zapata counties and Lake Amistad in Val Verde county (Thompson et al., 1992).

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1.5 Eskimo Curlew (*Numenius borealis*)

1.5.1 Introduction

The Eskimo Curlew (*Numenius borealis*) may be one of the rarest birds in North America and many ornithologists believe it may have gone extinct in the early part of the 20th century. Eskimo Curlews are smaller than Whimbrels which they generally resemble, but they have comparatively shorter, more slender bills and a less pronounced central crown stripe (Robbins et al., 1983). Food items include wild fruits and insects. Breeding historically takes place on the barren Arctic tundra of North America. After breeding, most of the population moves to staging areas in Labrador and then flies directly to South America where they winter on the pampas of Argentina. In the spring Eskimo Curlews fly from South America to staging grounds in a few traditional areas from Texas to South Dakota and then directly to the breeding grounds (Gollop et al., 1986).

1.5.2 Status and Trends

Market hunting in the late 19th century is blamed for the rapid decline in the numbers of Eskimo Curlews. Hunters found the few traditional spring staging areas and fully exploited this species. Reports from Nebraska stated Eskimo Curlews were harvested by the wagonload prior to 1900 (Faanes and Senner, 1991). Although the species has been protected from hunting in the United States and Canada since the passage of the Migratory Bird Treaty Act in 1918, it has continued to decline while other species, such as the Lesser Golden-Plover (*Pluvialis dominica*), with nearly identical ranges began to recover. Therefore, the recovery of Eskimo Curlews may have been hampered by loss of habitat both in the wintering grounds of South America and the spring staging areas in the United States. On the staging areas in the United States, the preferred food was found to be grasshopper egg pods (Faanes and Senner, 1991). Because of the fragmentation of the Great Plains grasslands due to cultivation there was a decline in the number of grasshoppers which may have further hampered the recovery of the Eskimo Curlew.

The Eskimo Curlew was placed on the United States Endangered Species List in 1967 and it was declared Endangered in Canada in 1980. In 1990 the Eskimo Curlew Advisory Group comprised of representatives of the US Fish and Wildlife Service, Canadian Wildlife Service, International Council for Bird Preservation, and the Western Hemisphere Shorebird Reserve Network, was established to review historical information, educate the public about Eskimo Curlews and assess the degree of the protection of habitats on which the curlews have been historically dependent (Faanes and Senner, 1991). Because so little is known about the current status of the Eskimo Curlews or even if they continue to exist it was decided that a formal recovery team was not yet warranted.

According to Gollop et al. (1986) 35 Eskimo Curlews were reported in 11 separate sightings from 1945 through 1985. All but two of the reports were from Texas and only one was confirmed by a photograph (Bleitz, 1962). Although there have been many unconfirmed reports of Eskimo Curlews within the CCBNEP area (Gollop et al., 1986; Atkinson et al., 1991), a single specimen collected in Nueces County in 1877 (Oberholser, 1974) is the only confirmed record.

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1.6 *Lepidochelys kempii* (Kemp's Ridley Sea Turtle)

1.6.1 Introduction

The Kemp's Ridley Sea Turtle (*Lepidochelys kempii*) was first described by Samuel Garman in 1880 as *Thalassochelys kempii* or *Colpochelys kempii* (USFWS AND NMFS, 1992) from a specimen from Key West, Florida. After determining that *L. kempii* and the Indo-Pacific olive ridley, *Lepidochelys olivacea* were congeneric, the genus *Lepidochelys* was designated. Currently, *L. kempii* is recognized as a full species clearly distinct from *L. olivacea* (Bowen et al., 1991).

Lepidochelys kempii is the smallest sea turtle, rarely exceeding 65 cm (26 in) straight carapace length (CL) (USFWS AND NMFS, 1992) and ranging in weight from 36-45 kg (79-99 lbs) (USFWS, 1991). Juvenile turtles have been described as <20 cm (8 in) CL and subadults 20-60 cm (8-24 in) CL (Ogren, 1989). Adult turtles are recognizable by a broad oval shaped shell usually olive gray in color, whereas young are black. Color changes significantly during development from the gray-black dorsum and venter of hatchlings to the lighter gray-olive carapace and cream-white or yellowish plastron of adults (USFWS AND NMFS, 1992). Generally, there are five vertebral scutes, five pairs of costal scutes and 12 pairs of marginals on the carapace. Males are not well described, yet are reported to resemble females in size and color (USFWS AND NMFS, 1992). Secondary sexual characteristics of male sea turtles in general are present in *L. kempii*: a longer tail, increased distal vent, recurved claws and during breeding, a softer mid-plastron.

Lepidochelys kempii is the only species where adults nest during the day. Females require approximately 45 minutes to complete the terrestrial nesting process. Emerging from the sea, they trudge up the beach, dig a nest cavity about 0.5m deep, deposit approximately 100 eggs (one clutch), cover the nest and return to the sea. Incubating eggs are left undisturbed, naturally heated by the warmth of the surrounding sand and the metabolic heat generated by their embryonic development.

Hatchlings range from 42-48 mm in straight line CL, 32-44 mm in width and 15-20 g in weight (Fontaine and Caillouet, 1985). The National Park Service (NPS, 1985) recorded hatchlings from the 1984/1985 imprinting project with mean carapace lengths (straight-line measurements) of 43.5 and 43.25 mm, respectively and mean weights as 16.37 g, 15.74 g respectively.

Ogren (1989) describes hatchlings, post-hatchlings, and juveniles as pelagic, planktonic, and surface-foraging; whereas subadults and adults are benthic and bottom dwellers. Hatchling *L. kempii* are presumed to feed on sargassum and associated infauna or other epipelagic species found in the Gulf of Mexico (USFWS AND NMFS, 1992). In post-pelagic development, *L. kempii* are carnivorous (crab eating), primarily foraging on portunid species (Ogren, 1985; Dobie et al., 1961). Shaver (1991) examined gut contents from wild subadult and adult turtles, and reported crabs as the primary content, followed by molluscs, fish, and vegetation (Table IV.C.1.6.1).

Table IV.C.1.6.1. Percent frequency and percent dry mass of food groups found within digestive tract contents of 5 juvenile, 86 subadult, and 10 adult *Lepidochelys kempii* from south Texas. W = wild, H = head started, F = frequency, and DM = dry mass (after Shaver, 1991).

	W (N = 50)		H (N = 51)	
Food Item	% F	% DM	% F	% DM
Juveniles (N = 5)				
Crabs	50.00	11.77	0.00	0.00
Molluscs	50.00	23.52	0.00	0.00
Fish	0.00	0.00	0.00	0.00
Vegetation	100.00	17.65	66.67	81.30
Shrimp	0.00	0.00	0.00	0.00
Other materials	50.00	47.06	33.33	14.03
Trash	0.00	0.00	66.67	4.67
Subadults (N = 86)				
Crabs	76.32	90.95	77.08	63.29
Molluscs	57.89	2.23	70.83	11.42
Fish	18.42	0.17	37.50	8.57
Vegetation	57.89	0.29	64.58	1.71
Shrimp	5.26	0.39	14.58	1.14
Other materials	76.32	5.80	47.92	13.74
Trash	34.21	0.17	18.75	0.13
Adults (N = 10)				
Crabs	100.00	99.71	-	-
Molluscs	60.00	0.20	-	-
Fish	0.00	0.00	-	-
Vegetation	40.00	0.09	-	-
Shrimp	0.00	0.00	-	-
Other materials	60.00	0.00	-	-
Trash	40.00	0.00	-	-

Although a high numbers of portunid crabs were taken from the turtles examined, large quantities of other crabs were also eaten. Shaver (1991) postulated *L. kempii* foraging to be opportunistic rather than selective for a particular crab species. Additional studies of stomach contents of dead turtles suggests *L. kempii* is a shallow water, benthic feeder (Dobie et al., 1961; Ernst and Barbour, 1972; Hildebrand, 1982; Lutcavage and Musick, 1985).

1.6.2 Status and Trends

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Lepidochelys kempii (in addition to the flatback turtle, *Natator depressus)* has the most restricted distribution of any sea turtle, occurring mainly in coastal waters of the Gulf of Mexico and the northwestern Atlantic Ocean. Adults of the species are usually confined to the Gulf of Mexico, however, adults sometimes are discovered on the eastern seaboard of the United States (USFWS AND NMFS, 1992). Post-pelagic individuals are commonly found dwelling over crab-rich sand or mud bottoms, while juveniles persist in bays, river mouths and coastal lagoons. Seasonally, adults are found near the mouth of the Mississippi River in addition to the Campeche Banks (Mexico), concentrating annually (in spring and early summer) on the Rancho Nuevo (Mexico) nesting grounds.

Less than fifty years ago, *L. kempii* was flourishing and abundant in the Gulf. Currently, it is the most endangered sea turtle, with less than 2000 adults remaining. Virtually all nesting occurs on a 20 km stretch of beach at Rancho Nuevo, Tamaulipas, Mexico, located approximately 322 km south of Brownsville (Marquez et al., 1989) (Fig. IV.C.1.6.1). In 1947, Dr. Henry Hildebrand showed an amateur film obtained in Mexico during a herpetologist meeting. This film showed an estimated 40,000 females nesting in a daytime aggregation or arribada (diurnal, synchronized landings) (Hildebrand, 1963). When the Mexican nesting beach was first discovered in 1961, the population was severely depleted; exploitation had been high for years reducing the population to near extinction. In 1966, biologists finally re-discovered the nesting beach and implemented protective strategies; however, Pritchard (1969) reported that as of May, 1968, only 3,000 to 5,000 females nested in the largest, single arribada. Fewer than 700 females are presumed to be the entire nesting population today (Shaver, 1992).

This estimate excludes males, immature turtles and smaller breeding groups or single nesters located between Padre Island, Texas and Isla Aguada, Campeche (USFWS AND NMFS, 1992). Quantitative evaluations need to be performed to adequately estimate total adult populations. An index of adult female population trends has been produced by comparing the number of nests/season laid at the Rancho Nuevo nesting beach (Table IV.C.1.6.2).

1.6.3 Probable Causes

Historically, exploitation is for the observed modern decline of *L. kempii* (Magnuson, 1990). Wherever man has gained access to any populations of sea turtles, he has tended to over-utilize the resource. The Texas coast was once known for turtle cannery production at four different sites during the mid 1800's (USFWS AND NMFS, 1992; Shaver, 1990). It is suspected the cannery commerce refers mainly to *Chelonia mydas* (green turtles), however, due to recorded populations in excess of 40,000 as late as 1940, it is probable that *L. kempii* and *Caretta caretta* (loggerheads) were also captured along the Texas coast. Most of the turtles were caught in Aransas Bay, Matagorda Bay , and Lower Laguna Madre. Nets and seines were set in shallow lagoons and channels and fishing vessels were equipped with trawls (Doughty, 1984). By 1900, the catch had declined to an extent that turtle fishing and the processing industry came to a

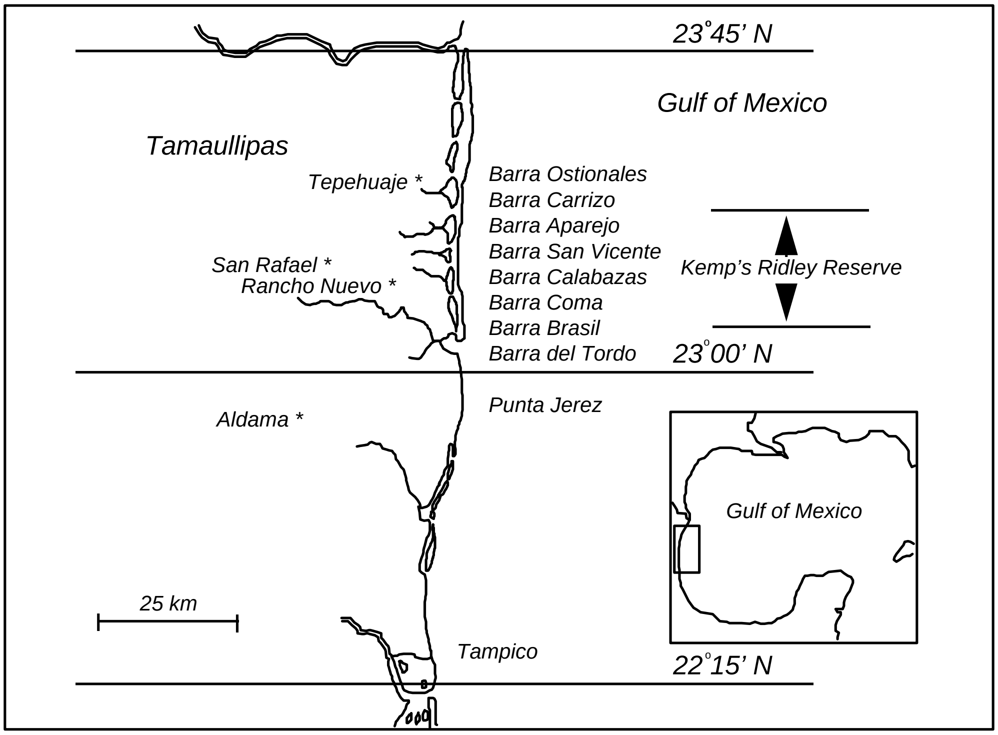

Fig. IV.C.1.6.1. *Lepidochelys kempii* nesting beach, Tamaulipas, Mexico (after USFWS AND NMFS, 1992).

virtual halt (Shaver, 1990b). Activities such as dredging, boating, and recreational/commercial fishery operations have recently threatened sea turtles occupying Texas inshore waters, however, there is a lack of information whether turtles inhabiting these areas are receiving adequate protection (Shaver, 1990b).

Direct exploitation of eggs occurred at the Rancho Nuevo nesting beach during the 1940's and continued through the early 1960's. During this time, eggs were taken out in mule trains, truck, and on horseback (Hildebrand, 1963). Hildebrand cautioned that continued exploitation would lead to the decline of the species and documented information of disappearances of various arribada beaches along the coast of Rancho Nuevo.

Presently, the most important factor affecting the reproductively valuable, large juveniles and adults is the growth of the shrimp trawling industry in the Gulf (Crouse, et al., 1987). There were an estimated 9,047 commercial boats under 25 feet in length and 5,439 vessels greater that 25 feet in length trawling for shrimp in the Gulf during 1987 (NOAA, 1989). These estimates do not include recreational or weekend trawlers, which probably number around 40,000. In addition to nest poaching activities, the decline of the *L. kempii* population coincided with the buildup of

Table IV.C.1.6.2. Kemp's ridley turtle Rancho Nuevo project summary (after USFWS, 1991)

Year	Nests Protected *	Known Nests **	Eggs Protected	Hatchlings Produced	% Hatch
1978	834	924	85,217	48,009	56
1979	954	954	98,211	63,996	65
1980	796	868	82,374	37,378	45
1981	897	897	89,906	53,282	59
1982	750	750	77,745	48,007	62
1983	746	746	77,432	32,921	43
1984	798	798	80,798	58,124	72
1985	677	702	67,633	51,033	75
1986	675	744	65,357	48,818	75
1987	714	737	72,182	44,634	62
1988	830	842	83,229	62,218	75
1989	826	878	84,802	66,752	79
1990	973	992	93,937	74,795	79
1991	1,107	1,155	107,134	75,953	71

* nests moved from the site of oviposition for incubation
** includes all known nests; nests protected, nests left *in situ* and depredated nests

the fishery industry during the late 1940's and 1950's. Intensification of shrimping activities in the United States and Mexico with the consequent entrapping of turtles in trawls was a major cause for the decline of *L. kempii* (USFWS AND NMFS, 1992).

Sea turtle strandings along coastal shorelines of the southeastern United States are used as an indicator of mortality due to shrimping (Magnuson et al., 1990). Increases in sea turtle strandings during commercial shrimping seasons and decreases with the closing of these seasons have been observed on the Atlantic and Gulf of Mexico coasts (Hillestad et al., 1978; Magnuson *et al*., 1990). There is unequivocal documentation that sea turtles are caught in shrimp trawls (Murphy et al., 1989; Magnuson et al., 1990). Sea turtles probably congregate in shrimping areas to feed on discarded bycatch. Caillouet et al. (1991) analyzed sea turtle strandings (all species) in the northwestern Gulf of Mexico during 1986-89. *C. carreta* and *L. kempii* stranded most frequently followed by E*retmochelys imbricata* (hawksbills), *Chelonia mydas*, and *Dermochelys coriacea* (Table IV.C.1.6.3). Results did not include strandings of head-starts (captive-reared) because distribution may be affected by location of release.

A three-year survey of sea turtles on south Texas beaches revealed an increase in strandings in 1978 and 1979. No definite cause was established, but increased trawling activity in nearshore waters has occurred in conjunction with periods of high incidence of strandings (Hillestad et al., 1978). A greater frequency of turtle strandings occurred along certain portions of the coast

Table IV.C.1.6.3. Species composition of sea turtle strandings in the northwestern Gulf of Mexico by month, summed over years 1986-89 (after Caillouet et al., 1991)

SPECIES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Loggerhead *Caretta caretta*	9	10	46	146	95	33	40	37	31	29	19	20	515
Kemp's ridley *Lepidochelys kempii*	0	6	36	82	48	36	27	51	23	22	17	9	357
Hawksbill *Eretmochelys imbricata*	0	1	2	0	1	5	4	15	18	14	2	5	67
Green *Chelonia mydas*	1	0	5	7	6	6	2	2	0	4	1	4	38
Leatherback *Dermochelys coriacea*	0	0	1	8	5	3	0	1	0	2	3	0	23
Undetermined	0	0	6	6	2	5	10	4	5	6	1	2	47
Total	10	17	96	249	157	88	83	115	77	78	43	40	1047

(Little Shell and Big Shell beaches, North Padre Island and Mustang Island) where increased trawling activity in nearshore waters was documented (Fig. IV.C.1.6.2). Year-round coverage is necessary to monitor stranding frequency and provide biological data and tissue samples, specimens for necropsy, and other information related to human activities and oceanographic shifts to determine causes and consequences of strandings.

1.6.4 Future Threats

Continued human population growth and expanding development pressure will increase threats to the nesting beach in Mexico (USFWS and NMFS, 1992). Human encroachment and access along the entire nesting area is of paramount concern at the primary nesting beach in Rancho Nuevo, Mexico. Plans for massive expansion of La Pesca (north of nesting area) as a fishing center, or dredging the Gulf Intercoastal Waterway (GIWW) from Brownsville, Texas, to Barra del Tordo (southern part of nesting beach) have been developed.

Additional potential threats to the nesting area include armoring, nourishment, or cleaning of the beach. Currently, motorized equipment and non-native dune vegetation do not pose an immediate problem nor does erosion, nest depredation or other nest loss agents. However, when increasing numbers of nests necessitate leaving the nests *in situ* and unprotected, these factors must to be addressed. One threat that occurs due to management practices at Rancho Nuevo is the concentration of all of the collected nests in corral enclosures. The eggs are more susceptible to reduced viability from the act of movement, disease vectors and inundation (USFWS AND NMFS, 1992).

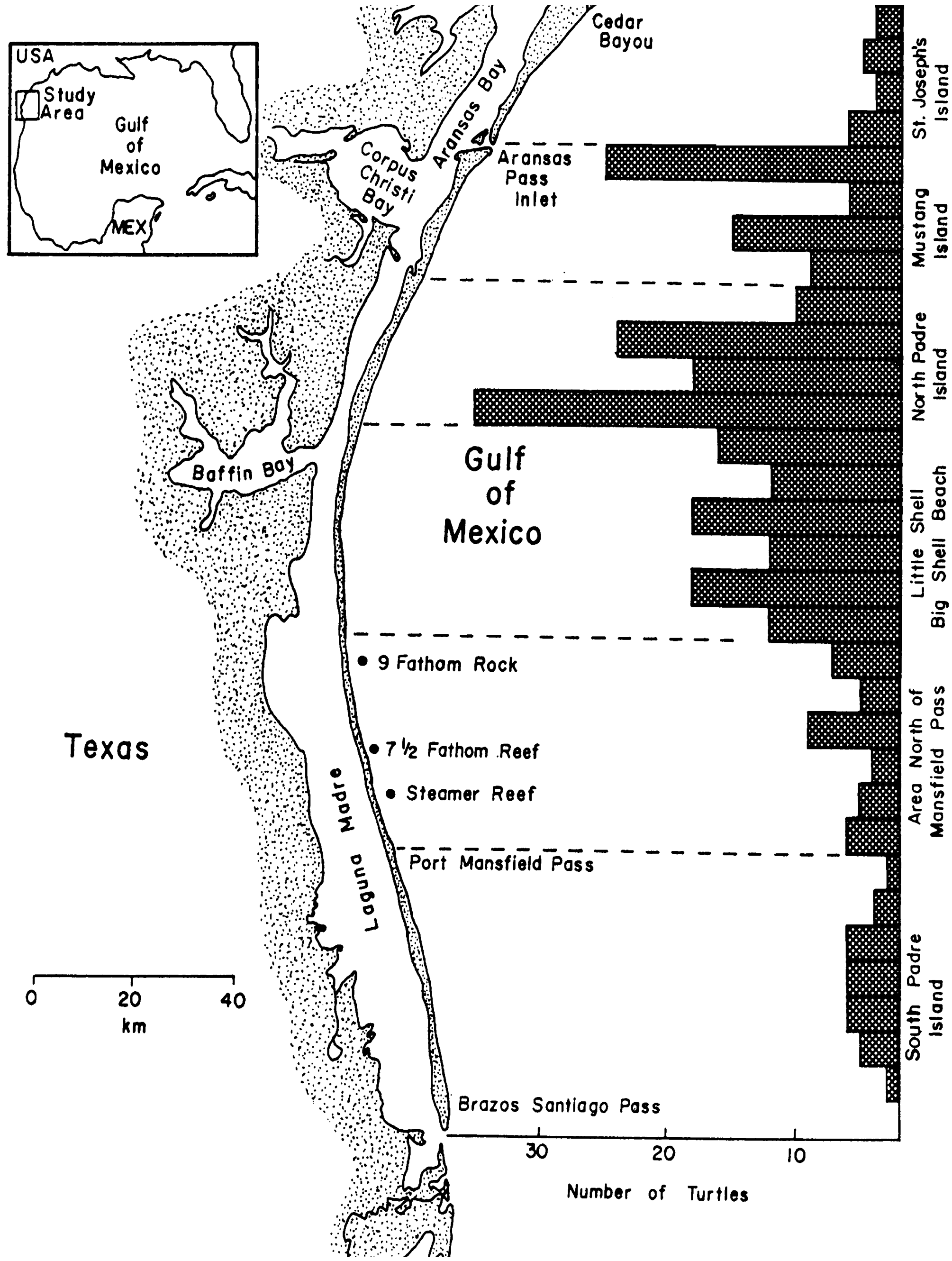

Fig IV.C.1.6.2. Location of study area and number of stranded sea turtles recorded by distance along south Texas beaches (1976-1979) (after Rabalais et al., 1980).

Threats in the marine environment include commercial fisheries, pollution, debris, dredging, the explosive removal of obsolete oil platforms (Klima et al., 1989), impact of hulls or propellers of boats, power plant entrapment, various human activities affecting foraging grounds (and any other known probable man-induced stress which have yet to be fully quantified) (Magnuson et al., 1990).

1.6.5 Conservation and Management

In 1978, the *L. kempii* Sea Turtle Restoration and Enhancement Project was undertaken by the Instituto Nacional de Pesca (INP) of Mexico, US Fish and Wildlife Service (USFWS), National Marine Fisheries (NMFS), National Park Service (NPS), and Texas Parks and Wildlife Department (TPWD) in accordance with Section II of the Endangered Species Act (Shaver, 1990a). Establishment of a secondary breeding population at Padre Island was one of several project goals. Padre Island National Seashore (PINS) was chosen because the species had been known to nest there historically and because the NPS would be able to provide some protection in the event that a new breeding population became established. A portion of the restoration program included a 10-year experimental attempt to establish a secondary breeding colony at PINS through "imprinting" (Shaver, 1990a). Each summer, from 1978-1988, about 2000 eggs were collected at Rancho Nuevo as they were laid, placed in styrofoam boxes containing Padre Island sand and transported via aircraft to the PINS. The styrofoam boxes were placed in an outdoor predator-proof, screen-enclosed incubation shed. The overall hatching rate of the 22,507 eggs sent to Padre Island during the eleven years was 77.1 %. Hatchlings were released on the beach at Padre Island and allowed to crawl down the beach, enter the surf, and swim approximately 10 yards where they were recaptured using aquarium dip nets. From 1978 through 1988, 15,875 recaptured hatchlings were transported to the NMFS laboratory in Galveston, Texas for one year of "head-starting" (Table IV.C.1.6.4). Overall, approximately 80 % of the hatchlings survived head starting and most of these head started turtles (approx. 12,000) were released offshore from Padre Island.

To date, no turtles released from this project have been found nesting outside of captivity at PINS or elsewhere; however it is unknown how many survived after release or whether the turtles are mature yet. A pair of mating *L. kempii* was sighted within the Mansfield Channel, located at the southern end of the PINS on 3 June 1991 (Shaver, 1992). Unfortunately, the turtles could not be indentified as either wild or head-started and nests were not found following mating. One *L. kempii* was found nesting at PINS in 1991, one at PINS in 1994 (Shaver, 1994), one at Mustang Island and two at PINS in 1995 (Shaver, pers. comm.). These turtles did not bear apparent markings that would link them to the head-start project.

PINS received 19,487 *L. kempii* eggs and sent 13,668 hatchlings to Galveston for head starting during the nine years of the restoration and enhancement program (Shaver, 1987). Although PINS no longer receives *L. kempii* eggs from Rancho Nuevo, Mexico for incubation, PINS continues active conservation projects conducted on behalf of this species. Operation of the PINS incubation and hatchling rehabilitation facilities continue (Shaver, 1994). Public education programs, beach patrols, and protection and monitoring of nesting sea turtles and nests will

Table IV.C.1.6.4. General results of 1978-1988 Kemp's ridley incubation and imprinting at Padre Island National Seashore (after Shaver, 1990).
.

Year	Number clutches from Rancho Nuevo	Number eggs from Rancho Nuevo	Number (%) eggs hatched	Number (%) hatchlings died at Padre Island	Number (%) hatchlings lost during release	Number hatchlings to Galveston	Mean incubation period (days)
1978	17	2,191	1,931 (88.1)	64 (3.3)	19 (1.0)	1,848	51.5
1979	20	2,053	1,769 (85.7)	15 (0.9)	93 (5.3)	1,661	52.0
1980	32	2,976	2,502 (84.1)	14 (0.6)	65 (2.6)[a]	1,611	50.5
1981	23	2,279	1,898 (83.3)	11 (0.6)	19 (0.8)	1,868	48.3
1982	20	2,017	1,563 (77.6)	5 (0.3)	34 (2.2)	1,524	51.0
1983	18	2,006	242 (12.1)	10 (4.1)	2 (0.8)	230	52.0[b]
1984	19	1,976	1,792 (90.7)	239(13.3)	9 (0.5)	1,544	51.1
1985	20	1,978	1,664 (84.1)	13 (0.8)	25 (1.5)	1,623[c]	48.8
1986	22	2,011	1,776 (88.3)	1 (0.1)	16 (0.9)	1,759	46.7
1987	20	2,001	1,288 (64.3)	5 (0.4)	1 (0.1)	1,282	47.6
1988	10	1,019	933 (91.6)	4 (0.4)	4 (0.4)	925	46.9
Total	221	22,507	17,358 (77.1)	381 (2.2)	287 (1.7)	15,875	49.7

[a]Calculated excluding 810 hatchlings from 11 clutches intentionally released into the Gulf of Mexico.
[b]Calculated based only upon the 9 clutches that hatched.
[c]Calculated excluding 69 hatchlings from a Padre Island natural nest head started at the Galveston NMFS laboratory.

continue at the park for the forseeable future (D. J. Shaver, pers. comm.). Attempts will be made to continue volunteer participation in this project.

Nesting beach protection in the vicinity of Rancho Nuevo has increased significantly over the past two decades. Collaboration of Mexican and US conservationists under INP and USFWS is now used as a model for an international multi-agency effort (USFWS AND NMFS, 1992). For adult females, a downward trend in population numbers continued through 1985, in spite of efforts to stop egg poaching and harm to nesting females on the beach since 1966. Over one million hatchlings have been released at the nesting beach with an increase in the number of nests documented at Rancho Nuevo since 1985. Wider coverage of the nesting beach by the binational protection team is partially responsible, in addition to increased numbers of nests. Poaching of adult turtles on the nesting beach has not been documented since 1980 due to intensive vigilance of the binational protection team, adequate motorized beach patrols, and presence of armed marines.

Another important management effort is the implementation of the Turtle Excluder Devices (TED) by the US shrimp fleet. The publication of regulations requiring TED's in 1987 was a major accomplishment for this century in protecting sea turtles in their foraging and migratory habitats. TED trials are currently being conducted in Mexico and requirements for using TED's aboard the Mexican shrimp fleet will soon be announced. In addition to TED's, future management efforts include enforcement of the Marine Pollution Treaty (MARPOL), habitat research and continued protection at the nesting beach at Rancho Nuevo, Mexico. The overall goal of recovery objectives is the preservation of current populations and enhancement of future populations so that the species can be reduced from Endangered to Threatened status.

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1.7. *Caretta caretta (*Loggerhead Sea Turtle)

1.7.1 Introduction

Caretta caretta (Loggerhead Sea Turtle) is the most common sea turtle found in the southeastern US (USFWS, 1991). *Caretta caretta*, described by Linnaeus (1758) and initially named *Testudo caretta*, was the subject of two centuries of 35 name changes (Dodd, 1988), however, there is now a general agreement on *C. caretta* as the accepted name.

