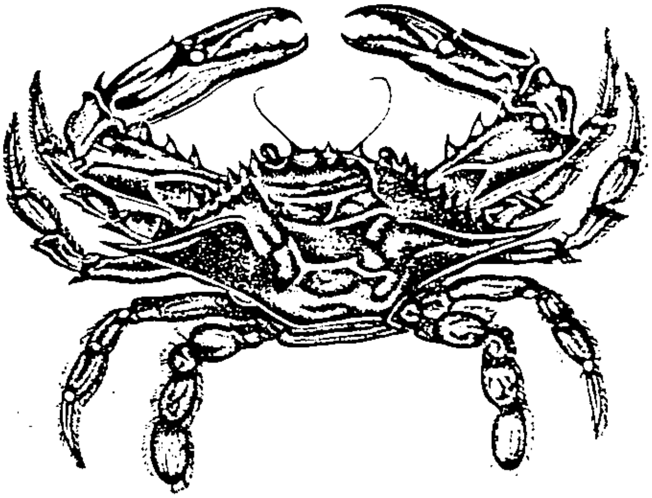
A BIOLOGICAL AND FISHERIES PROFILE OF LOUISIANA

BLUE CRAB, *Callinectes sapidus*



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BATON ROUGE, LOUISIANA

A BIOLOGICAL AND FISHERIES PROFILE OF THE BLUE CRAB, Callinectes sapidus

by

Vincent Guillory
Paul Prejean
Martin Bourgeois
John Burdon
Jerry Merrell

Marine Fisheries Division
Louisiana Department of Wildlife and Fisheries
Bourg, Louisiana

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1.0 INTRODUCTION

The blue crab (Callinectes sapidus) is a crucial component in the estuarine food web and supports one of the largest commercial and recreational fisheries in the coastal waters of Louisiana and other Gulf states (Steele and Perry 1990). In addition to the commercial and recreational fisheries for hard crabs, there is an expanding fishery for soft crabs.

The blue crab fishery ranks third in value of all food fisheries of the Gulf of Mexico after shrimp and oyster (Rees 1969) and is the largest crab fishery in the United States (Williams 1965). Louisiana has accounted for more than one-third of the total Gulf blue crab harvest since 1968 and more than half since 1983 (Steele and Perry 1990).

Extensive statistical data must be accumulated before regulatory measures for management of a fishery and conservation of the resource are adopted (Alverson 1976; Duel 1980). Perret (1981) recommended that fisheries management should be based upon the best technical data concerning the resource and its habitat, coupled with relevant social and economic parameters. The Magnuson Fishery Conservation Management Act requires a similar assessment.

The most current literature and data on the biology and ecology of the species and the fisheries are summarized. This report will serve as a source document for management recommendations and actions to address issues related to the fishery.

1.1 Data Bank

The importance of the commercial and recreational fisheries for the blue crab along the Atlantic and Gulf of Mexico coasts of the U.S. is reflected in the large amount of basic and applied research that has been conducted on this species. Interest in blue crab biology and the fishery has resulted in a proliferation of comprehensive bibliographies or synopses of life history and fishery information. Partial bibliographies of the species were published by Cronin et al. (1957) and Benardy (1961). Tagatz and Hall (1971) provided an annotated bibliography on the fishing industry and biology of the blue crab. A comprehensive review of biological and fishery data was published by Millikin and Williams (1984). A detailed species profile (Perry et al. 1984) and regional fisheries management plan (Steele and Perry 1990) for blue crab in the Gulf of Mexico were published by the Gulf States Marine Fisheries Commission. Fisheries management plans for Texas and Chesapeake Bay were prepared by Cody et al. (1991) and the Maryland Department of Natural Resources/Virginia Marine Resources Commission (1989), respectively. Summaries of blue crab biology and ecology were prepared for the Gulf of Mexico (Perry and McIlwain 1986) and South Atlantic (Van Den Avyle and Fowler 1984) as part of the U. S. Fish and Wildlife Service series "Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates". Williams (1974, 1984), Powers (1977), and Van Engel (1987) also provided literature compilations of blue crab biology. Haefner (1985) reviewed the biology and exploitation of brachyuran crabs, including blue crab. Concise summaries on toxicological studies (Williams and Duke 1979); parasites, diseases, or symbionts (P. T. Johnson 1978, 1985; Overstreet 1978, 1982; Moody 1982; Couch and Martin 1982; Iversen 1986; Messick and Sindermann 1992); factors causing mortality (Van Engel 1982b, 1987); recruitment dynamics (Sulkin and Epifanio 1986; Epifanio 1988a; Smith and Knappenberger 1989); economics (Dressel and Whitaker 1982); histology (Johnson 1980); behavior (Hall 1980); and fishing regulations (Miller 1976; Bearden 1978) were also prepared.

Symposia or workshops, some with published proceedings, have also reflected increased interest in blue crab research. Workshops on the blue crab industry (Rhodes and Van Engel 1978) and soft crab fishery (Cupka and Van Engel 1979) were held in South Carolina. Chesapeake Bay blue crab workshops have been held on management (Cronin 1987), stock dynamics (Jones et al. 1983) and recruitment dynamics (Smith et al. 1989). The Gulf States Marine Fisheries Commission sponsored symposia on blue crabs in general (Perry and Van Engel 1982) and on the soft crab fishery (Perry and Malone 1985); these proceedings contain numerous review articles pertinent to Louisiana and the northern Gulf of Mexico. The proceedings of a blue crab conference held in Virginia Beach, Virginia, during May 1988 were published as a complete volume in Bulletin of Marine Science (1990, Volume 46, No. 1). A national soft crab symposium was sponsored by the Virginia Institute of Marine Science in 1987, but to date remains unpublished. A portunid ecology workshop was held at the Smithsonian Environmental Research Center in 1987; only abstracts were published.

Early research on basic biology of the blue crab and on its fisheries occurred on the Atlantic Coast, particularly in Chesapeake Bay. These studies, many of which are classics, included Hay (1905), Churchill (1921), Gray and Newcombe (1938a, 1938b), Newcombe and Gray (1941), Cronin (1942, 1947), Hard (1942), Pearson (1942, 1948, 1951), Sandoz and Rogers (1944), Hopkins (1943, 1944, 1947), Newcombe (1945, 1948), Newcombe et al. (1949a, 1949b), Pyle and Cronin (1950), Green (1952), Cargo (1954, 1958a), Van Engel (1958, 1962), Costlow and Bookhout (1959), Farragut (1965), Fischler (1965), Costlow (1965, 1967), Davis (1965), Tagatz (1965, 1968a, 1968b, 1969, 1971), Jeffries (1966) and Dudley and Judy (1971,1973). More recent comprehensive life history, ecological, or fishery studies included Mahood et al. (1970), McKenzie (1970), Palmer (1974), Eldridge and Waltz (1977), Music (1979), Low et al. (1987), Mense and Wenner (1989), and Archambault et al. (1990). Management oriented research was conducted by Hester and Mundy (1982), Shively (1984), and Mundy and Anninos (1985). Overviews of life history and ecology (Harris 1982), and fisheries (Sholar 1982) of blue crabs on the Atlantic Coast have also been prepared. A detailed chronology of the fishery and fishermen in Chesapeake Bay was written by Warner (1976). During the 1970s and 1980s, published literature on blue crab research along the Atlantic Coast greatly expanded, emphasizing predator-prey relationships, early life history, habitat preferences, and recruitment dynamics.

Research on the biology and fishery of the blue crab in Louisiana and the northern Gulf of Mexico has received considerably less emphasis than that along the Atlantic Coast, although there has been recent interest in the species. While basic biology and movements may be similar in both Chesapeake Bay and the Gulf of Mexico, temperature and habitat differences probably result in significant differences in habitat selection, age, growth, and spawning. Consequently, where available, information from Louisiana and other northern Gulf literature will be emphasized here in describing life history attributes of the blue crab.

Relatively little work has been done on blue crab biology and fishery in Louisiana. Gunter (1938) commented on the occurrence of the species in the Atchafalaya River. Blue crab predation on Eastern oysters (Crassostrea virginica) was evaluated by Menzel and Hopkins (1956). Food habits (Darnell 1958), life history (Darnell 1959), and trophic relationships (Darnell 1961) in Lake Pontchartrain were described. The Louisiana fishery, production, and early literature on ecology and biology were reviewed by Lindall and Hall (1970). The blue crab fishery (Jaworski 1972) and history of the soft crab fishery (Jaworski 1971 and 1982) were documented in the Barataria Bay estuary. The biology and fishery were studied by Adkins (1972a, 1982) throughout coastal Louisiana. Day et al. (1973) calculated biomass and respiration rates of the blue crab in Barataria Bay. The occurrence and abundance of blue crabs was studied in Vermilion Bay (Perret 1967) and upper Barataria Bay (Daud 1979). Economics of the fishery in Lake Pontchartrain were surveyed by Roberts and Thompson (1982). Occurrence of the rhizocephalan parasite (Loxothylacus texanus) in Louisiana was detailed by Harris and Ragan (1970), Adkins (1972b), and Ragan and Matherne (1974). The use of escape vents in traps (Guillory and Merrell 1993; Guillory 1989) and their impact on premolt crab catches (Guillory 1990a) has been evaluated. Guillory (1993) quantified capture, mortality, and escapement of crabs in ghost traps while Arcement and Guillory (1993) compared ghost fishing mortality and mortality in vented and unvented traps. A comprehensive recreational survey of the blue crab fishery in Terrebonne Parish was conducted by Guillory (1990b), while additional survey data was provided by Titre et al. (1988). Keithly et al. (1988b) described production, processing, and markets of the blue crab industry in Louisiana. Horst (1985) and Supan (In press) reviewed the current status and future outlook of the Louisiana soft-shell crab fishery. The most comprehensive survey of the soft-shell fishery was that of Caffey et al. (1993). West (1981) predicted commercial harvests of blue crabs in Barataria Bay using environmental factors. Anecdotal data on abundance, seasonal occurrence and ecology of blue crabs are also available in numerous estuarine survey publications.

Elsewhere in the Gulf of Mexico, the blue crab has been studied since the early 1950s. Overall life history and fishery studies include Daugherty (1952), Leary (1967), and More (1969) in Texas; Perry (1975) and Perry and Stuck (1982) in Mississippi; Finucane and Saloman (undated), Evink (1976), and Oesterling (1976) in Florida; and Hsueh (1992) and Hsueh et al. (1992) in Alabama. Biological or fishery overviews by state (Hammerschmidt 1982b; Steele 1982; Tatum 1980 or 1982b) or the entire Gulf (Moss 1982; Tatum 1982a) were prepared for the Blue Crab Colloquium (Perry and Van Engel 1982). Food habits were described in Texas (Alexander 1986), Florida (Laughlin 1982), and Alabama (McClintock et al. 1991; Hsueh et al. 1992b). Movements and migrations were quantified by Oesterling and Evink (1977), Oesterling and Adams (1982), and Benefield and Linton

(1990). Abundance, habitats, seasonal occurrence, and population trends were addressed by Menzel (1964), Copeland and Bechtel (1974), Galloway and Strawn (1975), Meeter et al. (1979), Laughlin (1979), Hammerschmidt (1982a, 1985), Hammerschmidt and McEachron (1986), Meador et al. (1988), Mambretti et al. (1990), Thomas et al. (1990), Williams et al. (1990), Dailey et al. (1991), Hsueh et al. (1992a), McClintock et al. (1993), and Steele and Bert (1993). Research on parasites and diseases include Reinhard (1950a, 1950b, 1951, 1956), Christmas (1969), Overstreet (1978), Wardle and Tirpak (1991), and Hochberg et al. (1992). Sport fishery surveys were conducted by Benefield (1968) and Herring and Christmas (1974). Economics and processing were described by Lynne (1982), Moody et al. (1982), Perkins (1982), Prochaska and Taylor (1982), Prochaska et al. (1982), Miller and Nichols (1986) and Keithly et al. (1988a). Morphological characteristics and seasonality of larvae were studied by Stuck and Perry (1981 and 1982). Pullen and Trent (1970) determined width-weight relationships. Effects of diet, water temperature, and salinity were evaluated by Holland et al. (1971) and Das and Stickle (1993). Population genetics in the Gulf of Mexico were addressed by Kordos and Burton (1993) and McMillen-Jackson et al. (1994).

Literature on the soft crab fishery is largely applicable throughout the range of the species; therefore, literature will not be presented by geographic area. The history of commercial production of soft crabs has been documented in Louisiana (Jaworski 1972) and U.S. as a whole (Otwell and Cato 1982). The evolution of shedding technology from floats to flow-through to closed recirculating systems, which initially utilized biological filters and later incorporated sand upflow filters, was traced through original research and papers by Beaven and Truitt (1940), Newcombe (1945), Young (1955), Jachowski (1969), Overstreet and Cook (1972), Epifanio et al. (1973), Winget et al. (1973), Haefner and Garten (1974), Bearden et al. (1979), Cupka and Van Engel (1979), Otwell et al. (1980), Bishop et al. (1982), Ogle et al. (1982), Perry et al. (1982), Kumar (1984), Malone and Manthe (1984), Wescott (1984), Whitaker et al. (1987), Malone and Burden (1988), Oesterling (1988, In press), Perry and Malone (1989), North Carolina Sea Grant (1991), and Hochheimer (In press). These publications also provide valuable information on harvest, identification, care of peeler crabs, system management, and marketing. Harvest and identification of peeler crabs was also addressed by Otwell (1980), Horst (1982), Bishop et al. (1983, 1984), Springborn (1984), Christian et al. (1987), Hines (1991), Supan (In press), and Whitaker (In press). Studies concerning soft crab production under restricted conditions or techniques include those using heated power plant effluents (Reimer and Strawn 1973; Parker et al. 1976; Biever 1981; Wang 1982); those investigating shipboard systems (Supan et al. 1986; Hines, In press); in artificially heated systems (Oesterling 1990); in fresh (Wescott, In press) or low salinity waters (Bridges, In press); in ponds (Springborn 1984); in low calcium water (Freeman et al. 1986 and In press); and, through the use of eyestalk ablation (Wang 1982) and hormones (Freeman and Perry 1985) to initiate ecdysis. Additional research on evaluation of system design and management was accomplished by Manthe et al. (1983 1984, and 1985), Lakshmi et al. (1984), Gates et al. (1985), Malone and Manthe (1985), Wheaton (1985), Malone and Burden (1987), Manthe and Malone (1987), North Carolina Sea Grant (1991), Malone et al. (In press), and Poirrier et al. (In press). On a practical basis, water quality concerns (Perry and Wallace 1985), artificial seawater preparation (Perry 1983), conversion tables (Hochheimer 1985) and trouble shooting guidelines (Oesterling 1982; Manthe 1984) were published for extension service use. Soft crab fishery regulations were compiled by Bearden (1978) and Sholar (1982). The influence of bacterial and viral infections on soft crab production was discussed by P. T. Johnson (1985), Sizemore (1985), and Messick and Kennedy (1990). Reviews of molting physiology, the molt cycle, and biological aspects of shedding were completed by Van Engel (1982a), Mangum et al. (1985a), Cameron and Wood (1985) and Freeman and Perry (1985). Marketing (DuPaul 1985; Conway, In press) and profitability (Roberts 1985) of the fishery was also addressed. The status and future outlook of the soft crab fishery in each state was reviewed by various authors in the National Symposium on the Soft-shelled Crab Fishery (Perry and Malone 1985), while overall future extension and research needs were discussed by Hochheimer (In press).

Commercial fishery dependent data were primarily obtained from the National Marine Fisheries Service (NMFS). However, reported landings for hard and soft crabs are at best poor estimates of annual catch (Steele and Perry 1990; Moss 1982). Landings underestimate actual production because some dealers may not report all landings and not all market channels are included in NMFS statistical surveys. Roberts and Thompson (1982) observed that 60% of hard crab landings from Lakes Pontchartrain and Borgne moved through market channels not covered by government statistical surveys. In a survey involving only 70% of Louisiana crab wholesalers, Keithly et al. (1988b) accounted for 46.5 million lb in 1986 relative to total reported landings of 31.6 million lb; this survey did not include the rather large volume of crabs sold directly by commercial crabbers to restaurants, retail markets, and individuals. Lindall and Hall (1970) suggested that actual production may be as much as 3 or 4 times greater than reported landings, while Jaworski (1971) suggested that actual crab harvest (including the sport fishery) may be twice as high as that indicated in landings records. A study of the Louisiana coastal area (U. S. Army Corps of Engineers 1974), stated that the Louisiana blue crab yield on a per-acre basis should be comparable to Chesapeake Bay, and that the Louisiana fishery could produce an annual harvest >100 million lb.

1.2 Status of the Fishery

Blue crabs have been commercially exploited in Louisiana since the 1800s, with documented landings dating from at least 1880. However, the data were not continuous prior to 1948. Little is known of the early blue crab fishery in Louisiana, which initially developed near New Orleans. According to Perry et al. (1984), the uniqueness of the product hindered early development of the fishery.

Commercial soft crab landings averaged 192,277 lb annually prior to 1940 and were obtained primarily from brush traps, haul seines, trotlines, dip nets, and drop nets. Soft crab landings varied between 350,000 to 881,000 lb through the late 1940s and 1950s. However, during the 1960s, 1970s, and early 1980s production steadily declined to a low of 75,000 lb in 1984. This downward trend in soft crab production was probably due to the continued decline in estuarine water quality and the lack of a reliable source of peeler crabs (Jaworski 1971, 1972, 1982; Perry et al. 1984). After 1984, production increased annually until 249,000 lb were landed in 1990. This recent increase in soft crab production was associated with the development and wide spread adoption of high technology, closed recirculating systems and the recognition by hard crab fishermen that peeler crabs are a valuable bycatch.

Commercial hard crab landings averaged approximately 7.7 million lb annually prior to 1969. From 1880 through the late 1960s, landings were obtained primarily from baited trotlines, but also from drop nets, trawls, handlines, and hoop nets. Louisiana hard crab landings, while exhibiting year-to-year fluctuations, steadily increased from 1967 through the 1980s in association with the introduction and wide spread use of wire crab traps. The fishery rapidly expanded after 1983 in both effort and volume of landings. Landings increased dramatically with several successive harvest records set until peaking at 53.5 million lb in 1988. This rather dramatic increase in Louisiana commercial hard crab landings was largely due to increased fishing effort attributed to several factors: an apparent abundance of the resource; the relatively low fixed investment requirements; economic difficulties of individuals previously employed in the recently depressed oil and gas industry; economic overfishing in interdependent fisheries; reductions in available oyster resources; and a sudden influx of Indochinese refugees into the fishery (Roberts and Thompson 1982; Keithly et al. 1988b; Steele and Perry 1990). In the 1990s, the number of trap fishermen decreased to a low of 2,503 in 1994. Declining catch rates, increased number of traps per fisherman, increased expenses, and cyclic variations in stock abundance during the late 1980s and early 1990s have apparently contributed to declining numbers of crab fishermen.

No documentation of the earliest blue crab recreational activities exists. Although the recreational crab fishery is less prominent than the recreational finfish fishery and yields only a small percentage of the commercial harvest, it nevertheless is an important recreational fishery. Recreational fishing effort and harvest, for finfishes and shellfishes, has increased substantially in the last 25 years with much of the increased demand stemming from marked increases in mobility of coastal residents and from attendant increases in leisure time and discretionary income. Two-thirds of the state's population resides within a 2-h drive of the coastal zone (Davis 1982).

The recreational catch of blue crabs in Louisiana was estimated by the U. S. Department of Commerce (1977); their figures are now considered overestimates. Guillory (1990b) estimated that the recreational catch in Terrebonne Parish, Louisiana was 4.1% of the commercial catch for a year in which Terrebonne Parish contributed 28.8% of the total Louisiana commercial harvest.

2.0 BIOLOGY

2.1 Taxonomy and Nomenclature

2.1.1 Suprageneric

The classification of Crustacea (Bowman and Abele 1982) and Reptantia in particular (Schram 1986) is unsettled, and a diversity of taxonomic groupings have been espoused. The following classification of Schram (1986), is a compromise that incorporates some recent taxonomic advances:

Phylum: Crustacea
Class: Malacostracea
Subclass: Eumalacostraca
Order: Decapoda
Suborder: Reptantia
Infraorder: Brachyura
Section: Heterotremota
Family: Portunidae
Subfamily: Portuninae

2.1.2 Generic

Callinectes Stimpson, 1860.

Stimpson (1860) included in the genus *Callinectes* those portunids in which the merus of the outer maxillipeds is short, sharply prominent, and curved outward at its external angle, and whose males have a T-shaped abdomen. This limited view of the genus was soon broadened by Ordway (1863) who recognized nine species distinguished in part by the structure of the male first pleopods. Rathbun (1896, 1930), in classic papers, provided additional analyses of 11 species included in the genus *Callinectes*. Stephenson (1962) and Stephenson and Campbell (1959) challenged the validity of *Callinectes*; however, Stephenson et al. (1968) agreed to its validity after applying numerical analyses to 57 characters in 41 species in 4 genera of portunids. Williams (1966) described *C. similis* and reviewed the closely related *C. ornatus* and *C. danae*. Williams (1974) reviewed in detail the taxonomic history of the genus *Callinectes* and noted that recent confusion regarding the genus was attributed to a description of a juvenile *Portunus* from the South Pacific as *C. alexandri* by Rathbun (1907). The distinctness of *Callinectes* is further strengthened by the absence of an internal distal spine on the carpus of the chelipeds, whereas this spine is always present, occasionally prominent, in all *Portunus* species (Millikin and Williams 1984).

Gross morphological features having greatest usefulness in distinguishing species of *Callinectes* are: 1) the number, shape, and arrangement of frontal teeth; 2) shape of the metagastric area; 3) shape and curvature of the anterolateral teeth and the lateral spine; 4) granulation of the dorsal surface; and, 5) viewing ventrally, shape of male and mature female abdomen (Williams 1974). Shape of the chelipeds is also useful, as are colors in fresh specimens. In addition to gross features, male first pleopods are diagnostic, and shapes of female gonopores are aids to identification. Williams (1974) constructed dichotomous keys for adult and mature male *Callinectes*, while Felder (1973) and Williams (1984) provided keys for the northwestern Gulf of Mexico and Atlantic Coast, respectively.

Fourteen species of *Callinectes* were recognized by Williams (1974). Another species was later described from northern Brazil (Fausto-Filho 1980). Manning and Holthuis (1981), in a revision of African species, disclosed older names and separated the amphi-Atlantic species into closely related eastern and western Atlantic species. Sixteen different species are now currently recognized: *C. affinis* Fausto-Filho, 1980; *C. amnicola* (De Rochebrune, 1883); *C. arcuatus* Ordway, 1863; *C. bellicosus* (Stimpson, 1859); *C. bocourti* A. Milne Edwards, 1879; *C. danae* Smith, 1869; *C. exasperatus* (Gerstaecker, 1856); *C. larvatus* Ordway, 1863; *C. maracaiboensis* Taissoun, 1969; *C. marginatus* (A. Milne Edwards, 1861); *C. ornatus* Ordway, 1863; *C. pallidus* (De Rochebrune, 1883); *C. rathbunae* Contreras, 1930; *C. sapidus* Rathbun, 1896; *C. similis* Williams, 1966; and, *C. toxotes* Ordway, 1863.

The evolutionary relationships within the genus *Callinectes* are not entirely clear. Williams (1974) concluded that *Callinectes* was a portunid group that evolved at the geographical limits of the family and became specialized estuarine occupants. Stephenson et al. (1968) examined morphological similarities within the genus using numerical taxonomic methods and found several sets of conflicting results. Williams (1974) reported that numerical taxonomic methods yielded results inconsistent with interpretations of relationships based on classical taxonomic methods. Based on both classical taxonomic methods and experience with live specimens, Norse and Fox-Norse (1982) placed *Callinectes sapidus* in the "bocourti group", along with *C. bocourti*, *C. maracaiboensis*, and *C. toxotes*; other groups included "marginatus", "danae", and "gladiator."

The fossil record of *Callinectes* was reviewed by Williams (1974). The chelipeds, usually the dactyls and portions of the propodi, are the most abundant *Callinectes* fossil remnants in Tertiary formations in eastern North and Middle America. It was largely on the basis of cheliped fragments that Rathbun (1919a, 1919b, 1926, and 1935), Withers (1924) and Blake (1953) identified fossil *Callinectes*. Williams (1965) uncritically accepted determinations for Atlantic and Gulf Coastal Plain records from the Miocene to Recent.

2.1.3 Specific

The species type is *Callinectes sapidus* Rathbun, 1896, by designation of the International Commission on Zoological Nomenclature (1964:336). The scientific name given to this crustacean was derived from Latin: *Calli*, beautiful; *nectes*, swimmer; and *sapidus*, savory (Rees 1969). Thus, a literal translation might be the beautiful, savory swimmer. The common name of this species is blue crab.

The taxonomic synonymy of *C. sapidus* was itemized by Williams (1974):

Portunus hastatus Bosc, 1802.
Lupa hastata Say, 1817.
Portunus diacantha Latreille, 1825.
Lupea dicantha H. Milne Edwards, 1834.
Lupa dicantha Gould, 1841.
Callinectes diacanthus Stimpson, 1860.
Callinectes hastatus Ordway, 1863.
Neptunus hastatus Brochs, 1875.
Neptunus (Callinectes) diacanthus Ortmann, 1894.
Callinectes sapidus Rathbun, 1896.
Callinectes sapidus acutidens Rathbun, 1896.
Callinectes africanus A. Milne Edwards and Bouvier, 1900.

Williams (1974) identified two fossil museum specimens from the Pleistocene as *C. sapidus* and concluded that some published records of Pleistocene occurrence are valid.

Variation in populations of *C. sapidus* has been discussed by several researchers. Chace and Hobbs (1969) concluded that extreme variants are so different from each other that they could easily be interpreted as distinct species, but there is no point of demarcation -- morphological, geographic, or bathymetric -- between the "typical" rather blunt-spined form predominating along the east coast of the United States and the "acute-spined" form named *C. sapidus acutidens* (Rathbun, 1896) predominating from Florida southward. Williams (1974 and 1984) considered the whole *C. sapidus* complex to be a single species which has diverged into ill-defined populations in certain parts of its range, but further suggested that speciation into forms associated with temperature regimes is progressing. Olmi and Bishop (1983) concluded that observed carapace variation in *C. sapidus* was not attributable to population variation because individual crabs changed carapace form between instars and because their samples were collected within a 15 km area. Porter (1955) also found morphological variation in adult females within Delaware Bay.

Callinectes sapidus is the only species in the genus which has two prominent, broad-based, triangular teeth between inner orbitals (Williams 1974).

2.2 Morphology

2.2.1 Larvae

Morphological variability in larvae of *C. sapidus*, perhaps due to genetic variation throughout its range and differences between laboratory reared and planktonic specimens, has complicated the specific identification of different larval stages and the separation of closely related species. Consequently, the morphological descriptions of larvae of *C. sapidus* from Atlantic specimens (Costlow and Bookhout 1959; Bookhout and Costlow 1977) are not completely applicable to blue crab larvae of the Gulf of Mexico. Stuck and Perry (1982) noted morphological differences in size and setation between larvae of C. sapidus reared from Gulf of Mexico stocks and descriptions of larvae reared from Atlantic stocks. Distinct seasonal variation was also noted; megalopae and first crabs reared from the plankton were significantly larger in the spring, although seasonal differences could not be duplicated in the laboratory.

Descriptions of selected zoeal stages of Atlantic Coast C. sapidus were first presented by Churchill (1942) and Hopkins (1943, 1944). More detailed descriptions are found in Costlow and Bookhout (1959), Costlow et al. (1959) and Bookhout and Costlow (1977). Variability in larval stages was detailed by Tyler and Cargo (1963) and Costlow (1965), while Costlow (1963a, 1963b) analyzed larval metamorphosis in relation to regeneration. Rice (1980) reviewed zoeal morphology of brachyuran crabs, including portunids, and developed a zoeal key to families.

Detailed morphological descriptions of C. sapidus larvae from the northern Gulf of Mexico can be found in Stuck and Perry (1982). Selected general characteristics of larval stages in blue crab development are listed in Table 2.1, while various larval stages are illustrated in Figure 2.1.

2.2.2 Juvenile and Adult

Williams (1974 and 1984) provided a detailed morphological description of C. sapidus. Rathbun (1896) compared and contrasted the "acutidens" and "typical" forms. The "acutidens" form is wider, prominences more strongly marked, areolations separated by deeper depressions, granules more raised, gastric ridges stronger and more sinuous, frontal teeth narrower and more acute and bearing two small intervening teeth, and lateral spines longer than the "typical" form.

Dorsal carapace and cheliped color may vary, with different shades and tints of gray, blue, and brownish green most common (Williams 1974). Ventral surfaces are off-white with hints of yellow and pink. Spines have reddish tints, tubercles at leg articulations are orange, and legs are blue and white with lesser amounts of red and brownish green. The propodi of male chelae are blue on the inner and outer surfaces and have red tips. The chelae propodi of mature females are orange with purple tips.

Color variations other than those attributable to sexual dimorphism and molt cycle are also known (Williams 1974). Partial albinism was described by Sims and Joyce (1966) and Lawler and Shepard (1978). An adult male with a "robin egg blue" dorsal carapace and pale leg coloration was described by Haefner (1961). Haefner also pictured a bilateral gray and brown colored specimen.

A comprehensive literature review concerning internal anatomy and external morphology is beyond the scope of this document; however, selected comprehensive or classical publications are listed. Johnson (1980) presented a detailed monograph on histology of various tissues and cell types. The external morphology, sense organs, and internal systems were detailed by Lockhead (1949) and Pyle and Cronin (1950). Skeletal - (Cochran 1935) and neuro - (Maynard and Daud 1974) muscular system, sinus gland (Andrews et al. 1971), cardiac ganglion (Hawkins and Howse 1978), ovarian tissue (Cronin 1942; Hard 1942), male reproductive system (Cronin 1947; Tcholakian 1967; Van Engel 1990), myocardium (Hawkins et al. 1977), mandibular gland (Yudin et al. 1980), sperm morphology (Brown 1966), neurosecretory system (Porter 1954; Maynard 1961), osmoregulatory tissue (Copeland and Fitzjarrell 1968), and blood histology (Toney 1958) have been described. With respect to external morphology, the swimmerets (White and Spirito 1973), gills (Gray 1957; Aldridge and Cameron 1982), chelipeds (Brown et al. 1979; Hamilton et al. 1976), claw deformities (Shuster et al. 1963), regeneration (Ary et al. 1985), post- and inter-molt stages (Freeman et al. 1987) and adult female variability (Porter 1955) have also been described.

Regression equations for carapace width (CW) versus carapace length or weight were developed for C. sapidus in Chesapeake Bay (Newcombe et al. 1949a) and Texas (Pullen and Trent 1970). Variations in CW-weight regression relationships with sex, maturity, molt stage, and carapace type for C. sapidus in South Carolina were reported by Olmi and Bishop (1983).

2.3 Stock Identification

Effective management of fisheries resources requires an extensive knowledge of population structure, particularly the identification of stocks and estimates of gene exchange between stocks. When a population or stock is modeled, biological parameters of individuals within the stock are assumed to be consistent. In practice, a stock is often defined operationally as a production or management unit about which conclusions can be made while ignoring differences within the group and exchanges with other groups, or biologically as a genetically discrete population (Larkin 1972; Gulland 1983).

Blue crab populations or stocks in the fishery management context have not been adequately defined among estuarine areas along the Atlantic or Gulf coasts of the U.S. However, recent work by Cole and Morgan (1978), Kordos and Burton (1993) and McMillen-Jackson et al. (1994) evaluated the genetic population structure, and Stuck et al. (1981) and Stuck and Perry (1982) discussed morphological variation between Atlantic and Gulf populations.

Genetic variability of Chesapeake and Chincoteague Bay populations was estimated using starch-gel electrophoretic procedures (Cole and Morgan 1978). Genetic similarity between these two populations was attributed to larval intermixing in the mid-Atlantic Bight.

Morphological differences in size and setation were observed between C. sapidus larvae reared from Gulf of Mexico stocks (Stuck and Perry 1982) and descriptions of those reared from Atlantic stocks (Costlow and Bookhout 1959; Bookhout and Costlow 1977). Based on preliminary data, Stuck et al. (1981) suggested that these differences may be due in part to genetic isolation of Gulf and Atlantic stocks. Stuck and Perry (1982), however, later suggested that differences in laboratory rearing procedures, or seasonal variations may account for a portion of the observed variability between Atlantic and Gulf larvae.

Kordos and Burton (1993) evaluated allelic frequencies at three gene loci for megalopae and adults of blue crab from along the Texas coast. Significant temporal and spatial variation at all three loci were found. They concluded that the spatial heterogeneity in allelic frequencies suggests that interpopulation gene flow is not sufficient to overcome population differentiation resulting from genetic drift, natural selection, or both.

McMillen-Jackson et al. (1994) performed electrophoretic allozyme analyses on 31 gene loci in blue crabs taken at 16 locations from New York to Texas. Significant genetic population structuring was detected at the EST-2 locus: a genetic patchiness was observed with a superimposed latitudinal cline along the Atlantic Coast. They suggested that the lack of apparent genetic populations in the Gulf of Mexico may be attributed to long distance migration of females or to masking of genetic structuring by genetic patchiness. Atlantic Coast populations are more segregated than those in the Gulf, possibly because of low incidence of long distance migrations among adults and high retention of locally spawned larvae.

Williams (1974) concluded that dispersal of larvae of C. sapidus, coupled with movement of adults, seems to assure genetic continuity over broad areas. There are indications that larvae and megalopae are widely transported with prevailing offshore currents. Smith et al. (1989) concluded that larval mixing may be more prevalent in the Gulf, where the spawn from all states may be completely mixed while on the shelf. Consequently, progeny from one estuarine population may be recruited into other estuaries far removed from their point of origin. Marginal, northern records of C. bocourti in south Florida, along the Atlantic Coast (Williams and Williams 1981), and in Mississippi (Perry 1973); C. marginatus in North Carolina; C. similis in New Jersey ; and C. sapidus in Nova Scotia all point to extension of range by larval transport in currents (Garth 1966).

Louisiana populations of C. sapidus are assumed to represent one stock because of a well mixed gene pool sustained by significant pelagic larval dispersal and possibly by adult migration. Such species generally exhibit genetic variation only where historical geo- or eco-physical barriers have separated gene pools (Bert 1986, and references therein).

2.4 DISTRIBUTION AND ABUNDANCE

2.4.1 Range

Callinectes is a warm water genus whose range appears to be restricted by summer water temperatures (Norse 1977). With the exception of the presence of C. toxotes in the

Juan Fernandez Islands, no species occurs regularly in waters where peak summer temperatures fail to approach 20 °C, the temperature required for hatching of eggs and zoeal molting and survival. Norse concluded that conditions in the most severe season of the year are less important than conditions in the least severe season, when most species reproduce.