Adults and subadults of *C. caretta* possess a large reddish-brown carapace with dorsal and lateral head scales; dorsal scales of the extremities are reddish-brown, but with light yellow margins (USFWS, 1991; USFWS AND NMFS, 1992). The thick, bony carapace is covered by non-imbricated horny scutes. Mean straight carapace length (CL) of adults in the southeastern US S.) population is about 92 cm (36 in) with weights up to 113 kg (248 lbs). Kaufman (1975) reports adult loggerheads are somewhat smaller on average in Colombia. Hatchlings differ from adults, possessing three dorsal and two plastral keels, lacking the reddish tinge, and varying from light to dark brown on the dorsum. Hatchling mean body mass is approximately 10 g and mean CL is approximately 45 mm (USFWS and NMFS, 1991).

1.7.2 Status and Trends

The geographic distribution of *C. caretta* includes the temperate and tropical water of both hemispheres, often inhabiting the continental shelves and estuarine environments along the margins of the Atlantic, Pacific and Indian Oceans (USFWS and NMFS, 1991).

On 28 July 1978, *C. caretta* was listed as a Threatened species under the Endangered Species Act of 1973 (USFWS AND NMFS, 1991). The stock of nesting female loggerheads in the southeastern US has been reported to be declining (Ehrhart, 1989). The greatest concentration of *C. caretta* is found along the Atlantic coast from North Carolina to southern Florida (Hildebrand, 1981) and ranks as the second largest in the world (Ross, 1982), with larger assemblages in Oman as the only other large group. Smaller populations have been observed along the entire Gulf Coast from the Florida Keys to Quintana Roo, Mexico. Although there are no reliable population estimates in the Gulf of Mexico (Hildebrand, 1981), Lund (1974) estimates the eastern US population at 25,000 to 50,000 adults.

Caretta caretta has been documented in Gulf waters adjacent to Texas throughout the summer months around oil platforms, rock reefs, and other obstructions (Hildebrand, 1981) where it forages on a variety of crabs, jellyfish, and molluscs (USFWS, 1991). The results of a study of the feeding ecology of *C. caretta* showed sea pens as the highest ranked prey, occurring in 56.1% of the samples and accounting for 58.7% of total prey dry weight (Plotkin, et al., 1993).

1.7.3 Probable Causes and Future Threats

Even though there are no fishery threats to *C. caretta* in Texas, loggerheads likely suffer mortality from various other causes attributable to the activities of humans. Hildebrand (1981) describes observing dead turtles on the beaches of south Texas, but no counts were made prior to or during the early 1950s. Rabalais and Rabalais (1980) studied strandings of marine turtles on the coast of Texas from Cedar Bayou to Brazos Santiago. During September 1976 to 1 October 1979, 202 dead loggerheads were recorded. Strandings were greatest during fall and spring corresponding with peak inshore and nearshore shrimping (Rabalais et al., 1980).

Between 1980 and 1989 the Texas Sea Turtle Stranding and Salvage Network (STSSN) database documented 166 sea turtles (30 of which were loggerheads) stranded alive and dead within Texas state inshore waters (Shaver, 1990a). Considerably more wild turtles were stranded during 1989 with *C. caretta* stranding primarily during April and June. The number of wild turtles stranded during the first five months of 1994 (227) exceeded the entire year of 1991 (176) (Shaver, 1994). Sixty-six of the 227 wild turtles stranded in 1994 were *C. caretta*. More turtles were documented stranded within Texas waters during 1995 than any year on record with the STSSN (established in 1980). Out of the 527 turtles found stranded, 194 were *C. caretta* (D. Shaver, pers. comm.).

A severe and widespread hypothermic stunning event occurred in February, 1989, where water temperatures in lower Laguna Madre dropped to as low as 3^{o} C. Stranded live and dead sea turtles, including *C. caretta* individuals, were found immediately after the drop in temperatures (Shaver, 1990a).

Future threats to the nesting and marine environment of the *C. caretta* population include: shrimping, menhaden fishing, illegal gill netting, improperly installed or non-utilized Turtle Excluder Devices (TED's), trawling; beach erosion, armoring, an nourishing, artificial lighting, beach cleaning, increased human presence, recreational beach equipment, beach vehicular driving, nesting depredation, poaching, dredging, marina and dock development, pollution, hook and line fisheries, longline fisheries, entanglement, and, ingestion of marine debris (USFWS and NMFS, 1991).

1.7.4 Conservation and Management

A number of education activites and efforts are underway to enlighten public awareness and understanding of sea turtle conservation. Personnel conducting turtle projects are in touch daily with tourists on how to minimize disturbance to nesting turtles. In addition, state and federal parks which conduct public awareness of sea turtle status provide information to visitors and signs have been posted on many beaches informing people of the laws protecting sea turtles (USFWS and NMFS, 1991).

One of the most difficult issues in habitat management is to minimize or eliminate construction of seawalls, rip-rap, groins, sand bags and improperly placed drift or sand fences (USFWS and NMFS, 1991). Several state and federal laws have been designed to protect beach and dune habitat, some of which had varying degrees of success at maintaining stable nesting sites for *C. caretta*. NMFS implemented a gear development program in 1978 that would prevent drowning of turtles in shrimp trawls. When properly installed and utilized, TED's have proven to reduce turtle drownings. These programs are intended to achieve recovery goals to delist the species in the US.

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1.8 *Chelonia mydas* (Green Sea Turtle)

1.8.1 Introduction

Chelonia mydas (Green Sea Turtle) is described by Hildebrand (1981), as being the most important species in Texas, with numbers reported in the thousands during the early 1800's. *Chelonia mydas* is a medium to large brownish sea turtle with a radiating or mottled pattern of markings on the shell (USFWS, 1991). In comparison to other sea turtles, the head is small and the biting edge of the lower jaw is serrated. Adult shell lengths range in size from 91-109 cm (36-43 in) and weights average 440-660 kg (200-300 lbs) (USFWS, 1991). Juveniles are generally found in Florida waters, especially in areas abundant in seagrasses.

1.8.2 Status and Trends

Historic accounts substantiate reports of large numbers of *C. mydas* once occupying Texas bays (Shaver, 1990b, 1990c) One hundred years ago, the Atlantic form of the green turtle (known for its green fat) was common in Texas waters (Doughty, 1984). In 1915, John K. Strecker noted that "if all the green turtles shipped from the coast country are captured in Texas waters, the animal must be quite abundant."

Nesting grounds of *C. mydas* which supported fishery production in the nineteenth century have not been identified. Nesting still occurs in Mexico on Cayo Arcas, Cayo Arenas, Arrecife Alacranes, and Arrecife Triangulos on Campeche Bank (Hildebrand, 1981) with an occasional sighting at Rancho Nuevo. In addition, Hildebrand (1981) suggests the population is probably increasing, but the assumption is based solely on the number of reports received concerning the species from various sources. Increased populations may be attributed to head-starting efforts in Isla Mujeres resulting in emigration to Texas (Hildebrand, 1981).

The first confirmed nesting of *C. mydas* on the Texas coast was recorded in 1987. On 13 July 1987, two turtle eggs were collected from a nest in Kenedy County, Texas, on Padre Island National Seashore (PINS) (Shaver, 1988). Tracks of the nesting female extended from the high tide line to the embryonic dune area where a depression and mound of sand were located at the termination of the tracks. After imprinting was performed at the Kemp's ridley incubation laboratory, one of the hatched eggs was sent to the University of Texas at Austin, Marine Sciences Institute (UTMSI) for approximately seven months of head-starting. Unfortunately, the turtle died after a few weeks of care (D. Shaver, pers. comm.).

USFWS (1991) reports the status of *C. mydas* as Endangered in Florida and in east Pacific breeding populations and Threatened everywhere else.

1.8.3 Probable Causes And Future Threats

Large numbers of *C. mydas* were exploited along the Texas coast early in the nineteenth century. By 1890, turtles ranked tenth among forty-six fishing products caught in the Gulf states and fifth in Texas (Doughty, 1984). During the late 1800's, approximately 10,909 kg (24,000 lbs) of *C.*

mydas were landed in Texas; in Louisiana, 13,636 kg (30,000 lbs) were landed and valued at $1,200. The turtle catch in Texas reached a record high in 1890, with the take of green turtles that year increasing more than twentyfold over that of 1880. A cannery was established in Aransas Bay at Fulton, in Aransas County in 1881. Many turtles for Fulton probably came from local feeding grounds of seagrass in Aransas Bay. *C. mydas* was the leading marine product by weight in the Laguna Madre and lower Rio Grande tidal zone (Doughty, 1984). In Texas, overall weight of turtles landed was large, substantiating the unprecedented growth of readily available cheap turtle meat. In turn, this commodity lead to the establishment and expansion of canneries for processing *C. mydas* in the late 1800's.

Nesting and congregating in and around beaches made *C. mydas* easy targets for humans. They were slaughtered for meat, oil, skins, and shells. The Karankawa Indians hunted turtles which they boiled in earthern pots or roasted in the ashes of fire (Doughty, 1984).

Strandings of sea turtles are common along south Texas beaches. Rabalais and Rabalais (1980) reported results of a three year survey of sea turtle strandings on south Texas beaches: ten green turtles were among the 259 individuals recovered from September 1976 through September 1979. In recent years, occurrence of these strandings has been formally recorded as part of a long-term study of bird populations utilizing Mustang Island beach (Amos, 1989). One hundred twenty individuals from five species, have been reported stranded on Mustang Island from 1983 to 1985 including *C. mydas*. Two hundred and forty-six sea turtles were documented stranded along the Texas coast from 1 January to 31 May 1994 including 14 *C. mydas* (Shaver, 1994c). Fisheries operations, including shrimping, menhaden fishing, and illegal gill netting are a few of the suspected probable causes. Improperly installed and malfunctioning Turtle Excluder Devices (TED's) were also implicated.

Dredging, ingestion of and entanglement in marine debris, collision with boat propellers, and capture by hook and line are also threats to sea turtles on the Texas coast (Shaver, 1990).

1.8.4 Conservation and Management

In 1978, NMFS implemented a gear development program to reduce drownings of turtles in shrimp trawls through the use of TED's. Seven types of TED's have been certified for use by NMFS; however, lack of widespread use of the device on a voluntary basis resulted in regulations requiring their use.

Public support for sea turtle conservation efforts is essential for the long-term success of conservation programs. Investigations of suggested and known stranding factors are ongoing. Government agencies and their personnel, in addition to private organizations have cooperated to document and investigate strandings. Personnel conducting turtle projects on the Atlantic coast often advise tourists on what can be done to minimize disturbance to nesting turtles, protect nests and rescue misoriented hatchlings (USFWS AND NMFS, 1991). Agencies included in conservation and management efforts are the Sea Turtle Stranding and Salvage Network (STSSN), National Marine Fisheries Service (NMFS), National Park Service (NPS), National Biological Service (NBS), Texas Parks and Wildlife Department (TPWD), University of Texas at

Austin Marine Sciences Institute (UTMSI), University of Texas at Pan American, Marine Mammal Stranding Network (MMSN), Center for Marine Conservation, and Help Endangered Animals-- Ridley Turtles (HEART). Signs have been posted on many beaches informing people of the laws protecting sea turtles and providing either a local or a hotline telephone number to report violations.

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1.9 *Dermochelys coriacea* (Leatherback Sea Turtle)

1.9.1 Introduction

Dermochelys coriacea (leatherback sea turtle) is the largest living turtle and is so unique that is placed in a separate family, Dermochelyidae. The generic name *Dermochelys* was introduced by Blainville (1816) and refers to the distinctive leathery, scaleless skin of adults (USFWS AND NMFS, 1992). The specific name *coriacea* was first used by Vandelli (1761) and adopted by Linneaus (1766) (Rhodin et al., 1982).

Dermochelys coriacea possesses a distinct skeletal morphology from other turtle species (Rhodin et al., 1981). Recent karyological studies support classifications which separate extant sea turtle species into two discrete families, whereas all other extant species are in the family Cheloniidae (Medrano et al., 1987; Gaffney, 1975, 1984; Bickham et al., 1983). *Dermochelys coriacea* can attain a shell length of 1.8 m (6 ft) and weights to 3,080 kg (1400 lbs). The shell is black with white blotches, without scales and is covered by a firm, rubbery skin accompanied by seven longitudinal ridges or keels (USFWS, 1991). The carapace is about 4 cm thick and is made of tough, oil-saturated connective tissue raised into seven prominent longitudinal ridges and tapered to a blunt point posteriorly (USFWS AND NMFS, 1992). The front flippers are proportionally longer than in other sea turtles and in adult turtles may measure 270 cm (106 in). Morgan (1989) reported the largest leatherback (male) on record in 1988, stranded on the coast of Wales weighing 916 kg (2,015 lbs).

Hatchlings are covered with tiny polygonal, bead-like scales and are dorsally black in color. Flippers are margined in white and rows of white scales resemble stripes along the length of the carapace (USFWS AND NMFS, 1992).

Adult leatherbacks are highly migratory and believed to be the most pelagic of all sea turtles, however, habitat requirements for juveniles and post-hatchling leatherbacks are not known.

1.9.2 Status and Trends

Dermochelys coriacea is considered endangered throughout its global range and was listed as Endangered under the authority of the Endangered Species Act by the United States Department of the Interior on 2 June 1970. Declines in the number of nesting females have been documented and reported world wide and it is not known at present whether leatherback populations within the US are stable, increasing or declining (USFWS AND NMFS, 1992).

Information on *D. coriacea* is rather sparse in the western Gulf of Mexico with reported numbers being so small that mortality is not significant (Hildebrand, 1982). Nesting grounds are distributed around the world (Sternberg, 1981); the Pacific coast of Mexico supports the world's largest known concentration of nesting leatherbacks. *Dermochelys coriacea* is widely distributed in Mexican waters with aggregations concentrated off Barra de San Pedro from August to November. Pritchard (1982) estimated that 115,000 adult female leatherbacks remain worldwide and 50% probably nest in western Mexico. In the wider Caribbean regions, the largest nesting colony is found at Yalima po-Les Hattes, French Guiana where the estimated total number of adult females is from 14,700 to 15,300 (Fretey et al., 1989). Leary (1957) recorded an estimated 100 leatherbacks in December, 1956, ranging in length from 1-2 m, along a 50 km line extending north from Port Aransas, Texas. In addition, Dixon (1987), reported *D. coriacea* from six coastal counties including Jefferson, Galveston, Brazoria, Aransas, Nueces, and Kenedy.

The species has been reported nesting in the past at Rancho Nuevo, Tamaulipas, according to residents (Hildebrand, 1982). No nesting has been reported on the west coast of Florida since the year the state began keeping records in 1979; however, in 1974, a nest was reported on St. Vincent Island off the northwest coast of Florida (LeBuff, 1976). There are records of nesting on the Texas coast, in the vicinity of Little Shell Beach on PINS in the 1920's and 1930's but no records since the 1940's (Hildebrand,1981).

1.9.3 Probable Causes

Dermochelys coriacea strandings on US shores are generally adult or subadult size which may be an indicator of the importance of pelagic habitat under US jurisdiction to turtles breeding in tropical and subtropical latitudes (USFWS AND NMFS, 1992). Migration/movements account for a small percentage of the decline in leatherback populations, however, evidence currently available from tag returns and strandings in the western Atlantic suggests that adults engage in routine migrations between boreal, temperate and tropical waters (Pritchard, 1976). From 1980 to 1991 there were 816 reported strandings along the continental US coastline. Judd et al. (1991) reported 36 strandings in Texas coastal counties from January 1981 through December 1989.

The leatherback was never harvested to any great extent along the southeastern United States, however, there are reports of turtle shootings in Florida and harvesting along the eastern coast of Mexico. In February 1980, Hildebrand (1982) observed the head and entrails of a leatherback that had been butchered near Veracruz. Residents had rendered a leatherback for oil on more than one occasion. One leatherback will yield up to 30 liters of oil and is reputed to have medicinal value particularly for skin and lung disorders (Hildebrand, 1981).

1.9.4 Future Threats

There are numerous threats to the recovery of existing populations of *D. coriacea* including increased human presence, population growth and expanding development pressures. Other threats to the nesting environment include poaching, beach erosion, beach armoring, beach nourishment, artificial lighting, beach cleaning, recreational beach equipment, hatchling mortality, and beach vehicular driving. Existing threats to the marine environment are entanglement at sea, ingestion of marine debris, commercial fisheries, boat collisions, oil and gas exploration, development transportation and storage and pollution (USFWS AND NMFS, 1992).

1.9.5 Conservation and Management

Dermochelys coriacea was Federally listed as Endangered on 2 June 1970 and since then conservation efforts have greatly improved. Lighting ordinances designed to control light pollution on nesting beaches have been passed by nine counties and over 20 towns, cities, and parishes (USFWS AND NMFS, 1992). In 1986 it became illegal to drive vehicles or ride horses on beaches in the US Virgin Islands (USVI). In December 1990, the Governor and Cabinet of the State of Florida approved a beach armoring policy restricting armoring (seawalls, rip-rap, revetments, groins, and sand bags) to structures threatened by a 5-year return interval storm event.

Fishery regulations of the early 1980's were amended in Puerto Rico to ban nets with greater than 10 cm mesh and in 1985 regulations were passed for the management and regulation of endangered species with fines assessed as high as $5,000 (USFWS AND NMFS, 1992). A substantial effort is being made by government and non-government agencies and private individuals to increase public awareness of sea turtle conservation. Recovery objectives are designed to protect and manage habitats so the US population of leatherbacks can be reduced from Endangered or delisted completely (USFWS and NMFS, 1992).

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1.10 *Eretmochelys imbricata* (Hawksbill Sea Turtle)

1.10.1 Introduction

Eretmochelys imbricata (Hawskbill Sea Turtle) is reported by Hildebrand (1981) to be the rarest marine turtle in the Gulf of Mexico with few records from Texas. *Eretmochelys imbricata* is a small to medium sea turtle with a colored shell of thick overlapping scales from which the term “tortoise shell” is derived (USFWS, 1991). Adult of the species range in size from approximately 76-91 cm (30-36 in) in straight carapace length (CL) and weighs approximately 45-90 kg (100-200 lbs). This shy, tropical reef dwelling turtle forages principally on sponges (USFWS, 1991).

1.10.2 Status and trends

Currently, the status of *E. imbricata* is listed as Endangered, with populations facing significant threats in the marine environment from human pressure and exploitation. There is a lack of available information on *E. imbricata*; however, despite the gathering of eggs and capturing turtles of all sizes for curio trade, Hildebrand (1981) reported a small population of *E. imbricata* living near Veracruz, Mexico. Fishermen report nests from Isla de Lobos in northern Veracruz state to Anton Lizardo in the south.

During a study of the occurrence of sea turtles on the south Texas coast, Rabalais and Rabalais (1980) observed four *E. imbricata*, less than 20 cm (CL), off the Aransas Pass Inlet jetties in late summer from 1970 to 1975. Throughout 25 years of studying and observing sea turtle nesting habits, Hildebrand (1981) observed only two hawksbills which were captured in healthy condition. Any other observations made on *E. imbricata* were small individuals that washed up on the beach in a moribund condition.

Sea turtle nests may go undetected along the Texas coast each year, however south Texas beaches are at present and probably in the past were insignificant as nesting beaches (Hildebrand, 1981). Records of sea turtles nesting on the Texas coast are rare and few have been confirmed. In August, 1987, a live *E. imbricata* hatchling was found stranded on the beach at Mustang Island near Port Aransas (Shaver, 1988). The hatchling measured 5.46 cm straight CL, 4.47 cm straight carapace width (CW) and weighed 28 g and possessed an egg tooth. It is uncertain whether this hatchling emerged from a Texas nest. No confirmed *E. imbricata* nests have been located on the Texas coast (D. J. Shaver, pers. comm.).

1.10.3 Probable Causes And Future Threats

The coastal areas in the state of Veracruz, Mexico are sparsely to densely populated by humans. The northern part of the state around Cabo Rojo and the area from Isla de Lobos to Alvarado have been reported to be good nesting and feeding ground for sea turtles including *E. imbricata*. Even though official records document small catches of turtles, fishing has always been very intense (Hildebrand, 1981). Fishing nets are still used near Veracruz although the catch is very low.

Few *E. imbricata* strandings have been reported along the Texas coast; however, *E. imbricata* that are found stranded along the Texas coast are post-hatchlings and small juveniles. Most are found entangled in marine debris or injured, but often alive (Amos, 1989a). From 1 January to 31 May 1994, one *E. imbricata* was included among 227 turtles reportedly stranded along the Texas coast (Shaver, 1994).

Amos (1989b) reported 120 sea turtles (5 species) stranded from 1983 to 1985, including 12 juvenile hawksbills. The Texas Sea Turtle Stranding and Salvage Network (TSTSSN) recorded stranded turtles, dead or alive, within state inshore waters between 1980 and 1989 (Shaver, 1990). One hundred sixty-six wild sea turtles were documented which included eight *E. imbricata*. Incidental capture of sea turtles in shrimp trawls is one of the most important human causes of mortality (Caillouet et al., 1991). Among the five species of turtles (1,047 individuals reported) reportedly stranded by shrimp trawling in the northwestern Gulf of Mexico from 1986 to 1989, *E. imbricata* was the third highest with 67 stranded (Caillouet et al., 1991).

1.10.4 Conservation and management

Sea turtle conservation requires long-term public support over a large geographic area. Complete and factual information of issues concerning conservation must be made public, especially when measures conflict with human activities such as commercial fisheries, recreational boating, beach development, and public use of nesting beaches.

Conservation efforts for the protection and restoration of all sea turtle populations has been implemented both nationally and internationally. One of the most significant measures achieved is the ratification of Protocol to the Cartagena Convention concerning specially protected areas and wildlife (USFWS AND NMFS, 1992). Parties to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (Cartagena Convention) adopted the Protocol for Specially Protected Areas and Wildlife in January, 1990 (USFWS AND NMFS, 1992). Annex II of the Protocol, which includes all six sea turtle species in the wider Caribbean, prohibits the taking, possession or killing of commercial trade in such species, their eggs, parts or products, and the disturbance of such species, particularly during periods of breeding, incubation, estivation or migration, as well as other periods of biological stress.

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1.11 Marine Mammals

1.11.1 Introduction

Interest in marine mammals stems from their phylogenetic similarity to humans, their size, ability to survive in aquatic environments, and charismatic qualities. Perhaps of most importance, marine mammals may be excellent ecological indicators to estimate the health of our shared environments (Fritts et al., 1983). The diversity of marine mammals is exhibited in their size ranges and position in the aquatic food web. Size of the marine mammal species and food size preference is generally an inverse relationship; baleen whales, while being quite large in size, consume quite small prey (small shrimplike crustaceans to schools of small fish), and smaller toothed whales typically prey upon larger organisms. Their higher position within the food web may result in bioaccumulation of natural and anthropogenic contaminants. Levels of contaminants in marine mammals and the potential effect on the health of the animal are difficult to determine; however, an apparent increase in marine mammal strandings has resulted in placing the status and trends of marine mammals in the western Gulf of Mexico as a high priority item. Several projects have been initiated to monitor numbers of strandings and determine causes of strandings along the Gulf coast.

1.11.2 Status and Trends

Current status of *T. truncatus* (Atlantic bottlenose dolphin) within the CCBNEP study area appears to be stable. Estimates of population sizes along the Texas coast are difficult to enumerate due to the seasonal abundance and uneven sizes of local herds (aerial surveys by S. Leatherwood and associates 1978,1979; Fritts, et al., 1983). Population of this species appears to migrate between bays and estuaries and inshore and offshore areas (Schmidly, 1981; Shane and Schmidly, 1978; Brager, 1993). Migrations may be short-term, and studies in Aransas Pass area showed the movements may be related to water temperature changes (Shane and Schmidly, 1979).

Volunteers of the Texas Marine Mammal Stranding Network (TMMSN) have been responding to beached or stranded marine mammals since the 1970's. However, comprehensive documentation of strandings were not begun until the mid 1980's. At that time the TMMSN, under the guidance of Dr. Raymond Tarpley, was organized into a comprehensive response team which attended all reported strandings along the Texas coastline. The efforts of the TMMSN were lauded by local, state and national government agencies, but little financial support was forthcoming until the 1990's when Dr. Graham Worthy became the state director and strandings appeared to become more frequent. Whether this appearance of a rise in strandings was a fact or a function of a more highly publicized stranding network is not known.

The word "stranding' or "stranded" is commonly used to define any marine mammal that has come aground whether it is alive or dead. A mass-stranding is two or more marine mammals, other than a female and calf, that have grounded in the same general area and a mass die-off indicates that a large scale mortality has taken place. A marine mammal may also be considered stranded if it is reported in open waters but in a situation which threatens its ability to survive (eg., hit by a boat).

1.11.2.1 Texas Coast Stranding Data

A total of 1447 individuals of marine mammals have been documented between 1987 and 1994 within the TMMSN database (Table IV.C.1.11.1). Year totals do not actually correspond to increased stranding personnel numbers and effort over time; 1987 total (152 individuals) ranked fourth highest in the eight-year period (113 individuals in 1989 to 296 individuals in 1994). However, stranding totals by year were highest in 1994, due to two months, March and April, in which strandings were tabulated as 460 and 278 individuals, respectively.

The TMMSN database does exhibit seasonal peaks for Texas coast strandings; in all years, March was documented as having the highest monthly totals, ranging from 31 individuals in 1989 to 103 in 1992. April ranked second highest totals in all years, with the exception of 1990 and 1991 in which February exhibited second highest of individuals. Network personnel have learned to anticipate highest stranding numbers from January through April during any given year. During the remainder of the year, strandings are characteristically low and are typically below 15 individuals per month.

1.11.2.2 Stranding Data by Regions Above, Within, and Below CCBNEP Study Area

The TMMSN has divided the Texas coast into several regions (Table IV.C.1.11.2). The regions of interest within the CCBNEP study area are Port Aransas and Corpus Christi regions. Precise correspondence between TMMSN regions and CCBNEP study area are not possible due to the differences in boundary designations. Southern portions of Rockport region were within the study area in the first county designations, but this region was eliminated by the last quarter of 1988. Southern portions of Corpus Christi region are outside the study area, but regular sightings within the Padre Island National Seashore resulted in valuable information closely adjacent to the CCBNEP study area.

All data from regions above Port Aransas region were grouped into an upper designation, South Padre Island was used as the lower designation to determine any coastwide trends in strandings above and below the CCBNEP study area. In all years, total strandings were higher above the Port Aransas/Corpus Christi regions and strandings lower in the South Padre Island region (Fig. IV.C.11.1 & IV.C.11.2). Only when monthly stranding totals by region were low (months other than Jan-April) did Port Aransas/Corpus Christi region exceed Upper regions totals. Low stranding totals in South Padre Island region may be attributable to fewer sightings from general in-accessibility to the northern part, although sighting effort has increased over time from regular flyovers and public education.

1.11.2.3 Stranding Data for Regions Within CCBNEP Study Area

Overall stranding totals are low for Port Aransas and Corpus Christi (PA/CC) regions which represent the CCBNEP study area. Normally strandings are distributed randomly throughout the

Table IV.C.1.11.1. Total strandings by month for 1987-1994 from Texas Marine Mammal Stranding Network quarterly reports.

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
1987	6 LYM	24	52 HMY	36	12	6	2	3	3	0 LYM LMY	4 LYM	4 LYM	152
1988	7	22	37 HMY	28	4 LMY	4 LMY	4 LMY	4 LMY	4 LMY	4 LMY	4 LYM LMY	9	131
1989	13	10 LYM	31[1] HMY	18	3	1 LYM LMY	4	8	5	9	6	5	113 LY
1990	43 HYM	39 HYM	65 HMY	17	1 LYM LMY	5	4	2 LYM	5	10	13 HYM	8	212
1991	10	22	40 HMY	16 LYM	1 LYM LMY	6	4	4	4	5	8	9	129
1992	16	26	103 HYM HMY	66	15 HYM	9 HYM	2 LMY	4	4	5	6	9	265
1993	10	18	59 HMY	20	6	1 LYM LMY	1 LYM LMY	7	2 LYM	3	7	15 HYM	149
1994	22	30	92 HMY	81 HYM	10	3 LMY	7 HYM	13 HYM	9 HYM	12 HYM	6	11	296 HY
total	127	191	479 HM	282	52	35	28 LM	45	36	48	54	70	1447

By row:
- HM Highest month for entire dataset
- HMY Highest month within a given year
- LM Lowest month for entire dataset
- LMY Lowest month within a given year

By column:
- HY Highest year for entire dataset
- HYM Highest year within a given month
- LY Lowest year for entire dataset
- LYM Lowest year within a given month

CCBNEP area and in general, the animals are dead when sighted. Most of the live-stranded animals are found on Gulf beaches. Similar peaks reported for the entire Texas coast between January and April are exhibited in the PA/CC region, with monthly totals seldom exceeding ten individuals (Fig. IV.C.1.11.3). *Tursiops truncatus* is the species which strands most often in the CCBNEP study area. Ten other species have been recorded as stranding in the region, primarily on Gulf of Mexico beaches. Most strandings reported in the bay areas are single-animal strandings. However in 1992 an event occurred which can be labeled a mass die-off. Eighty-three *Tursiops spp.* were recovered from the bays in the CCBNEP area. There has been no definite consensus as to the cause of death of so many animals in such a small area in a four

Table IV.C.1.11.2. Region designations of the Texas coast established by the Texas Marine Mammal Stranding Network (TMMSN) (Tarpley, 1987, 1988).

Name	Code	Counties 1st Qtr 1987-3rd Qtr 1988	Counties 4th Qtr 1988- present
Sabine Pass	SB	Jefferson, Chambers	Jefferson, Chambers
Galveston	GA	Galveston, Brazoria	Galveston, Brazoria
Port O'Connor	PO	Matagorda	Matagorda, Calhoun
Rockport	RP	Calhoun, Aransas	
Port Aransas	PA	San Patricio, Aransas, Nueces	San Patricio, Aransas, Nueces
Corpus Christi	CC	Kleberg, Kenedy	Kleberg, Kenedy
South Padre Island	SP	Willacy, Cameron	Willacy, Cameron
Other	Other	Harris County, Texas (noncoastal) and Calcasieu Parish, Louisiana	Harris County, Texas (noncoastal) and Calcasieu Parish, Louisiana

month (January to April) period. With the exception of the 1992 mass die-off, no apparent trend is discernible as to whether one region within the CCBNEP study area has more strandings than the other. As noted previously, lower numbers in the lower part of Corpus Christi region may be a result of fewer sightings, not a result of fewer actual strandings. Similarly, some animals may be missed within the bays and estuaries. Considering the topography, amount of isolated bay shores, and the lack of funding for regular patrols in the area it is probable that marine mammals may die before they are found and reported.