Eight species of Callinectes have been documented in the Gulf of Mexico: C. bocourti, C. danae, C. ornatus, C. exasperatus, C. marginatus, C. sapidus, C. similis and C. rathbunae (Williams 1974). Callinectes sapidus, the blue crab, and C. similis, the lesser blue crab, show gulfwide distribution and are the primary species found in Louisiana waters. However, C. similis generally occurs in higher salinity waters than C. sapidus and is not normally found in low salinity estuaries where C. sapidus is common (Darnell 1958; Perret et al. 1971; Tarver et al. 1976; Barrett et al. 1978).

The temperature and latitudinal distributions are better known for C. sapidus than for other species of the genus. According to Williams (1974), C. sapidus originally ranged from Nova Scotia and throughout the Gulf of Mexico to northern Argentina, including Bermuda and the Antilles. Callinectes sapidus is seldom found north of Cape Cod (Burbanck 1962), but has been recorded in Maine (Scattergood et al. 1951; Scattergood 1960) and Nova Scotia (Piers 1923) following consecutive warm years.

The introduction of C. sapidus, probably in ship ballasts (Wolff 1954) into Europe, north Africa, and southwest Asia has been summarized by Holthuis and Gottlieb (1955, 1959), Holthuis (1961, 1969), Baynoub (1963), Froglia (1972) and Maury (1975). Introductions into the Mediterranean Sea and adjacent waters have produced breeding populations whereas others were probably temporary occurrences (Williams 1974). This species has also been introduced into Japan (Williams 1984).

2.4.2 Abundance

2.4.2.1 Juvenile and Adult. Monaco et al. (1989) and Czapla et al. (1991) summarized the distribution and abundance of 44 fish and invertebrate species for 31 estuaries along the Gulf of Mexico. They listed the adult blue crab as highly abundant to abundant (i.e., predominant to other species) in waters from 0.0 to 25.0 ppt salinity in Sabine Lake, Calcasieu Lake, Atchafalaya and Vermilion bays, Terrebonne and Timbalier bays, Barataria Bay, Breton and Chandeleur sounds, Lake Pontchartrain, Lake Borgne, and Mississippi Sound. In some years, Louisiana has led the country in commercial blue crab landings (Steele and Perry 1990). Guillory (1990b) noted that the 1989 recreational crab harvest in Terrebonne Parish was 381,500 lb, or 9.74% of the total Alabama commercial catch. Day et al. (1973) calculated biomass estimates of C. sapidus in several Louisiana estuaries and found that values (grams dry/square meter) ranged from 0.23 g during summer to a low of 0.02 g during winter.

Although adult blue crabs are generally abundant throughout an estuarine system, season, salinity, and sex influence local distributional patterns. Peak abundance of adult crabs occurs during the warmer months, with males more common at lower salinities than females; however, during winter months crabs concentrate in areas of tidal exchange in the lower estuary (Jaworski 1972). Adkins (1972a) recorded peak abundance of adult crabs during summer months, with the largest catches taken from mid-salinity waters. Spawned females were seasonally abundant in July, August, and September in higher salinity waters (15-25 ppt); however, few males were caught and those caught were taken during peak mating activity (June and July). Only males were captured in freshwater areas. Additional data on adult abundance of adult blue crabs can be found from Texas (More 1969) and Mississippi (Perry 1975).

Most general survey reports do not distinguish between adult or juvenile blue crabs in summary data. Juveniles usually include those crabs which are ≤50 mm carapace width (CW) (Rounsefell 1964; Perret 1967; Adkins 1972a). Otter trawls and seines are the primary sampling gears utilized in estuarine surveys.

Czapla et al. (1991) listed the spatial distribution and relative abundance of juvenile blue crabs as highly abundant to abundant in the mid-salinity zone (0.5-25 ppt) of Louisiana estuaries. In statewide otter trawl and seine surveys (Perret et al. 1971; Barrett et al. 1978) the blue crab was the third most abundant macroinvertebrate. In two marsh stations sampled with fine meshed traps, juvenile C. sapidus <25 mm CW were ranked third and fifth overall in numerical abundance (Rogers and Herke 1985a and 1985b). Selected area specific data is available for Lake Pontchartrain and Lake Borgne (Darnell 1959; Rounsefell 1964; Tarver et al. 1976), Barataria Bay (Daud 1979; Baltz and Gibson 1990), Terrebonne and Timbalier bays (Adkins 1972a), Vermilion Bay (Perret 1967; Juneau and Barrett 1975) and Calcasieu Lake (Rogers and Herke 1985a, 1985b).

Densities of juvenile C. sapidus were determined with quantitative drop net samples at several sites along the Texas coast, including Galveston Island (Zimmerman and Minello 1984), Christmas and West bays (Thomas et al. 1990), Galveston Bay (Zimmerman et al. 1990a) and Lavaco Bay (Zimmerman et al. 1990b), and along the Alabama coast (Williams et al. 1990). Blue crab abundance determined by the use of trawls or seines has also been documented in Texas (Gunter 1950; More 1969; Galloway and Strawn 1975; Hammerschmidt 1985; Hammerschmidt and McEachron 1988; Meador et al. 1988; Dailey et al. 1991), Mississippi (Christmas and Langley 1973; Perry 1975; Perry and Stuck 1982), Alabama (Swingle 1971; McClintock et al. 1993; Hsueh et al., 1993) and Florida (Livingston et al. 1976). Steele and Bert (1993) characterized population structure and abundance of blue crabs in Tampa Bay, Florida. Along the Atlantic Coast, abundance of blue crabs was quantified by Fitz and Wiegert (1991b, 1992), Rothschild et al. (1991), and Van Montfrans et al. (1991).

Juvenile blue crabs, though widely distributed, are most abundant in middle and upper estuarine waters of low to intermediate salinity, with soft mud bottoms (Swingle 1971;

Holland et al. 1971; Perret et al. 1971; Adkins 1972a; Perry 1975; Livingston et al. 1976; Daud 1979; Perry and Stuck 1982). The catch per unit effort of blue crabs by salinity interval in the northern Gulf is summarized in Table 2.2.

Juvenile blue crabs occur throughout the year in Louisiana coastal waters but are usually most abundant during winter months. In Vermilion Bay, Perret (1967) found small crabs in every month, with the greatest abundance from December through April. Juveniles were most abundant in Lake Borgne from December to March (Rounsefell 1964). In Lake Pontchartrain, abundance of juveniles was highest in late spring-early summer and in fall (Darnell 1959). Adkins (1972a) observed a dense population of juvenile crabs in the Terrebonne-Timbalier system from November to May with peak catches occurring during February.

Copeland and Bechtel (1974) analyzed survey data on C. sapidus in the Gulf of Mexico and calculated catch ratios (samples with ≥2 crabs/number of samples) in relation to water temperature, salinity, season, and location. Catch ratios increased with water temperature until the 15-20 °C interval, then declined. A negative relationship between catch ratios and salinity was found. No significant shift in catch ratio with season was evident, although there were slight peaks in March-April and October-November. Blue crabs were found in all available habitats, but were most abundant in secondary streams, marshes, and tertiary bays.

Tagatz (1968a) and Evink (1976) noted that blue crab biomass appeared to follow food availability. Daud (1979) suggested that the principal factors controlling abundance of blue crabs are food, salinity, water temperature, water circulation, and tides.

Day et al. (1973) attributed the very high productivity of several species, including blue crab, in Louisiana estuaries to several factors: 1) near subtropical climatic regime and abundant rainfall; 2) the broad near-sea level plain that has resulted from land building by the Mississippi River; 3) the large input of fresh water and nutrients by the Mississippi River; 4) the low coastal wave activity; and, 5) daily tidal flushing which is so important in all coastal marshes. Thomas et al. (1990) attributed a higher abundance of blue crabs in the northern Gulf of Mexico than on the Atlantic Coast to more marsh edge, lower tidal amplitudes, and longer periods of tidal inundation. A direct relationship was found between crab landings and vegetated habitat in the Gulf (Orth and Van Montfrans 1990); however, because no similar relationship was found across latitudes, they suggested that other factors are also important. Orth and Van Montfrans (1990) listed seven factors that define habitat quality, and which in conjunction with habitat quantity determine juvenile crab abundance and ultimately production: 1) proximity to and rate, duration and magnitude of larval supply; 2) postlarval settlement factors which may entail active behavior (i.e., response to chemical cues) or passive deposition; 3) frequency and duration of tidal inundation and habitat accessibility; 4) physical factors (e.g., water temperature, salinity and hydrodynamics); 5) quantity and quality of food; 6) architectural complexity (e.g., biomass, leaf area, and shoot density); and, 7) predation intensity resulting from the density and diversity of predators.

Blue crabs exhibit large interannual fluctuations in abundance, characteristic of an "r" (reproductive) selected strategist (Van Engel 1987). This species type is also characterized by a large number of young, rapid growth, early attainment of reproductive maturity, high mortality rates, and short life span. Physical, chemical, and biological environmental factors strongly influence abundance, resulting in widely fluctuating population sizes.

Cyclic variations in blue crab landings and juvenile abundance were discussed by Prochaska and Taylor (1982) and Lipcius and Van Engel (1990), respectively. Prochaska and Taylor (1982) identified a 5-year cycle in Florida west coast landings for 1960 to 1976. Lipcius and Van Engel (1990) documented significant interannual fluctuations in juvenile crab abundance in Chesapeake Bay from 1972-1988. Population abundance did not generally vary greatly from year to year, but appeared to remain consistently high or low for 2 or more years before changing. The blue crab population in Chesapeake Bay apparently fluctuates in response to long term or periodic sources of variation superimposed on yearly variation. Marked fluctuations in blue crab abundance were also noted by More (1969), Hurt et al. (1979), Kennish et al. (1982), Jones et al. (1990) and many others. For instance, Jones et al. (1990) established that the 1987 spawning stock in Chesapeake Bay was only 29% of the stock size in 1986.

Several research projects on blue crab sampling methodologies have been conducted: effect of tickler chain and tow duration on trawl catches (Chittenden and Van Engel 1972); utilization of crab and oyster dredges as sampling devices (Sulkin and Miller 1975); and, comparison of gears for sampling juvenile blue crabs (Miller et al. 1980).

2.4.2.2 Larvae. The larval abundance of C. sapidus in the Gulf of Mexico is poorly documented due to temporal and spatial overlap in the spawning habits of C. sapidus and C. similis and difficulty in distinguishing between larvae of the two species (Stuck and Perry 1982), based upon early morphological descriptions from the Atlantic Coast (Costlow and Bookhout 1959). This suggests that early published accounts of seasonality of larvae of C. sapidus are questionable. Although Daugherty (1952), Menzel (1964), and Adkins (1972a) specifically discussed blue crab larval distribution, the possible joint occurrence C. sapidus and C. similis larvae must be considered. More (1969), King (1971), Perry (1975), and Andryszak (1979) did not differentiate between larvae of C. sapidus and C. similis.

Since only Perry and Stuck (1982) separated larvae of C. sapidus from those of C. similis, their Mississippi Sound data will be used to illustrate larval abundance of blue crab in the northern Gulf of Mexico. Megalopae of Callinectes sapidus were collected in every month except January and February. Two peaks in abundance were observed, the first in late spring-early summer, and a second, larger peak in late summer-early fall during which maximum densities of 2,530.8/1,000m^3 were obtained. Large catches of megalopae of C.

sapidus were not made between December and April. Megalopae of Callinectes sapidus made up 70% of the total portunid megalopae. Literature reports of winter peaks (February) of Callinectes larvae are in all probability referable to C. similis (Steele and Perry 1990). Other studies report peaks of megalopae of Callinectes in late spring-early summer and late summer-early fall (More 1969; King 1971; Adkins 1972a; Stuck and Perry 1981).

2.5 Habitat

The life history of the estuarine dependent blue crab involves a complex cycle of planktonic, nektonic, and benthic stages, which occur throughout the estuarine-nearshore marine environment. A variety of habitats within the estuarine environment are occupied depending upon the particular physiological requirements of each life history stage (Perry et al. 1984). Spawning females and early larval stages (zoea I-II) inhabit lower estuarine and adjacent marine waters where salinities are >20 ppt, a level necessary for zoeal development. Later stage zoea (III-IV) exist mainly in the open gulf. The megalopal stage of C. sapidus reenters the estuaries and adopts a largely benthic existence. The molt to the benthic first crab stage takes place within estuaries.

Juvenile and adult blue crabs exhibit wide seasonal and areal distribution within estuaries. Laughlin (1979) concluded that the temporal and spatial distribution of C. sapidus in the Apalachicola estuary appeared to be determined by complex interactions of abiotic, trophic, and other biotic factors, which have different significance with respect to season and area. Specific habitat requirements by life history stage are profiled in the following sections.

2.5.1 Larvae

Stuck and Perry (1982) were the only authors to distinguish between C. sapidus and C. similis larvae along the northern Gulf; however, data from other studies will supplement Stuck and Perry (1982) where needed to characterize larval habitat.

Female C. sapidus spawn near the mouths of estuaries. After hatching, first stage zoeae swim toward the surface and into the neuston layer (McConaugha et al. 1981; Provenzano et al. 1983; Johnson, D. R. 1985). Perry and Stuck (1982) noted that early stage zoeae (I and II) of Callinectes spp. were present in Mississippi coastal waters in the spring, summer, and fall. Both Andryzak (1979) and Perry and Stuck (1982) found that only early stage zoeae of Callinectes spp. were abundant nearshore. On the Atlantic Coast, early stage zoeae of C. sapidus were collected in lower estuaries and adjacent marine surface waters (Tagatz 1968a; Dudley and Judy 1971; Sandifer 1973; Dittel and Epifanio 1982).

Perry (1975) showed that areal distribution of Callinectes zoeae was apparently limited by salinity. Most zoeae were found at salinities >20 ppt, the level needed for zoeae to successfully complete their first molt (Costlow and Bookhout 1959). Callinectes zoeae were uncommon at water temperatures <17 °C.

Based on observations of Perry and Stuck (1982) and on the data of Menzel (1964) and Andryszak (1979), it appears that development of later zoeal stages (III-VII) of C. sapidus takes place in offshore waters. Numerous studies along the Atlantic Coast support this observation (Epifanio 1988a, 1988b; Smith and Knappenberger 1989).

Megalopae immigrate into estuaries through the Gulf passes. Daugherty (1952), More (1969), King (1971), and Perry (1975) documented the presence of megalopae of Callinectes spp. in Gulf passes. Megalopae of C. sapidus were collected in Mississippi Sound passes from March through December (Perry and Stuck 1982). Megalopae were found at greater water temperature and salinity extremes than zoeae. Some specimens were collected in salinities as low as 4.0 ppt, although most were found in salinities >20.0 ppt.

On the Atlantic coast, movement of megalopae of blue crab into estuaries has been well documented (Williams, 1971; Sulkin and Epifanio 1986; Epifanio 1988a and 1988b; Goodrich et al. 1989; Smith and Knappenberger 1989; Johnson and Hess 1990; Lipcius et al. 1990; Olmi et al. 1990; Van Montfrans et al. 1990; Little and Epifanio 1991; Metcalf and Lipcius 1992).

The vertical distribution of megalopae of Callinectes has been defined in numerous surveys. Available field data from the Atlantic Coast indicates that megalopae and zoeae are found in the neuston or surface layer offshore (Johnson, D. R. 1985; McConaugha 1988) while the vertical position of megalopae in estuaries varies significantly over time (Meredith 1982; Olmi 1986; McConaugha 1988). King (1971), Williams (1971), Perry (1975), and Smyth (1980) collected greatest numbers of megalopae of Callinectes spp. in surface waters. Perry and Stuck (1982) found that portunid megalopae (C. sapidus and C. similis) showed no affinity for surface or bottom waters and noted that the majority of large catches of megalopae of C. sapidus were taken on rising or peak tides.

Lipcius et al. (1990) postulated behavioral progression in megalopae of C. sapidus as they switch from a surface dwelling to benthic mode. Behavior promoting retention near the surface in young megalopae (e.g., negative geotaxis, positive phototaxis, and high barokinesis) is likely replaced with behavior inducing a more benthic habit in older megalopae (e.g., reduced locomotory activity, negative phototaxis, positive geotaxis, and high thigmokinesis) (Sulkin 1984; Sulkin and Van Heukelem 1986).

Little data are available on the spatial distribution of settling of megalopae of C. sapidus in Gulf of Mexico estuaries. Holt and Strawn (1983) collected megalopae in the upper reaches of Galveston Bay, Texas. Mense and Wenner (1989) sampled blue crab megalopae with a plankton net along a salinity gradient in a South Carolina estuary. They reported decreasing abundance of megalopae from the polyhaline (75% of total), to mesohaline (23% of total), to oligohaline (2% of total) zones. The recent consensus of researchers is that settlement of megalopae on artificial collectors is greatest near mouths of estuaries, declining up-estuary (Smith et al. 1989). Meredith (1982) and Olmi (1986) showed that megalopae invade shallow subestuaries and tributaries. Seasonal and spatial patterns in settlement of blue crab megalopae in Chesapeake Bay were documented by Lipcius et al. (1990), Olmi et al. (1990) and Van Montfrans et al. (1990).