1.11.3 Probable Causes

Often stranded animals are discovered in a progressive stage of decomposition and an obvious cause of death is difficult to determine, although some causes have been reported in TMMSN quarterly reports (Table IV.C.1.11.3). Increases in strandings have been attributed to time of year (i.e., during calving periods) and to inclement weather (i.e. freezing water conditions), although investigations are underway to determine both reproductive condition and levels of contaminants in animals which have stranded and died. Stranding events tend to occur during the months of January to April coinciding with the calving season with a second peak in October to November, a second calving season. The TMMSN has standardized their procedures to aid in determining cause of death and collecting various tissues for later analysis. The first action of the TMMSN volunteer after responding to a stranded marine mammal call is to attempt to determine the cause of death. Unless there are obvious signs (e.g., entanglement, gunshot wounds, knife wounds, etc.) it is impossible to make a determination on site. Volunteers will

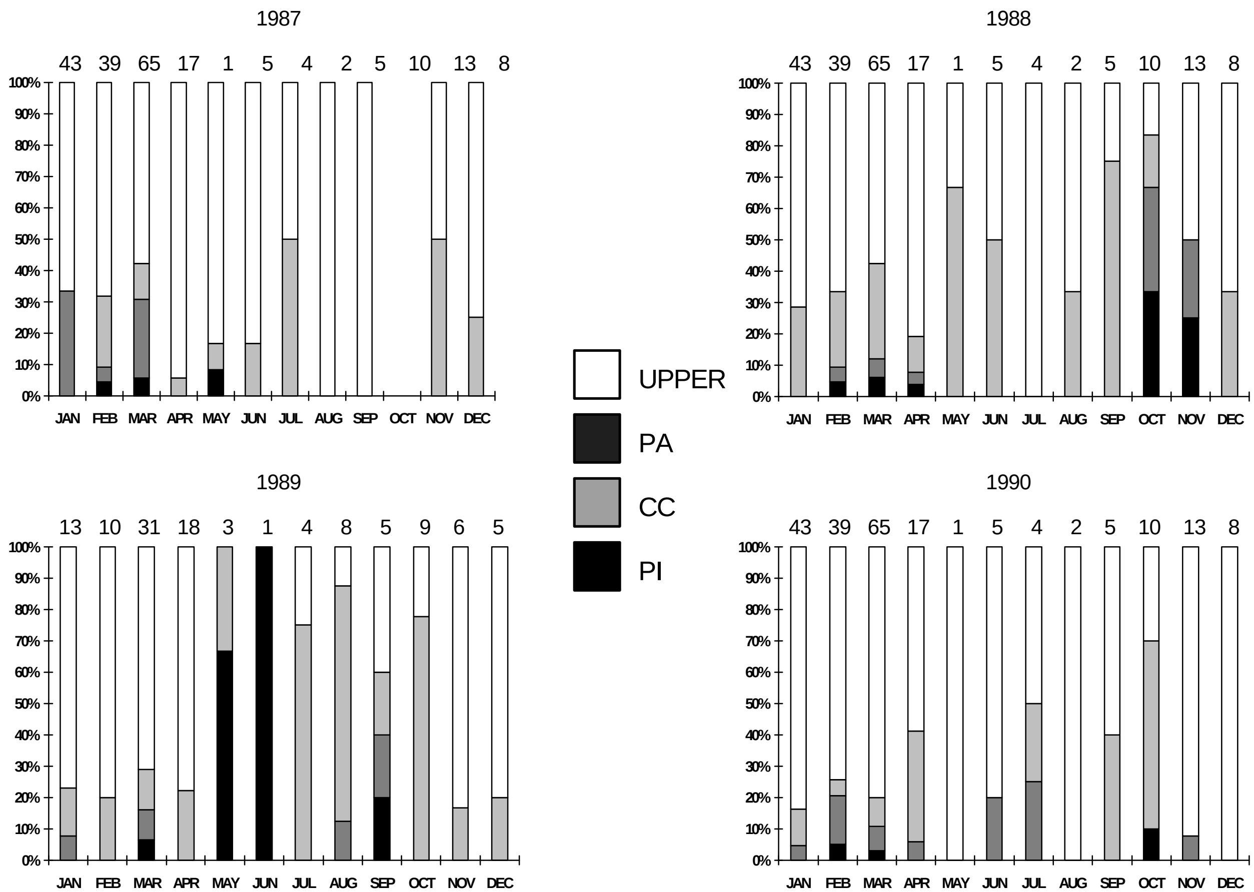

Fig. IV.C.1.11.1. Monthly data for 1987-1990 of proportion of total marine mammal strandings by Upper Coast [Sabine Pass, Galveston, Rockport (early data), and Port O'Connor regions combined], Port Aransas and Corpus Christi regions of middle coast (representative of CCBNEP study area), and Padre Island of lower coast. Values above frequency bars are monthly totals for a given month.

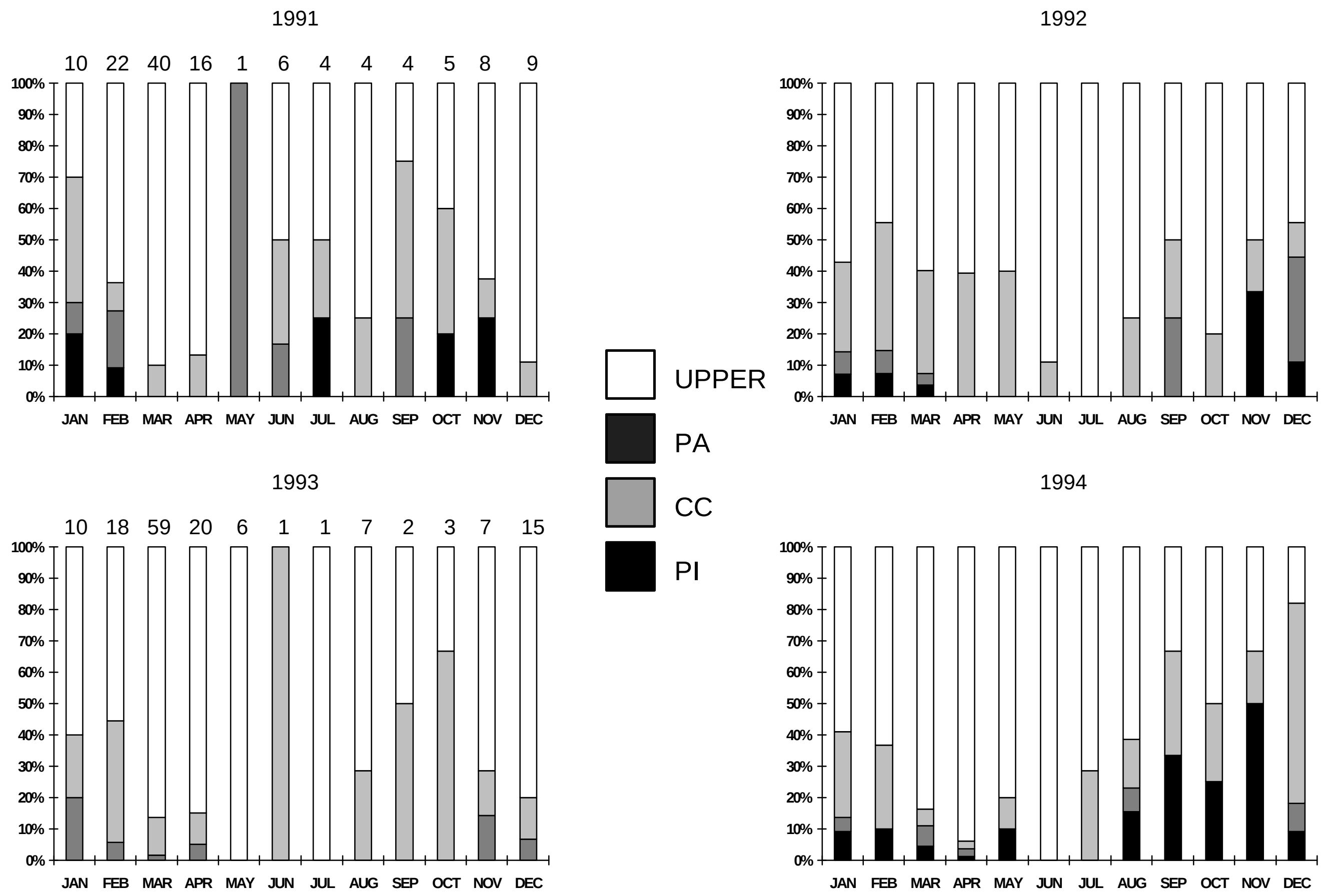

Fig. IV.C.1.12. Monthly data for 1991-1994 of proportion of total marine mammal strandings by Upper Coast [Sabine Pass, Galveston, and Port O'Connor regions combined], Port Aransas and Corpus Christi regions of middle coast (representative of CCBNEP study area), and Padre Island of lower coast. Values above frequency bars are monthly totals for a given month

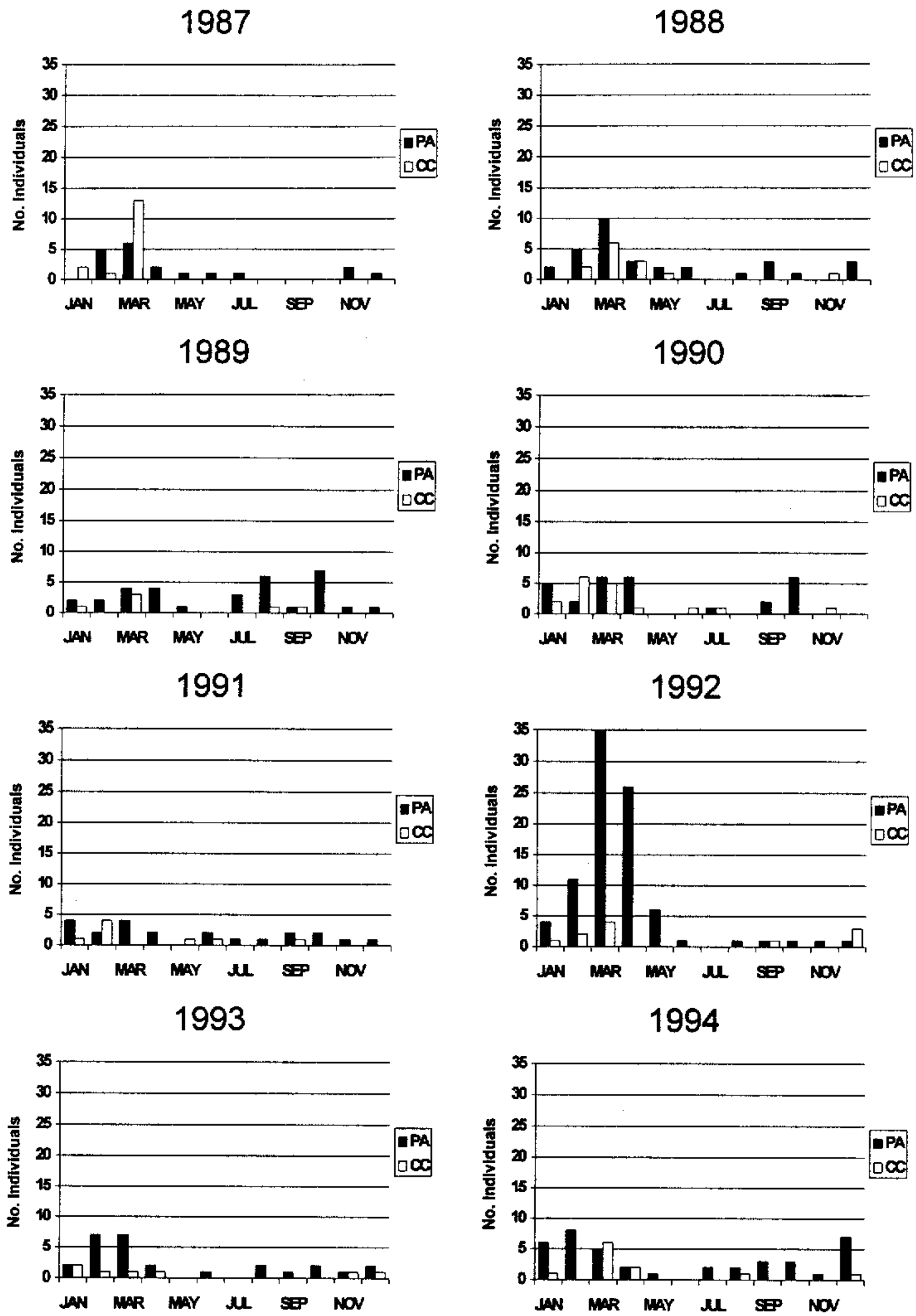

Fig. IV.C.1.11.3. Monthly totals of marine mammal strandings for 1987-1994 within the CCBNEP study area: PA - Port Aransas Region and CC - Corpus Christi Region (source of data, Texas Marine Mammal Stranding Network).

Table IV.C.1.11.3. Uncommon marine mammals and those individuals for which cause of death was determined that have stranded along Gulf and bay beaches within the CCBNEP study area (source, Texas Marine Mammal Stranding Network Quarterly Reports).

Scientific Name	Common Name	Quarter/Year	Location	Cause of Death
Physeter macrocephalus	sperm whale	3/1992	Kenedy Co.	not determined
Kogia breviceps	Pygmy sperm whale	4/1994	Nueces Co.	not determined
Kogia simus	dwarf sperm whale	2/1993	Nueces Co.	not determined
Kogia spp.		4/1989	Nueces Co.	not determined
Kogia spp.		3/1990	Kleberg Co.	not determined
Mesoplodon europaeus	Gervais' beaked whale	4/1994	Nueces Co.	not determined
Steno bredanensis	rough-toothed dolphin	2/1994	Kleberg Co.	not determined
Lagenodelphis hosei	Fraser's dolphin	1/1994	Kleberg Co.	not determined
Tursiops truncatus	Atlantic bottle-nosed dolphin	2/1987 3/1987 4/1987 4/1987 1/1989 1/1994	Nueces Co. Nueces Co. Nueces Co. Nueces Co. Port Aransas area Nueces Co.	trauma due to severe laceration along the left dorsal surface which penetrated the thoracic cavity, cranial trauma and severe pulmonary congestion during attempts to free from shrimper's net, caught in gill net with severe laceration to tailstock, no definitive cause of death, neonate, death prior to parturition, asphyxiation from eels in the nasal passages, possible *Morbillivirus*
Grampus griseus	Risso's dolphin	1/1988 2/1993	San Jose Island Kleberg Co.	not determined
Stenella clymene		3/1989	Nueces Co.	not determined
Stenella longirostris	long-snouted spinner dolphin	2/1987	Nueces Co.	verminous pneumonia due to heavy lungworm infestation
Stenella spp.		1/1990	Nueces Co.	not determined
Stenella spp.		4/1990	Kleberg Co.	not determined
Stenella spp.		1/1991	Kenedy Co.	not determined
Stenella spp.		2/1991	Kenedy Co.	not determined
Stenella spp.?		2/1992	Aransas Co.	not determined
Stenella spp.		2/1994	Kleberg Co.	not determined

document the exact location of the stranding, take morphometrics and photographs, then proceed to perform a necropsy. This necropsy consists of collecting tissues such as blubber and muscle, kidney, liver, bone, reproductive organs, the whole head and the entire stomach. These tissues are then sent to Galveston and archived in freezers to await examination. Since funding for the examination is rarely forthcoming, due to the high cost of running toxicological tests, many tissues are simply held indefinitely. Data taken on-site is put into a data base and sent to the Southeast Regional Director in Florida and then on to the Smithsonian Institute in Washington, D.C.

Along with the work being performed by the TMMSN, the Marine Mammal Research Program (MMRP) began quarterly low-level monitoring of *Tursiops truncatus* stocks in the CCBNEP area as part of a coastwide effort to detect large-scale interannual changes in relative abundance and/or production of the species in the southeast US This area was selected as a study site because of the existing database provided by Master's thesis work conducted by Shane (1977; Shaver & Schmidly (1980), McHugh (1985), and the ongoing thesis work of L. May and T. Tenbrink at TAMU-CC. Further monitoring data is available from a project conducted by Sherman C. Jones from 1987 to 1989.

Several toxicological studies are being conducted at the College of Veterinary Medicine at Texas A&M University for three species including *T. truncatus* and preliminary reports are available (Haubold et al., 1990; Haubold et al., 1991). Contaminants loads in the marine mammals were explained as related to both the specific region of tissue collection and the differential abilities of species examined to eliminate heavy metals. Research is ongoing to determine heavy metal concentrations and the influence of geographical region, age, and sex to establish monitor effects of the marine mammals of the Gulf of Mexico.

1.11.4 Future Threats

Both natural disturbances (e.g., freezes and subsequent decreases in food supply, natural infectious agents) and human-related disturbances (e.g., environmental contaminants, industrial wastes, tarballs, and oil slicks) most likely affect the sustained health and status of marine mammals, (Leatherwood and Reeves, 1983; Fritts et al., 1983) although no comprehensive studies have been funded within the CCBNEP study area. Some contaminants that have accumulated in female marine mammal tissues may be transferred to the fetus during gestation and/or young during lactation (Wagemann et al., 1988). Environmental contaminants have been documented as severely impacting populations in the St. Lawrence River and estuary in Quebec, Canada (Martineau et al., 1988).

1.11.5 Conservation and Management

Marine mammals are variously protected by several conservation and management measures. In 1979 the International Whaling Commission prohibited the massive harvesting of certain species of whales (rorquals, right whales, gray whale, bowhead whale, and sperm whale) in the Antarctic by the factory-ship method. Other oceans have been designated sanctuaries, such as the Indian Ocean, although these protected areas are subject to status reviews. Scientists and conservationists have strongly urged the commission to include other species of marine mammals under protection from commercial hunting and incidental taking during other fishery harvest activities. While regulations may be imposed upon whale harvesting, the high numbers of marine mammals killed from incidental taking have had deleterious consequences on several species, particularly the smaller dolphins and porpoises, and are difficult to control.

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1.12 *Perna perna* (Edible Brown Mussel)

1.12.1 Introduction

Invasive mussels, *Perna perna* (family Mytilidae), in South Texas were first detected on the jetties at Port Aransas (27°50' N) in February of 1990 (Hicks & Tunnell, 1993). Within four years of their discovery, mussels have colonized jetties, navigation buoys, petroleum platforms, wrecks, and other artificial hard substrates as well as natural rocky shores between Matagorda Peninsula (28°35' N; Davenport, 1994), Texas, and Playa Escondida (18° 35' N; Hicks and Tunnell, 1994), southern Veracruz, Mexico, a distance of over 1,300 kilometers. Worldwide records of geographic distribution for the brown mussel, *P. perna*, include: Aden, the Red Sea, Madagascar, the east coast of Africa from central Mozambique to False Bay in the Cape, the African west coast from Luderiz Bay northwards, the Mediterranean from Gibraltar to the Gulf of Tunis, Brazil, Uruguay, Venezuela, the West Indies, and the Straits of Magellan (Berry, 1978).

Perna perna is a ciliary-mucoid filter feeder that occupies the littoral and sublittoral (<5m) zones where it feeds on phytoplankton, zooplankton, and detritus (Vakily, 1989). The genus *Perna* is characterized by the anterior position of the pedal retractor muscle, widely separated posterior retractor muscles, the absence of any anterior adductor muscle, and the often green color of the shell (Rios, 1975; Seed, 1976). *Perna perna* is described as up to 170 mm long (90 mm average) and smooth with concentric growth lines; it has a purple, nacreous interior, and the ventral margin is straight with one or two teeth. The periostracum is dark brown with yellow-greenish bands near the ventral margin (Rios, 1975, 1985). The most reliable anatomical character used to distinguish *P. perna* from other members of the genus is the presence of enlarged sensory papillae along the mantle margins (Siddall, 1980).

Members of the genus *Perna* exhibit some sexual dimorphism. The sexes of truly mature animals can often be determined by the color of the gonads, white indicating a male and orange to red-orange indicating a female. *Perna perna* release sperm and eggs freely into the water where fertilization takes place, then developing into a veliger larvae in 16 hours (Vakily, 1989). The larvae remain free-swimming for 15-20 days. As in many other mytilids, primary settlement of early plantigrades in *P. perna* occurs on filamentous substrata followed by a secondary settlement of later plantigrades on established mussel beds or clumps (Berry, 1978). Mytilid recruitment events are periodically very heavy and spatfalls often cover entire areas of shoreline to the virtual exclusion of all else (Seed, 1976). In such cases, late plantigrades attach to every available hard substrate irrespective of whether establish mussel beds were present or not, while occasionally smothering the receiving mussel population (Seed, 1976; Berry, 1978). On most rocky shores, space is the major resource (Dayton, 1971) and competition for space among barnacles, algae and mussels may be intense (Seed, 1976). Under these conditions, mussels are usually the competitive dominant (Paine, 1974). In intertidal situations, brown mussels tend to grow best on gently sloping, slow-draining platforms (Berry, 1978). *Perna perna* can withstand sand burial for periods of at least 12 days (Berry, 1978). Because of its capability to adapt to a wide range of environmental conditions, *Perna* is found in both brackish estuaries and open ocean waters (Vakily, 1989).

Once brown mussels have invaded a new habitat their population growth can be explosive. Thorough collecting efforts on the natural rocky shore area at Boca Andrea, southern Veracruz, Mexico, yielded no mussel specimens in October 1990. However, collections made exactly three years later revealed mussel densities of 5,216/m^2 (Hicks and Tunnell, 1994). Similarly, collecting efforts at Playa Escondida, south of Boca Andrea, in October 1993 produced only a few mussels (< 1 /m^2). At the same site four months later, a massive settlement of spat had occurred with densities as high as 200,000 /m^2 (Hicks and Tunnell, 1995). Recruitment events along the western Gulf of Mexico occurred during the months of November - December 1993 & 1994, March 1994, May 1994, and July-August 1994, with December and March events being most notable (Hicks and Tunnell, 1994). Fluctuation in seawater temperature is likely a major stimulus triggering spawning events.

Mytilids are known to be responsible for the formation of very complex biological substrates (Paine, 1976). Mussels are attached to the substratum and one another by a dense network of byssal threads, forming a bed that traps particulate debris. The matrix of mussels and trapped material completely encrust the underlying substratum, preventing the attachment of other sessile organisms, including their own recruits, to the primary substrate. On artificial substrates in south Texas, beds can be composed of several layers and attain thicknesses in excess of 20 cm. In south Texas, *P. perna* have been found attached to a variety of artificial substrates including steel, concrete, nylon rope, rock, plastic, as well as biological substrates (e.g., algae, wood, and whip coral). The presence of mussels on any shore drastically modifies the local environment (Seed, 1976). Water retention between individual mussels allows many species to penetrate further into the littoral zone than would be possible in the absence of mussels (Seed, 1976). This newly established biome on Gulf artificial and natural hard substrates, created by the mussel-formed mat of byssal threads and trapped materials appears to be quite productive containing algae, anemones, polychaetes, gastropods, bivalves, cirripeds, decapods, isopods, amphipods, and ophiuroids. Mussels are normally found as a carpet covering a layer of mud which is partly deposited by the mussels themselves (as faeces or pseudofaeces) and partly the result of accretion (Seed, 1976). The biodeposition of "mussel mud" together with the shelter afforded by the mussels themselves, encourage a species enrichment on shores where mussels are present (Seed, 1976). In areas where large quantities of sand are held in suspension, e.g. Texas coastal jetties, mussels continuously produce pseudofaeces composed almost entirely of sand grains (Berry, 1978). The deposition of "mussel mud" on the surface of Texas coastal granite rock jetties provides an additional component to the substrate, creating habitat for infauna species, such as polychaetes. Furthermore, the mussel shells themselves provide "secondary space" for colonization by many species, including algae and barnacles (Dayton, 1971; Seed, 1976). Organic production (pseudofaeces, rapid growth, high rate of mortality) of mussel populations contribute to decomposer and detrital food chains (Dare, 1976).

Known predators of the brown mussel in south Texas include *Stramonita* spp. (oyster drills), *Murex fulvescens* (Giant Eastern Murex), *Menippe adina* (stone crab), *Archosargus probatocephalus* (sheepshead) and *Haematopus palliatus* (American Oystercatcher) (Hicks and Tunnell, 1995). Potential predators include *Octopus vulgaris* (octopus), and various other fishes (*Lagodon rhomboides*, *Diplodus holbrooki*, *Trachinotus* spp. and *Blennius* spp.). Conspecifics and congeners of these potential predators are known to feed upon *P. perna* in its native range (Berry, 1978; Smale & Buchan, 1981; Hockey & Underhill, 1984; McQuaid, 1994). The primarily herbivorous sea urchin, *Arbacia punctulata*, is known to indiscriminatingly ingest small *P. perna* individuals (Pestovic, pers. comm.) and thus may influence settlement densities in areas that have significant urchin populations (jetties from Port Aransas south). Limpets are known to destroy settling barnacles while grazing on algae and likely affect settling brown mussels in a similar manner. Large predatory starfish, the primary predator of mytilids in their native habitats, are absent from the Gulf coast.

1.12.2 Status and Trends

Size composition and modal progressions from monthly length-frequency data have been used to interpret patterns of growth, mortality, and recruitment of invasive mussel populations in southern Texas (Hicks and Tunnell, 1994). Densities of up to 27,200 individual small mussels ($x = 16$ mm $\pm$ 0.3 SE) were recorded on a square meter area of jetty rock at the Fish Pass jetty (Corpus Christi Water Exchange Pass). Densities averaged 5,080/m^2 over 12 months. Growth parameters [asymptotic length ($L\infty$) and growth coefficient (K) of the von Bertalanffy growth equation] were estimated for mussel populations at two south Texas jetties: Fish Pass and Mansfield Pass. The mussel population at Fish Pass was estimated to attain a length of 44 mm in twelve months ($K = 1.08$, $L\infty = 66.2$). Mussel populations from the Mansfield Pass jetty had a lower K value (0.58) but were larger at age (52.4 mm / year) and had a larger maximum size ($L\infty = 117.3$ mm) (Hicks and Tunnell, 1994). Annual growth estimates as well as estimates of population parameters, $L\infty$ and K, from the Gulf of Mexico are within the range of values determined by other authors. Lasiak and Dye (1989) found that *P. perna* from the Transkei coast of southern Africa attain a length of 30 - 40 mm in their first year of growth, whereas on the Natal coast of southern Africa, mussels were found to attain lengths of 50-60 mm in their first year (Berry, 1978). Carvajal (1969) found *P. perna* to attain 64.5 mm in approximately eight months in Venezuela. Vakily (1989) assembled a list of values from published data for parameters $L\infty$ and K for *P. viridis*, an important commercial species, that ranged from 89.4 to 184.6 and 0.25 to 2.14, respectively. Berry (1978) calculated population parameters $L\infty$ and K for *P. perna* from the Natal coast of southern Africa to be 122.2 and 0.8, respectively.

Growth in *P. perna* from the Texas coast has the potential to be higher than that reported in Hicks and Tunnell (1994). The populations sampled in Hicks and Tunnell (1994) were at, or near, their upper intertidal limits and as such periodically exposed during falling tides. Consequences of periodic exposure include reduced time available for feeding; therefore, growth rates of those sampled are likely lower compared to their subtidal counterparts. In addition, mussel populations on jetties in southern Texas show a marked seasonal fluctuation in growth which corresponds with seasonal fluctuations in wave energy. Because jetties are positioned perpendicular to the shoreline, they interfere with longshore currents and food supply, therefore, food supplies may be periodically interrupted during seasonal fluctuations in current direction and wave energy.

The chronology of discovery events indicates southward expansion of brown mussels from the initial point of discovery, Port Aransas, Texas (Hicks and Tunnell, 1995). Colonization success in areas south of the initial point of discovery is likely the result of hydrographic factors, such as longshore and nearshore-surface currents (Hicks and Tunnell, 1994). Accordingly, the slow establishment of mussel populations to the north is likely due to a lack of incoming recruits, rather than environmental constraints posed by decreasing temperature and salinity gradients from south to north that exist along the Texas coast. Longshore currents flow southeasterly along the upper Texas coast and northeasterly along the southern Texas and northern Mexico coasts, converging at approximately 27° north latitude (Britton & Morton, 1989). The persistent southeasterly direction of longshore and nearshore-surface currents to the north of 27° north latitude is probably responsible for the slow establishment of mussel beds to the north. Cold fronts, while having only moderate effects on longshore systems to the north have dramatic effects on longshore and nearshore current systems southward along the coastal bend (Watson and Behrens, 1970; Britton and Morton, 1989). The rapid expansion of mussels to the south is likely due to the coincidence of mass spawning events with seasonal changes in current direction.

We expect the dispersal of mussels to the north of Port Aransas to continue, driven by deviations from seasonal patterns in current direction and spawning cycles, and as increasing sources of recruitment, e.g., offshore oil production platforms, become colonized, but at a much slower rate than has been observed to the south.

1.12.3 Management

Dare (1976) estimated production values (P = ash-free flesh weight + ash-free shell organics) for *Mytilus edulis* at Morecambe, Wales to range between 2.15-3.85 kg m^{-2} yr^{-1}; the highest production estimates for any animal species published at that time. Production estimates determined by Berry (1978) for *P. perna* in southern Africa were twice (6.6-7.6 kg m^{-2} yr^{-1}) those reported by Dare (1976). Production estimates for brown mussels at the Fish Pass jetty are 4.1 kg m^{-2} yr^{-1}. Although substrata available for colonization along the Texas Gulf coast are exclusively artificial, the total area available for colonization is significant. Texas coastal jetties contribute approximately 35 km of artificial shoreline. If mussels are to colonize all of these areas as they have the Brazos, Mansfield, Fish, and Aransas passes, annual production values could surpass 145 metric tons (160 tons). This estimate does not include large areas of artificial shoreline in bays such as Corpus Christi or offshore structures. While artificial substrates along the Texas coast will unlikely ever support a commercial fishery, these impressive production figures makes *P. perna* a potentially suitable organism for cultivation. Mussels of the genus *Perna* are extensively farmed in Thailand, the Philippines, and New Zealand. Experimental culture in many other countries including Asia, Africa, and the Atlantic coast of Latin America, has demonstrated the potential of this mussel as a candidate for coastal aquaculture (Vakily, 1998).

Local people are currently collecting mussels to eat from Gulf jetties. The first evidence of colonization within bay areas was recently reported from the Lavaca-Tres Palacious estuary in February 1995 (Davenport, in press). *Perna perna* will likely invade and establish themselves in Nueces Bay. The use of *P. perna* for food will likely increase as mussels become common on the rip-rap of various Texas bay systems. In the event that an increase in human consumption occurs, an increased burden would be placed upon those agencies responsible for evaluating the health of local mussel populations (i.e., Texas Department of Health - Shellfish Sanitation Control).

Mussels have also been found colonizing the skeletal structures of petroleum platforms and navigation buoys along the south Texas coast as far as 27 km offshore from Port Aransas, Texas. On petroleum platforms, mussels colonize structures from the intertidal zone down to depths of nine meters. This aggressive new member of the fouling community in the Gulf of Mexico has the potential to dramatically increase the maintenance and/or replacement interval of offshore navigation aids. The concern is that heavy infestations of mussels could partially sink navigation buoys and thus affect shipping safety. In Brazil, a native locality of the brown mussel, the Navy is responsible for maintaining navigation buoys, and has to remove fouling layers due to *P. perna* infestations every six months (E.C. Rios, pers. comm.). The US Coast Guard's "Aids to Navigation Team" is currently responsible for maintaining approximately 150 navigation buoys in the nearshore waters of the Gulf of Mexico annually.

Perna perna were found on the jetty at Port O'Conner adjacent to the Gulf Intracoastal Waterway (GIWW) on 4 February 1995 (Davenport, in press). The discovery of *P. perna* in the Lavaca-Tres Palacios estuary is very significant considering both the environment and the area's high barge traffic. The Lavaca-Tres Palacios estuary, the location of one of the state's largest oyster fisheries, is a low salinity environment, and at the specific site where mussels were found, salinities normally range between 15-25 ppt. This is the first report of this species inhabiting any Texas bay system, however, they are normally found in similar environments in South America. This species is known to colonize the hulls of boats and considering the frequency of barges utilizing the GIWW, mussels are now in good proximity to propagate themselves to various ports of call along the GIWW.

Lower mid-intertidal hard substrata available for mussel colonization in south Texas are primarily artificial groins and jetties, and have existed for only a century (Britton & Morton, 1989). Therefore, the invasion by *P. perna* in south Texas is not disrupting a co-evolved, natural assemblage. However, to the south the invader is rapidly colonizing volcanic rocky shores which will inevitably bring about physical modifications to the natural substrate and therefore effect the ecology of this co-evolved assemblage. These volcanic outcroppings are unique, limited to portions of central Mexico from approximately 24° north latitude to the Tuxtlas Mountain Province southeast of the city of Veracruz (Freeland, 1971).

Compared to species of the closely related genus *Mytilus*, particularly *Mytilus edulis*, little work has been done on *P. perna* (Berry, 1978). Questionable taxonomy, large geographic range, and ecological plasticity has made predictions concerning behavior in the introduced population impossible without knowing the origin of the introduced population. Determination of key physiological tolerances are a logical and potentially profitable first step toward management strategies of invasive species. Nutritional requirements are largely undetermined for this species (Seed, 1976).

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1.13 *Oostethus lineatus* (**Opossum pipefish**)

1.13.1 Status and Trends

Oostethus lineatus (Kaup), Opossum pipefish, has been described as a euryhaline, tropical species seldom found in subtemperate and temperate waters (Gilmore, 1977). The spiny projections on the trunk and tail rings and the location of the brood pouch on the males under the belly are characteristic of this species. *Oostethus lineatus* was first recorded as *Doryichthys lineatus* Kaup from North America by Fowler (1945) who reported collecting two specimens including a brooding male at McClellanville, South Carolina (Gilmore, 1977).

This species may be found in many habitats, including *Spartina* marshes and *Sargassum*; however, there are no records of occurrence from the northwestern Gulf of Mexico (Dawson, 1970). As of 1977, only 87 specimens have been recorded from the United States (Fowler, 1945; Dawson, 1970); most occurrences were in or around Indian River Lagoon and its freshwater tributaries in east Florida (Gilmore, 1977).

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1.14 *Syngnathus fuscus affinis* (Texas Pipefish)

1.14.1 Status and Trends

One of the most intriguing and interesting of marine fishes is the pipefish, Family Syngnathidae. Their characteristic armored body and odd shape have made the members of the Syngnathidae family a favorite aquarium fish (Hoese et al., 1977). Generally this family is often observed in vegetated areas, closely resembling the vegetation in which they occur. Syngnathids have an interesting biological characteristic where the male carries the fertilized eggs in a special brood pouch (Hoese et al., 1977). This unique reproductive characteristic has been reported as resulting in substantial reproductive costs to the males by lowering food intake, slowing growth, and increasing risk of predation (Roelke et al., 1993).

Little is known or reported about certain members of this family which includes *Syngnathus fuscus affinis,* Texas pipefish. Hoese et al. (1977) describes *Syngnathus fuscus affinis* as a distinct subspecies of *Syngnathus fuscus*, Northern pipefish, with only four specimens (15 cm; 6 in) reported from Corpus Christi Bay. The American Fisheries Society reports *S. fuscus* and *S. fuscus affinis* as two distinct and separate species (Robins et al., 1991). In contrast, Hubbs et al. (1994) describe and classify *S. affinis* and include Gulf of Mexico specimens identified as *S. fuscus* in the *S. affinis* species classification. To distinguish *S. affinis* from other *Syngnathus* spp., the preorbital bone must be measured for width and the trunk (body) rings must be counted (Dawson et al., 1982). Both *S. fuscus* and *S. fuscus affinis*, have been observed in Corpus Christi Bay and Corpus Christi Ship Channel (Hoese et al., 1977; Hubbs et al., 1994). Twenty-four specimens have been reported collected since 1926; two from south of the Corpus Christi Water Exchange Pass (Fish Pass) (1926), 20 from the Fish Pass (1976), and three collected from the vicinity of Corpus Christi Bay (Gourley, 1985; Dawson et al., 1982).

Since *S. fuscus affinis* is considered to be a C2 - candidate, further biological research field study will be necessary to ascertain the status and/or taxonomic validity of this taxa. Little or no literature is available describing specific characteristics, physiology, or habitat of *S. fuscus affinis*.

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2. TARGET ORGANISMS: FISHERIES RESOURCES

Table Of Contents

2. FISHERY RESOURCES

2.1 Introduction

Marine ecosystems within the Corpus Christi Bay National Estuary Program (CCBNEP) area have been valuable and productive sources of living resources since the time of the earliest native peoples. Finfish and shellfish artifacts from ancient (prehistoric) villages and campsites clearly demonstrate the dependency of native Indians upon nearshore and bay and estuary ecosystems for food. In modern times, living aquatic resources of the CCBNEP area support productive and economically valuable fisheries, both commercial and recreational.

As coastal populations have grown, so has the demand for living aquatic resources. To meet the demand, fishing technology has become modernized and more effective, and more species have been added to the list of sought-after resources. Concurrent with human population growth, habitats essential to the well-being of the nearshore populations of marine fauna have been degraded or lost due to industrial and urban development. Consequently, health, stability and sustainability of living marine resources are issues of major concern. Public cries for management of living aquatic resources of Texas were recorded in the late 1800s, and active efforts to study, monitor, and manage living aquatic resources of the Texas coast began in the early 1900s.

"Management of living aquatic resources" is a misnomer, when in fact it is the behavior and activity of humans that is managed. Exceptions to this are implementation of modern day stocking programs and development of artificial reef programs for enhancing and stabilizing populations of certain species. From a fisheries perspective, the goal is to manage harvest and other human activities that have the potential for stressing naturally occurring populations of living resources beyond that point at which the population can no longer sustain and renew itself. As the demand for living resource grows, so to do groups with socioeconomic dependency upon the harvest of living resources and the concurrent need for resource management.

In theory, management guidelines are based on comprehensive understanding of the population biology of the targeted organism, taking into account weather and other naturally occurring events which impact the species as-well-as anthropogenic impacts. In reality, because of the vastness and complexity of the marine ecosystem and population dynamics of the living resources of the ecosystem, and the financial cost to study the system and its living component, management is often based on limited information.

Living resources, although renewable, can become finite if populations are pushed beyond a point of reproductive sustainability. Historic records chronicle numerous catastrophic collapses of important fisheries including the anchovy fishery of South America, the sardine fishery off Southern California, the recent collapse of George's Bank cod fishery, and the tarpon fishery that once flourished in the CCBNEP area during the 1940s and 50s. In the study and management of the living resources of the CCBNEP area, the goal must be to acquire adequate knowledge and understanding in order to manage living marine resources in a manner that assures continued sustainability of the population in the face of all stresses, natural and anthropogenic. To achieve this goal will require aggressive efforts by professionals with adequate financial resources, and most important, the support of an informed populace, and community, business, and elected leadership. To fail in this pursuit will ensure the addition of the CCBNEP area fisheries, commercial and recreational, to the list of collapsed fisheries and lost resources.

Discussions in this chapter present an overview of CCBNEP area commercial and recreational fisheries productivity and fishery management strategies since 1972, and the economic value of these living resources to the Coastal Bend area of Texas. Although harvest records are not a measure of actual population densities, they do provide insight into harvest pressures and sustainability of targeted populations under existing management guidelines.

2.2 Trophic Roles

The estuarine ecosystem seems to favor generalists, and fishes which inhabit the study area are no exception (Table IV.C.2.1). A generalist-feeding strategy allows fishes to adjust to shifts in community structure (both predators and prey) which occur seasonally and in response to dramatic fluctuations in abiotic parameters such as temperature, rainfall, and salinity. *Pogonias cromis* (black drum) is a benthic feeder, but consumes many food types within that feeding niche, and shares many of the same foods with other sciaenids (Pearson, 1929; Silverman, 1979; Matlock and Garcia, 1983). *Mugil cephalus* (striped mullet), *Brevoortia patronus* (Gulf menhaden), *Micropogonias undulatus* (Atlantic croaker), and *Anchoa mitchilli* (bay anchovy) experience ontogenetic diet shifts in their lifetimes (Darnell, 1958; Matlock and Garcia, 1983; Sheridan et al., 1984). *Micropogonias undulatus* also consume a wide variety of food items during each life stage (Matlock and Garcia, 1983).

General characteristics of feeding relationships among estuarine fishes have been categorized by Day et al. (1989) as: (1) flexibility of feeding in time and space; (2) sharing of the common pool of most abundant food resources among many species; (3) taking of food from different levels of the food web by each species; (4) changing of the diet with growth, food availability, and locality within the estuary; and, (5) use of both the pelagic and benthic pathways by a given species.

Trophic-level research within the study area, or on species found in the study area but from other bay systems has been conducted by Matlock and Garcia (1983), who looked at diets of 17 species including several forage species, Moffett et al. (1979) on *Cynoscion arenarius* (sand seatrout) diets, Simmons and Breuer (1962) on *Sciaenops ocellatus* (red drum) and *P. cromis*, Miles (1949) on several species, Gunter (1945) on several species, and Pearson (1929) on sciaenids.

One of the most complex issues faced by estuarine ecologists today is understanding the carbon and energy flow through the system; the first step is to measure primary productivity. Hellier (1962) estimated that the annual gross primary production in the Laguna Madre was 4,177 g m^{-2} yr^{-1} expressed as oxygen whereas annual fish production was estimated at 15.4g m^{-2} dry weight.

Table IV.C.2.1. Ecology of selected organisms using the study area. Life history stage codes are E=egg, L=larvae, PL=post larvae, J=juvenile, SA=sub adult, A=Adult, S=Spawn. Sources: Pearson (1929); Simmons and Breuer (1962); Copeland (1965); Hildebrand (1954); Moffett et al. (1979); Matlock and Garcia (1983); Dokken et al. (1984); Shlossman and Chittenden (1984); Cody et al. (1985); Monaco et al. (1989).

COMMON NAME	SCIENTIFIC NAME	BAY USE STAGES	ADULT FOOD	SPAWNING
Oysters	*Crassostrea virginica*	ALL	Filter feeder	Apr-Oct
Blue Crab	*Callinectes sapidus*	E,L,PL,J,SA,A	Omnivore	Dec-Oct
Brown shrimp	*Penaeus aztecus*	PL,J,SA	(Juv.) Omnivore	Mar-Dec
White shrimp	*Penaeus setiferus*	PL,J,SA	(Juv.) Omnivore	Apr-Oct
Pink shrimp	*Penaeus duorarum*	PL,J,SA	(Juv.) Omnivore	Spring-Summer
Red drum	*Scianops ocellatus*	L,PL,J,SA,A	Crabs, shrimp, fish	Aug-Nov
Black drum	*Pogonias cromis*	ALL	Clams, veg., fish	Dec-Jun
Spotted seatrout	*Cynoscion nebulosus*	ALL	Shrimp, fish	Summer Apr & Sep peaks
Sand seatrout	*Cynoscion arenarius*	ALL	Fish, crustaceans	Mar-Aug Spring peak
Southern flounder	*Paralichthys lethostigma*	L,PL,J,SA,A	Fish, shrimp	Nov-Apr
Gafftopsail catfish	*Bagre marinus*	All	Decapods, fish	Summer
Sheepshead	*Archosargus probatocephalus*	PL,J,SA,A	Decapods, fish, mollusks, veg.	Jan-May
Striped mullet	*Mugil cephalus*	J,SA,A	Herbivore/Detritivore	Oct-Jan
Atlantic croaker	*Micropogonias undulatus*	L,PL,J,SA,A	Macrobenthos, fish	Aug-Mar
Gulf menhaden	*Brevoortia patronus*	L,PL, J, SA,A	Detritus, plankton	Oct-Jan
Spot	*Leiostomus xanthurus*	PL,J,SA,A	Detritus, microbenthos	Oct-Jan
Anchovy	*Anchoa mitchilli*	All	Phyto- and zooplankton	All year
Silversides	*Menidia beryllina*	All	Zooplankton, detritus	Spring & Fall peaks
Pinfish	*Lagodon rhomboides*	J, SA, A	Macrobenthos, crustaceans, fish	

Conversion efficiency of gross plant production into fish production on a dry weight basis was estimated at 0.074% (Hellier, 1962).

Biomass and production rates of fishes have been assessed within the CCBNEP study area. Hellier (1962), in an 18-month study, estimated the biomass of fish and larger invertebrates in upper Laguna Madre ranged from summer highs of 37.8 g m^{-2} to 2.0 g m^{-2} in the winter. He also estimated annual fish production, measured as weight increase of fish per unit time while the fish were in the study area, at 15.4 g m^{-2}. Jones et al. (1963) measured fish biomass in Corpus Christi Bay using a helicopter-deployed purse net. Biomass from monthly samples from September through March ranged from 5.1 to 18.7 g m^{-2} and averaged 12.2 g m^{-2}.

A different approach to measuring net productivity in bays was used by Copeland (1965). Emigration from bays into the Gulf through Aransas Pass was measured using a tide trap for one year (April 1963 to April 1964). Average biomass of organisms leaving bays during ebb tides over the 1-yr study period was 7.16 g m^{-3}. Copeland calculated a conservative estimate of the yearly average biomass of 11.65×10^7 kg exiting through Aransas pass by extrapolating the trap data by total ebb tide time and average ebb tide velocity over a year. From a spatial perspective, Copeland stated that if the half million acres of bay area from south of San Antonio Bay to the Land-Cut in upper Laguna Madre were dependent on Aransas Pass for access to the Gulf, that figure would represent a net production level of 233 kg $acre^{-1}$.

While attempts to quantify primary production have met with great success, the understanding of secondary production (consumers) has been slow to follow. Early studies, which pointed out that the quantity of energy fixed by green plants is dissipated within 3-4 energy transfers due to efficiency rates of only a few percent, failed to consider that consumers rarely conform to a specific trophic level (Darnell, 1961). In his classic work on trophic relationships of fishes in Lake Pontchartrain, Louisiana (which shares many species in common with the CCBNEP study area), Darnell presented his results as a trophic spectrum (Fig.IV.C.2.1). This represented an alternative model to the more typical trophic level approach, and could be evaluated both quantitatively and comparatively. The importance of detritus and attendant bacteria in the estuarine food web and the tendency of organisms to utilize foods from more than one level were also stressed in his research. These points became the basis for a new paradigm in estuarine food web research. Generalized food webs are now recognized as being fueled either by a phytoplankton source of energy, a detritus source or both (de Sylva, 1975).

2.3 Dependence on Biological Habitats

2.3.1 Dependence on the Estuary

The complexities of an estuarine ecosystem and life history strategies of organisms that rely on it cannot be overstated. While the CCBNEP study area may have discrete boundaries defined through the language that created the program, the estuaries within it are actually one link in an aquatic continuum running from rivers to the Gulf of Mexico. For example, though it has been estimated that up to 97.5% of the total commercial fisheries catch of Gulf states are dependent on

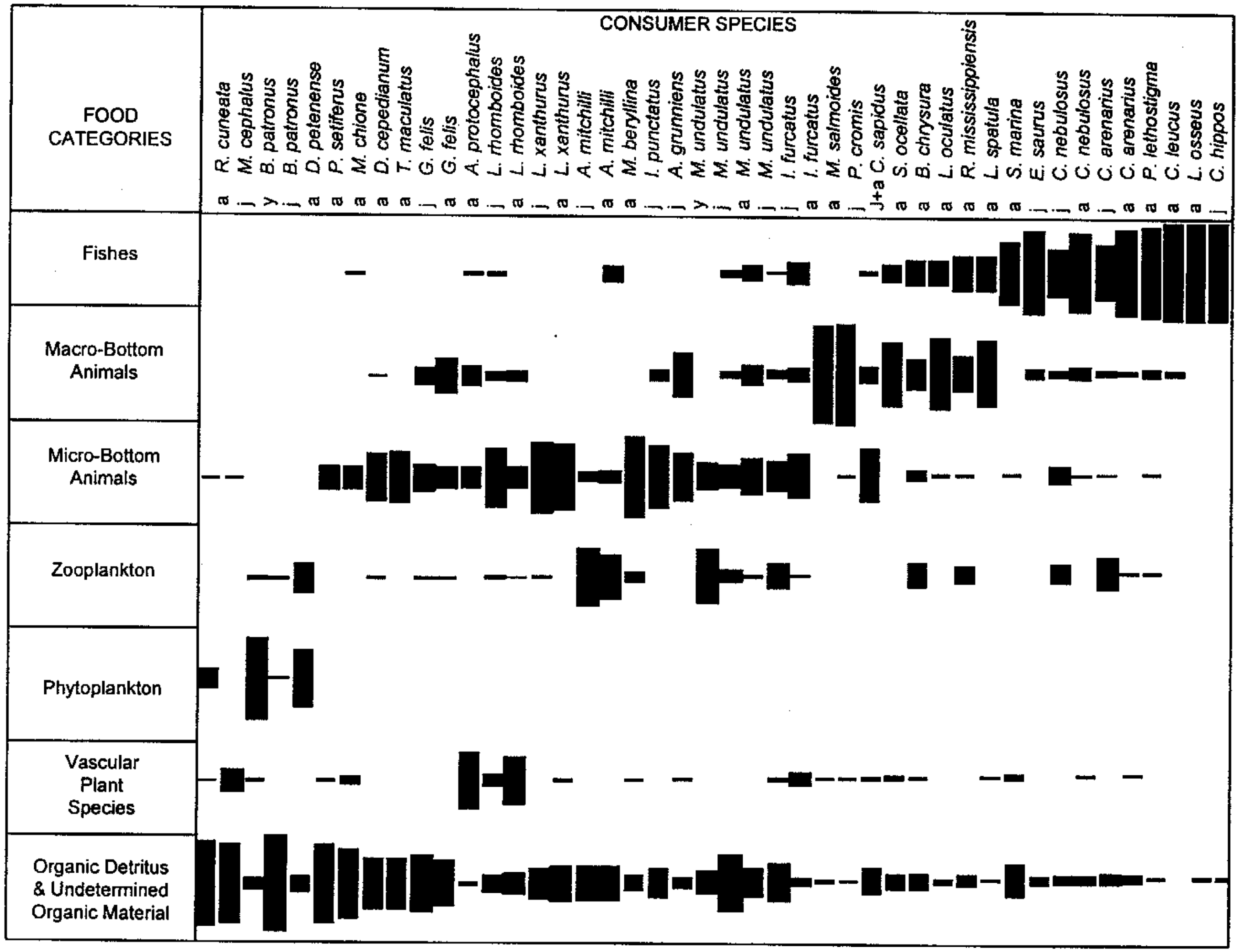


Fig. IV.C.2.1. Trophic spectrum of an estuarine community based on data from Lake Ponchartrain (from Darnell, 1961; copyright © 1961 by the Ecological Society of America, reprinted by permission).

estuaries for some portion of their life history (Gunter, 1967), relatively few species of fishes spend their entire lives exclusively in an estuary. Fishes that use estuaries have been split into six ecological classifications (McHugh, 1967); examples from the CCBNEP study area for each category are given:

1) Freshwater fishes that occasionally enter brackish waters [*Ictalurus punctatus* (channel catfish), *Lepomis macrochirus* (bluegill)]
2) Truly estuarine species which spend their entire lives in the estuary [*Gobiesox strumosus* (skilletfish)]
3) Anadromous and catadromous species [*Dorsoma cepedianum* (gizzard shad), *Anguilla rostrata* (American eel)]
4) Marine species which pay regular, seasonal visits to the estuary, usually as adults (sharks, bluefish)
5) Marine species which use the estuary primarily as a nursery ground, usually spawning and spending much of their adult life at sea but often returning seasonally to the estuary (*Sciaenops ocellatus*, penaeid shrimp)
6) Adventitious visitors which appear irregularly and have no apparent estuarine requirements [*Lutjanus campechanus* (red snapper), *Rachycentron canadum* (cobia)]

Many of the most economically important species harvested in the CCBNEP study area, including penaeid shrimp and *S. ocellatus* (see Table IV.C.2.1), are classified under category 5, the most common of these life history strategies. High primary productivity, relative to that of the marine systems, ensures a vast and varied food supply for larval and juvenile stages of such species. Structurally complex habitats offered by seagrass beds and coastal marshes provides cover, thereby reducing predation potential (Orth et al., 1984; Heck and Crowder, 1988). The salinity gradient between the head of the estuaries to the passes where they link with Gulf waters provides optimal habitat for species which experience ontogenetic shifts in salinity preference such as *Anchoa mitchilli* (bay anchovy) and penaeid shrimp throughout their life cycle (Monaco et al., 1989).

2.3.2 Dependence on Individual Biological Habitats

The CCBNEP study area is a heterogenous ecosystem, offering several biological habitats and broad ranges of abiotic parameters to its inhabitants. Shallow bay grassflat areas are often densely populated with fishes seeking the protection of submerged and emergent aquatic vegetation. Of the several species which use these areas, those found in the greatest number include *Menidia beryllina* (tidewater silverside), *Cyprinodon variegatus* (sheepshead minnow), *A. mitchilli*, *Mugil cephalus*, and *Fundulus similis* (longnose killifish) (Gunter, 1967). Larger fishes, including *Cynoscion nebulosus*, *Sciaenops ocellatus*, and *Paralichthys lethostigma* are also frequently found in shallow bay flat areas.

Seagrass beds and coastal marshes offer structurally complex cover for larval and post-larval fishes and juvenile penaeid shrimp. Hoese and Jones (1963) found the seagrass community in Redfish Bay to be very distinctive, and characterized by the presence of *Lucania parva* (rainwater killifish), *Gerres cinereus* (yellowfin mojarra), *Lagodon rhomboides*, *Gobiosoma* *robustum* (code gobie), *Penaeus duorarum* (pink shrimp), *Neopanope texana*, and *Palaemontes pugio*, with *Micropogonias undulatus* notably absent. Other studies on fish relating to the use of seagrass beds included work by Zimmerman (1969) on macrofauna in *Thalassia testudinum* beds, Holt and Arnold (1982) and Holt et al. (1983) on *S. ocellatus* eggs, larvae and juveniles, and Gourley (1989) on nekton use of adjacent *T. testudinum* and *Halodule wrightii* beds.

Open bay bottoms are important habitat for *M. undulatus*, *A. mitchilli*, *Arius felis* (hardhead catfish), and *Cynoscion arenarius* (sand seatrout) (Gunter, 1967). Deeper waters of the open bays are also important as a thermal refuge when winter cold water temperatures drive fishes, both large and small, off the shallow flats.

Fishes that use oyster reefs as habitat are often poor swimmers, equipped for living among oyster shells and in some cases lay demersal eggs. Several blenny species, *Opsanus beta* (Gulf toadfish), and *Gobiesox strumosus*, make use of this habitat (Gunter, 1967). Oyster reefs are also among the favored feeding places of the *P. cromis*. In fact, resource management law at one time made special provisions for the protection of oyster leases from *P. cromis* by allowing the use of seines in waters normally closed to them if the lease holder took an oath that the fish were seriously damaging the oysters (Anonymous, 1963).

The surf zone of the Gulf side of barrier islands is also frequented by a variety of fish species. Shaver (1984) sampled the surf zone off Padre Island National Seashore monthly for 17 months, during high, low, incoming and outgoing tides and night and day temporal periods. Beach seine samples yielded 67 different species, and plankton net samples produced a total of 57 species. Shaver's found that nine species comprised 88.2% of the total seine catch, including *Harengula jaguana* (scaled sardine), *Anchoa nasuta* (longnose anchovy), *Opisthonema oglinum* (Atlantic threadfin herring), *Mugil cephalus*, *Micropogonias undulatus*, *Anchoa hepsetus* (striped anchovy), *Polydactylus octonemus* (Atlantic threadfin), *Trachinotus carolinus* (Florida pompano) and *Mugil curema* (white mullet). The same pattern of nearshore ichthyofauna being dominated by a few species was also found in studies by Gunter (1958) and McFarland (1963).

2.4 Status and Trends

An important approach in evaluating the health of living resources in the CCBNEP study area is to compare trends in the populations and community structure of organisms living within the area. Estimates of fish biomass per unit area, population size, or even development of a relative index of abundance in estuaries can be difficult (Hellier, 1962; Jones et al., 1963). Habitat heterogeneity requires stratified sampling to detect and appropriately represent the different communities specific to each habitat. Temporal variability (diel, seasonal, cyclical) in fish distribution must also be addressed.

The most robust database for trends in fish abundance in the CCBNEP study area has been collected by the Texas Parks and Wildlife Department's Coastal Fisheries Division (Dailey et al., 1992). Fishery-independent data have been collected using standardized methodology (bag seines, gill nets and trawls) since 1975, and multiple-year trend reports are produced annually (McEachron et al., 1985; Crowe et al., 1986; Hammerschmidt et al., 1988; Rice et al., 1988;

Meador et al., 1988; Dailey et al., 1988; Maddux et al., 1989; Mambretti et al., 1990; Dailey et al., 1991; Dailey et al., 1992; Kana et al., 1993). Since detailed trend analysis of the data specific to the CCBNEP study area will be conducted through a separate project in year two, that data base will not be addressed in this section.

2.4.1 Historical Perspectives

Harvest of marine resources in the CCBNEP study area dates back to prehistoric times, there having been three major periods of prehistoric estuarine resource use in the area (Ricklis, 1993): (1) ca 7,500-7,000 YBP, earliest evidence for shellfish harvest; (2) Mid-Holocene ca 5,900-4,200 YBP continued use of shellfish and limited use of finfish such as *Pogonias cromis*, *Sciaenops ocellatus*, *Cynoscion nebulosus*, *Micropogonias undulatus* and marine catfish; and (3) Late Holocene after ca 3,000 YBP, heavy fish and shellfish harvest.

Since 1887 data have been collected from seafood dealers on commercial landings of marine species from Texas bays and the Gulf of Mexico (Perret et al., 1980). Data were collected intermittently until 1936 when the Texas Game, Fish and Oyster Commission (TGFOC), presently the Texas Parks and Wildlife Department (TPWD) began an annual survey program. Currently, the Monthly Aquatic Products Report program monitors landings and value of marine fishes, oysters, crabs and shrimp (Robinson et al., 1994). Through a cooperative agreement, National Marine Fisheries Service (NMFS) has collected harvest and value data for shrimp since 1956 (Prytherch, 1980).

The Texas coastal fishery was briefly characterized in a report by Evermann and Kendall (1894) as being somewhat smaller than those of other Gulf states (ranked fourth in number of persons engaged and third in value of products) but growing rapidly since 1800. Sixteen vessels (greater than 5 tons) and 115 boats plied the waters of Refugio, Aransas, Nueces counties harvesting the vast marine resources of the local estuaries and adjacent Gulf in 1890. The 385 people employed by the vessel, boat shoreline fisheries in these three counties harvested predominantly oysters, seatrout, *S. ocellatus*, and *Archosargus probatocephalus* (sheepshead) (Table IV.C.2.2).

Table IV.C.2.2. Commercial harvest from Refugio, Nueces and Aransas Counties in 1890. Data from Everman and Kendal (1894).

Product	Pounds	Value	$/100 Pounds
Oysters	643,650	24,950	3.88
Red Drum	632,800	23,753	3.75
Sea Trout	609,250	21,414	3.51
Turtles	535,000	8,935	1.67
Sheepshead	431,190	14,408	3.34
Croakers	95,000	2,775	2.92
Flounders	74,000	2,837	3.83
Mullet	29,000	775	2.67
Crabs	25,000	840	3.36
Snook	9,500	305	3.21

Commercial harvest of sea turtles, a common practice in the early 1900s, was banned in state waters in 1963 (TPWD, 1963). Sea turtles became protected in federal waters in 1970 (Doughty, 1984) and fall under the jurisdiction of the Endangered Species Act of 1973.