Habitat selection by settling megalopae of C. sapidus was discussed by Orth and Van Montfrans (1990). They cited unpublished data on substrate choice experiments which implied a chemically mediated or tactile response mechanism. However, they also noted that when molting to the first crab stage becomes obligatory, and if a preferred habitat is not present, settlement and metamorphosis can occur anywhere.

2.5.2 Juvenile

Data on areal and seasonal occurrence, or distribution in relation to physio-chemical parameters of juvenile C. sapidus in northern Gulf of Mexico estuaries were provided by Darnell (1959), Rounsefell (1964), Perret (1967), Perret et al. (1971), Swingle (1971), Adkins (1972a), Christmas and Langley (1973), Galloway and Strawn (1975), Perry (1975), Livingston et al. (1976), Daud (1979), Laughlin (1979), Perry and Stuck (1982), Baltz and Gibson (1990), Thomas et al. (1990), Williams et al. (1990), McClintock et al. (1993), and Hsueh et al. (1993).

Juveniles of C. sapidus occupy Louisiana estuaries during every month, but are most common in winter (Darnell 1959; Rounsefell 1964; Perret 1967; Adkins 1972a; Daud 1979). In general, juvenile blue crabs show wide areal distributions but are most abundant in middle and upper estuarine waters of low to intermediate salinity (Perret et al. 1971; Swingle 1971; Adkins 1972a; Daud 1979; Perry and Stuck 1982). Perret et al. (1971), Swingle (1971), Christmas and Langley (1973), and Perry and Stuck (1982) characterized blue crab distribution (primarily juveniles) with temperature-salinity matrices.

The association of juvenile crabs with soft mud bottoms has also been well documented by More (1969), Holland et al. (1971), Adkins (1972a), Perry (1975), Livingston et al. (1976), and Perry and Stuck (1982). Juvenile C. sapidus are more commonly associated with vegetated than with nonvegetated habitats (Zimmerman and Minello 1984; Thomas et al. 1990; Williams et al. 1990). In addition, correlative and direct evidence from Evink (1976), Laughlin (1979), Livingston and Loucks (1979), and Williams et al. (1990) indicates that food availability and intraspecific and interspecific interactions could influence local juvenile C. sapidus distribution. Distribution of juvenile crabs is apparently inversely related to the spatial distribution of larger C. sapidus or other predators (Laughlin 1979).

Habitat segregation of juveniles of C. sapidus by size was described by several researchers (Daud 1979; Perry and Stuck 1982; Rounsefell 1964; Thomas et al. 1990; Williams et al. 1990). Distribution of juvenile blue crabs in Mississippi waters was as follows: 1) first and early crab stages (3-10 mm CW) occurred most often in salinities from

15 to 20 ppt; 2) 10-20 mm CW juveniles were most frequently found in salinities <10 ppt; and, 3) maximum number of 20-40 mm CW crabs were sampled from salinities <5 ppt (Perry and Stuck 1982). Rounsefell (1964) and Daud (1979) observed a movement of crabs into low salinity Louisiana marshes with growth. Juvenile crabs in Christmas Bay, Texas, were larger in salt marshes than in seagrass or on sand and mud bottoms (Thomas et al. 1990); possible reasons for habitat related size patterns included differential predation, differential recruitment of megalopae, inability of small crabs to effectively move with tides in and out of salt marshes, and active selection. In Mobile Bay, Alabama, newly recruited crabs (≤5 mm CW) exhibited some association with high density submergent vegetation; slightly larger individuals (5-10 mm CW) showed a tendency toward association with low density grass, and juveniles >10 mm CW exhibited no association with any particular substratum. In Barataria Bay, larger juvenile blue crabs (>20 mm CW) moved out of marsh-edge microhabitats (Baltz and Gibson 1990).

Overwintering habitat of juvenile crabs was documented by Thomas et al. (1990). Crab density from January through March decreased in vegetated habitats while increasing in subtidal sand and mud bottom habitats. They collected burrowed, torpid crabs from mud substrates during cold periods and suggested that intertidal salt marshes are largely unavailable during winter because of low water regimes.

Microhabitat selection of molting juveniles of C. sapidus was discussed by Hines et al. (1987a), Ryer et al. (1990), Wolcott and Hines (1990), and Shirley and Wolcott (1991). In Chesapeake Bay crabs approaching ecdysis aggregated in seagrass meadows, possibly to escape predators (Ryer et al. 1990), or selected shallow, marsh-lined banks of tidal creeks for ecdysis (Hines et al. 1987a; Wolcott and Hines 1990). The adaptive significance of habitat selection by molting blue crabs was discussed by Shirley et al. (1990).

Baltz and Gibson (1990) compared densities of C. sapidus juveniles in Barataria Bay, Louisiana, to environmental variables. Crab density decreased with high water temperatures and increased with shallow water, high dissolved oxygen concentrations, and organic detritus substrates. Information on microhabitat selection in other northern Gulf estuaries was provided by Zimmerman and Minello (1984), Thomas et al. (1990), Williams et al. (1990), and Zimmerman et al. (1990a, 1990b).

Copeland and Bechtel (1974) reviewed blue crab survey data and associated environmental parameters from the Gulf of Mexico and proposed that catches were distributed as follows:

(a) Water temperature - range, 0 to 40°C; optimum catch between 10 and 35°C.
(b) Salinity - range, 0 to 40 ppt; optimum catch between 0 and 27 ppt.
(c) Season - range, all months; maximum catch during spring and fall.
(d) Location - range, all estuarine locations; optimum catch in primary rivers, secondary streams, marsh and tertiary bays.

Along the Atlantic Coast, habitats of juveniles of C. sapidus have been described by Tagatz (1968a), Dudley and Judy (1973), Miller et al. (1975), Heck and Orth (1980), Kennish et al. (1982), Penny (1982), Heck and Thoman (1984), Hines et al. (1987a), Orth and Van Montfrans (1987), Wilson et al. (1987), Mense and Wenner (1989), Wilson et al. (1990), Fitz and Wiegert (1991b and 1992), Van Montfrans et al. (1991), and Ruiz et al. (1993). Beds of submergent vegetation rather than salt marsh habitats appear to be preferred juvenile crab habitat. Thomas et al. (1990) suggested that more marsh edge, lower tidal amplitudes, and longer periods of tidal inundation favor utilization of salt marshes by juvenile crabs in the northwestern Gulf of Mexico, whereas similar habitats along the Atlantic coast appear hardly used at all.

Orth and Van Montfrans (1990) reviewed habitat utilization of juvenile C. sapidus with respect to latitude. They concluded that seven factors (see section 2.4.2.1) ultimately determine habitat quality.

2.5.3 Adult

In the Gulf of Mexico, adults of C. sapidus are widely distributed and occur on a variety of bottom types in fresh, estuarine, and shallow oceanic waters. In Louisiana, blue crabs have been reported 305 km (189 mi) upstream in the Atchafalaya River (Gunter 1938); other published records of their freshwater occurrence are found in Florida (Odum 1953; Gunter and Hall 1963), Texas (Wurtz and Roback 1955), Virginia (Mangum and Amende 1972) and Delaware (Ettinger and Blyle 1981). Conversely, C. sapidus has been collected in hypersaline lagoons in Texas at 60 ppt salinity (Simmons 1957) and in Florida at 55 ppt salinity (Rouse 1969). In the Gulf of Mexico, the species has been recorded offshore to depths of 90 m (Franks et al. 1972). Laughlin (1979) suggested that the spatial distribution of adult crabs in Apalachicola Bay, Florida, appeared unrelated to abiotic or depth regimes, but that crabs sought areas of high food abundance regardless of salinity or water depth.

Blue crabs, after attaining an average size of ≥ 80-85 mm CW, move from shallow areas into larger bays and bayous (Adkins 1972a). Although adult blue crabs are ubiquitous throughout an estuarine system, they are distributed seasonally with respect to salinity and sex (Steele and Bert 1993). Three subhabitats (spawning, wintering, and maturation) were recognized in the Barataria estuary by Jaworski (1972). The spawning habitat for females included tidal passes and nearshore Gulf waters in lower Caminada and Barataria bays. The lower portions of Caminada and Barataria bays, where juvenile and male crabs concentrated after water temperatures fell below 15 °C, comprised the winter habitat. The maturation habitat included the shallow brackish marshes of northern Barataria Bay, Little Lake, Lake Salvador, and southern Lake des Allemands. Darnell (1959), Perret (1967), and Adkins (1972a) provided additional data on the spatial distribution of blue crabs by sex in Louisiana estuaries. Other investigators have also documented similar distribution patterns (Hay 1905; Churchill 1921; Pearson 1948; Gunter 1950; Daugherty 1952; Van Engel 1958; Fischler and Walburg 1962; Tagatz 1968a; Dudley and Judy 1971; Perry 1975; Eldrige and Waltz 1977;

Hines et al. 1987a). Overwintering habitats in Chesapeake Bay were documented by Schaffner and Diaz (1988).

Norse and Fox-Norse (1982) concluded that the migratory patterns of Callinectes sapidus within the estuarine environment suggest that they are catadromous, storing energy primarily while in low salinity water but spawning and releasing larvae only in high salinity water. Distributional patterns of C. sapidus in tropical estuaries were elucidated by Norse (1978) and Buchanon and Stone (1988).

Chambers (1980) analyzed nekton communities in the upper Barataria Basin and placed the blue crab in a group which also included bay anchovy (Anchoa mitchilli), brown shrimp (Penaeus aztecus), Atlantic croaker (Micropogonias undulatus), gulf menhaden (Brevoortia patronus), inland silverside (Menidia beryllina); rough silverside (Membras martinica), white shrimp (Penaeus setiferus), and sand seatrout (Cynoscion arenarius). Callinectes sapidus was also classified as a member of the high salinity inshore Eastern oyster reef community (Gunter 1950; Hedgpeth 1953; Parker 1960). Other prominent members of the oyster reef community included mud crabs and the stone crab (Menippe adina). Wenner (1986) placed C. sapidus in a species group with grass shrimp (Palaemonetes pugio and P. vulgaris), pink shrimp (Penaeus duorarum), and white shrimp in South Carolina coastal impoundments.

2.5.4 Condition of the Habitat

The Louisiana estuaries contain approximately 720,648 ha of emergent marsh vegetation and 4100 ha of seagrass (Orth and Van Montfrans 1990). Chabreck et al. (1968) determined by vegetative mapping that the Louisiana coastal marsh comprised four major vegetative groups: saline marsh -- 862,973 acres; brackish marsh -- 1,203,790 acres; intermediate marsh -- 650,756 acres; and, fresh marsh -- 1,193,325 acres.

According to Lindall et al. (1979), the major man induced activities that affect the estuarine environment are: 1) construction and maintenance of navigation channels; 2) discharges from wastewater plants and industries; 3) dredge and fill for land use development; 4) agricultural runoff; 5) ditching, draining, or impounding wetlands; 6) oil spills; 7) thermal discharges; 8) mining, particularly for phosphates and petroleum; 9) entrainment and impingement from electrical power plants; 10) dams; 11) marinas; 12) alteration of freshwater inflows to estuaries; 13) saltwater intrusion; and, 14) nonpoint source discharges of contaminants.

Marsh loss, wetland impoundments, and salinity intrusion are critical topics in Louisiana with regards to management of estuarine dependent species such as the blue crab. Wetland loss of approximately 35 mi^2 annually is approaching crisis proportions (May and Britsch 1987). Land loss is the synergistic culmination of both natural and man induced factors (Craig et al. 1980; Salinas et al. 1986). Subsidence, eustatic sea-level rise, and erosion due to wave and wind action are naturally occurring factors. Man induced factors include levee construction along the lower Mississippi River (which eliminated the major source of sediment introduction to marshes), canal construction, dredge and fill activities, and land reclamation. Salinity levels may have increased in portions of coastal Louisiana in association with marsh loss and canal construction. Approximately 30% of the total wetland area in the Louisiana coastal zone was intentionally impounded before 1985 (Day et al. 1990). Impoundment of marshes will probably increase in the future due to interest in mariculture and development of marsh management units to combat coastal marsh loss (Herke and Rogers 1989).

Habitat and hydrological changes occurring in Louisiana estuaries could have detrimental impacts on blue crabs. Orth and Van Montfrans (1990) found a significant relationship between blue crab production and total vegetated habitat among Gulf states. Other investigators have shown positive correlations between yield of estuarine species other than blue crab and extent of vegetated habitat (Turner 1977, 1979; Nixon 1980; Deegan et al. 1986). The impact of marsh loss on blue crab production may not be evident initially. Biological productivity increases temporarily in deteriorating marshes (Gagliano and Van Beek 1975), possibly due to an increase in "edge" (marsh-water) habitat and in detrital input to the estuarine food web. However, biological productivity will eventually decrease as the conversion of marsh habitat to open water continues and suitable marsh habitat of appropriate salinity regimes declines below the critical point. Low salinity marsh is an important nursery habitat for juvenile blue crabs and increased salinity may adversely impact the species (Rounsefell 1964). Marsh management by means of levees and weirs, or other water control structures, is usually detrimental to fisheries in the short term because of interference with migratory cycles of estuarine dependent species (Herke 1968 and 1979; Rogers and Herke 1985a, 1985b; Herke et al. 1987; Herke and Rogers 1989;). During the course of their life cycle, blue crabs utilize all salinity regimes of an estuary, with various life cycle stages occupying specific salinity regimes. Disruption of estuarine salinity gradients in association with physical habitat alteration could have adverse impacts on blue crab populations.

2.6 Reproduction

2.6.1 Dimorphism

Blue crabs are heterosexual and exhibit obvious sexual dimorphism as described in detail by Churchill (1921), Hopkins (1963), Teytaud (1971), Williams (1974), and Millikin and Williams (1984). Male blue crabs have a T-shaped abdomen readily distinguishable from both female stages. Immature females have triangular shaped abdomens with fused segments; however, at the terminal or pubertal molt, the final ecdysis and onset of sexual maturity, the mature female abdomen becomes broad and rounded with all segments free (Williams 1974).

Typical color differences between sexes are mentioned in section 2.2.2. Two bisexual crabs (bilateral gyandromorphs) from different areas of Chesapeake Bay were described by

Cargo (1980) and Johnson and Otto (1981). Sexual alteration in blue crab was verified by Reichard and Tcholakian (1966).

2.6.2 Maturity

Females reach maturity after 18-20 postlarval molts (Van Engel 1958). Johnson (1980) described histological changes in ovarian tissue as maturation approaches. Immature ovaries are strands of white tissue, difficult or impossible to see in small individuals. At about 4 cm CW (approximately the 16th crab stage) the ovary extends posteriorly to the posterior cecum of the midgut and well into the lateral spine area. Upon conclusion of the penultimate molt the ovaries are considerably developed and easily visible, although oocyte development is limited. During the prepubertal instar the ovaries increase in volume and the seminal receptacle reaches full size. Following the pubertal molt, vitellogenesis occurs and the ovaries dramatically increase in size as oocytes develop and the color changes from pink to bright orange as yolk material accumulates. In the laboratory, oocyte maturation occurred regardless of fertilization (Johnson 1980), but in nature almost all females are fertilized (Churchill 1921; Wenner 1989; Wenner and Daugherty 1990). The mature ovary, swollen with large ova and with many lobes, has a pebbled appearance. The ovary, one of the largest internal structures, covers the hepatopancreas, much of the cardiac stomach, and sometimes the heart and posterior cecum of the midgut, and extends to the end of the cephalothorax.

Hard (1942) described ovarian tissue changes before, during, and after the first and second spawnings. Immediately after copulation, the ovary is small and white with the large pinkish spermathecae distended with sperm. Following copulation, ova require at least 2 months to develop the increased ovarian size and orange color. Females may ovulate more than once. Before the first ovulation, follicles expand. After the first ovulation, the ovary remains large and orange colored. Egg shell remnants remain on the pleopods after hatching. After the second ovulation, the ovary is collapsed and appears gray or tan colored.

Unlike females, male blue crabs display no prominent external sign indicating sexual maturity (Teytaud 1971). Male crabs reach maturity after 18 or 19 postlarval molts (Millikin and Williams 1984). The abdomen of immature males is tightly sealed to the ventral surface but in mature individuals the abdomen hangs free or is fastened by a pair of sternal tubercles (Van Engel 1958). Immature males have small vasa deferentia and a white middle vas deferens while mature males have vasa deferentia with large prominent ducts and a bright-pink middle vas deferens (Tagatz 1968a). The middle vas deferens in mature males may be only slightly pink or white following copulation or during the winter (Johnson 1980).

Van Engel (1990) described mature, male blue crabs as having spermatophores present in the anterior vas deferens, the abdomen completely free from sternum or locked by sternal tubercles, and the penes and second pleopods inserted into the first pair of pleopods. The mature sperm are roughly spherical in shape depending on the plane of section and they lack flagella which is typical of sperm in arthropods (Johnson 1980).

Age and size at sexual maturity are important variables not only because they mark the onset of reproductive activity but are also frequently used in decapod fisheries in determining minimum legal size limits (Cobb and Caddy 1989). Time to reproductive maturity is dependent upon water temperature and length of growing season. Blue crabs in the Gulf of Mexico may reach maturity within 10-12 months (More 1969; Adkins 1972a; Perry 1975; Tatum 1980), while crabs in Chesapeake Bay require up to 18 months (Van Engel 1958). Age at maturity may vary in specific areas with time of hatching; crabs hatched in early summer in Chesapeake Bay reach sexual maturity within 12 to 16 months, while individuals that are hatched in late summer and early fall reach sexual maturity within 18 to 20 months (Lippson 1973).