Commercial fisheries of Texas bays have seen dramatic changes in technology since the early 1800s. For example, in 1920 the TGFOC's boats demonstrated that shrimp could be caught in the Gulf using a trawl behind a motorized boat fishing at a depth of 40 feet (TGFOC, 1920). It was noted in a subsequent annual report that the Corpus Christi Bay shrimp harvest increased dramatically when shrimpers switched from cast nets and seines to trawls towed by motorized boats (TGFOC, 1922).

The TGFOC hired its first biologist in 1934 (TGFOC, 1935). The department claimed in their annual report for fiscal year 1936-37 that they had, for the first time in history, a fairly accurate record of the Texas coastal marine catch due to legislation requiring that commercial fishers and dealers maintain records of pounds caught by species and area (TGFOC, 1937).

Commercial harvest data were published in TGFOC and TPWD annual reports in fairly consistent format from 1942 forward (Table IV.C.2.3). Harvests were grouped and recorded by district and those presented herein are from Aransas and Laguna Madre Districts.

Harvests in the early to mid-1940s were relatively high, and at least partially explained by the relaxation of state fishing regulations during WWII (Heffernan and Kemp, 1982) and were strongly influenced by socio-economic, marketing factors. A development program to promote harvest and marketing of *Mugil cephalus* (striped mullet), an under-utilized resource, was begun in the late 1940's. The program resulted in higher catches, but market support was insufficient to maintain the fishery (TGFOC, 1949).

A surge in crab harvest in the mid-1940's resulted from packing plants gearing up to accommodate that product; however, when they closed, crab landings dropped. Crab harvests increased in the 1960's as a result of commercial fishers shifting to crabbing to supplement their dwindling income from the declining finfish fishery (TGFOC, 1962). *Pogonias cromis* harvests also increased substantially in the 1960's, partially a result of the Texas Game and Fish Commission's (TGFC)contract removal program in Cameron and Willacy Counties (TGFC, 1962).

2.4.2 Commercial Fishery Data

Commercial fisheries data are currently synthesized annually and reported in the Coastal Fisheries Branch Management Data Series, the most recent of which includes data through 1993 (Robinson et al., 1994). The following discussion relies heavily on data from this report.

Table IV.C.2.3. Commercial harvest (thousands of pounds) from Aransas and Laguna Madre Districts 1942-1970. Data from TGFOC, TGFC, and TPWD Annual Reports.

Year	Red Drum	Spotted Seatrout	Black Drum	Flounders	Croaker	Sheeps-head	Mullet	Shrimp	Crabs	Oysters
42-43	934	1,153	1,085	77	1	0	8	4,392	6	318
43-44	761	1,501	892	148	5	16	3	2,360	1	531
44-45	907	1,475	984	130	4	33	3	3,777	<1	416
45-46	583	1,081	1,176	72	9	21	<1	2,194	135	593
46-47	469	510	648	59	5	7	1	2,110	69	288
47-48	394	418	410	55	7	5	1	8,286	16	165
48-49	421	394	464	108	0	5	289	2,439	0	68
49-50/a	378	311	522	131	3	11	133	24,966	0	12
50-51	216	256	563	85	0	9	20	40,993	1	31
51-52	158	309	470	66	0	39	16	53,411	0	44
52-53	260	405	627	129	0	51	0	49,776	0	98
53-54	278	331	321	58	0	4	6	54,742	0	18
54-55	371	522	904	71	0	22	31	65,213	86	30
56-57	309	371	1,173	73	0	15	8	50,790	0	13
57-58	376	372	484	31	<1	14	3	45,681	7	76
58-59	531	522	738	75	0	12	7	47,970	1	240
59-60	666	796	1,462	98	0	15	62	49,036	843	415
60-61	713	845	1,317	96	5	20	2	42,921	1,323	830
61-62	617	695	1,374	97	11	39	30	41,260	1,769	242
62-63	634	870	1,388	133	1	52	1	35,031	1,040	294
63-64/b	479	703	1,185	158	<1	88	1	39,398	353	224
64-65	407	673	1,258	151	1	98	1	44,828	516	226
65-66	496	668	583	199	1	91	3	45,041	680	92
66-67	562	756	971	189	2	109	1	54,861	403	322
67-68	696	1,112	613	121	5	125	11	47,501	494	145
68-69	720	827	490	158	11	99	35	46,659	2,157	36
69-70	1,371	801	646	134	2	90	1	48,127	1,982	215

/a from this time forward includes both bay and Gulf harvest
/b began to segregate spotted seatrout from other trout

TPWD identified the following data limitations (Robinson et al., 1994):

- The level of inaccurate/incomplete reporting is unknown;
- Different reporting requirements can affect the amount of non-reporting;
- Unlicensed consumers who purchase seafood products directly from commercial fishers without the intent to resell are exempt from reporting;
- Marine products harvested by licensed commercial fishers and sold to a licensed bait or seafood dealer and sold as bait were not reported until September 1991; and
- Marine products harvested by licensed commercial fisheries and sold directly to a restaurant are not reported.

Because fishing effort by gear type is not collected through the existing program, it is not possible to standardize the catch as catch-per-unit-effort (CPUE). Thus, it is not possible to discern to what extent a rise or decline in landings is due to a change in relative abundance of resources, a change in the amount of fishing effort, or a change in consumer preferences.

Although a long-term data series such as this provides an excellent means of identifying trends in the commercial fishery, it is a less-perfect indicator of overall resource abundance for several reasons. Management regulations have become increasingly restrictive and have influenced harvests for commercial finfish (Table IV.C.2.4), commercial shrimp (Table IV.C.2.5) and recreational (Table IV.C.2.6) fisheries. Designation of a species as a game fish, imposition of harvest quotas, size restrictions, area or time closures all may influence total harvest levels and size distribution statistics. Changes in gear efficiency via technological advancements such as the advent of monofilament net, or by regulations imposed for management purposes (i.e. mesh size restrictions) can also affect landings, and makes time series analyses difficult to perform. Commercial fishing effort may also be strongly influenced by ex-vessel seafood prices, which respond to laws of supply and demand. Thus, fishery-dependent data are not surrogates for fish population data, and direct extension of landings trends to represent population trends is not advisable. However, these data do provide a means of describing the actual commercial fishery and secondarily, a means of corroborating trend hypotheses based on fisheries-independent data.
Just as importantly, these data provide a snapshot of the socioeconomic importance of living resources in the CCBNEP study area.

Percent contribution of landings by each product type from the study area to total landings for all Texas bays was calculated to illustrate the relative importance of the area to the commercial fishery (Table IV.C.2.7). Commercial landings in the CCBNEP study area comprised an average of 28% (range 23-37%) of the total landings in all Texas bays during 1972-1992. Finfish harvest from the study area represented an average of 48% of the statewide finfish catch, shrimp an average of 29%, and blue crab an average of 24%. Oyster landings from the study area comprised only 4% of the total oyster harvest for all Texas bays.

An average of 8.4 million pounds of marine species was commercially harvested in the study area from 1972-1992, with landings ranging from a low of 5.2 million pounds in 1989 to a high of 12.0 million pounds in 1991 (Fig. IV.C.2.2). Ex-vessel value of commercial landings in the study area exceeded an average of $1.00 per pound only during 1986 and 1990-1993. For comparative purposes, annual landings' values were standardized to 1993 dollars by adjusting by the Consumer Price Index (CPI) as follows:

$$Value_{iadj} = Value_i \frac{CPI_i}{CPI_{93}}$$

Where: i = a given year

The adjusted value represents an inflation-adjusted figure which can be compared across time in terms of current dollar value. Four distinct peaks are evident, where adjusted value exceeds pounds landed (i.e. price averaged greater than $1.00 per pound), in 1979, 1983-1984, 1986-1987

Table IV.C.2.4. Size restrictions, quotas, and area and gear restrictions for the commercial finfish fishery. Data from TPWD (1979, 1981, 1983, 1985, 1987, 1989, 1991, 1993).

Size restrictions for the commercial finfish fishery in the study area, listed as minimum, maximum sizes in inches (*=no limit).

	1970	1980	1981[1]	1988
Red Drum	14,35	Game Fish	No Sale	
Spotted Seatrout	12,*	Game Fish	No Sale	
Flounder	12,*			
Sheepshead	9,*			12,*
Gafftopsail	11,*			
Black Drum				14,30
Snook		Game Fish	No Sale	
Tarpon		Game Fish	No Sale	

[1] Sale banned as of May 1981.

Commercial harvest quotas for red drum, 1978-1981

	10/1/78	10/1/79	10/1/80	10/1/81
Mission/Aransas	260,540	225,640	231,280	231,280
Nueces	119,280	105,420	103,320	103,320
U. Laguna Madre	215,460	219,940	180,880	180,880

Time, area and gear restrictions on commercial harvest of finfish.

Effective Date	Regulation
11/77	Nets and trotlines prohibited on weekends (1 p.m. Fridays to 1 p.m. Sundays)
12/79	Fish taken incidental to shrimp harvest may be retained EXCEPT red drum and spotted seatrout caught in inside waters with a trawl between 16 Dec. and 28 Feb.
7/80	Monofilament nets banned
9/80	Trotlines prohibited in Baffin and Alazan Bays on weekends
10/80	Trammel nets, gill nets and drag seines prohibited in waters of Port Bay, St.Charles Bay, and Aransas County portions of Copano and Redfish Bays. All remaining waters of Aransas County closed to the use of gill nets.
10/80	Nueces County waters closed all year to seine and net fishing EXCEPT: Corpus Christi Bay one-half mile from shoreline from Naval Air Station around the bay to Ingleside point, trammel nets, drag seines and gill nets with not less than 1.5” square mesh may be used EXCEPT during May through August.
9/80	Gill nets and trammel nets banned in state waters of Gulf
5/81	Commercial sale of red drum and spotted seatrout prohibited
9/82	Illegal to keep red drum or spotted seatrout caught in any net except a dip net
9/82	Illegal to retain red drum or spotted seatrout caught on trotline other than a sail line
9/88	Gill nets, trammel nets and bag seines banned in Texas coastal waters
3/91	Summer trotline ban is repealed

Table IV.C.2.5. Commercial bay and bait shrimp regulations for the CCBNEP study area.

1979	**Commercial Bait[1] Shrimp**	**Commercial Bay[2] Shrimp**
Season	Year round; days[3] only 15 Aug. to 15 Dec. except 24 hrs. in Laguna Madre	Spring: 15 May to 15 July Fall: 15 Aug to 15 Dec.
Size	No size restriction	No size restriction spring; 65 headed or 39 with heads/lb during fall season
Daily Limit	150 lb/day; 50% live	300 lb/day spring season; no limit during fall season
1990		
Season	Year round; 15 Aug. to 31 Mar. days[3] only; 1 Apr. to 14 Aug short days[5] only; 1a.m. to 1 hr. before sunrise only in Intracoastal Waterway in Nueces Co. portion of Laguna Madre	Winter: 1 Feb. to 15 April[4] ; Spring: 15 May to 15 July, short days[5;] Fall: 15 Aug. to 15 Dec., days[3] only.
Size	No size restriction	50/lb count 15 Aug. to 31 Oct.
Daily Limit	200 lb/day, 50% live	600 lb/day spring season
1994		
Season	Year round in bait bays short days[5] 1 April to 14 August; 1 a.m. to 30 min before sunrise in Intracoastal Waterway in Nueces Co.	Winter: 1 Feb. to 15 April[4] ; Spring: 15 May to 15 July, short days[5]; Fall: 15 August to 15 Dec. days[3] only;
Size	No size restriction	50 heads on/pound 15 Aug. to 31 Oct.
Daily Limit	200 lb/day 50% live 16 Aug. to 14 Nov.	600 lb/day spring season

1 Bait bays=Alazan, Baffin, Copano east from Rattlesnake Point to N.E. boundary of Bayside, Gulf Intracoastal waterway exclusive of tributaries, Nueces Bay from bridge at State Hwy. 181 west to second overhead power line crossing the bay, upper Laguna Madre
2 Commercial bay shrimp trawling allowed in major bays (Aransas, Mesquite, and Corpus Christi Bays, exclusive of tributary bays and inlets) only.
3 Day = 30 min. before sunrise to 30 min. after sunset.
4 Night = 30 min. before sunset to 30 min after sunrise
5 Short day= 30 min. before sunrise to 2 p.m.

Table IV.C.2.6. Recreational fishing regulations listed as bag limit, possession limit, minimum size in inches, maximum size in inches. Data from TPWD (1979, 1981, 1983, 1985, 1987, 1989, 1991, 1993).

	1974	1977	1981	1984	1988	1989	1992	1994	1995
Red Drum	*,*,14,*	10,20,14,35[1]	10,20,16,30	5,10,18,30	3,6,20,28			3,6,20,28[2]	
Sp. Seatrout		*,*,12,*	20,40,12,*	10,20,14,*		10,20,15,*			
Flounder					20,40,12,*				
Sheepshead					5,10,12,*				
Gafftopsail					*,*,14,*				
Snook					5,10,18,30	3,6,20,28		3,6,20,28	1,2,24,28
Tarpon					1,1,48,*	0,0		1,1,80,*[3]	
Black Drum					5,10,14,30				
King Mack.					2,2,14,*		2,4,14,*		
Span. Mack.				*,*,14,*	3,3,14,*		7,14,14,*		
Sharks						5,5,*,*	5,10,*,*		
Mullet					*,*,*,12[4]				
FL Pompano					*,*,9,*				

1/ no more than two over 35" allowed
2/ one fish >28" allowed with trophy tag; if filled tag is turned in, a second is offered which allows one fish >28"
3/ one fish >80" allowed with trophy tag
4/ no fish > 12" may be kept Oct.-Jan.

Table IV.C.2.7. Percent contribution of commercial harvest from the CCBNEP study area to the total commercial harvest for the Texas coast. Data from Robinson et al. (1994).

Year	Finfish	Shrimp	Blue Crab	Oysters	Other	Total
72	48.14	21.73	21.92	1.55	0.00	23.30
73	45.43	25.01	19.59	0.52	9.83	25.54
74	49.69	16.65	23.27	0.80	0.00	27.13
75	46.16	23.67	17.26	0.76	0.00	25.86
76	46.46	20.59	21.71	0.62	4.31	24.22
77	48.57	25.25	30.04	2.52	0.00	28.00
78	45.68	23.05	29.73	6.29	0.00	27.41
79	51.95	32.02	30.25	10.80	38.67	33.62
80	57.30	24.95	30.62	1.24	0.00	29.59
81	50.17	29.86	25.70	4.77	0.00	29.24
82	53.71	27.09	28.73	1.42	1.24	26.41
83	65.43	30.51	31.31	1.47	5.38	26.79
84	44.49	37.98	30.90	6.97	13.66	32.39
85	33.43	31.99	25.35	4.22	54.54	25.91
86	48.53	27.54	20.10	1.72	27.52	22.61
87	44.87	28.62	18.29	14.97	47.88	25.37
88	42.89	28.67	27.82	12.21	72.67	28.20
89	34.77	23.01	16.09	6.02	79.86	20.24
90	43.67	38.85	17.01	0.61	62.29	31.63
91	42.01	48.20	16.06	0.01	14.60	37.12
92	55.32	41.48	32.29	0.00	27.29	36.38
93	48.86	32.48	30.62	0.14	37.24	30.07
Mean	**47.61**	**29.06**	**24.76**	**3.62**	**22.59**	**28.05**
High	**65.43**	**48.20**	**32.29**	**14.97**	**62.29**	**22.61**
Low	**33.43**	**16.65**	**16.06**	**0**	**0**	**37.12**

Landings appeared to have an upward trend in the Mission-Aransas and Nueces-Corpus Christi Bay system and a downward trend in upper Laguna Madre (Fig. IV.C.2.3). Again, because effort data are lacking, it is unclear whether this is due to an effort shift among bay systems, a change in relative abundance of resources, or a shift in consumer demand. CPI adjusted value for upper Laguna Madre rarely exceeded the number of pounds landed (Fig. IV.C.2.3), which is explained by the dominance of fish and the relatively low percent contribution of products with relatively higher ex-vessel prices such as shrimp and crabs to the total catch.

Marine organisms landed in the commercial fishery were partitioned into five categories: (1) finfish, (2) shrimp, (3) blue crab, (4) oysters, and (5) other. Percent composition of the catch was and 1990-1992 (Fig. IV.C.2.2). These periods represented years in which shrimp made a higher than usual contribution to the total catch for the area.

calculated by bay area (Figs. IV.C.2.4-IV.C.2.7). Commercial harvest in the CCBNEP study area consisted of almost equal proportions of shrimp, finfish, and blue crabs in the mid-1970s, but has gradually shifted to being dominated by shrimp to present (Fig. IV.C.2.4). Shrimp

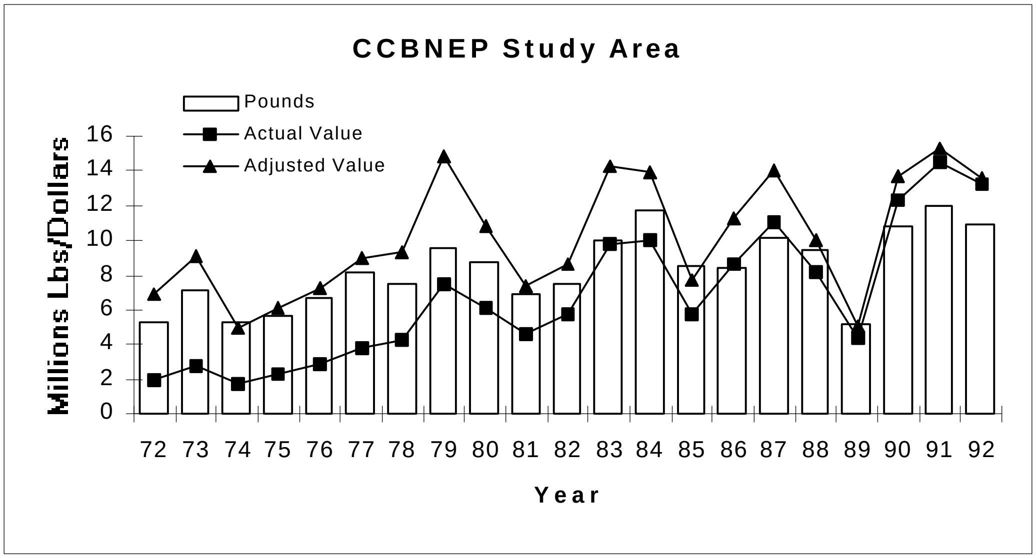


Fig. IV.C.2.2. Commercial pounds, actual value and Consumer Price Index (CPI) adjusted value for the CCBNEP study area, 1972-1992. Data from Robinson et al., (1994).

harvests have more than tripled, from 1.8 million in 1972 to 6.0 million in 1993, whereas finfish harvests have diminished. Crab harvest for the study area have remained fairly stable.

Commercial harvest of the Mission-Aransas system was comprised of nearly equal parts of finfish, shrimp and blue crab for 1972-1976 beyond which time finfish contributions steadily declined (Fig. IV.C.2.5). Shrimp and blue crab landings remained nearly equal until 1981 when shrimp landings began to increase. Shrimp comprised over 75% of the total landings since 1989 in the Mission-Aransas system. Shrimp dominated the catch in the Nueces-Corpus Christi Bay system since 1975, although shrimp landings fluctuated greatly with extreme peaks in 1984 (3.9 million pounds) and 1990-1992 (3.3, 3.4, 3.7 million pounds, respectively) (Fig. IV.C.2.6).

Finfish landings remained at less than half of their 1980 level for a decade, but showed a marked increase in 1992 and 1993. Blue crabs did not make a significant contribution to landings in the bay until 1986; levels were highly variable from that point on.

Finfish comprised greater than 80% of the total harvest from upper Laguna Madre in 13 of the 22 years (Fig. IV.C.2.7). However, total poundage of finfish landings decreased dramatically in 1984, partially due to the imposition of harvest restrictions, and has remained below historical levels to present. Shrimp and crab landings were extremely low between 1979 and 1984 after which they began a parallel pattern of increases and decreases, respectively, between 1985 to present.

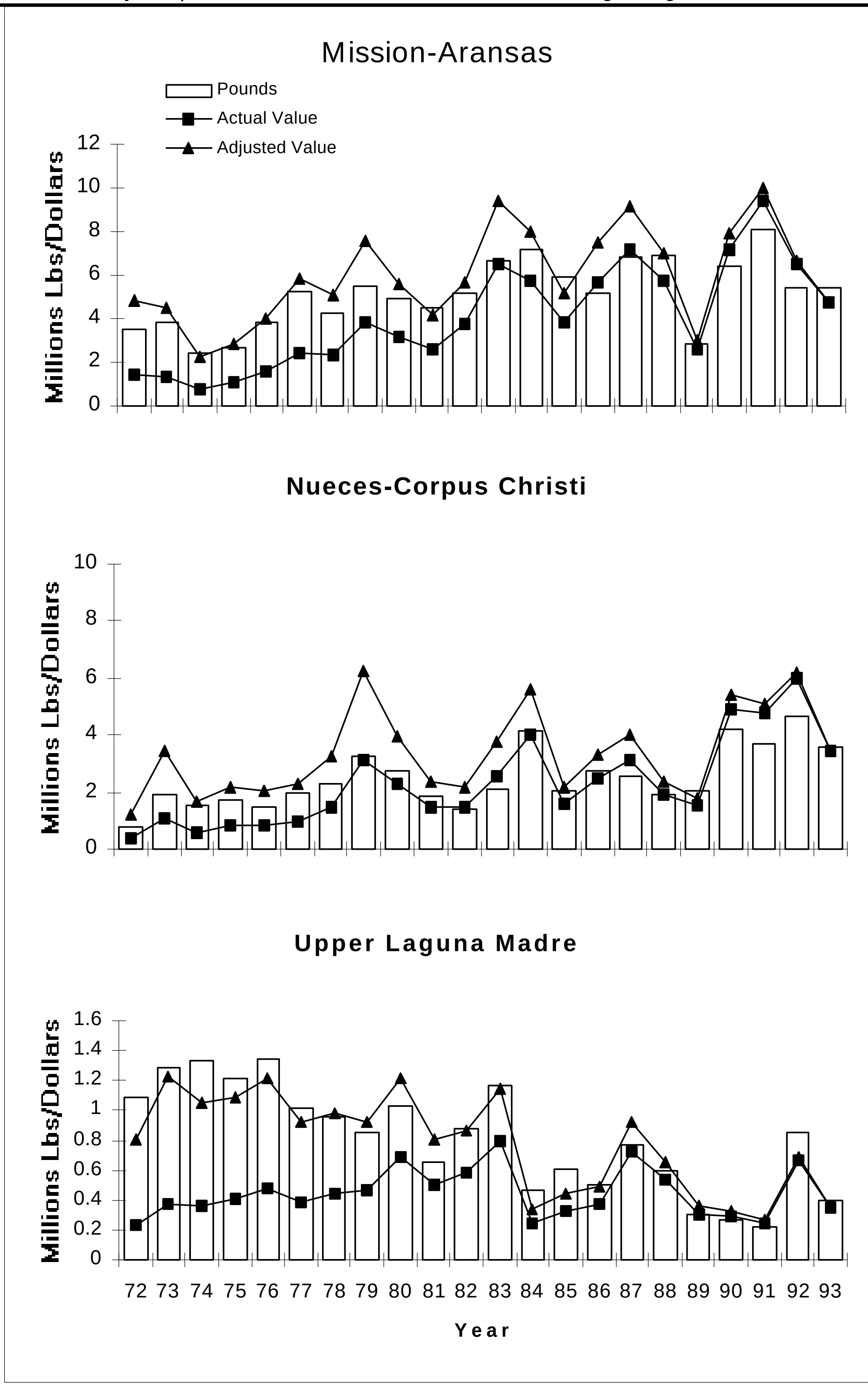


Fig. IV.C.2.3. Commercial pounds, actual value, and Consumer Price Index (CPI) adjusted value by estuary in the CCBNEP study area, 1972-1993. Data from Robinson et al. (1994).

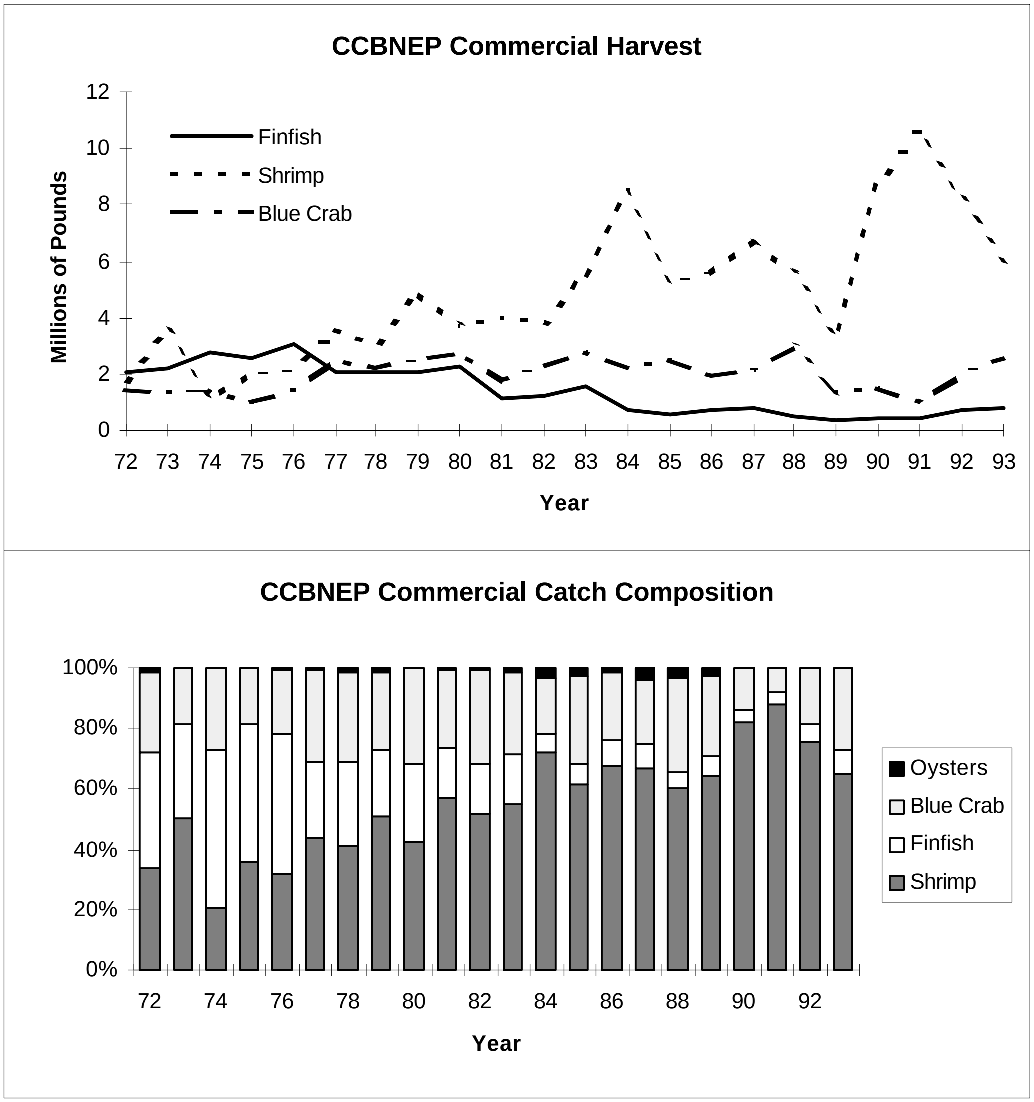
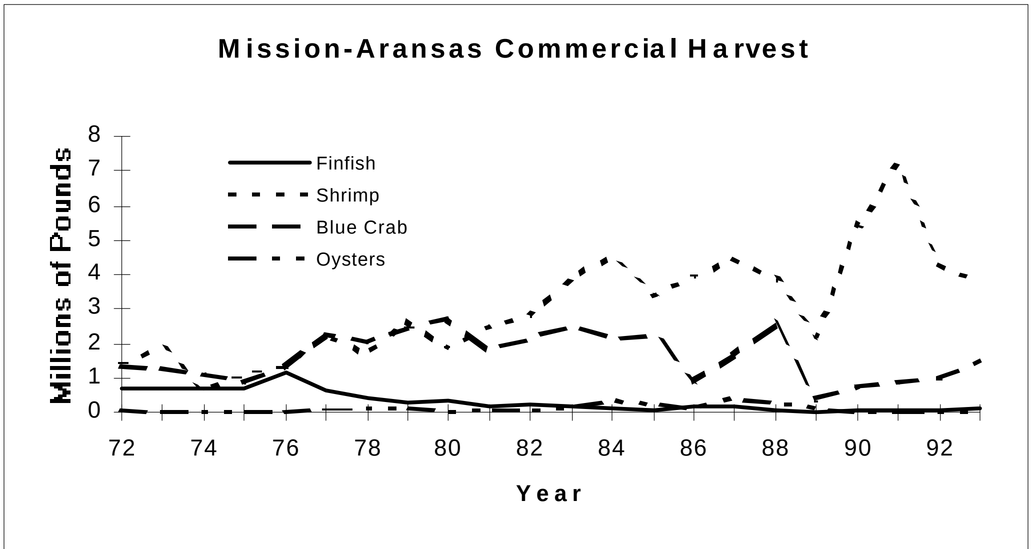


Fig. IV.C.2.4. Commercial harvest and percent composition by species group for the CCBNEP study area 1972-1993. Data from Robinson et al. (1994).

Although effort data are not available to standardize the commercial landings over time, records of the number of commercial vessel licenses by species group are maintained for state-wide bayfishing. Some comparison can be made between number of vessels licensed state-wide to the harvest of organisms in the CCBNEP study area. While not a true measure of CPUE, it does provide a relative index. Purchase of bay shrimp boat licenses, state-wide, steadily increased through 1984, beyond which it has steadily declined to levels experienced in the mid-1960s (Fig. IV.C.2.8). Shrimp harvest in the CCBNEP study area has been highly variable but has generally increased since 1974.



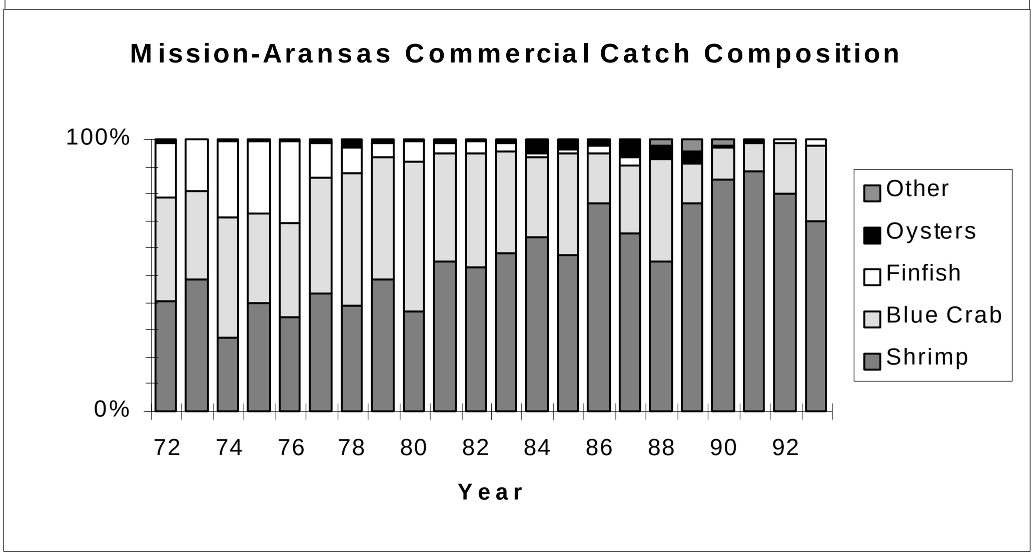


Fig. IV.C.2.5. Commercial harvest and percent composition by species group for the Mission-Aransas estuary, 1972-1993. Data from Robinson et al. (1994).

Finfish boat license sales have remained at fairly constant levels especially over the last 10 years, during which time they averaged around 1,100. However, finfish harvest dropped precipitously from a peak year in 1976 of over 6.5 million pounds to a record low of 0.9 million pounds in 1989 and gradually increased until present. This trend can be partly explained by the designation of *Sciaenops ocellatus* (red drum) and *Cynoscion nebulosus* (spotted seatrout) as a game species in 1981, banning sale of both species.

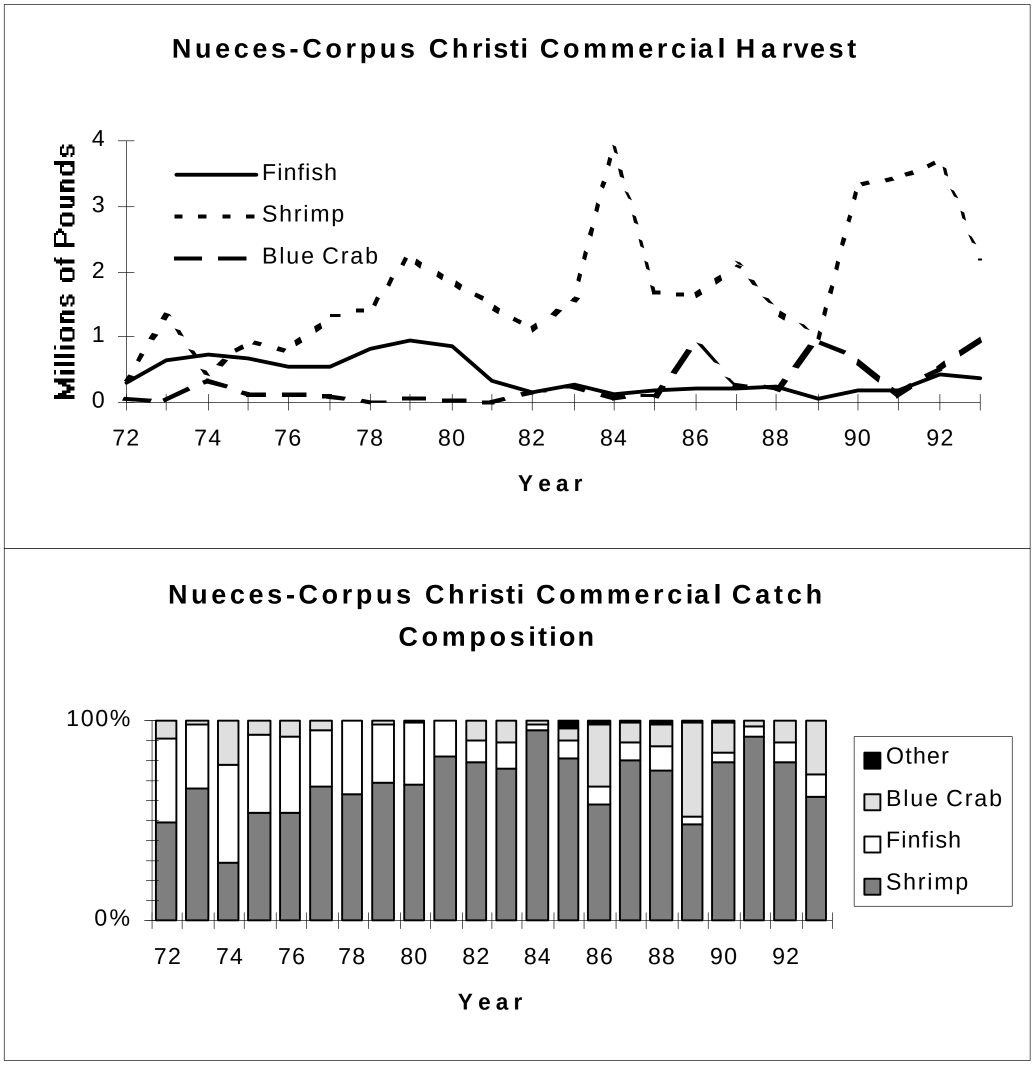


Fig. IV.C.2.6. Commercial harvest and percent composition by species group for the Nueces-Corpus Christi estuary, 1972-1993. Data from Robinson et al. (1994).

2.4.3 Private Boat Recreational Fishery Data

Surveys of sport boat anglers have been conducted by TPWD since 1974 (Heffernan et al., 1976). Data collected are used to estimate annual fishing pressure and landings for Texas bays, including those in the CCBNEP study area, and for Gulf of Mexico waters. Private boat data have been collected from the study area since 1974, and party boat (a boat carrying 10 or fewer paying passengers) and head boat (a boat carrying 11 or more paying passengers) since 1983. A detailed account of survey methods and results from 1974-1992 are presented in Warren et al. (1994); this section relies heavily on data from this report. Private boat data will be the focus of analyses since they have been collected consistently over the longest time period.

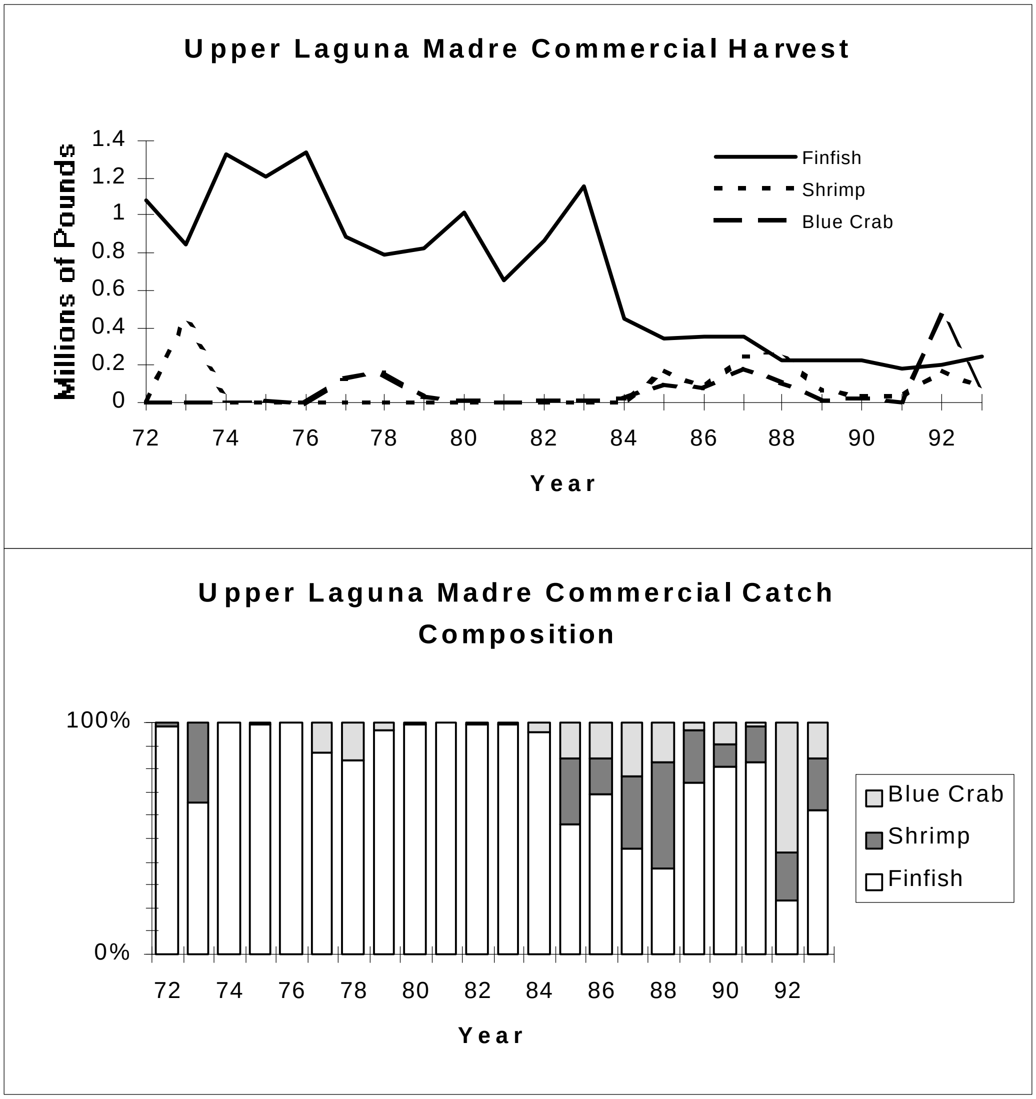


Fig. IV.C.2.7. Commercial harvest and percent composition by species group for upper Laguna Madre, 1972-1993. Data from Robinson et al. (1994).

Catches are all reported as numbers of fish and fishing pressure is reported as fish caught per hour of fishing effort. Recreational data are reported by sampling year, which is defined as beginning on May 15 of one calendar year through May 14 of the next year. In the first year of the program (May 1974 to May 1975) only Mission-Aransas and Upper Laguna Madre were sampled, and in the second year (May 1975-May 1976) only Nueces-Corpus Christi Bay was sampled. Each of the three bay systems in the CCBNEP study area were sampled annually from May 1976 thereafter.

Fishing regulations have a strong influence on the harvest of the recreational fishery and therefore must be considered when looking for trends in catch and effort statistics. Several

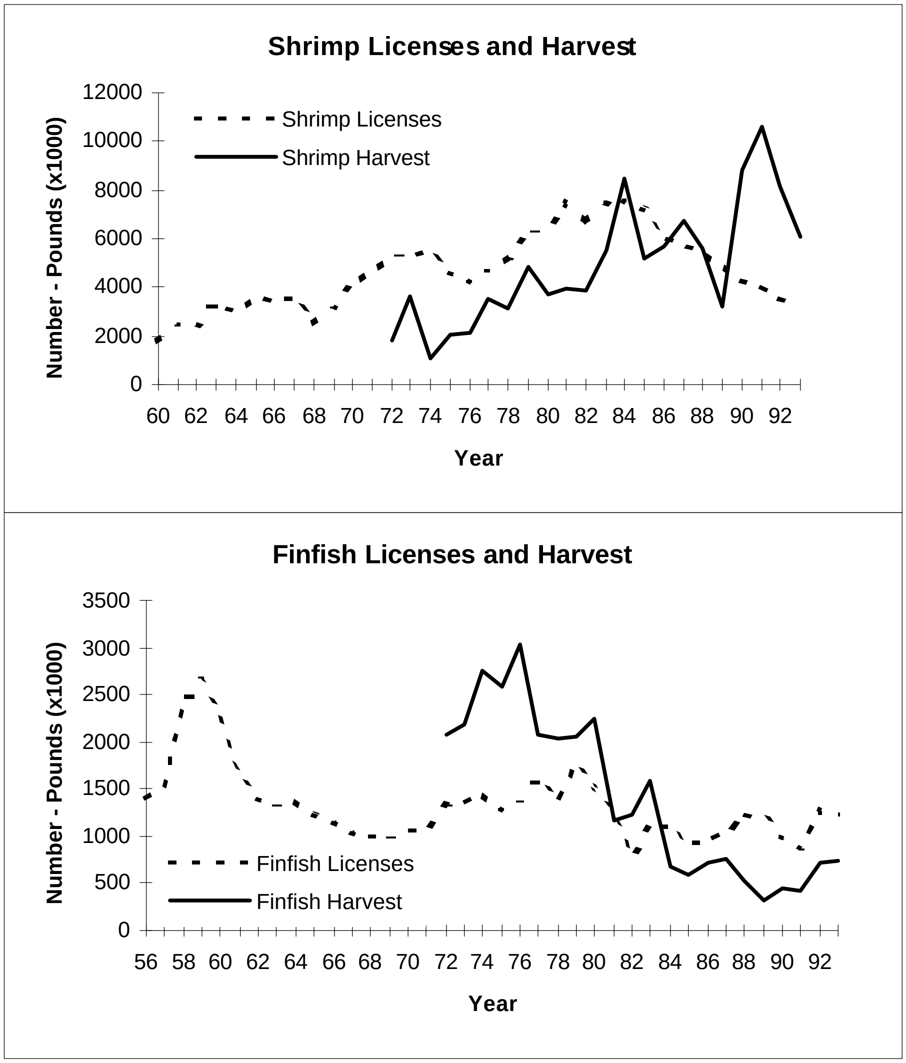


Fig. IV.C.2.8. Shrimp licenses sold for all Texas bays vs shrimp harvest and finfish sold for all Texas bays vs finfish harvest in the CCBNEP study area. Data from Robinson et al., 1994).

changes in finfish bag and possession limits and size restriction regulations were made during 1974-1993 (see Table IV.C.2.6).

Recreational fishing in the CCBNEP study area contributed an average 32% of total fishing pressure and 28% of total catch in all Texas bays combined from 1976 to 1991. The percent contribution of the CCBNEP study area to total Texas bay landings has been consistently lower than the percent contribution of fishing pressure since 1983 (Fig. IV.C.2.9). This implies that catch per unit effort (CPUE) has been lower in the CCBNEP study area than average CPUE throughout the remainder of the Texas coast.

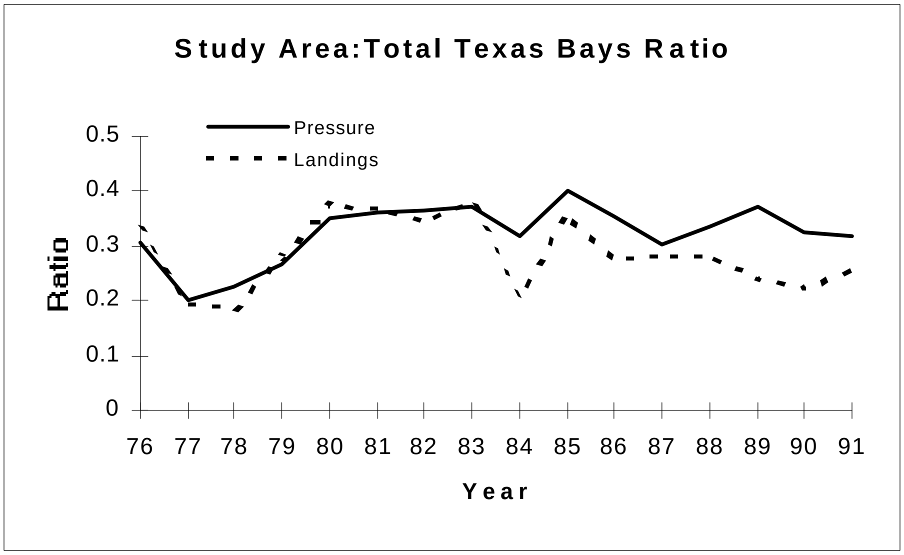


Fig. IV.C.2.9. Ratio of recreational fishing pressure and landings for private boats in the CCBNEP study area to that of all Texas bays combined. Data from Warren et al. (1994).

Fishing effort and catch for the study area has been highly variable through time (Fig. IV.C.2.10). Effort appears to have an increasing trend in both the Mission-Aransas and Nueces-Corpus Christi Bay systems, and a decreasing trend in upper Laguna Madre (Fig. IV.C.2.11). With the exception of a notable peak in number of fish caught in Nueces-Corpus Christi Bay in 1980, recreational harvest has shown similar patterns but of somewhat different magnitude in each of the three bays. The sharp decline in both fishing effort and catch in 1984 is a result of several factors relating to a severe freeze December 1983- January 1984. The freeze resulted in catastrophic mortality, particularly in the shallow waters of the Laguna Madre (Texas Parks and Wildlife Department, 1985), prompting the promulgation of emergency regulations reducing bag and possession limits of *S. ocellatus* and *C. nebulosus* by half (from 10 fish per day to 5 and from 20 fish per day to 10, respectively) and narrowing the size slot for legal retention (*S. ocellatus* from 14-35" to 18-30" and increasing *C. nebulosus* 12" minimum length to a 14" minimum).

Private boat effort generally increased in the Mission-Aransas and Nueces-Corpus Christi Bay systems and has been highly variable but generally decreasing in the upper Laguna Madre with the exception of the last two years (Fig. IV.C.2.11). Catch has been fairly variable, but has generally decreased between 1987 and 1990, after which time it began to increase in all three bay systems.

CPUE, reported as fish caught per hour of fishing effort, for all species combined has been below the historical mean (1974-1991) since the early 1980s (Fig. IV.C.2.12). Again, changes in size restrictions and bag/possession limits enacted during this time (see Table IV.C.2.7) would have been expected to have a strong affect on CPUE. Designation of *S. ocellatus* and *C. nebulosus* as game fish in 1981 effectively banned commercial harvest and sale, and should have increased the number of fish available for recreational harvest. However, recreational bag and possession limits and size restrictions for the two species became progressively more conservative

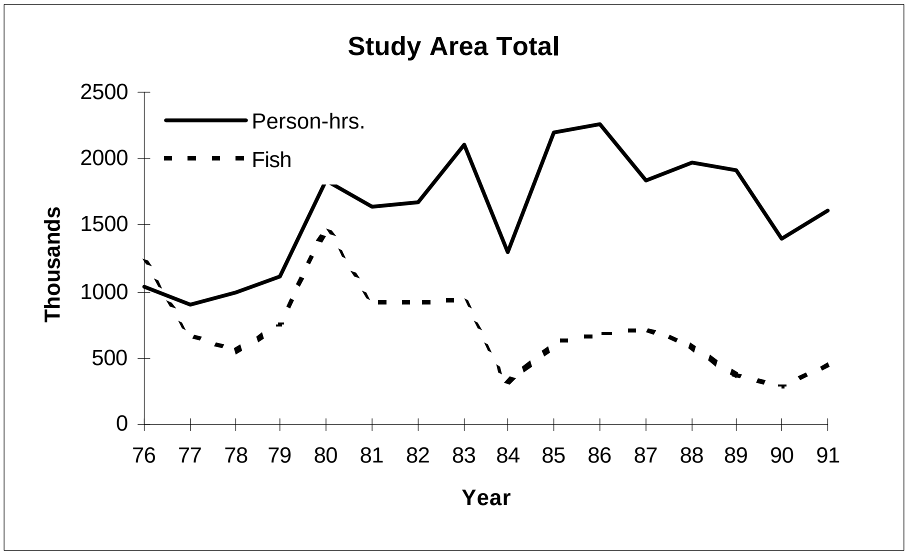


Fig. IV.C.2.10. Recreational fishing pressure and catch for private boats in the CCBNEP study area. Data from Warren et al. (1994).

thereafter, so if increases did in fact occur, they were not manifested in increased recreational CPUE. The most notable changes, or patterns of fluctuation in CPUE occurred in three species: (1) *C. nebulosus*, (2) *C. arenarius*, and (3) *M. undulatus* (Warren et al., 1994) the latter two being unregulated species.

Cynoscion nebulosus CPUE has been below its long-term mean since 1984 (Fig. IV.C.2.13), with the exception of 1988 in upper Laguna Madre, although regulation changes strongly influenced the overall trend. Sale of *C. nebulosus* was banned in 1982 after being designated a game species. The recreational bag limit was reduced from 20 fish per day to 10 fish per day and the minimum size limit increased from 12 to 14 in in 1984 in response to the fish kills due to freezes in December 1983 and January 1984 (TPWD, 1985) The minimum size was again increased from 14 to 15 in in 1990 following two severe freezes (TPWD, 1991). Preliminary data indicate the proportion of private boat fishers filling their bag limit is less than 5%, meaning the size slot has a stronger influence on overall CPUE than does the bag (TPWD, unpublished data). Increases in CPUE in all three bay systems were experienced for the first time since 1988 in 1991.

Cynoscion arenarius CPUE has been highly variable among the three bay systems and among years (Fig. IV.C.2.14). Catch rates in the Nueces-Corpus Christi system were an order of magnitude higher than those of the Mission/Aransas and upper Laguna Madre systems. During 1974-1981 *C. arenarius* CPUEs in Nueces-Corpus Christi Bay were second only to those for *C. nebulosus* among the major recreational species, but tapered off to well below the 17-year average after 1981. Catch rates were generally low with peaks in 1976 and 1986 in the Mission-Aransas system. CPUE in upper Laguna Madre followed the same trend except for a strong peak in 1990. Since this is an unmanaged species, the CPUE trend is not confounded by bag or size regulations. Fuls (1995) found that that *C. arenarius* was prevalent in commercial bay shrimp

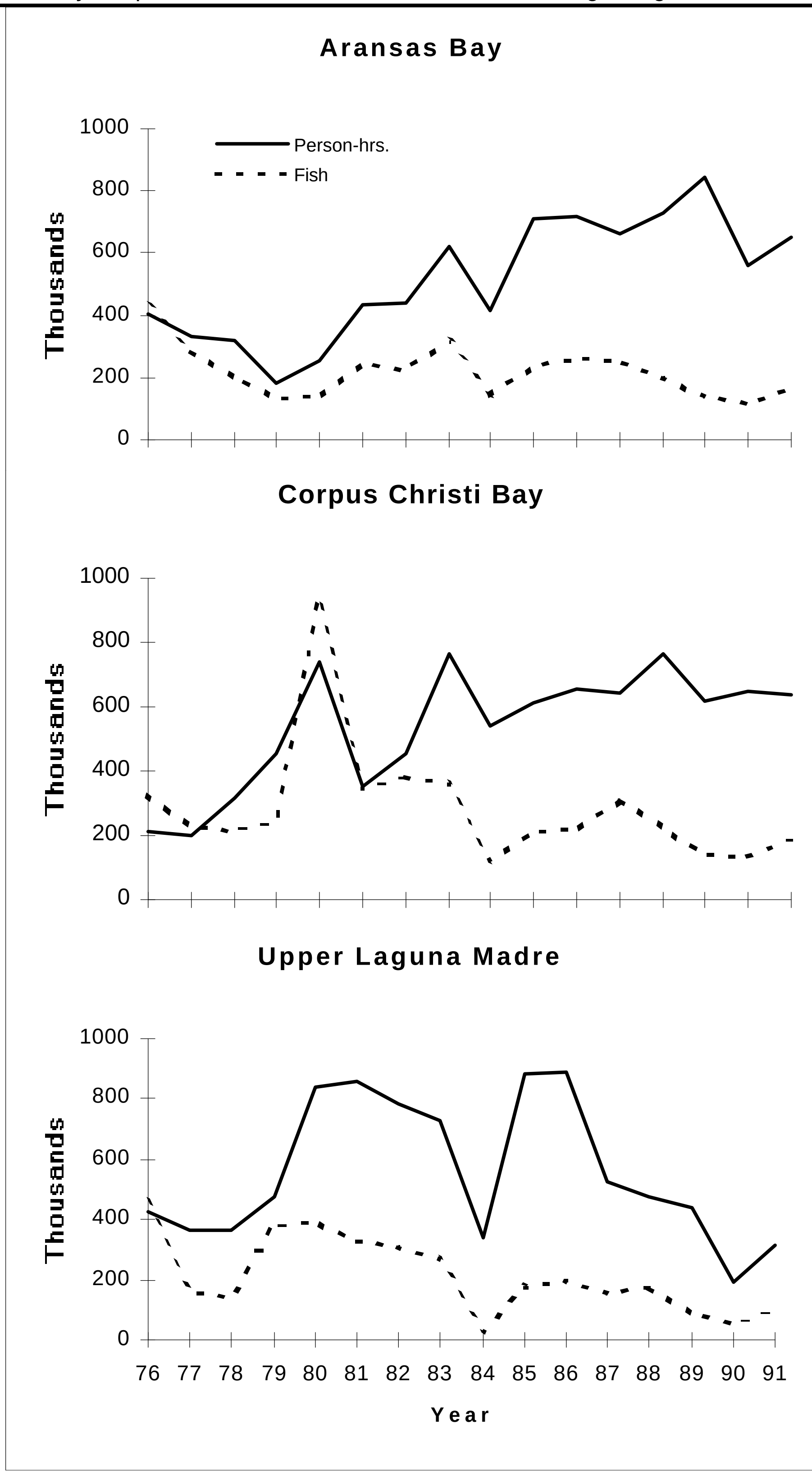


Fig. IV.C.2.11. Recreational fishing pressure and catch for private boats by estuary. Data from Warren et al. (1994).

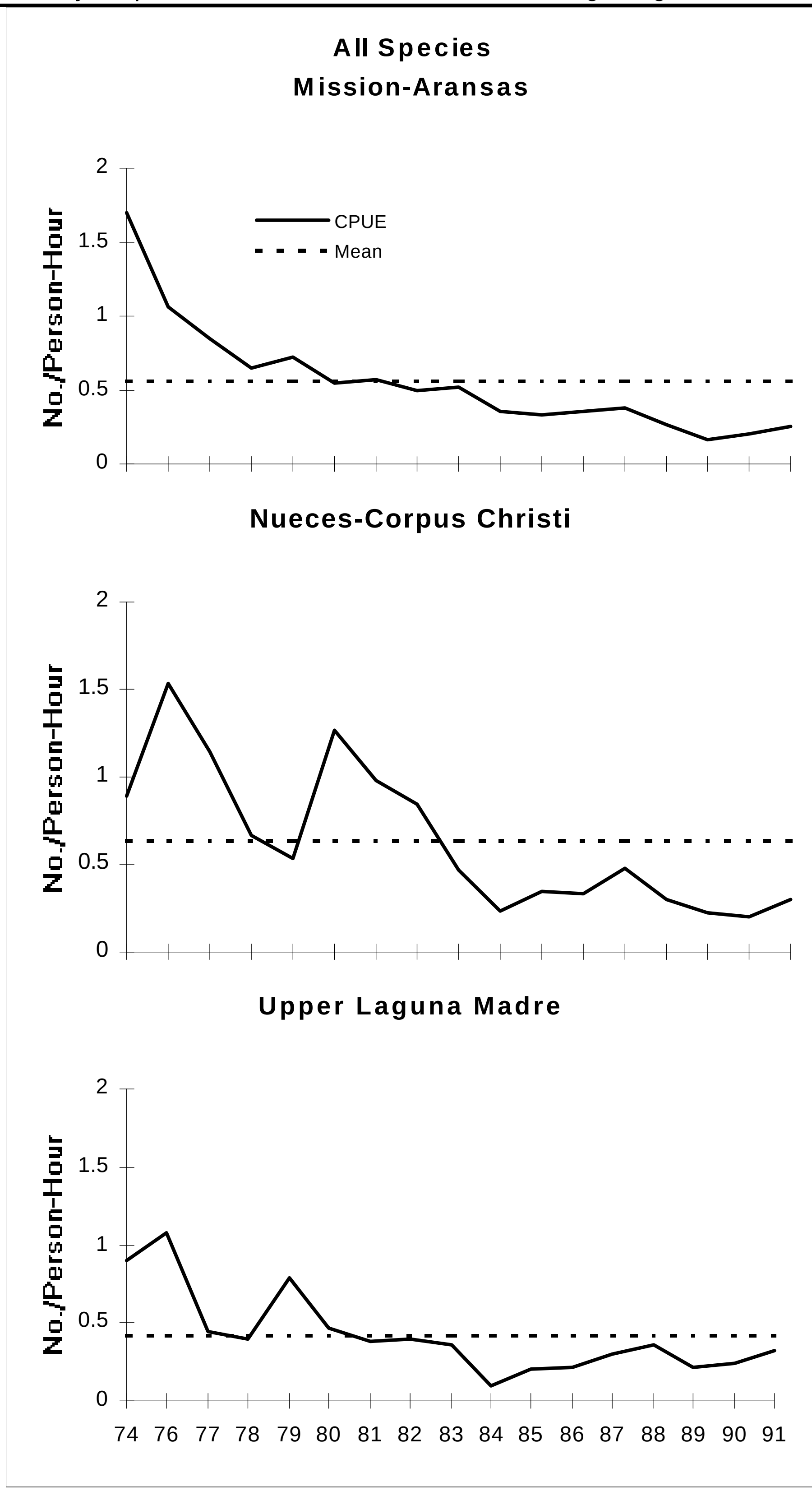


Fig. IV.C.2.12. Catch per unit effort (CPUE) for all finfish species combined for private boats by estuary. Data from Warren et al. (1994).