Average size of at maturity of male blue crabs is about 89 mm CW (Gray and Newcombe 1938b). Van Engel (1990) showed that in males about 3% in the 65-69 mm CW size class, 50% in the 80-84 mm CW size class, and 95% or more in >95 mm CW individuals had spermatophores.

Average size at maturity of female blue crabs has been reported as 150-160 mm CW in Florida's St. Johns River (Tagatz 1968b) and 147 mm CW in Chesapeake Bay (Prager et al. 1990). However, extremely small ovigerous females have been reported by Overstreet et al. (1983) (a 46.7 mm CW individual from Louisiana), Fischler (1959) (three 52-55 mm CW specimens from North Carolina), Tagatz (1968a) (a 99 mm CW individual in Florida) and Hay and Shore (1918) (a 80 mm CW specimen in North Carolina). Size at maturity has been shown to vary widely; Tagatz (1968a) found that the smallest mature and largest immature females were 99 mm CW and 177 mm CW, respectively.

2.6.3 Mating

Darnell (1959) and Jaworski (1972) suggested that in Louisiana waters the primary mating seasons for blue crabs are May-June and September-October. In the St. Johns River, Florida, Tagatz (1968a) observed that mating occurred sparingly in January and February, was common in March to July, decreased sharply in late summer, and was common again from October through December. The peak in copulatory activity as indicated by a higher percentage of turgid seminal receptacles occurs from May-June and from August-October in South Carolina (Wenner 1989).

In blue crabs, mating primarily occurs in low salinity upper estuarine waters (Pyle and Cronin 1950; Darnell 1959; Williams 1965; Tagatz 1968a). Mating takes place in areas selected by female crabs for molting -- shallow areas with marsh lined banks or beds of submergent vegetation (Tagatz 1968a; Hines et al. 1987a; Ryer et al. 1990; Wolcott and Hines 1990).

Sexual recognition in blue crabs is by visual, chemical, and tactile stimuli. The ability of females to recognize mature males is adaptive since females are vulnerable when molting and would likely be killed and eaten by any other blue crab than a mature male (Teytaud 1971). Gleeson (1980) demonstrated that the presence of a pheromone in the urine of pubertal females elicited courtship behavior in males. Detection of this pheromone occurs through chemoreceptors located on the outer flagella of antennules. Courtship response in males is initiated within 6 min following introduction of pubertal female urine. A male exhibiting courtship behavior approaches female crabs, with its chelae extended in the lateral position, the swimming appendages (fifth pereiopods) waving anterodorsally from side to side above the carapace and walking legs extended such that the body is elevated to a near maximum height above the substrate.

Courtship in blue crabs further progresses when a receptive prepubertal female is encountered and picked up by a mature male. The male uses its first pair of walking legs to carry the female against his sternum in a "cradle carry" position (Van Engel 1958; Hartnoll 1969; Gleeson 1980). The male carries and protects the female until ecdysis is imminent and then releases her, but he remains near and may assist her in the process (Hartnoll 1969).

The copulation in blue crabs was described by Hartnoll (1969). Mating occurs while the female is in the soft shell state. During copulation the pair face each other head to head, with sternal surfaces closely opposed and abdomens extended. The abdomen of the female overlaps that of the male; the apical portions of the first pleopods of the male are inserted into the paired vulvae of the female. The spermatozoa with secretions of the vas deferens form oval shaped bundles called spermatophores, which are ejected by muscular action through the penis into the lumen of the first pleopod. Pumping action of the piston-like second pleopod pushes the spermatophores into the female spermatheca, where they are stored until ovulation. After insemination, the male continues to carry and protect the female until her integument hardens sufficiently. Unimpregnated female crabs retain sexual receptivity for some time and are able to copulate even though the exoskeleton is quite hard (Teytaud 1971). According to Van Engel (1958), mating may occur day or night and lasts from 5 to 12 h. Unlike males, females mate only once.

2.6.4 Spawning

Mating and spawning in the blue crab occur at different times. Viable spermatozoa can be stored in the seminal receptacles for later oocyte fertilization. Prior to fertilization, spermatophores break open to liberate spermatozoa, and seminal receptacles become more flaccid (Wenner 1989). Pyle and Cronin (1950) and Van Engel (1958) suggested that sperm may live in female seminal receptacles for a year or more and be used for repeated spawnings. Johnson (1980) noted that sperm can be stored for several months for either of the two ovulations and, for females that mate in the fall, encapsulated spermatophores may be retained as late as March. However, it is not known whether these individuals will produce viable clutches in the spring (Wenner 1989). The interval between mating and spawning varies with season (Tagatz 1968a; Perry 1975); in the spring and summer spawning usually occurs within 2 months of mating while females that mate in the fall usually delay spawning until the following spring.

During blue crab spawning, oocytes are forced from the ovaries through the seminal receptacle, where they are fertilized. The fertilized eggs are then extruded and attached to fine setae on the endopodites of the pleopods (Churchill 1942; Van Engel 1958). Eggs are about 0.25 mm in diameter. A large, bright yellow egg mass is formed, and as the embryos develop and absorb yolk the sponge darkens and turns black just prior to hatching. The eggs hatch about two weeks after extrusion.

Spawning in the blue crab occurs in high salinity waters in lower estuaries, sounds, tidal passes, and nearshore areas (Churchill 1921; Van Engel 1958; Darnell 1959; More 1969; Perry and Stuck 1982). Van Engel (1958) suggested that hydrological conditions in these areas compare well to optimum conditions determined for hatching and growth in the laboratory -- water temperatures of 19-35 °C and salinities of 21-28 ppt (Sandoz and Rogers 1944; Costlow 1967).

Spawning of the blue crab in the northern Gulf is protracted, with ovigerous females occurring in estuaries and nearshore Gulf waters primarily in the spring, summer, and fall (Darnell 1959; More 1969; Adkins 1972a; Jaworski 1972; Perry 1975; Andryszak 1979; Daud 1979). A bimodal peak in occurrence of ovigerous females has been observed -- late winter-early spring and summer. There is evidence of some winter spawning in the Gulf based upon the occurrence of ovigerous females from December-February in Louisiana (Adkins 1972a) and during January in Florida and Mississippi (Gunter and Hall 1963). In south Texas, Daugherty (1952) suggested that crabs may spawn year-round in Texas during years with mild winters. Williams (1984) suggested that records of ovigerous females in museum collections implies a year-round spawning season in the tropics.

Many, if not all, female blue crabs spawn twice, which may be during the same season or over two seasons (Tagatz 1968a; Johnson 1980; Wenner 1989). Tagatz (1968a) and Adkins (1972a) also suggested that females often return to inland waters to develop their second sponge. However, after hatching of the second sponge, females generally do not reenter estuaries (Tagatz and Frymire 1963; More 1969). Gulf crabs reentering estuaries can be identified by their dull colored shells and an encrustation of fouling organisms, especially the acorn barnacle, Chelonibia patula (Tagatz 1968a). Hard (1942) demonstrated that the reproductive history of the adult females may be reconstructed from examination of the gonads and swimmerets, and Humes (1942) and Hopkins (1947) pointed out the significance of nemertean parasites as further indicators of reproductive history.

Large numbers of spent female blue crabs occasionally litter barrier island beaches during the late summer in Mississippi (Perry 1975). These crabs were usually heavily infested with the parasites Carcinonemertes carcinophila and Octolasmis lowei and fouled with acorn barnacles. The ovarian stages described by Hard (1942) were used by Perry

(1975) to define the reproductive potential of the population. Recently mated females (Stage I) and crabs with developing ovaries (Stage II) were observed in the spring, summer, and fall. Females with mature ovaries (Stage III) occurred throughout the year. The appearance of berried females (Stage IV) in March and April indicated that overwintering Stage III females spawn when water temperatures begin to rise in the spring. Stage IV crabs were most abundant during the middle and late summer, corresponding with the influx of "gulf" crabs from offshore waters. Percentages of female blue crabs in various stages of the spawning cycle in lower Galveston Bay are depicted in Table 2.3.

In the laboratory, Sulkin et al. (1976) induced female blue crabs to spawn in January by holding them in good quality water, feeding them frequently, and maintaining them at 19 °C under ambient lighting conditions. Crabs held at 15 °C did not produce egg masses, and in crabs which did not spawn, ovarian development was greater at 19 °C than at 15 °C. The authors concluded that proper temperature and diet are sufficient to induce spawning, and that lengthening or summer simulated photoperiods are not required.

2.6.5 Fecundity

Realistic estimates of the annual fecundity of the blue crab are based on the number of eggs spawned per batch and the number of batches spawned per season. Early studies found that blue crabs produce between 1.75×10^6 and 2.00×10^6 eggs per spawn (Churchill 1921; Graham and Beaven 1942; Pyle and Cronin 1950; Van Engel 1958). Prager et al. (1990) and Hsueh et al. (1993), however, found somewhat higher mean batch fecundities of 3.2×10^6 and $2.1\text{-}3.2 \times 10^6$, respectively. Blue crabs may spawn once or twice per year (Tagatz 1968a; Johnson 1980; Wenner 1989).

According to Roberts and Leggett (1980), a female blue crab produces approximately 30 g (wet weight) of eggs in a single spawning. Tagatz (1965) recorded female sponge weights ranging from 24 to 98 g with an average value of 37 g.

Prager et al. (1990) investigated the fecundity of blue crabs in Chesapeake Bay. Batch fecundity was significantly related to carapace width and modeled as $E = -2.25 + 0.38\ CW$, where E is predicted fecundity (10^6 eggs), and CW is measured in cm. Mean fecundities varied between years -- 2.6×10^6 in 1986 and 4.0×10^6 eggs in 1987.

2.6.6 Sex Ratios

Sex ratios of adult blue crabs differ spatially with respect to salinity and temporally with female migrations to high salinities for spawning (Millikin and Williams 1984). Deviation from a 1:1 sex ratio has also been attributed to size (Miller et al. 1975) and fishing mortality (Eldrige and Waltz 1977). In general, males predominate in low salinity areas while females predominate in high salinity areas. This trend has been documented in Louisiana (Darnell 1959; Perret 1967; Adkins 1972a; Jaworski 1972) and elsewhere in the northern Gulf (Gunter 1950; Daugherty 1952; More 1969; Perry 1975).

2.7 Age and Growth

Growth is the increase in size, length, or weight with time. In crustaceans, which have a largely inextensible exoskeleton, growth is a stepwise, discontinuous process consisting of a succession of molts (ecdyses) separated by a period of intermolts. During intermolt the integument is hard and growth is suppressed; at each molt the integument is shed and rapid growth in a very short period occurs before the new integument hardens (Hartnoll 1982). Consequentially, crustacean growth is described in two components. One is the molt increment or increase in size occurring at a molt and the other is the molt interval (instar length) or duration between two successive molts. These two components frequently exhibit different responses to intrinsic and extrinsic factors, often making crustacean growth difficult to assess. Molt frequency is likely determined by environmental (water temperature, light, and salinity) and physiological (nutrition and regeneration) states (Havens and McConaugha 1990).

2.7.1 Molting

The mechanism controlling ecdysis is an antagonistic interaction between a molt inhibiting hormone produced in the x-organ sinus gland located in the eyestalks, and the molting hormone ecdysone produced in the y-organ located ventral to the eyestalks (Chang and O'Conner 1978). Just prior to molting, inorganic salts are withdrawn from the exoskeleton and stored in the gastroliths and elsewhere. The old exoskeleton is broken down by enzymes in the molting fluid, and a new cuticle is secreted. The crab rapidly absorbs water, ruptures the old exoskeleton along sutures between the carapace and sternum, and backs out of the old exoskeleton. This is followed by a rapid redeposition of salvaged inorganic salts to harden the new cuticle. Tissue growth is rapid; blue crabs ranging from 10-160 mm CW attained maximum expansion of their new exoskeleton within 6 h following molting (Gray and Newcombe 1938b). Tissue water is replaced with protein during the next intermolt period. Intermolt periods increase with age, but are generally shortened by ample food availability, high dietary nutrient quality, and higher water temperatures.

Nearing ecdysis, blue crabs cease feeding (Van Engel 1958; Hartnoll 1982); increased susceptibility to physical stress, predation, and cannibalism leads these individuals to seek shelter from nonmolting blue crabs (Reaka 1976; Botsford and Wikham 1978; Laughlin 1982; Lipcius and Herrnkind 1982).

A lunar rhythm in blue crab molting has been observed. In larger crabs (>70 mm CW) especially, peak molting activity occurred during full moons (Ryer et al. 1990). Anecdotal information from commercial shedding operations also suggests that peak molting occurs several days prior to and immediately following full moons (Oesterling 1984). Synchronized molting may be evolutionarily selected. When molting is synchronized, predators become limited by the rate at which they can utilize prey during brief peaks in molting activity, resulting in lower individual risk than if molting is spread over time (Ryer et al. 1990).

Stages of the molt cycle of the blue crab as described by Millikin and Williams (1984) and Mangum (1985) are listed in Table 2.4.

Several papers in Perry and Malone (1985) addressed physiological aspects of molting in blue crabs: general physiological changes (Mangum et al. 1985a); hormonal regulation (Freeman and Perry 1985); and, postmolt calcification (Cameron 1985). Additional research on molting physiology of blue crabs includes Smith (1973), Lewis and Haefner (1976), Singer and Lee (1977), Chang and O'Conner (1978), Vigh and Dendinger (1982), Dendinger and Alterman (1983), Soumoff and Skinner (1983), Cameron and Wood (1985), deFur et al. (1985), Fields (1985), Henry and Kormanik (1985), Mangum et al. (1985b), Mangum (1985), Towle and Mangum (1985), Wheatly (1985), Engel (1987), Engel and Brouwer (1987, 1991, 1993), deFur et al. (1988) and deFur (1990).

2.7.2 Larval Development

Freshly extruded blue crab eggs in early developmental stages measured 0.273 x 0.263 mm, and enlarged to 0.320 x 0.278 mm before hatching (Davis 1965). Approximate age of egg masses can be determined by sponge color. Yellow to orange sponges are from 1 to 7 d old while brown to black sponges are 8 to 15 d old (Bland and Amerson 1974). At 26 °C, hatching occurs between 14 and 17 d after spawning, and at 29 °C, between 12 and 15 d (Churchill 1921).

Blue crab larvae normally develop through seven zoeal stages requiring 31-49 d and one megalopal stage persisting for 6-20 d (Costlow and Bookhout 1959). Larvae, however, have successfully metamorphosed to the megalopal stage after only six zoeal stages (Sulkin et al. 1976) or occasionally after an eighth zoeal stage, in the laboratory (Costlow and Bookhout 1959; Costlow 1965). Duration of zoeal development (7 stages) in the laboratory at 25 °C and 26 ppt salinity, ranged from 31 to 49 days (Costlow and Bookhout 1959), whereas the average duration of zoeal development that included only six zoeal stages was 35.7 d (Sulkin et al. 1976). Average duration for complete zoeal development (7 stages) ranged from 32 to 43 d in control groups of four separate chemical contamination studies (Bookhout and Costlow 1975; Bookhout and Monroe 1977; Bookhout et al. 1976 1980). Stuck and Perry (1982) noted that time required for development of spring brood larvae cultured at 25 °C was approximately half that of larvae reared at 16 °C. Spring brood larvae required an average of 34.3 d to become megalopae when cultured at 25 °C, compared to 65.3 d when cultured at 16 °C. Fall brood larvae held at 25.0 °C and 30.0 °C required an average of 43.2 and 43.0 d, respectively, to reach megalopal stages.

A prezoeal stage in blue crabs has been reported by Robertson (1938), Churchill (1942), Truitt (1942), and Davis (1965). The duration of prezoeal stages has varied from 1 to 3 min (Davis 1965) to several hours (Robertson 1938). Sandoz and Hopkins (1944) and

Sandoz and Rogers (1944) noted that larvae emerge as prezoeae only in response to adverse conditions. Costlow and Bookhout (1959), however, made specific reference to the lack of a prezoeal stage.

Costlow (1965) observed a high degree of variability in several zoeal stages of laboratory reared blue crabs. In later zoeal stages, some molts were not accompanied by any morphological change, a molt stage was omitted entirely, or a molt resulted in a larvae sharing characteristics from the previous stage that are usually not retained.

2.7.3 Juvenile and Adult Development

Growth and maturation of the blue crab occur during a series of molts and intermolt phases, each of which is termed a "crab" stage, according to the number of molts that have occurred since the megalopal stage (Van den Avyle and Fowler 1984). Millikin and Williams (1984) noted that growth occurs during molting, although during the intermolt period weight increases occur through relative changes in tissue content (relative increases of whole body protein compared with moisture).

First crabs measure about 2.5 mm CW and undergo a series of 18-20 molts before attaining maturity (Van Engel 1958). Molt frequency decreases as carapace width increases: 5 mm CW crabs -- 3-5 d; 12-25 mm to about 100 mm CW crabs -- 10-15 d; and, larger crabs -- 20-50 d.

Tagatz (1968b) found that summer molt intervals of juvenile blue crabs were apparently not affected by sex or salinity, but were influenced by size and water temperature. The smallest crabs (20-29 mm CW) molted after an average of 11 days while crabs >120 mm CW molted after an average of 42 d. Molt intervals were 3 to 4 times as long in winter as in summer. Intermolt periods of juvenile blue crabs reared in the laboratory are presented in Table 2.5 (Millikin, unpubl. data, cited in Millikin and Williams 1984).