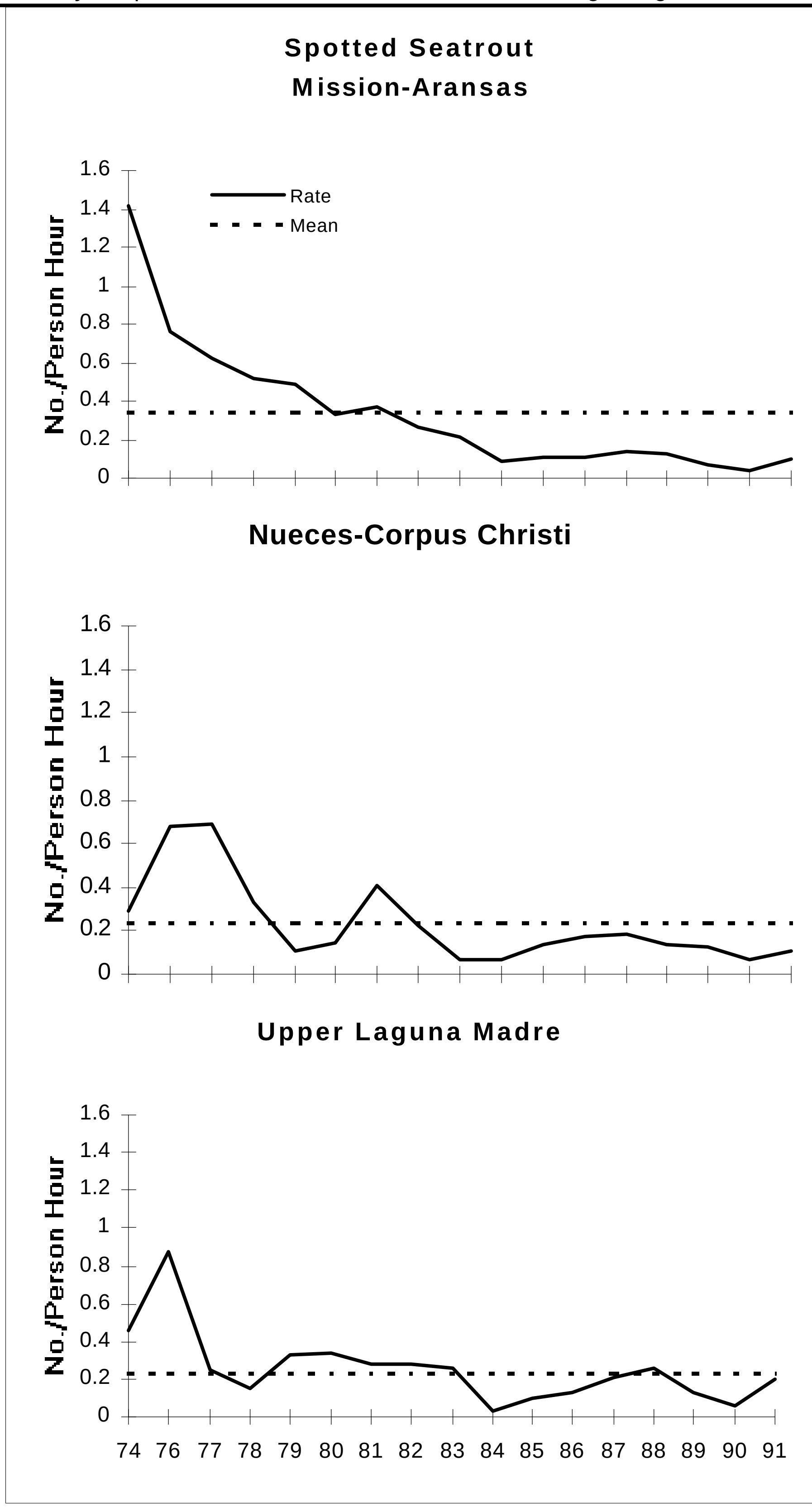


Fig. IV.C.2.13. Catch per unit effort (CPUE) for spotted seatrout for private boats by estuary. Data from Warren et al. (1994).

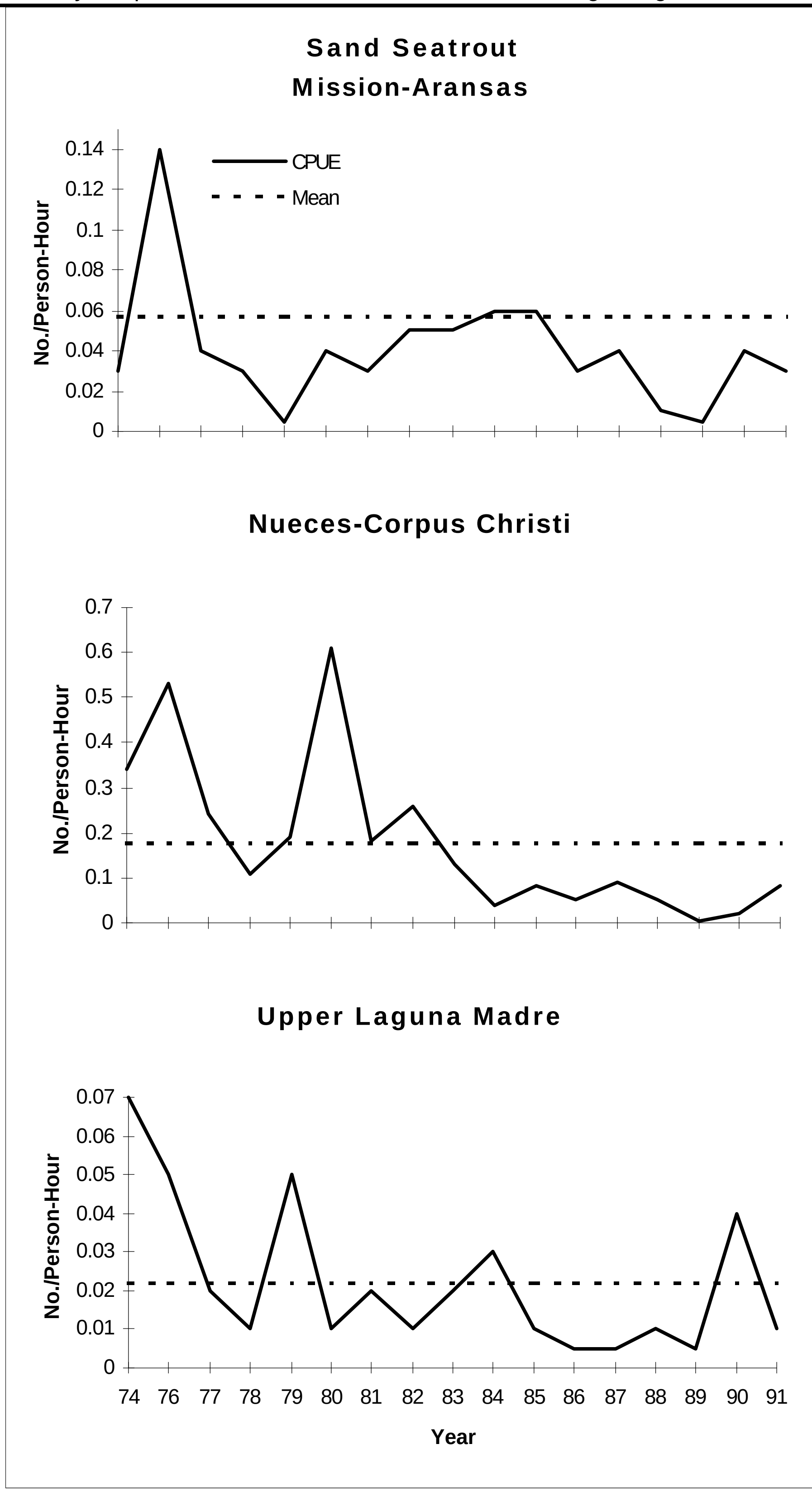


Fig. IV.C.2.14. Catch per unit effort (CPUE) for sand seatrout for private boats by estuary. Data from Warren et al. (1994).

trawl bycatch, particularly in Corpus Christi Bay where it comprised of 6.34% and 28.35% (by number) of total bycatch in the spring and fall bay shrimp seasons, respectively. These values, coupled with directed harvest by the recreational fishery and/or other yet undetermined causes, may have contributed to the decline.

Catch rates for *Micropogonias undulatus*, also an unregulated species, have been highly variable among the three bay systems and among years (Fig. IV.C.2.15). In upper Laguna Madre, CPUE has been below its historical mean since 1979, and pronounced peaks have occurred in each of the three bay systems. This species also contributed significantly to bycatch in bay shrimp trawls, particularly in spring when it comprised 10.71% and and 6.61% (by number) of the Aransas Bay and Corpus Christi Bay total bycatch, respectively (Fuls, 1995).

2.4.4 Commercial and Recreational Bycatch

Bycatch, the incidental harvest of fish or shellfish other than the species for which the gear was set, or the incidental harvest of a target organism that is either out of season or of unmarketable size, is a worldwide problem (Food and Agriculture Organization, 1994). Since the introduction of the otter trawl in the early 1900s as the primary gear for shrimp harvest in the Gulf of Mexico, bycatch has been recognized as detrimental in the Texas fishery. Finfish bycatch in the Gulf of Mexico's offshore shrimp fishery is estimated to be 400 million pounds annually and is made up primarily of juvenile groundfish such as *M. undulatus* and *Leiostomus xanthurus* (spot) (Nichols et al., 1990). Turtle Excluder Devices (TED), required on trawl gear in Gulf waters since 1987 to reduce sea turtle mortality, had an added benefit of also reducing finfish bycatch. As mandated in the 1990 amendment to the Magnuson Fishery Conservation Management Act, continuing research is underway to develop gear modifications specifically designed to further reduce finfish bycatch (National Marine Fisheries Service, 1992; Hoar et al., 1992).

Three studies on bycatch have been conducted in the CCBNEP study area, two on the commercial bay shrimp fishery and one on the recreational fishery. An investigation of *Paralichthys lethostigma* bycatch in the commercial shrimp trawl fishery in Texas bays was conducted April through November, 1978 (Matlock, 1982). Monthly estimates of *P. lethostigma* catch in shrimp trawls ranged from 0.0 to 45.4 per hour in the three bay systems of the study area. Matlock estimated the coastwide bycatch of *P. lethostigma* during that time period was 9,740,800 ± 552,860 fish, which was 13 times higher than the directed catch of 737,000 fish from the recreational and commercial fisheries during 1974 to 1976.

A study of bycatch in commercial shrimp trawls, conducted during the 1993 spring and fall bay shrimp season (Fuls, 1995) revealed finfish bycatch was higher during the fall commercial season in both Aransas and Corpus Christi Bays, and was higher overall in Corpus Christi Bay than in Aransas Bay (Table IV.C.2.8). Highest ratio of finfish bycatch to shrimp by number (1.86) occurred in Corpus Christi Bay during the fall season, and highest ratio by weight (4.18) occurred in Port Aransas, also during the fall season. The number of individual species represented in the bycatch was higher during the fall than in the spring season in both bays (Table IV.C.2.9).

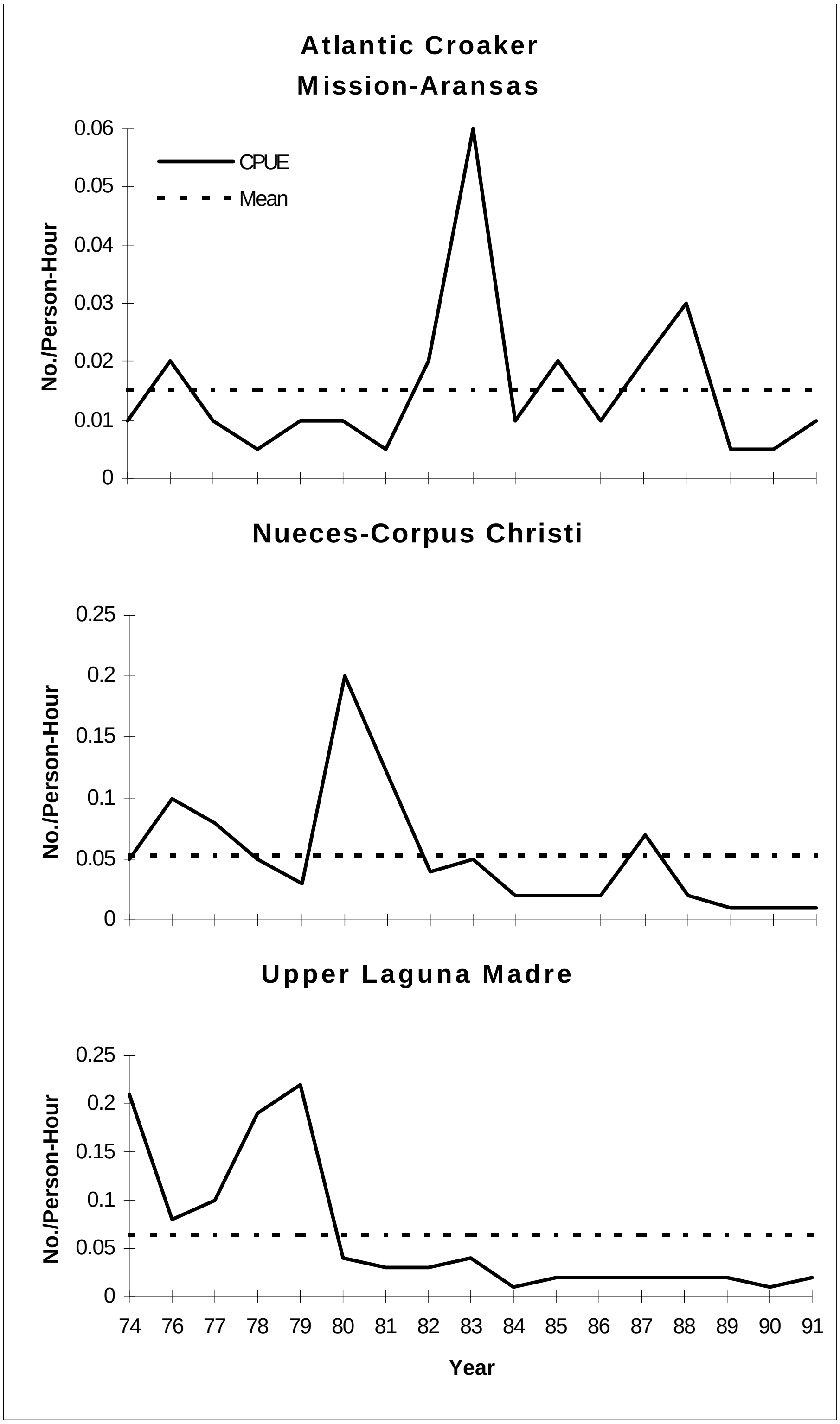


Fig. IV.C.2.15. Catch per unit effort (CPUE) for Atlantic croaker for private boats by estuary. Data from Warren et al. (1994).

Table IV.C.2.8. Mean ratios (± 1 S.E.), in number and weight, of finfish bycatch to shrimp and total bycatch (finfish and other invertebrates) to shrimp for commercial bycatch samples collected in Aransas Bay and Corpus Christi Bay during the 1993 spring (15 May-15 July) and Fall (15 August-15 December) commercial shrimp seasons. No.= ratio by number; Wt.= ratio by weight, and S.E. = standard error. Data from Fuls (1995).

	Spring Season				Fall Season			
	No.	S.E.	Wt.	S.E.	No.	S.E.	Wt.	S.E.
Aransas Bay								
Fish to shrimp (x:1)	1.10	0.24	1.65	0.47	1.73	0.60	4.18	1.21
All bycatch to shrimp(x:1)	1.22	0.22	2.35	0.43	1.91	0.60	4.85	1.28
Corpus Christi Bay								
Fish to shrimp (x:1)	1.65	0.61	5.19	2.94	1.86	0.95	4.12	2.12
All bycatch to shrimp (x:1)	2.32	0.78	6.82	3.46	2.49	1.02	5.14	2.24

Table IV.C.2.9. Number of species and top four contributors by bay and season to commercial bycatch samples collected in Aransas Bay and Corpus Christi Bay during the 1993 spring (15 May-15 July) and Fall (15 August-15 Decempber) commercial shrimp seasons. Data from Fuls (1995).

	SPRING	FALL
Aransas Bay	42 species Top 4 species: 87% mean CPUE by no. 89% mean CPUE by wt. Gulf menhaden Spot croaker Atlantic croaker Blue crab	72 species Top 4 species: 80% mean CPUE by no. 66% mean CPUE by wt. Gulf menhaden Pinfish Bay anchovy Spot croaker
Corpus Christi Bay	69 species Top 4 species: 73% mean CPUE by no. 60% mean CPUE by wt. Sand seatrout Lesser blue crab Spot croaker Bay anchovy	71 species Top 4 species: 53% mean CPUE by no. 40% mean CPUE by wt Gulf menhaden Roughback shrimp Lesser blue crab Star drum

Recreational bycatch was also investigated in Texas' coastal and Gulf waters for private boat fishers from 15 May to 15 November 1993 (Campbell and Choucair, 1995). Bycatch estimates by species were generated from data collected by angler interviews and through tally sheets completed by anglers. Ratios of bycatch estimates to landing estimates ranged from a low of 0.82 for *C. arenarius* to a high of 4.01 for *Bagre marinus* (gafftopsail catfish) (Table IV.C.2.10).

2.4.5 Natural Causes of Population and Community Variability

Estuarine fish communities can be highly variable in structure. Day et al. (1989) proposed four reasons to explain the characteristically large variations in the fish community structure of

Table IV.C.2.10. Ratio of total coastwide estimated bycatch released (based on angler interviews) to landings by private boat anglers fishing in Texas bays and passes 15 May to 20 November 1993. (Data from Campbell and Choucair, 1995)

Species	Bycatch/Landings
Atlantic croaker	1.23
Black drum	1.89
Gafftopsail catfish	4.38
Red drum	2.21
Sand seatrout	0.56
Sheepshead	2.55
Spotted seatrout	2.12
Other species	6.31
All species	2.46

estuaries: (1) species migrate in response to seasons; (2) species utilize estuaries for feeding in response to seasonal events, such as river flooding; (3) species utilize estuaries seasonally for spawning and as nursery grounds for young fish; (4) and, absolute abundances of any given species vary from one year to the next. Among these, the first three are probably the easiest to quantify since changes occur annually. Interannual variability in populations within communities has proven to be difficult to measure, but is of critical importance to understanding the ecosystem. It is an interesting paradox that while estuaries are critically important ecosystems to the ichthyofauna of the area, they are systems of harsh environmental extremes. Episodic, natural events such as heat waves, freezes, droughts, floods, hurricanes and algal blooms can cause dramatic, intermittent perturbations to the ecosystem and concomitant changes in the community structure of inhabitants.

2.4.5.1 Passage through Inlets

The ability to move freely between bay and Gulf waters is a critical requirement in the life history of several fish species using the study area. Several species of fishes migrate from the bays to spawn in the Gulf of Mexico, leaving their young with the perilous task of entering the bays through tidal passes to reach nursery grounds (Simmons and Hoese, 1960; Copeland, 1965; King, 1971; Allshouse, 1983). Mechanisms of inshore transport are complex and not well understood (Norcross and Shaw, 1984). Some species spawn well offshore, such as the penaeid shrimps and *M. cephalus*, and the young must first traverse extended distances of open Gulf before entering the inlets (Hoese, 1965). Other species, such as *S. ocellatus*, spawn adjacent to bays, relying on passive mechanisms to successfully enter the estuarine system (Holt et al., 1989). Changes in prevailing winds, hydrologic and meteorologic events, number of open passes, and pass conditions all influence successful larval transport.

Changes in the number of open passes from the Gulf into the CCBNEP study area have occurred through time, both naturally and through dredging projects. Corpus Christi Pass was first dredged in 1939 and required maintenance dredging 2-3 times within the first 5 years (Burr, 1945). Both Hurricane Carla in 1961, and Beulah in 1967 opened the pass, but both times it filled back in with drifting sediment. Though a feasibility study on reopening the pass was conducted on behalf of the Texas Parks and Wildlife Commission (Turner, Collie, and Braden, 1967), the project was not carried out.

Yarborough Pass was first dredged in 1938 to improve circulation in upper Laguna Madre and to offer a reprieve from drought-year salinities that reached as high as 105 ppt (Burr, 1945). The pass closed late that same winter, and was dredged again in 1941, 1942, twice in 1944, and for the last time in 1952, only to fill back in shortly thereafter (Simmons, 1957).

Cedar Bayou, which has opened intermittently by natural processes through time (Burr, 1945), was dredged for the first time in 1939 (Lockwood and Andrews, 1953). The pass closed in 1955, was again dredged open in 1956, closed again in 1957, and was reopened by Hurricane Audrey July 1957 (Simmons and Hoese, 1960). Cedar Bayou was dredged in 1959 with modifications to improve flows (TGFC, 1959). In 1987, Cedar Bayou was again dredged to improve flow of water through the pass. The most recent dredging occurred in 1995, again to improve flows by following the “natural channel” (T. Heffernan, pers. comm.).

A study was conducted in 1960 to develop inlets which were self-maintaining by design (Carothers et al., 1960). Littoral transport, water exchange velocity, tide differentials, and sediment transport capacity were some of the parameters built into the proposed designs for new passes or improvements on existing passes, and to explain some of the past failures to keep dredged passes open.

2.4.5.2 Freezes

The relative shallowness of CCBNEP study area, particularly upper Laguna Madre, increases fish populations vulnerability to freezes. A portion of the fish population may respond to decreasing temperatures by seeking deeper holes and channels which provide some thermal sanctuary, or by migrating out of the shallow bay systems into Gulf waters; however, severe freezes often result in catastrophic mortality. Fishes near the margin of their thermal tolerance, such as the tropical species *Centropomus undecimalis* (snook) (Shafland and Foot, 1983), are particularly vulnerable although in extreme cases, loss of temperate estuarine species has also been extensive.

Gunter (1952) reviewed some of the freeze events in Texas through time, listing the results of freezes in 1940 and 1951 as catastrophic. Fish mortalities occurred in 1886, 1899, and 1924. January temperatures in 1940 averaged colder than for any other month on record (Game, Fish and Oyster Commission, 1940). In 1947, a freeze resulted in a fish kill which extended from San Antonio Bay to 8th Pass of Mexican Laguna Madre, with a loss estimated to be nearly 16 million pounds of mixed species including seatrout, *S. ocellatus*, and *P. cromis* (black drum) (Baughman, 1947). Freezes in 1941, 1948, and 1949 caused low mortality (Gunter, 1952). Biologists from the TGFOC conservatively estimated that 60-90 million pounds of fish, at least 8 million of which were food fish, were killed in the 1951 freeze (Gunter, 1952).

Another freeze in 1962 resulted in an estimated loss of food and gamefish of up to 2 million pounds (Simmons, 1962), with the loss of *Cynoscion nebulosus* mortality equalling that of the 1951 freeze (Hedgpeth, 1967). A severe freeze in the winter of 1983-84 caused an estimated loss of 15 million marine organisms including 567,000 *C. nebulosus*, 285,000 *P. cromis*, 183,000 *Archosargus probatocephalus*, 160,000 *M. undulatus*, and 90,000 *S. ocellatus* (Osburn and Ferguson, 1987). This freeze prompted the promulgation of regulations reducing the recreational bag limit and size slot for *S. ocellatus* and *C. nebulosus* (Texas Parks and Wildlife, 1985). The freeze of February 1989 resulted in an estimated loss of 11 millon fish and 13,000 invertebrates and a second freeze in December 1989 caused the loss of 6 million fishes and 155,000 invertebrates (McEachron et al., 1994). During the last three freezes 103 species of fishes were represented in the fish kills, and in each freeze, *M. cephalus*, *Lagodon rhomboides* (pinfish), *Brevoortia patronus*, and *Anchoa mitchilli* (bay anchovy) comprised over 50% (by number) of the fishes killed (McEachron et al., 1994).

2.4.5.3 <u>Algal Blooms</u>

The earliest record of an algal bloom resulting in fish mortality occurred in 1935 in a report to the Game, Fish and Oyster Commission, in which a fish kill spanning 250 miles (402.3 km) of coastal beach from the Rio Grande northward was described (Game, Fish and Oyster Commission, 1935). A conservative estimate of two million pounds of fish washed up onto the beach, with *B. patronus* accounting for 85% of the total, *M. cephalus* for 10%, and a variety of other fish making up the remainder. Thus, the poundage of fish killed in this event was two-thirds of the total finfish landings for the whole state that year. Since then, there have been three red tide blooms caused by the dinoflagellate *Ptychodiscus brevis*, and six or seven *Gonyaulax monilata* blooms (Wilson and Ray, 1956; Snider, 1986).

The *P. brevis* bloom in 1986 occurred in the fall during the *S. ocellatus* spawning season providing researchers the opportunity to investigate its effect on hatching success and larval survival (Riley et al., 1989). The organism had no effect on hatch rates of *S. ocellatus* eggs in the laboratory, but larvae exposed to *P. brevis* showed significantly higher mortality rates in all concentrations exceeding 23 cells/ml . Similar findings occured with older larvae, although their survival times were longer than those of newly hatched larvae.

Following the 1989 freeze, upper Laguna Madre experienced a dense bloom of an undescribed chrysophyte. The bloom has persisted, with densities of 10^9 cells per/liter (Stockwell, 1991), causing great concern regarding the future health and productivity of Laguna Madre. Stockwell (1991) determined that during peak bloom conditions, microzooplankton grazing pressures were greatly reduced from their normally high levels. Density measurements of zooplankton grazers, including *Acartia tonsa*, also declined in the first year after the bloom (Whitledge, 1991).

Concern was raised that increased light attenuation, caused by the bloom, would impact the distribution and growth of seagrasses, which rely on relatively transparent water for sunlight penetration. An assessment of seagrass distribution and biomass conducted prior to the bloom (Quammen and Onuf, 1993) was used as a baseline to compare post-bloom data to determine what effects increased light attenuation had on seagrasses over four growing seasons (Onuf, 1995). Changes in distribution of seagrass were not detectable until four growing seasons after the onset of the bloom. Onuf hypothesized that the plants were maintaining themselves by metabolizing the carbohydrate reserves stored in sub-surface tissues during times of reduced light penetration. Onuf also discovered that seagrass biomass in deeper areas (115-139 cm) of the study site diminished by over 60% from pre-bloom levels.

2.4.5.4 Hypersalinity of Laguna Madre

The Laguna Madre is a negative estuary, in that there is a net flow of Gulf waters into the estuary. The upper Laguna Madre has a net freshwater inflow balance of -288,665 acre-feet per year (TWC, 1992), resulting in salinities frequently measuring in excess of 80 . and in some years in excess of 100 . (Hedgpeth, 1967). During the 1960s-1990s salinities in this range were rare.

Mortality of fishes due to hypersalinity of the upper Laguna Madre used to occurre on a regular basis. Fish kills attributed to hypersalinity are known to have occurred in 1936, 1937, 1939, 1943, 1944, and 1945 (Simmons, 1957). Although heavy fish kills had been reported about every 10 years, Gunter (1952) reported that the last complete kill was in the summer of 1937, which was recorded as the most drastic kill in the area since 1914. He estimated fishes killed in the Laguna Madre over time may have ranged from 2-25 million pounds. The Intracoastal Waterway was dredged through the entire length of the Laguna Madre by 1949, creating a refuge for fishes escaping salinity and temperature extremes in the shallow waters of upper Laguna Madre, and improving circulation between upper Laguna Madre and Corpus Christi Bay.

Simmons (1957) found that both temperature and salinity influenced the number of species found in the upper Laguna Madre, with a strong interaction between the two parameters (Fig. IV.C.2.16). As salinities increased, the following would occur: (1) lower species richness; (2) higher numbers of individuals within those species; (3) larger average individual size of vertebrate species; and, (4) smaller average individual size of invertebrate species.

A higher proportion of large *C. nebulosus* were evident in samples from this area as compared to Aransas Bay, from which Simmons (1957) speculated that younger fish were more sensitive to high salinities. Gunter (1961) also saw a positive relationship between size and salinity. A physiological study on *C. nebulosus*, from 17.4 to 43.5 cm size range, indicated that the optimal salinity, based on an estimation of maximum metabolic scope for activity, occurred at 20 at 28 °C, and that they are operationally limited below 10 and above 45 ppt (Wohlschlag and Wakeman, 1978). Simmons' (1957) observation that *C. nebulosus* did not spawn in salinities above 45 ppt was substantiated by a study where hatch rates were: (1) higher at 15 and 25 than at test levels of 5 and 35 ; (2) zero at 45 ; and (3) significantly higher at temperatures from 23 to 32°C than at 20°C. (Gray and Colura. 1988).