Mean incremental growth per molt in blue crabs has been shown to be highly variable. An increase in width of 25% to 33% of the initial size occurs at each normal shedding (Churchill 1921; Gray and Newcombe 1938b). Assuming that the number of molts in blue crabs is fixed (Newcombe et al. 1949a; Van Engel 1958), differences in size of crabs of the same age result from growth increment variations. Growth increments in terms of CW for crabs held in floating tanks in the St. Johns River varied from 7.8% to 50% with a mean of 25.3% (Tagatz 1968b). Growth per molt (percent increase in CW) during the terminal molt of females averaged 34.4% in salinities >5 ppt and 30.2% in salinities <1 ppt (Tagatz 1968b). Mean percent growth increments varied from 11.9% for small juvenile females (10-19.9 mm CW), 33.7% for larger females (100-109.9 mm CW) 14.4% for small juvenile males (10-19.9 mm CW) and 32.9% for larger males (80 - 89.9 mm CW) (Gray and Newcombe 1938b).

Growth of juvenile blue crabs can also be estimated by modal progression in monthly CW distributions or by calculation of means. Growth in Louisiana waters was approximately 14 mm/mo for young crabs, with slightly higher rates (15 to 20 mm/mo) for crabs >85 mm CW (Adkins 1972a). Darnell (1959) estimated a growth rate of 16.7 mm/mo for crabs in Lake Pontchartrain. More (1969) found a growth rate of 15.3 to 18.5 mm/mo in Texas. Perry's (1975) estimated seasonal (July through January) growth rate of 24 to 25 mm/mo was somewhat higher than rates in other Gulf estuaries. In Texas, growth rates of 21.4 mm/mon for crabs taken in seine samples and 25.2 mm/mon for those from trawl samples were reported by Hammerschmidt (1982b); these high rates were attributed to the use of seasonal (February through August) rather than annual data. Monthly growth rates of 19 10, and 5 mm/mo for crabs recruited in April, August, and December, respectively, were reported by Tatum (1980) for Mobile Bay, Alabama.

No data on maximum age of blue crabs is available from the Gulf of Mexico. Tagatz (1968a) reported that few blue crabs survive >1 yr after reaching maturity (2 yr) and estimated a maximum age of 4 yr for individuals from the St. Johns River, Florida. Van Engel (1958) estimated maximum age of 2-3 yr for blue crabs in Chesapeake Bay. Churchill (1921) and Williams (1965) estimated that the maximum age of blue crabs was about 3 yr along the Atlantic Coast.

Males become sexually mature at the 18 or 19th molt but may continue to grow and molt an additional 3-4 times thereafter (Van Engel 1958). Female crabs were initially thought to rarely, if ever, molt again following their pubertal molt (Churchill 1921; Van Engel 1958). However, mature females undergoing a second molt have been collected by Abbe (1974) and Olmi (1984). For several reasons, Havens and McConaugha (1990) deduced that females of C. sapidus may not enter into periods of permanent anecdysis following the "terminal" molt to maturity. First, 75% of mature females subjected to eyestalk ablation molted, which indicates the physiological ability of mature females to complete ecdysis. Second, analysis of catch data indicated two distinct shifts from smaller to larger mature females, one in early spring and a second in early fall which suggests molting within the same population. Finally, 11.2% of the field sample had regenerating-limb buds. Formation of limb buds is unknown in species which have terminal molts at maturity.

Tagatz (1968a) reported that adult males averaged 147 mm (117-181 mm CW, range) and adult females averaged 148 mm (128-182 mm CW, range). Evink (1976) reported similar sizes in the commercial catch from the Gulf coast: Florida (91-205 mm CW), Louisiana (125-205 mm CW), Mississippi (112-204 mm CW), and Texas (95-228 mm CW).

2.7.4 Effect of Temperature and Salinity

Water temperature has been shown to directly affect larval developmental rates of blue crabs under controlled laboratory conditions (Sandoz and Rogers 1944; Stuck and Perry 1982).

Larger blue crabs are often found in areas of low salinity. The data of Newcombe (1945), Porter (1956), Cargo (1958b), Van Engel (1958), Fischler (1959), and Tagatz (1965, 1968a) suggest a negative correlation of size with salinity. Van Engel (1958) suggested that differences in levels of salt concentration between the crabs and their environment affected the uptake of water, resulting in increased growth at lower salinities. Laboratory studies evaluating effects of salinity on growth of blue crabs, however, have yielded conflicting results. deFur et al. (1988) observed that molting of crabs held in fresh water was accompanied by a wet weight increase of nearly 100%, approximately twice that of crabs molting in high salinity water. They concluded that an increase in epithelium permeability to water would take advantage of the osmotic gradient. Tagatz (1968b) and Cadman and Weinstein (1988), however, found increased growth per ecdysis and growth per day of juvenile blue crabs with increased salinity. The effects of salinity on growth were found to be minimal in other studies. Millikin and Williams (1984) stated that salinities from 6-30 ppt did not differentially affect the growth of juvenile blue crabs. Female blue crabs held under different salinity regimens showed no significant difference in percent increase in body size at the terminal molt (Haefner and Shuster 1964; Haefner 1964). Holland et al. (1971) reported that salinities ranging from 6-21 ppt did not affect growth or food conversion of laboratory reared juvenile blue crabs (5-40 mm CW).

Water temperature strongly affects blue crab growth. Decreased growth rates with declining water temperatures is apparently due to increased intermolt intervals rather than to decreased molt increments. Tagatz (1968b) observed that growth per molt remained similar regardless of water temperature (summer vs. winter), but intermolt intervals were 3 to 4 times longer in winter. Appreciably shorter intermolt intervals with increasing water temperature for blue crabs of 20-69 mm CW were found in the laboratory (Leffler 1972). Growth virtually ceased at water temperatures < 13 °C and the increase in molt frequency continued at a slower rate from 27-34 °C. However, growth per molt frequently decreased as intermolt period decreased. Similarly, in another laboratory study, blue crabs molted more frequently at 30 °C than at 20 °C, but growth per molt was greater at 20 °C (Winget et al. 1976). Cadman and Weinstein (1988) observed that water temperatures affected growth of blue crabs more than salinity did. Based upon culture studies, Holland et al. (1971) suggested that growth of juvenile blue crabs increases with increasing water temperature until an optimum temperature (29-30 °C) is reached, and then decreases as water temperature increases to 35 °C.

The incidence of winter molting in blue crabs is related to water temperature. Ecdysis ceased in Chesapeake Bay from November to mid-April when water temperatures fell to about 16 °C (Graham and Beaven 1942). In Mississippi, Perry (1975) found 13.5% of blue crabs in a winter sample shedding or recently shed. In the St. John's River, Florida, juvenile blue crabs molted two or three times during winter (Tagatz 1968b).

2.7.5 Nutrition and Growth

The influence of diet on larval growth of blue crabs is unknown under natural conditions. Culture of blue crab larvae, however, has provided information on diet and development, although diets fed to blue crab larvae in the laboratory have varied over the years (Robertson 1938; Sandoz and Rogers 1944; Costlow et al. 1959; Costlow and Bookhout 1959; Rust and Carlson 1960; Costlow 1967; Sulkin 1975,1978; Sulkin and Epifanio 1975; Sulkin et al. 1976). A diet of either unicellular algae or recently hatched nauplii of Artemia salina (brine shrimp) resulted in low or no successful molting from first stage to second stage zoea (Costlow and Bookhout 1959). After comparing three dietary treatments (brine shrimp nauplii, gastrulae of the sea urchin Lytechinus variegatus and rotifer Brachionus plicatilis) fed to early stage zoeae, Sulkin and Epifanio (1975) found a rotifer diet yielded the highest frequency of successful molts. Sulkin (1975) concluded that successful completion of zoeal development requires the availability of one or more specific components in the diet which are present in brine shrimp and polychaetes (Hydroides dianthus) but lacking in rotifers and sea urchin larvae. Millikin (1978) reviewed the effects of diet on blue crab larval development and recommended that the first two zoeal stages be fed sea urchin (Arbacea punctulata) embryos and freshly hatched brine shrimp. Sulkin (1978) recommended feeding rotifers to blue crab larvae for the first 14 d of zoeal development, followed by brine shrimp nauplii beginning with the 15th d of development.

Juvenile blue crab dietary protein requirements have been investigated in several laboratory feeding studies. Juveniles with a mean size of 2.5 cm CW achieved better growth when fed 44% or 60% crude protein diets (precent dry weight) compared with individuals fed 27% crude protein (Millikin et al. 1980). Larger juveniles experienced greater weight gain when fed 25% or 40% crude protein compared to 15% crude protein (A. R. Fortner, pers. comm. cited in Millikin and Williams 1984). Winget et al. (1976) found no significant growth differences in juvenile blue crabs fed diets with 26%, 46%, 62%, or 75% crude protein over a 60-d period. Millikin and Williams (1984) suggested that a longer experimental period by Winget et al. (1976) may have resulted in differential growth based on dietary protein concentration.

Biddle et al. (1978) concluded that on the basis of growth, survival, and food conversion over a 9-week period, 3% or 9% dietary fiber (dry weight basis) was sufficient for blue crabs of two size groups (2.5 - 6.0 g and 6.1 - 36.4 g). However, crabs fed diets containing 27% fiber had poorer food conversion ratios, greater feed intake, and increased mortality from a herpes-like virus.

2.7.6 Width-Weight Relationships

Width-weight relationships differ between sexes of blue crabs, with males generally heavier than females for a given carapace width (Newcombe et al. 1949b; Tagatz 1965; Pullen and Trent 1970). Olmi and Bishop (1983) found that maturity, molt stage, and carapace form significantly affected width-weight relationships. Mature males weighed more than similar sized immature males; in contrast, mature females weighed less than immature females of equal size. Crabs with short lateral spines were heavier than those of the same sex and width with long spines. Intermolt (Stage C) and premolt (Stage D) blue crabs of both sexes were heavier than recently molted (Stages A and B) crabs of the same sex. Premolt females were heavier than intermolt females; this difference was not observed for males.

Pullen and Trent (1970) reported CW to total weight relations for crabs >25 mm CW from Galveston Bay, Texas: male (log weight = -3.74 + 2.775 log CW) and female (log weight = -3.54 + 2.639 log CW). Newcombe et al. (1949b) reported CW to total weight relationships for blue crabs from Chesapeake Bay using untransformed data: male weight = 0.00026 width$^{2.67}$ and female weight = 0.00034 width$^{2.57}$. Olmi and Bishop (1983) determined separate total width-weight relationships for males and females, immature and mature crabs by sex and carapace form (ie., typica, intermediate, and acutidens) by sex and molt stage (intermolt, premolt, and postmolt). Olmi and Bishop suggested that because of the influence of sex, maturity, molt stage, or carapace form, comparisons of width-weight relationships may lead to erroneous conclusions if these variables are not considered.

Carapace width has been historically used for minimum size regulations. However, measurements of carapace length or width at the base of the lateral spines would be more accurate in developing a regression analysis because of the variability in lateral spine length (Olmi and Bishop 1983). Carapace length was originally suggested by Gray and Newcombe (1938a) as an alternative to CW for prediction of body weight. Williams (1974) suggested the use of CW measured at the base of the lateral spines rather than from tip to tip to predict body weight.

2.7.7 Autotomy

Autotomy and regeneration of appendages is common in blue crab and other crustaceans (Weis 1976). When an appendage is firmly held or severely damaged, the break occurs along a fracture plane located at the appendage's distal base. A functional appendage is formed by regeneration following the next molt (Pyle and Cronin 1950; Weis 1976).

Smith (1990) investigated the effect of autotomy on growth and molting frequency in blue crabs. He reported that substantial numbers of blue crabs (24.8% in 1986 and 18.8% in 1987) in a subestuary of Chesapeake Bay were either missing or regenerating a limb. Loss of a single cheliped did not alter the molt increment, percent wet weight increase, or molting frequency of these crabs when compared to individuals with no limb loss. However, multiple limb loss significantly reduced the molt increment and percent weight increase in the first postautotomy molt but did not affect the intermolt interval. By the second molt following autotomy, molt increments for crabs missing four limbs did not differ significantly from those for intact crabs or crabs missing one appendage. Regenerating limbs measured 85%-88% of the lengths of undamaged contralateral limbs after the first molt following autotomy with up to three molts required for 100% length regeneration. Removal of the major crusher cheliped resulted in the regeneration of a minor, cutting cheliped in both single and multiple autotomy treatments. Crabs failed to regenerate a distinct crusher even after three molts. Smith (1990) deduced that the rarity of severe limb loss in the Rhode River suggested that population growth is not greatly affected by autotomy.

Smith and Hines (1991b) evaluated geographic, temporal, and ontogenetic variation in autotomy of blue crabs. A substantial percentage (17%-39%) of crabs were either missing or regenerating one or more limbs, suggesting that autotomy is an important mechanism for their survival. Injury levels were generally correlated positively with crab size, suggesting that intraspecific interactions may be a major cause of limb loss. The most frequent injury involved loss of a single cheliped.

Hamilton et al. (1976) showed that while all hatchery raised crabs had a right "crusher" cheliped (large) and a left "cutter" cheliped, only 79% of 1,156 crabs sampled from natural waters displayed this morphological pattern. Larger crabs tended to have a greater percent occurrence of a left "crusher" cheliped and right "cutter" cheliped, which Hamilton et al. (1976) attributed to reversed cheliped laterality through autotomy and regeneration. Shuster et al. (1963) attributed most bizarre deformities of blue crab claws to new growth due to duplication at the injury site rather than autotomy followed by regeneration. Hahn and Labarbera (1993) presented data on failure of limb segments.

May (1936), Skinner and Graham (1972), Ary et al. (1985, 1987), Smith and Hines (1991a), and Smith (1992) also provided information on autotomy in blue crabs. Triple regeneration of the fifth pereiopod was documented by Lawler and Van Engel (1973). Regeneration in larvae was detailed by Costlow (1963a and 1963b).

2.8 Trophic Relationships

2.8.1 Food Habits

The natural diet of larval blue crab has not been quantified, although their diet has been alluded to in a general sense and evaluated under controlled, culture situations. Blue crab zoea are filter feeders that consume both phytoplankton and zooplankton (Van Engel 1958; Benson 1982). Tagatz (1968b) reported that zoeae readily consumed dinoflagellates and copepod nauplii. A diet composed entirely of phytoplankton is thought to be deficient in protein (Costlow and Sastry 1966). Zoeae fed a phytoplankton diet exhibited longer survival times than starved zoeae, but did not successfully molt to second stage zoea (Costlow and Bookhout 1959). Millikin and Williams (1984) concluded that zooplankton are the principal prey of blue crab larvae. Prey organisms of blue crab larvae must meet criteria related to ease of capture and ingestion (Sulkin 1975). These criteria, which are apparently most significant in early zoea stages, almost certainly include critical relationships among physical factors such as size, shape and nature of external covering.

Megalopae have well developed chelae which are used to capture food in a manner similar to that of adults. Megalopae feed on other planktonic organisms while inhabiting the water column but become opportunistic benthic omnivores after settling to the bottom (Benson 1982). Van Engel (1958) and Darnell (1959) also classified megalopae as omnivores. Van Engel (1958) further noted that megalopae may be fed bits of fresh fish, shellfish, or green aquatic plants.

Effects of diet on cultured, juvenile blue crabs were evaluated by Holland et al. (1971), Winget et al. (1976), Biddle et al. (1978), Millikin et al. (1980) and Millikin (unpublished, cited in Millikin and Williams 1984).

The juvenile and adult blue crab has been described as an opportunistic benthic detritivore, omnivore, primary carnivore, cannibal, and general scavenger (Hay 1905; Darnell 1958; Tagatz 1969; Laughlin 1979 and 1982; Alexander 1986).

Blue crab diet has been the subject of numerous studies (Darnell 1958; Van Engel 1958; Tagatz 1968a; Norse 1975; Laughlin 1982; Alexander 1986; Stoner and Buchanan 1990; Fitz and Wiegert 1991b; Hsueh et al. 1992b). Norse (1975) and Steele and Perry (1990) compiled lists of known prey items of blue crab. A comprehensive list of documented prey items is included in Table 2.6.

Food habit studies have shown that predominant food items vary greatly. Darnell (1961) and Laughlin (1982) suggested that the blue crab did not conform to specific trophic levels and utilized alternate food sources from time to time depending upon availability. Studies have indicated that food availability strongly influences blue crab diet (Tagatz 1968a; Alexander 1986).

Laughlin (1982) reported that by weight the main food items taken by blue crabs of all size classes were: bivalves (35.7%), fishes (11.9%), xanthid crabs (11.4%), shrimp (4.6%), gastropods (4.8%), and plant material (3.9%). In order of frequency of occurrence, the following food items were tabulated by Tagatz (1968a): organic debris, fish, clams, mussels, amphipods, crabs, other crustaceans, algae, vascular plants, nemerteans, polychaetes (Nereis pelagicus), insects, ostracods, snails, and oysters. Darnell (1958) calculated the volumetric importance of different food items to blue crabs: molluscs -- 45.5%; crustaceans -- 24.3%; organic debris -- 21.7%; plants -- 4.3%; fishes -- 2.1%; hydroids -- 0.3%; and, insects --0.1%.

Ontogenic shifts in blue crab feeding habits were discussed by Darnell (1958), Laughlin (1982), Alexander (1986) and Stoner and Buchanan (1990). Changes in ontogenic feeding habits appear to be mediated by two factors: (1) differences in the functional morphology of the feeding apparatus, locomotory system, and sensory capabilities; and, (2) life cycles which may place size classes exclusively in the estuary at times when different food items are available (Laughlin 1982). Laughlin (1982) divided blue crabs from Apalachicola Bay, Florida, into three trophic groups based upon their stomach contents.

Juveniles <31 mm CW fed mainly on bivalves, plant material, detritus, and ostracods. Crabs 31 to 60 mm CW consumed fish, gastropods, and xanthid crabs. Animals >60 mm CW fed on fish, bivalves, xanthid crabs, and other blue crabs. In Lake Pontchartrain, Louisiana, Darnell (1958) noted that differences in juvenile and adult diets were not pronounced but in crabs >124 mm CW, molluscs, particularly Rangia, became the dominant food item. Stoner and Buchanan (1990) found that the diet of C. sapidus clustered into four major size classes: 10-20 mm CW, 21-30 mm CW, 31-80 mm CW , and 81-150 mm CW. Amphipods, which were major dietary constituents in 10-20 mm CW crabs, and foraminiferans, which were important in 21-30 mm CW crabs, were rare or absent in diets of larger crabs. The occurrence of polychaetes decreased as crab size increased. Detritus, important in smaller size groups, became less prevalent in crabs >80 mm CW. Crab and fish remains were important dietary items in crabs >30 mm CW. Bivalves were common in 81-150 mm CW crabs. According to Alexander (1986), young crabs (<31 mm CW) utilized vascular plants, algae, and foraminifera more frequently than molluscs, fish, and crustaceans, the reverse of adult crabs (>60 mm CW). Stomachs of young crabs also contained more sand. In contrast, Tagatz (1968a) found that all sizes of crabs basically ate the same food types.

Feeding habits of blue crabs may also vary as a function of locality and season (Laughlin 1982), which appears to reflect marked variation in food availability and diversity.

The importance of molluscs in blue crab diet has been documented by Menzel and Hopkins (1956), Darnell (1958), Tagatz (1968a), Tarver (1970) and Alexander (1986). Molluscs generally comprise the dominant food item, especially in the larger size classes.

Plant material may contribute significantly to the diet of blue crabs: about 10% plant material by volume (Darnell 1958); occurring in 8.5% (Tagatz 1968a) and 29% of stomachs (Alexander 1986); and, an average of 4% by weight (Laughlin 1982). Alexander (1986) attributed the presence of large amounts of plant material in blue crab diets to their association with salt and brackish marsh shorelines where plant material was abundant. Truitt (1939) found that roots, shoots, and leaves of eelgrass (Zostera), ditch grass (Ruppia), sea lettuce (Ulva) and salt marsh grass (Spartina) were commonly consumed by crabs in shallow estuarine areas. McClintock et al. (1991) used digestive carbohydrases to imply utilization of detritus as a trophic resource.

Callinectes sapidus is well known for its cannibalistic habits. Darnell (1958), Tagatz (1968a), and Laughlin (1979) observed that in some size classes blue crabs make up as much as 13% of the diet of other blue crabs. Healthy individuals may deter cannibalism but those in poor health, missing important appendages, heavily fouled with other organisms, and those within or immediately following ecdysis are more likely to fall prey to other blue crabs. Blue crabs have been observed to feed on crab scraps and injured or dead crabs that are discarded in the field or found in peeler crab shedding tanks. All sizes of papershell crabs regularly consume their own molted exoskeletons (Van Engel 1987). Peery (1989) evaluated effects of size and abundance on blue crab cannibalism.

Darnell (1958) suggested that juvenile crabs primarily feed either at night or early morning, while adults feed mainly during daytime. Ryer (1987) found a weak trend toward nocturnal feeding with an apparent peak at dusk.

Blue crabs feed in three different ways. Raptorial feeding involves feeding on large prey organisms; interface feeding involves feeding from the surface of objects and on sediment surfaces; and plankton feeding involves consuming small suspended material (Norse 1975). Distance and contact chemoreception, touch, and vision are used when appropriate.

Blue crabs move sideways or forward when searching for prey, testing objects with the chelae and sediments with the dactyli of the walking legs (Norse 1975). When chemical stimuli in low concentrations are detected blue crabs move from side to side in sweeping motions until the stimulus is located. Blue crabs may rush forward and pounce on a potential food object. In this manner, large objects in or on the sediment or suspended in or floating on the water can be seized. When a buried mollusc is located by chemosensory or tactile means, blue crabs thrust the walking legs into the sediment and excavate the mollusc using the chelae and walking legs (Blundon and Kennedy 1982a; Alexander 1986). Pits as deep as 10-15 cm, presumably dug by crabs, have been verified in clam beds (Dunnington 1956). Food is grasped by the chelae and first pairs of walking legs and brought to the oral area with assistance from the third maxillipeds. Hard objects are crushed and broken by chelae before swallowing (Norse 1975; Blundon and Kennedy 1982a). Molluscs which are too large to crush may be exposed by chipping the edge of the shell and prying it open (Blundon and Kennedy 1982a).

By interface feeding, blue crabs can feed on aufwuchs, and living and nonliving components in sediment (Norse 1975). In this type of feeding behavior, the feeding area is brought into the oral field or frontal area and the third maxillipeds and feeding appendages remove food particles from the interface. Using this method, crabs may seize encrusted blades of seagrass and process them through mouth parts to remove hydroids, foraminiferans and algae. While interface feeding on organic material in sediment, blue crabs sweep the chelae in gentle, alternating, gathering motions.

In plankton feeding, blue crabs use the three pairs of flagellae on the exopodites of the maxillipeds to create currents that bring food particles past the oral area where they are trapped by setae on the maxillipeds (Norse 1975).

2.8.2 Predator-Prey

Laughlin (1982) concluded that because of its opportunistic feeding habits and high abundance levels, blue crabs are a crucial factor in the estuarine food web. Blue crabs are especially effective estuarine predators because of their great tolerance to salinity extremes (Carriker 1967). Blue crabs also dig into sediments to both forage and hide, thus killing more organisms than they consume (Virnstein 1977). Given its high "feeding adaptiveness", blue crabs play an important role in determining the abundance and behavior of its prey.

Predator-prey interactions of blue crab were initially researched because of the impact of this species on other commercially important species. However, in recent years research has expanded to include more comprehensive analysis of prey assemblages or behavioral interactions: Naqvi (1968), Hamilton (1976), Krantz and Chamberlin (1978), Virnstein (1977 and 1979), Peterson (1979), Seed (1980), Holland et al. (1980), Nishimoto (1980), Heck and Thoman (1981), Hughes and Seed (1981), Kneib (1982), Blundon and Kennedy (1982a, 1982b), Arnold (1984), Orth et al. (1984), Gibbons and Castagna (1985), Kline et al. (1986), Lipcius and Hines (1986), West and Williams (1986), Heck and Wilson (1987), Bisker and Castagna (1987, 1989), Wilson et al. (1987), Bisker et al. (1989), Martin et al. (1989), Eggleston (1990a, 1990b, 1990c), Hines et al. (1990), Peterson (1990), Sponaugle and Lawton (1990), Junda (1991), Lin (1991), Mansour and Lipcius (1991), Smith and Hines (1991a), Abbe and Breitburg (1992), Eggleston et al. (1992), Hsueh et al. (1992a), and Wilson et al. (1990).

Blue crabs may have detrimental effects on commercial invertebrate species such as oysters (Lunz 1947; Marshall 1954; Menzel and Hopkins 1956; Menzel and Nichy 1958; Nichy and Menzel 1960; Krantz and Chamberlin 1978; Eggleston 1990). Eggleston (1990) found that predation by large male C. sapidus can lead to local extinction of juvenile oysters (15-35 mm shell length) regardless of density, with 30 mm shell height nearing the critical size for crushing by large crabs. Blue crabs were the most serious predators of young oysters (5-30 mm) in South Carolina waters (Lunz 1947). Laboratory studies indicated that juvenile blue crabs ranging from 10 to 15 mm CW consumed cultchless oysters up to 4 mm shell length, while crabs from 65 to 80 mm CW could not feed upon oysters >25 mm shell length (Krantz and Chamberlin 1978). Blue crab predation on Louisiana oysters was experimentally documented by Menzel and Hopkins (1956). They found that blue crabs consumed an average of 19 oyster spat/d and concluded that the species is an important predator of spat, but only a scavenger of adult oysters (i.e., eating only dead or sick individuals).

Blue crabs also prey upon clams such as Mercenaria mercenaria (Carriker 1951; Van Engel 1958), Rangia cuneata (Darnell 1958) and Mya arenaria (Hines et al. 1990). Blundon and Kennedy (1982a) investigated the mechanical and behavioral aspects of blue crab predation on eight bivalve species. Forces required to crack shells were determined and compared to the crushing strength of blue crabs. Only large (>40 mm) Rangia cuneata have shells strong enough to resist the crushing capabilities of large blue crabs. Blue crab predation is a major constraint in hard clam culture and without some form of protection clam mortality can approach 100% (Castagna et al. 1970; Menzel et al. 1976). Bisker et al. (1989) reported that the oyster toadfish (Opsanus tau) reduced xanthid and portunid crab predation on juvenile hard clams in field cultures. Bisker and Castagna (1989) compared crab predation on juvenile hard clams in trays and found that clam survival was 69.5% in the presence of toadfish and 2.3% without toadfish.

Predation intensity on blue crabs varies with characteristics of the predator (species, size, life history stage, physical characteristics, and feeding habits, and whether it is a resident or migratory species) and the chemical and physical conditions of the environment (Van Engel 1987). Predation on blue crab zoeae and megalopae is largely unknown because remains of early stage brachyurans in fish stomachs are seldom identified other than as "crab zoea", "brachyuran zoea" or "megalopa" (Van Engel 1987). Larval blue crabs are fed upon by other plankters, fish, jellyfish, and comb jellies (Van Engel 1958). Blue crab megalopae have been specifically identified in weakfish (Cynoscion regalis) (Van Engel and Joseph 1968), mummichog (Fundulus heteroclitus) (Kneib 1982), and possibly pompano (Trachinotus carolinensis) (Bellinger and Avault 1971). McHugh (1967) and Millikin and Williams (1984), however, suggested that herring or menhaden species, which consume zooplankton, are probably important predators of blue crab larvae. Predation by sand shrimp (Crangon septamspinosa) and grass shrimp (Palaemonetes pugio) may impact survival rates of megalopae settling into Chesapeake Bay grass beds (Olmi and Lipcius 1991).

Van Engel (1987) tabulated food habit studies of fishes and concluded that, for numerous species, <15% of the individuals occasionally consume blue crabs. At least 30 species of fish have been identified as blue crab predators (Table 2.7). Juvenile and adult blue crabs are important dietary items of sport and commercial fish such as spotted sea trout (Cynoscion nebulosus), red drum (Sciaenops ocellatus), sheepshead (Archosargus probatocephalus), black drum (Pogonias cromis), southern flounder (Paralichthys lethostigma), alligator gar (Lepisosteus spatula), yellow bass (Morone interrupta), largemouth bass (Micropterus salmoides) and blue catfish (Ictalurus furcatus) (Lambou 1961; Fox and White 1969; Fontenot and Rogillio 1970; Van Engel 1987).

Blue crabs also serve as important prey items for other vertebrate species (Table 2.7). Among reptilian predators, the American alligator (Alligator mississippiensis) may feed heavily on C. sapidus (Valentine et al. 1972). Van Engel (1987) concluded that loggerhead sea turtles (Caretta caretta) consume mostly horseshoe crabs, rock crabs, some blue crabs, spider crabs, and clams, but the Kemp's ridley (Lepidochely kempi) feeds exclusively on blue crabs. Avian predators include the clapper rail (Rallus longirostris), great blue heron (Ardea herodias), American merganser (Mergus merganser americanus), and hooded merganser (Lophodytes cucullatus) (Bateman 1965; Day et al. 1973; Stieglitz 1966). The primary mammalian predator of blue crab is the raccoon (Procyon lotor) (Norse 1975), although river otters (Lutra canadensis) have been reported to eat blue crabs (Wilson 1955 and 1959; Chabreck et al. 1982).

2.9 General Behavior

2.9.1 Larval Behavior

Larvae of C. sapidus exhibit differential depth distributions among developmental stages that reflect behavioral adaptations which may aid recruitment to an estuary.

Responses to various environmental stimuli result in a pattern of early stage zoeae inhabiting surface waters and later stage zoeae and megalopae existing at deeper depths, (Sulkin et al. 1980; Sulkin 1984).

Sulkin et al. (1980) and Sulkin (1984) investigated ontogenetic changes in geotaxis and barokinesis of larval C. sapidus and summarized the behavioral basis for depth regulation in brachyuran crab larvae. Early stage larvae are likely to stay near the surface by exhibiting positive phototaxis, negative geotaxis, high barokinesis, and increased swimming rate with increased salinity. By the fourth zoeal stage, behavioral changes have occurred which maintain larvae in a deeper vertical position. Stage IV zoeae have a higher sinking rate than stage I zoeae and are in a transitional period between negative and positive geotaxis. Additionally, the swimming rate of stage IV zoeae decreases as pressure and salinity increases and water temperature drops. Stage VII zoeae exhibit positive geotaxis and a reduced swimming rate in response to increased salinity and pressure and decreased temperature. Larval responses to light and gravity were evaluated by Forward (1977) and Latz and Forward (1977). Antipredatory adaptations of blue crab zoeae were observed by Morgan (1987).

Upon metamorphosis to the megalopal stage, behavioral traits which promote successful ingress to the estuary are expressed. Unlike planktonic zoeae, the megalopae may be benthic at times and exhibit rhythmic base activity levels due to exogenous or endogenous control (Sulkin et al. 1979; Sulkin and Van Heukelem 1982). Megalopae appear to be extremely sensitive to minute pressure differences which allow them to perceive changes in environmental conditions and to precisely regulate depth. Laboratory studies indicated a low barokinetic response threshold (0.4 atm) which caused megalopae to swim a short distance from the bottom (Naylor and Isaac 1973). Herrick (1911) observed megalopae picking up sand.

Luckenbach and Orth (1992) conducted laboratory experiments to evaluate swimming velocities and behavior of blue crab megalopae. Results suggested that at low to moderate current velocities megalopae can move in search of desirable settlement sites and maintain their positions, rather than only being passively moved by currents.

2.9.2 Agonistic and Escape Behavior

The term agonistic includes both aggressive and defensive behavior and all degrees of intermediate forms. Brachyuran crabs are highly aggressive animals, having agonistic interactions consisting of visual threat displays and actual physical combat, which may be formal and ritualized or wild and irregular (Schone 1968).

Agonistic behavior of blue crabs was reviewed in detail by Jachowski (1974) from both field and laboratory observations. Most agonistic acts employ chelipeds as organs of expression as well as weapons. Such acts as cheliped extending, shielding, leaning, fending, embracing, poking, striking, grasping, and crouching were described and illustrated. Responses during encounters varied with orientation of the two individuals, the distance between them, their size and sex, and presence of food. Vigorous combat was seen only when threats failed to deter crabs attracted to food or only among males when a sexually receptive female was held by one of them.

Agonistic behavior was also studied by Teytaud (1971) and Norse (1975). Blue crabs react to predatory attacks with two general types of behavior: "stand and fight" which involves displaying, fending, and striking, much the same as in encounters with other blue crabs; and "fleeing" accomplished by walking, swimming, or digging (Norse 1975). Blue crabs have chelae which may act as substantial weapons of defense. Chelae may be extended to angles >160° in high intensity displays, while during lower levels of defensiveness, chelae may be angled slightly forward from the resting position (Wright 1968).

Passive and attack autotomy play roles in blue crab escape behavior (Robinson et al. 1970). Attack autotomy may deter attackers while passive autotomy, a well known defense mechanism in lizards, may serve to appease or confuse predators.

Most blue crabs, especially smaller individuals, usually resort to flight when confronted with danger rather than standing and fighting (Norse 1975). Unless pursued, escape flight is usually followed by attempts at concealment.

2.9.3 Swimming

The portunids are known popularly as swimming crabs. This family has the most widespread morphological adaptations for swimming among the Brachyura. Hartnoll (1971) described the occurrence, methods, and significance of swimming in brachyuran crabs. The swimming of C. sapidus was studied through analysis of high speed cinematographs (Spirito 1972). Progression through water is effected by means of a sculling motion of the broad oar-like posterior limbs. Blue crabs can swim forward to a limited extent, hover, and swim backwards quite well. However, swimming sideways is the most common and fastest means of locomotion and is used in escape (Norse 1975).

2.9.4 Other

In addition to previously discussed behavioral traits, a complex behavioral repertoire has been documented, including climbing behavior (Abbott 1967), death feigning (Bullock and Horridge 1965), predator avoidance (Gunter 1954), galvanotropism (Kellogg 1958), burying (MacGregor 1950), crab schooling (Tyler and Cargo 1963), cleaning mechanisms (Norse 1975), directional orientation (Nishimoto and Herrnkind 1978 and 1982), tonic immobility (O'Brien and Dunlap 1975), rhythms of color change (Fingerman 1955), detection of food (Pearson and Olla 1977) or pollutants (Pearson and Olla 1979, 1980), sexual recognition (Chidester 1911; Teytaud 1971; Jachowski 1974), mate competition (Smith 1992), pheromone communication (Gleeson 1980, 1982), movement patterns and behavior in the intertidal zone (Nishimoto 1980), locomotory activity patterns (Halusky 1975), avoidance reactions to storm water runoff (Laughlin et al. 1978), and symbionts on scyphozoans (Jachowski 1963; Phillips et al. 1969; Cargo 1971). Hall (1980) reviewed blue crab behavior in relation to power plants.