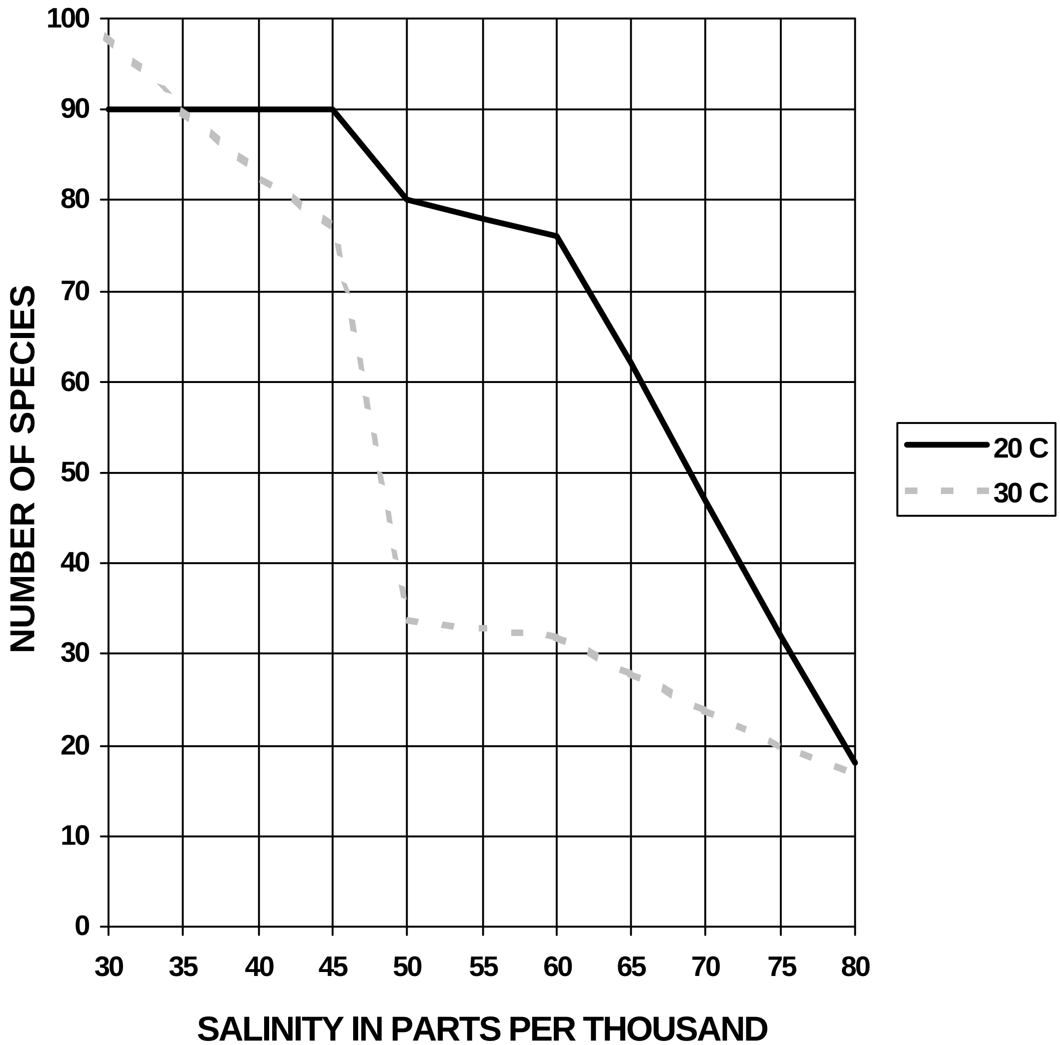


Fig. IV.C.2.16. Relationship between number of species represented in surveys of the upper Laguna Madre and water temperature and salinity of the sampling site. Data from Simmons (1957).

2.4.5.5 Rainfall and Floods

Water budgets for the bay three systems in the CCBNEP study area are dramatically different (Table IV.C.2.11) and salinities vary greatly, both spatially and temporally. Regardless of how freshwater arrives, it is a critical component in the array of abiotic parameters that influence fish in the system. The salinity gradient between the head of the estuary and the Gulf inlet creates a heterogeneous environment that accommodates the salinity preferences of a diversity of species and different life stages within species.

While the flow of freshwater is essential to an estuarine system, floods can have catastrophic repercussions on living resources. For example, major flooding in 1935 converted the bays into veritable freshwater lakes and reduced the salinity of Gulf waters for several kilometers.

Table IV.C.2.11. Water budgets (acre-feet/year) for the Mission/Aransas, Nueces and upper Laguna Madre estuaries. Data from TWC (1992).

	Gauged Inflow	Ungauged Inflow	Evaporation	Precipitation	Inflow Balance
Mission/Aransas	130,665	298,524	614,715	379,450	193,923
Nueces	584,303	49,294	608,969	301,927	326,555
U. Laguna Madre	21,400	135,528	842,899	397,306	-288,665

Countless tons of fish died either from fresh water or unknown causes in some way related to the floods (TGFOC, 1935).

2.4.5.6 Hurricanes

Hurricanes and intense tropical storms can have positive and/or negative effects on an estuarine system. Accompanying storm surges have incised temporary passes through barrier islands, and improved access to the bays for eggs and larvae of marine spawning fishes. Improved circulation, provided by new passes, and heavy rainfall reduce the bays' salinity, can mitigate hypersaline conditions in the Laguna Madre. Conversely, flood conditions can either reduce salinities below the tolerance level of obligate bay inhabitants, flush them out of the system, or prevent them from being able to enter the system due to heavy positive outflow to the Gulf. Hurricanes Beulah (1967) and Fern (1971) contributed to peak autumn freshwater inflows from the Mission and Aransas Rivers into the Mission/Aransas Estuary of 796,000 and 612,000 acre-ft, respectively, compared to the mean of 122,800 acre-ft (TDWR, 1981).

Hurricanes and severe tropical storms are a common event on the Texas coast. Based on observed frequency of hurricanes affecting the Texas coast between 1900 and 1965, there was a probability of 0.42 of experiencing at least one hurricane/year. A total of 96 hurricanes affected Texas between the 1766 and 1958 (Carr, 1967). Matlock (1987) reported the influence Hurricanes Beulah (1967) and Fern (1971) may have had on the year-class strength of *Sciaenops ocellatus*. Numbers of young *S. ocellatus* in the Laguna Madre increased after both hurricanes, hypothetically due to the reduction of salinities to 20-25 ppt. and the creation of additional passages into the bay. Physical destruction of nursery grounds, such as seagrass beds and coastal marshes result from severe storm surges. Hurricane wind currents and storm surges also affect distribution of larval and pre-adult organisms.

2.5 Resource Values

From an economic perspective, fish and shellfish in the CCBNEP study area are an invaluable renewable resource. As previously described, the study area supports large commercial and recreational fisheries which harvest resources within the bay systems and in adjacent Gulf waters.

Saltwater recreational fishing is a popular activity in Texas. In 1986, a study was conducted to determine economic impacts of sport fishing for Texas bays and estuaries (Fesenmaier et al., 1987). During 1986, an estimated 6,032,892 visits were made to the Texas coast for saltwater fishing trips, 43% of which were taken in the Nueces and Mission/Aransas Bays and 21% in the entire Laguna Madre (Table IV.C.2.12). A previous study conducted in 1977, estimated 319,000 fishing parties visited the Nueces and Mission/Aransas estuaries annually (TDWR, 1981).

Table IV.C.2.12. Number of visits, direct expenditures and total economic impact of the Texas coastal recreational fishery in 1986. Data from Fesenmaier et al. (1987).

	Number of Visits (millions)	Direct Expenditures (millions $)	Total Economic Impact (millions $)
Statewide	6.0	364.2	1,159.9
Mission/Aransas - Nueces	1.7	146.6	468.6
Laguna Madre	0.7	74.4	237.9

According to the 1986 study, of the total $365,240,991 spent statewide directly by fishers for transportation, lodging, restaurant, grocery, rental fees and fishing related items, 40% was spent in Nueces and Mission/Aransas Bays, and 20% in the Laguna Madre. Likewise, Nueces, and Mission/Aransas estuaries and Laguna Madre accounted for 40% and 20%, respectively of the total economic impact for recreational fishing (Fesenmaier et al., 1987).

Non-resident recreational fishers spent an average $744 on gear and equipment costs while fishing in Texas, based on a mail survey study conducted in 1986, although the authors suspect the value was an overestimate (Donaldson et al., 1987). The survey indicated that over 60% of non-resident fishers fished exclusively in fresh water, 35% fished both fresh water and saltwater and 6% fished exclusively in salt water.

Ditton et al. (1990) surveyed a random sample of the 218,000 individuals who purchased a saltwater sport fishing stamp in 1986 seeking information on their fishing habits. Based on 4218 (66.2%) useable responses, Ditton estimated saltwater anglers spent approximately $1,500 per angler on fishing tackle, camping equipment, boats, and vehicles in Texas in the previous 12 months.

Fesenmaier et al. (1987) estimated that in 1986, the total economic impact for the commercial fishery within all bays was $113.5 million and for all bays and the Gulf together was $650.6 million (Table IV.C.2.13). Total economic impact of the commercial fishery, which includes total business activity, employment, personal income and state and local tax revenue estimates. Nueces and Mission/Aransas Bays contributed 23% to the total economic impact for all bays, and Laguna Madre contributed 2% to the total. Percent contributions of the individual bays to the total ex-vessel value follow that same pattern.

Table IV.C.2.13. Ex-vessel value and total economic impact for the comercial fishery in 1986. Data from Fesenmaier et al. (1987).

	Ex-Vessel Value (millions)		**Total Economic Impact (millions)**	
	Inshore	Inshore + Offshore	Inshore	Inshore + Offshore
Statewide	34.5	205.3	113.5	650.6
Mission/Aransas & Nueces	7.8	56.1	25.7	184.6
Laguna Madre	0.55	3.4	1.8	11.2

Nationwide, Texas' commercial harvest ranked fifth in landed value of seafood and fourteenth in number of pounds landed based on the 1989 harvest (Haby et al., 1993). The high value of shrimp represented a large portion of the total catch accounted for the higher ranking in landed value. Those rankings increased to fourth and thirteenth, respectively, in 1991 (O'Bannon, 1992).

2.6 Conservation and Management

2.6.1 Historical Overview

An eloquent and impassioned plea for the funding and infrastructure necessary to support resource conservation was issued some time ago by an individual charged with natural resource protection in Texas. It reads,

> *"Our bays teemed with fish, and our rivers, bayous, and creeks supplied an enormous amount of food to the people. All this is in the past, and being that way, we realize our loss, our sinful wastefulness, and would like to bring back that which we have destroyed. Public opinion is growing fast day by day for conservation which means protection and propagation, therefore, the time is ripe for a departure from our present policies and the embarkation on new ones."*

While such a statement has a familiar, modern ring, it is surprising to find that this plea was made to the governor of Texas by the TGFOC in 1919.

Concerns were expressed as early as 1881 over the lack of fisheries regulations to protect the coast's marine resources, specifically condemning the waste of immature fishes through the use of seines in shallow bays. The first of a series of regulations prohibiting the use of nets to protect fish populations was imposed in 1887, and by 1925 an estimated 50% of the Gulf beaches and bays were closed to seine and net fishing (Heffernan and Kemp, 1982). Complaints by recreational fishing interests prompted the Texas Legislature to enact regulations in 1900 on the commercial harvest of *S. ocellatus*, setting minimum and maximum size restrictions at 14 and 32 inches, (355.6 and 812.8 mm) respectively (Christian, 1986).

During WWI, the Federal Government Food Administration suspended state fishing regulations in Texas, and replaced them with less conservative rules to ensure an adequate food supply (TGFOC, 1919). Through this shift of regulations, the ban on fishing within one mile (1.6 km) of Gulf passes was relaxed to within 500 yards (457 m), the ban on sale of fish exceeding 12 pounds (5.44 kg) was dropped, and the law against commercial fishing by foreigners was annulled. Relaxation of the laws resulted in total disregard for any rules or regulations, which was viewed by the Commissioner as an extreme threat to conservation of the resources he was charged to protect.

In 1922, a ban on drag seining the bays for shrimp during June-August was enacted to protect spawning adults of commercially important species. The ban was lifted when it was learned that *S. ocellatus* did not spawn in the bays, and that *C. nebulosus* and *Paralichthys lethostigma* (southern flounder) were not summer spawners. It was recommended instead that fishing for *C. nebulosus* be closed during March and April to protect spawning adults (TGFOC, 1923). However, the following year the Commissioner recommended the summer ban on drag seining be reinstated because of the seagrass destruction it caused and because roughly 90% of their harvest consisted of undersized fishes (TGFOC, 1924).

Much of the CCBNEP study area was completely closed to seines: Agua Dulce Creek, Oso Creek, Shamrock Cove, Nueces Bay, Ingleside Cove, Red Fish Cove, Shoal Bay, the mud flats and shallow bay of Aransas, between Port Aransas and Corpus Christi Bayou, between Harbor Island and Mud Island, Copano Bay, Mission Bay and all passes (TGFOC, 1926). Although distinct signs of overfishing were noted by the Commissioner in the mid-1920's, proposals to further regulate the commercial fishery were vehemently opposed by commercial fishers. Support among the recreational fishing interests and the general public for the Commissioner's recommendations was strong (TGFOC, 1926).

As technological advances increased fishing efficiency, they also generated conservation concerns. Bay shrimpers shifted from the use of cast nets and drag seines to trawls towed behind motorized boats in the early 1920's. However, wastage of undersized shrimp caught by trawlers prompted the Commissioner to recommend that back bays be closed to trawling in 1926 (TGFOC, 1926). This issue was addressed again in 1927 when it was noted that "an appalling loss of young shrimp due to trawlers operating in places and at times when shrimp are below marketable size". The Commission responded by imposing a minimum size restriction (only 15% of a catch may be less than 5 inches) on shrimp permits (TGFOC, 1927).

State conservation laws were once again temporarily relaxed during WWII to ensure the coastal food supply (Heffernan and Kemp, 1980), which resulted in high harvests of *S. ocellatus*, *C. nebulosus* and *P. cromis* (see Table IV.C.2.3). Another technological advancement which had a great effect on the fish populations of the CCBNEP study area was the introduction of monofilament nets into the fishery in the mid- 1960s (Heffernan and Kemp, 1982). Monofilament nets were ultimately banned in saltwater in 1980 (TPWD, 1981).

The Uniform Wildlife Regulatory Act of 1967 provided the Texas Parks and Wildlife Commission partial management authority over finfish in Texas coastal waters. TPWD assumed full regulatory responsibility for *S. ocellatus* in all coastal waters was provided by the passage of the Red Drum Conservation Act by the 65th Legislature (TPWD, 1981).

The Wildlife Conservation Act was passed by the 68th Legislature and provided the Commission regulatory authority over coastal finfish resources. The Act, intended to provide the Commission with the flexibility to respond quickly to conservation problems, also established a bag limit of ten *S. ocellatus*, only two of which could exceed 35 in., established the red drum license for commercial fishers and established a coastwide quota of 1.4 to 1.6 million pounds to be pro-rated among the eight bay systems and the Gulf of Mexico (TPWD, 1978). *Sciaenops ocellatus* and *C. nebulosus* were ultimately designated as a game fish, and 1981 was the last year they could be harvested and sold commercially (TPWD, 1983). Between the years 1978 and 1992, 992.7 miles (1,597.6 km) of illegal nets were confiscated (TPWD, 1993).

A Senate Bill provided TPWD authority to regulate the shrimp fishery upon development and approval of the Texas Shrimp Management Plan in November 1989 (TPWD, 1991), through which several regulation changes were made in 1990 (see Table IV.C.2.5). Shrimp regulations became more stringent with the passage of the Shrimp Management Proclamation of 1994 (TPWD, 1994). The TPWD sited: (1) dramatic increases in bay shrimping effort and catch, with attendant increases in *Micropgonias undulatus* and *Cynoscion arenarious* and impacts on bottom habitat and estuarine food chains; (2) a shift to brown shrimp from white shrimp; and, (3) increase of small shrimp in the harvest all pushing the fishery into an unsustainable trend as the rational for the regulations.

2.6.2 Current Management and Conservation

Conservation and management of fisheries resources in the CCBNEP study is an enormous task in both proportion and importance. Several components of federal, state and local governments, private industry, and private non-profit conservation organizations are active participants in ensuring the sustainability of fisheries resources of the study area.

2.6.2.1 Harvest Regulations

State saltwater fish regulations fall under the jurisdiction of the Texas Parks and Wildlife Commission, which set the means, manners, methods, times and places for the taking of saltwater fishes. Regulations are adopted by the Commission after: (1) the proposed regulation is published in the Texas Register; and, (2) within 30 days of publication, public hearings are held in each affected coastal county (Perret et al., 1980).

Federal fishing regulations for the Exclusive Economic Zone off the Texas coast are generated through an elaborate process of amending existing Management Plans. Plan Monitoring teams, consisting of State and Federal scientists and resource managers, track the status of stocks against goals for rebuilding or maintenance established within the Fishery Management Plans (FMP). All recommendations for FMP amendments are sent on to the Scientific and Technical Committee, (comprised of upper level scientists and resource managers) and then to the Industry Advisory Panel for review. Input is then obtained through public hearings. All FMP amendments are subject to approval of the Secretary of Commerce through the National Marine Fisheries Service, and in all cases possible, state/federal consistency in regulations is sought.

2.6.2.2 Water Management

Management of water quality and quantity in the bay systems is as important as harvest management of the fishes in the CCBNEP study area. Freshwater inflow is essential to maintain the salinity gradient which typifies estuaries and brings nutrients and new organic carbon into the system. Primary production is strongly influenced by freshwater inflow. For example, in Nueces Bay, the environmental factor most strongly correlated with primary productivity was Nueces River flow, followed by water clarity, river nitrogen levels and wind (Flint, 1984).

A dual challenge exists to balance the human demand for water among many competing users, and still meet the ecosystems needs to maintain productive estuaries. The Texas Basins Project, a water development plan adopted by the US Study Commission for Texas in 1962, was designed to meet projected municipal, industrial, and irrigation requirements in the year 2010. However, it was estimated that the project as proposed would account for a one third reduction in the amount of water reaching Texas estuaries, and that in combination with the introduction of toxic pesticides would reduce commercial fishery harvests by 118 million pounds and recreational fishing effort in estuaries by 3 million person-days annually (Chapman, 1964).

Freshwater needs of the Nueces estuary were examined with respect to the construction and operation of the Choke Canyon Reservoir and Harbor Island Deep-Water Port Projects (Henley and Rauschuber, 1981). The study examined the spatial and temporal, long and short-term freshwater needs of the system, the ecological impact of reduced water flow into the estuary and developed recommendations for water management for the estuary.

A series of functional models were developed to describe the statistical relationship between freshwater inflow and the harvest of organisms important to commercial and recreational fisheries (TDWR, 1981). A suite of statistically significant models were derived by temporally partitioning freshwater inflows which were used as independent variables to predict the harvest of shellfish, finfish, and several individual species within those groupings. Though the models did not explain the biologically complex mechanisms of the relationship, they did serve as good predictive tool to be used in water management decisions.

To ensure water resource issues were pursued in an integrated, systematic manner, the 72nd Texas Legislature in 1991 passed the Texas Clean Rivers Act. Under the Act, the Texas Natural Resource Conservation Commission established the Basin Planning Initiative to coordinate and integrate resource management programs (Office of Water Resource Management, 1994). Fifteen state and federal agencies are anticipated to participate in the program.

To accomodate ecological integrity of the estuary in the water planning processes, the Texas Water Development Board developed the Texas Estuarine Mathematical Programming Model (TxEMP) (Matsumoto et al., 1994). Designed to optimize freshwater inflows based on physical, chemical and biological constraints, TxEMP provides a series of solutions which can be treated as options for managers. The model relies on salinity versus inflow, and fishery harvest versus inflow regression equations and can also accommodate nutrient and sediment requirements if data are available.

2.6.2.3 Finfish Stock Enhancement

TPWD has undertaken an aggressive stocking program, through which hatchery produced *S. ocellatus* and *C. nebulosus* fry and fingerlings are released in coastal bay systems. The program began in 1975 with the release of 12.7 million *S. ocellatus* fry and fingerlings. Production capabilities have dramatically increased since then; and in 1994, 214.6 million *S. ocellatus* and 5.5 million *C. nebulosus* fry and fingerlings were released in the study area (Table IV.C.2.14). In 1988, the Ben F. Vaughn, Jr. Hatchery and Research Center at the Gulf Coast Conservation Association (CGGA)/ Central Power and Light Development Center was dedicated. Funds for the $6.0 million facility were raised by Gulf Coast Conservation Association, 69 acres of land were donated by Central Power and Light and hatchery technology is provided by TPWD.

Preliminary evaluations of the *S. ocellatus* stocking program as a means of enhancing native populations have been conducted periodically (Matlock et al., 1984; Dailey and McEachron, 1984; Matlock et al., 1986; Matlock, 1990), and indicate that some hatchery fish do survive when stocked in the wild, but the total fisheries and ecological impact is unknown. Other species that have been under investigation or consideration for hatchery enhancement include *Micropogonias undulatus*, *Archosargus probatocephalus*, *Centropomus undecimalis* (Colura and Matlock, 1989; Henderson-Arzapalo et al., 1988a), and *Paralychthys lethostigma* (Henderson-Arzapalo et al., 1988b).

2.6.2.4 Coastal Zone Management

In 1972, the Federal Coastal Zone Management Act was passed to establish a voluntary federal/state management program to jointly protect and manage the nation's coastline. Federal participation in this program is administered from the Office of Ocean and Coastal Resource Management, Coastal Programs Division of the National Oceanic and Atmospheric Administration and state participation is through the Texas General Land Office. Under the program, state governments have primary responsibility for development and implementation of a Coastal Zone Management Plan (CZMP). Texas' CZMP is currently under review by the Texas State Legislature.

2.7 Future Threats

Overall health of the ecosystem and threats to the living marine resources of the Gulf of Mexico have been identified and investigated by two regional-scope programs, the EPA Gulf of Mexico Program and NOAA's Regional Marine Research Program. The Gulf of Mexico Program has focused their work on eight issues: (1) marine debris; (2) toxic substances and pesticides; (3) habitat degradation; (4) nutrient enrichment; (5) coastal and shoreline erosion; (6) public health;

Table IV.C.2.14. Red drum and spotted seatrout stocking levels for 1975-1994. Data from Texas Parks and Wildlife database.

		Aransas		Corpus Christi		U. Laguna Madre		TOTAL	
Year	Stage	Red Drum	Seatrout	Red Drum	Seatrout	Red Drum	Seatrout	Red Drum	Seatrout
75	Fry			12,700,000				12,700,000	0
	Fingerling	17,000		3,000				20,000	0
76	Fry							0	0
	Fingerling							0	0
77	Fry							0	0
	Fingerling							0	0
78	Fry							0	0
	Fingerling	63,603						63,603	0
79	Fry	2,830,000		1,814,000				4,644,000	0
	Fingerling	981,685				18,596		1,000,281	0
80	Fry					1,900,000		1,900,000	0
	Fingerling	276,540						276,540	0
81	Fry							0	0
	Fingerling	577,500						577,500	0
82	Fry							0	0
	Fingerling	280,000						280,000	0
83	Fry							0	0
	Fingerling			4,708,456				4,708,456	0
84	Fry							0	0
	Fingerling					532,276	4,438	532,276	4,438
85	Fry							0	0
	Fingerling	422,765		1,122,668				1,545,433	0
86	Fry	221,500						221,500	0
	Fingerling					1,100,771		1,100,771	0
87	Fry	19,275,403						19,275,403	0
	Fingerling			487,570		250,000		737,570	0
88	Fry	41,702,640						41,702,640	0
	Fingerling	1,876,765				1,274,074		3,150,839	0

Table IV.C.2.14. Continued.

		Aransas		Corpus Christi		U. Laguna Madre		TOTAL	
Year	Stage	Red Drum	Seatrout	Red Drum	Seatrout	Red Drum	Seatrout	Red Drum	Seatrout
89	Fry	75,082,692	10,000					75,082,692	10,000
	Fingerling	1,029,368		977,901		225,999		2,233,268	0
90	Fry	169,506,970		1,559,900		37,000		169,506,970	0
	Fingerling	1,038,305		792,796		2,451,096	34,887	4,282,197	34,887
91	Fry	136,105,704		32,252,788		1,108,175	40,000	169,466,667	40,000
	Fingerling	1,248,740		2,309,178		5,242,595	249,537	8,800,513	249,537
92	Fry	97,373,695	207,170	1,018,875		126,573,171	289,037	224,865,741	496,207
	Fingerling	513,794		75,420		3,459,122	131,250	4,048,336	131,250
	Adult			2,863				2,863	0
93	Fry	111,927,079	24,000	18,817,120	6,239,038	83,794,533	25,989,750	214,538,732	32,252,788
	Fingerling	2,098,667	12,250	4,283,122		5,921,279	1,263,980	12,303,068	1,276,230
94	Fry	89,839,600		22,957,951	468,625	93,022,942	4,087,975	205,820,493	4,556,600
	Fingerling	2,550,400	224,172	1,972,890		4,162,300	726,282	8,685,590	950,454

(7) living aquatic resources; and (8) freshwater inflow. The status of estuarine populations can easily be linked, either directly or indirectly, with each of these programmatic areas.

Thirteen high-priority areas for marine research in the Gulf of Mexico were identified by research scientists and resource managers through workshops sponsored by the Gulf of Mexico Regional Marine Research Program: (1) habitat use assessment, loss, restoration and enhancement; (2) nutrient enrichment and cycling; (3) freshwater input; (4) ecosystem modifiers such as non-point source contaminants, their transport mechanisms and fates; (5) population stability of marine organisms; (6) trophic dynamics; (7) physical modifiers such as dredging, sediment dumping; (8) toxic materials; (9) coastal erosion, sediment transfer and loss; (10) saltwater intrusion; (11) catastrophic events such as storms, spills, and algal blooms; (12) global change; and (13) nuisance species (Dokken and Ponwith, 1993). Each research area is also of importance in the CCBNEP study area.

Many if not most future threats to fisheries resources in the CCBNEP study area are linked with human population growth and associated development. Between 1988 and 2010, the coastal population per shoreline mile of Texas is projected to increase by 22% (Culliton et al., 1990). Growth and industrialization of a coastal community generates additional environmental stresses on adjacent estuarine ecosystems. For example, Corpus Christi Bay ranks third and Aransas Bay, sixth among the 31 Gulf coast estuaries in the number of industrial point sources of pollution (Table IV.C.2.15) draining into the estuary.

Table IV.C.2.15. Environmental characteristics of the drainage systems affecting bays in the study area. Data from NOAA Strategic Assessment Branch (1990).

	% Urban[1]	% Ag.[1]	Industrial point sources of poll.	Waste water treat. plants	Wetlands (sq. mi.)	% of shellfish waters approved
Mission/Aransas	4	34	104	16	152	47
Nueces/CC	5	47	183	21	46	76
U. Laguna Madre	2	23	50	13	704	94
Baffin Bay	1	31	18	7	no data	80

[1] Percent of the total estuary drainage area

Adequate freshwater inflow into estuaries has been critical to the status of the living resources in the CCBNEP study area and will continue to be so in the face of urban development and industrial growth. Perhaps as important as the quantity of water entering the estuary is the quality of water. Nutrients and contaminants from industrial and municipal wastewater, stormwater and agricultural runoff and airborne pollutants which precipitate out into the system are all threats to the healthy function of the ecosystem.

Habitat degradation and loss also pose threats to estuarine resources. Dredging practices increase the amount of suspended solids in the water column, reducing water transparency (Onuf, 1994). Seagrass and coastal marsh loss constitute a reduction in critical nursery habitat for economically and ecologically important estuarine species. Water quality can be diminished when trapping of suspended particles in the water column is reduced by loss of submerged and emergent vegetation (Ward et al. 1984). Channelization and placement of dredge spoil can change the salinity regime and hydrography of an area (Hedgpeth, 1967).

Concurrent with population growth and its potential environmental impacts, demands for recreational fishing opportunities and seafood are projected to increase, thus imposing additional stress on the ecosystem. Murdock et al. (1992) estimated that between 1990 and 2025, the number of recreational saltwater anglers in Texas will increase by 60%, nearly keeping pace with the projected 66% increase in population. Per capita use (edible and industrial) of domestically harvested commercial fish and shellfish in the United States has increased to a record high of 37.4 pounds per person in 1991 (O'Bannon, 1992).

2.8 Knowledge Gaps

It is well documented that estuaries are among the most productive ecosystems in the world. Characteristic variability in year-class strength of fishes and shellfishes using estuaries as nursery grounds implies that combinations of biotic (e.g. predation, primary productivity, areal extent of seagrass beds) and abiotic factors (e.g. salinity, advective currents) can limit productivity to below its full potential. Mechanisms driving variability among years in recruitment are poorly understood. Which among the list of factors limiting production of estuarine organisms are within the control of humans? Is there a way to manipulate these factors to obtain the maximum benefit at a minimum cost? A better understanding of these processes and interactions is critical to defining and prioritizing management practices to maximize the economic benefits and ecological integrity of the system.

The long-term fishery-independent data on relative abundance of fish and shellfish collected by TPWD is an invaluable tool for monitoring trends in populations of estuarine organisms. The standardized sampling regime enables direct comparison of data through time, too often approached by piecing together results from several shorter studies with different objectives, temporal and spatial scales and methodologies to represent a temporal continuum. Conversely, a solid monitoring program is no substitute for hypothesis-driven research with a sampling regime dictated by the spatial and temporal scale required to approach a specific research problem. Continued allocation of financial and technical resources to both types of fisheries research is critical.

A better understanding of the early life history stages of marine organisms in the estuaries is important. Much of the research and monitoring in the CCBNEP study area is geared to organisms at or past the age where year-class strength for the cohort has been set. More work on early life history stages of the organisms may reveal critical habitat, water quality, or salinity needs which if met may reduce natural mortality rates.

Water quality is monitored in the study area by local, state and federal agencies, and some monitoring of contaminants in fish and shellfish tissue is conducted from a public health standpoint. Little, however, is known about impacts of water contaminants on the overall fitness of estuarine populations.

Collection of effort data for the commercial fishery would enable landings to be standardized as catch per unit effort (CPUE), a statistic important to management of the fishery.

Follow up seine surveys of bays stocked with hatchery produced *S. ocellatus* and *C. nebulosus* have shown that stocked fingerlings do survive in the wild. Research to refine stocking strategies (i.e., optimal size, spatial distribution, release timing, abiotic conditions) may increase survival rates. Studies on the effect of stocked fish on naturally occurring organisms would also be useful in understanding ecological impacts of the stocking program.

Considerable more work must be done to understand causes and effects of the brown tide in the upper Laguna Madre. Changes in submerged aquatic vegetation distribution and percent cover and how that affects larval and juvenile fishes and invertebrates dependent on seagrass beds as nursery grounds should be studied. Research on the trophic dynamics in infested waters should also be high priority.

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To Top