2.10 Movements and Migrations

2.10.1 Movements According to Lifestage

Blue crabs are migrants that occupy various estuarine and nearshore habitats, according to the physiological requirements of each stage of the life cycle. After larval development in high salinity waters and megalopal recruitment into estuarine waters, early crab stages (5-10 mm CW) of both sexes begin an up-estuary migration to shallow areas of low to intermediate salinity (Daud 1979). Female crabs mate at the pubertal molt and move to more saline waters to spawn while males tend to remain in brackish areas. Jaworski (1972), through his observations of commercial fishing activity, identified five migration patterns in the Barataria estuary that are probably applicable to other Louisiana estuaries: 1) spring up-estuary migration of large juveniles and adult males; 2) recruitment of small juveniles to the upper estuary; 3) return of spawned females from offshore to the lower estuary in the summer; 4) upper-to-lower estuary and offshore migration of gravid females in autumn (the fall run of females); and, 5) down-estuary migration of large juveniles and adult males from the upper estuary in November and December.

Similar migration patterns in which movements appear to be related to phases of the life cycle have been reported by Cronin (1954), Van Engel (1958), Darnell (1959), Tagatz (1968a), More (1969), Judy and Dudley (1970), Perry (1975) and Eldrige and Waltz (1977).

2.10.2 Tagging Studies

Movements of blue crabs have been well documented through tagging studies in the northern Gulf of Mexico (More 1969; Perry 1975; Benefield and Linton 1990), Florida (Oesterling 1976; Evink 1976; Oesterling and Adams 1982; Steele 1991; Steele and Hochberg 1987) and the Atlantic Coast (Porter 1956; Cargo 1958a; Fischler and Walburg 1962; Tagatz 1968a; Judy and Dudley 1970).

During the fall, Perry (1975) tagged and released 1023 adult blue crabs (155 males, 868 females) in Lake Borgne and Mississippi Sound. Total recoveries numbered 304 (29.7% return), of which 69 were males and 235 were females. Ninety-two % of females and 81% of males were recovered in Mississippi Sound northeast of release sites. Recovered crabs traveled from 2 to 38 mi, with recapture times ranging from 4 to 261 d. Results apparently confirmed Darnell's (1959) theory that female crabs leave the low salinity waters of lakes Pontchartrain and Borgne to overwinter in Mississippi and Chandeleur sounds.

During the spring and summer, Perry (1975) tagged and released adult crabs in the Biloxi Bay, Bay St. Louis, and Pascagoula River estuaries. Recoveries were generally made within 40 d of release. Movements appeared to be random with little movement between adjacent estuaries.

More (1969) studied adult crab movement in Galveston Bay, Texas. Approximately 85% of male and 45% of female crabs were recovered within 3.5 km (2.2 mi) of the release site. Females demonstrated a southward movement to areas of higher salinity, whereas male crabs remained in the brackish areas of the bay.

In Trinity Bay, Texas, Benefield and Linton (1990) tagged and released 300 adult blue crabs (249 males, 51 females) during December. Fifty-four crabs (48 males, 6 females) were recaptured (18% recovery). Crab movement was generally southward. Average distance traveled was 7.9 km (4.9 mi) for males and 19.1 km (11.9 mi) for females. Time to recapture averaged 112 d and ranged from 76 to 144 d.

Studies in the northern Gulf of Mexico revealed migration by female blue crabs from estuaries to nearshore marine waters and random movement of males. However, blue crabs along the west coast of Florida appear to deviate from northern Gulf patterns in their migratory habits. (Oesterling 1976; Evink 1976; Oesterling and Evink 1977; Oesterling and Adams 1982; Steele 1991). Instead of the classic onshore-offshore pattern, an onshore-alongshore movement of females to specific spawning areas was evident.

Oesterling (1976) tagged and released 6287 blue crabs (51.4% males, 48.6% females) from September through March along the west coast of Florida. The overall return rate was 10.7%, of which 51% were females and 48% were males. Females traveled the greatest distance, while 95% of recaptured males were found within 17.7 km (10.6 mi) of the release site. Approximately 25% of recaptured females moved >48.3 km (30.2 mi), 43% moved >16.1 km (10.1 mi), 4% traveled >322 km (201 mi) and 3 individuals traveled 494.1 km (306.9 mi) from release sites. All nonlocal movement of females was in a northerly direction along the west coast of peninsular Florida and westerly along the panhandle, with the majority of returns near Apalachicola Bay. Based on the return data, Apalachicola Bay is a primary spawning ground providing blue crab larvae for recruitment along the entire Gulf coast of peninsula Florida (Oesterling and Adams 1982). Surface circulation patterns associated with the Loop current and the Apalachicola River are probably responsible for transport of blue crab larvae to southwestern Florida (Oesterling and Adams 1982).

Steele (1991) tagged 13,366 blue crabs in Tampa Bay, Florida, during 1982-1983. An alongshore, single sex migration of female blue crabs in a northward direction was indicated. The overall return rate was 24.9%. Several crabs traveled >800 km (500 mi) in approximately 100 d. Twenty-nine % tag returns were recovered >765 km (478 mi) from Tampa Bay.

A two part tagging program during 1984-1985 by Steele (1991) was also conducted. In the first segment, crabs (n=2767) were tagged in Apalachee Bay. Forty-three percent of tagged crabs were returned, with only 5% recaptured west of the tagging area. This supports the hypothesis of a low salinity barrier near the Apalachicola River that impedes further westward migration. In the second part of the study, crabs were tagged along the southwest coast of Florida from Key Largo to Sarasota Bay to determine the contribution of various populations to westward migration. Some of these tagged crabs moved as far as Apalachee Bay.

Tagging studies along the Atlantic coast were conducted by Porter (1956), Cargo (1958a), Fischler and Walburg (1962), Tagatz (1968a), Judy and Dudley (1970), and Rothschild et al. (1991). These studies revealed movement patterns similar to most tagging studies in the northern Gulf of Mexico. Wolcott and Hines (1990), Fitz and Wiegert (1991b), Shirley and Wolcott (1991), and Van Montfrans et al. (1991) quantified local movement patterns of juvenile crabs.

2.10.3 Tagging Techniques

Haefner (1971) and Newman and Ward (1973b) described methods of immobilizing blue crab chelae to minimize fighting and cannibalism. Haefner (1971) utilized elastrator rings used in the castration of livestock for chelae immobilization. Two rings are required for large crabs and a special tool is needed for application of the rings. Newman and Ward (1973b) used plastic-coated wire tape for chelae immobilization. The wire tape offered advantages over the elastrator rings because unlike the rings the tape does not damage the claws of small or recently molted crabs. Wire tape wrapped by hand was effective on small, postmolt, and large crabs, with an identification tag easily fitted to the wire tape (Newman and Ward 1973b).

Cronin (1949) compared methods of tagging blue crabs and determined that the method of Fiedler (1930) produced the highest returns. A brightly colored plastic carapace tag is attached by slipping a preformed loop of stainless wire over one lateral spine, drawing the wire and tag taut over the back, and securely winding the other end of the wire around the opposite spine.

Carapace tags are limited to adult crabs because these tags are shed with molting. Fannaly (1978) described a method for tagging immature blue crabs using an external spaghetti-type tag. The tag was inserted through the thick membrane at the dorsoposterior articulation of the coxa of the fifth leg (paddle) with the body and anchored by the membrane. In the laboratory, crabs retained the tag through one molt although the tag somewhat hindered the molting process.

The use of microwire tags implanted into juvenile blue crabs was described by Van Montfrans et al. (1986) and Fitz and Wiegert (1991a). Microwire tags provide an effective longterm marking system for crabs because the retention rate is high, tags have no effect on growth or survival, and large numbers of crabs can be marked under field conditions.

Wolcott and Hines (1989) described an ultrasonic carapace transmitter which tracked free ranging premolt blue crabs and signaled ecdysis. A magnetic switch opens at ecdysis and doubles the output pulse of the transmitter.

2.11 Pathology and Parasitology

Parasites, diseases, and symbionts of blue crabs have been summarized and reviewed in a number of publications. Sindermann and Rosenfield (1967) reviewed the principal diseases of commercially important marine crustacea. Fungal diseases of blue crab eggs and larvae were discussed by Sindermann (1977b). Overstreet (1978) reviewed parasites and other symbionts associated with marine and estuarine hosts in the northern Gulf of Mexico. Bacterial (Johnson 1976c, 1977e; Moody 1982) and viral (Johnson 1977c 1977d 1978 and 1985) diseases have been summarized. Metazoan (Overstreet 1982) and protozoan symbionts and related diseases (Couch and Martin 1982) have also been reviewed. Messick and Kennedy (1990) evaluated bacterial and viral infections of blue crabs in shedding systems. Compilations of blue crab biology by Perry (1975), Steele (1982), Perry et al. (1984), Millikin and Williams (1984) and Steele and Perry (1990) also included sections on parasites, diseases, and symbionts. Norse (1975) and Van Engel (1987) compiled a list of known parasites and symbionts of blue crabs. Iversen (1986) provided a bibliography on blue crab parasites, diseases, and symbionts. Messick and Sindermann (1992) reviewed principal diseases and parasites of blue crabs.

Documented records of the more common and important parasites, symbionts, and diseases of C. sapidus are listed in Table 2.8. It is beyond the scope of this document to review in detail all aspects of blue crab pathology and parasitology. Therefore, only selected diseases, parasites and symbionts will be discussed.

2.11.1 Viral Infections

At least nine viruses (Table 2.8) either singularly or in combination are pathogenic to the blue crab (Millikin and Williams 1984). Viral diseases of blue crabs have been reviewed by P. T. Johnson (1977c, 1977d, 1978, 1985). Such infections are characterized by weakness, decreased clotting ability of the hemolymph, and eventual paralysis (Johnson 1976b, 1977b, 1977d, 1978). The impact of viral infections on blue crab populations is not known (Millikin and Williams 1984).

Herpes-like virus (HLV) may be fatal, although other than weakness, no external or internal signs are noticeable until shortly before death, when the hemolymph becomes chalky white (Johnson 1977b, 1977c). Chesapeake Bay Virus (CBV) infects the nervous system and is isolated from ectodermal tissue (Johnson, 1978). CBV infection is characterized by abnormal behavior and blindness, which may appear 2 mo before death.

Other viruses such as Baculovirus A may not cause serious disease in blue crabs (Millikin and Williams 1984).

Additional information on blue crab viruses can be found in Bang (1974), Yudin and Clark (1978 and 1979) and Hejkal and Gerba (1981).

2.11.2 Bacterial Infections

Some documented bacterial infections of blue crabs are listed in Table 2.8. Johnson (1976c) discussed the pathology and histopathy of bacterial infections in blue crabs. Bacterial diseases were reviewed by Johnson (1977e) and Moody (1982). The occurrence of microbes on blue crabs were surveyed by Colwell et al. (1975), Sizemore et al. (1975), Babinchak et al. (1982) and Elliot (1984). Noteworthy bacterial infections of blue crabs include that of the usually nonfatal bacteria responsible for "shell disease" and those from pathogenic species of Vibrio.

Shell disease of blue crabs is characterized by cratered lesions or dark areas in the exoskeleton which merge as the disease progresses. The pathology of the disease was discussed by Rosen (1967, 1970), Cook and Lofton (1973), Sandifer and Eldrige (1974), Iversen and Beardsley (1976), Sindermann (1977a, 1989), Getchell (1989), McKenna et al. (1990), and Weinstein et al. (1992). There is apparently no bacterial penetration of the epicuticle. Shell disease is contagious and occurs in natural populations. This disease can be epidemic in shedding tanks and artificial enclosures, resulting in heavy mortalities during periods of high water temperature. In nature, blue crabs often shed the diseased shell during ecdysis and become disease free. Older crabs are more susceptible to shell diseases due to longer intermolt periods. Extensive erosion of the integument usually leads to secondary infection of soft tissues by pathogenic bacteria and fungi, which may lead to death. Chitinoclastic species of Vibrio, Pseudomonas and Beneckea have been isolated from necrotic lesions.

Several species of Vibrio have been identified from blue crabs (Krantz et al. 1969; Colwell 1970; Cook and Lofton 1973; Keel and Cook 1975; Sizemore et al. 1975; Davis and Sizemore 1982; Moody 1982; Elliot 1984). In a study by Davis and Sizemore (1982), Vibrio species were the predominant bacterial types in the hemolymph, occurring in 50% of the crabs sampled in summer. Vibrio parahaemolyticus, responsible for mortalities in blue crabs and food poisoning in humans, was found in 30% of the surveyed crabs (Overstreet 1978). Prevalence of V. parahaemolyticus in coastal waters of Mississippi was related to water temperature and distance from land (Keel and Cook 1975). Vibrio cholerae and V. vulnificus were isolated from 3.5% and 9.0%, respectively, of the crabs examined by Davis and Sizemore (1982). Vibrio parahaemolyticus and V. cholerae were not found together, whereas V. parahaemolyticus and V. vulnificus were commonly isolated from the same crab. Zoonotic diseases and the history of the 1978 cholera outbreak in Louisiana was discussed by Moody (1982). Evidence indicated that the outbreak was due to poor sanitary practices in home prepared crabs. The role of Vibrio in mortalities of cultured soft crabs was discussed by Sizemore (1985).

2.11.3 Fungal Diseases

Fungal diseases reported in blue crabs are listed in Table 2.8. P. T. Johnson (1983), Bland (1974) and Sindermann (1977b) reviewed fungal diseases. The marine phycomycete, Lagenidium callinectes, attacks and kills eggs of blue crabs (Couch 1942; Sandoz and Rogers 1944; Sandoz et al. 1944; Newcombe and Rogers 1947; Rogers-Talbot 1948; Sinderman 1977b). Zoospores settle on egg masses, germinate, and proliferate germ tubes that develop into branched septate mycelia (Sinderman 1977b). Fungal invasion is limited to the periphery of the sponge with diseased portions appearing brownish in orange to yellow sponges and gray in more mature, black sponges. More than 25% of an egg mass may be destroyed. Up to 95% of ovigerous females may be infected, with incidence of infection varying with location and time (Bland and Amerson 1974). Lagenidium callinectes infects egg masses at salinities of 5-30 ppt (Sinderman 1977b). Additional literature on L. callinectes includes Johnson and Bonner (1960), Couch (1971 and 1973), Amerson and Bland (1973), Bland and Amerson (1973a and 1973b), Ruch and Bland (1973), Bland (1974), Bland et al. (1976) and Bahnweg and Gotelli (1980).

2.11.4 Protozoan Infections

Sprague and Couch (1971) and Sprague (1970, 1978) listed the known protozoan parasites, hyperparasites, and commensals of decapod crustacea. Representative protozoa documented from blue crabs are found in Table 2.8. Couch and Martin (1982) reviewed the protozoan symbionts and related diseases of blue crabs. An amoeba (Paramoeba perniciosa) and a dinoflagellate (Hematodinium) were identified as lethal pathogens.

Sprague and Beckett (1966, 1968) recognized Paramoeba sp. as the etiological agent of "gray crab" disease in blue crabs. Sprague et al. (1969) recognized P. perniciosa, new species, as parasitic in blue crabs. Sawyer (1969) discussed the epizootiology and host-parasite relationship of Paramoeba sp. in blue crabs. Johnson (1977a, 1977f) discussed the monthly prevalence of infection, histopathy, defense reactions of the host, and the laboratory transmission of P. perniciosa. Paramoeba perniciosa has been implicated as the cause of mass mortalities of blue crabs on the Atlantic coast (Sprague and Beckett 1966, 1968; Sawyer 1969; Newman and Ward 1973a). Physiological responses of blue crab to infection by Paramoeba were discussed by Sawyer et al. (1970) and Pauley et al. (1975). Paramoeba has not been isolated from blue crabs from the Gulf of Mexico (Steele and Perry 1990).

Hematodinium sp., a dinoflagellate primarily infecting the hemolymph (Newman and Johnson 1975), has been isolated from blue crabs in the northern Gulf of Mexico (Couch and Martin 1982). The organism was only found in crabs from salinities >11 ppt. The only visible signs of infection are weakness and lethargy. Heavily infected crabs have the dinoflagellate present in the musculature, gonadal, and hepatopancreatic tissues.

The haplosporidan hyperparasite Urosporidium crescens is responsible for the condition in blue crabs known as "buckshot" or "pepper" crabs. DeTurk (1940) elaborated on the occurrence and development of Urosporidium. Couch (1974) discussed the pathological effects of Urosporidium infection in microphallid metacecariae. This parasite infects the metacecariae of the digenetic trematode Microphallus basodactylophallus found in the hepatopancreas and musculature of blue crabs. Parasitized metacecariae containing mature U. crescens spores appear black, thus the name of the condition. Perkins (1971) found no evidence of mortality in infected crabs and noted that the spores were released from the metacecariae upon death of the crab. Buckshot crabs are fairly common in Louisiana (Adkins 1972a).

Newman et al. (1976) described a Minchinia-like haplosporidian parasitizing blue crabs. Minchinia spp. are known to be highly pathogenic in oysters, causing mass mortalities.

Ameson michaelis is a microsporidan parasite of blue crabs commonly isolated from crabs in Gulf and Atlantic waters (Sprague 1965, 1977). Sprague et al. (1968) examined the structure of Ameson sp. by means of electron microscopy. This parasite infects the musculature and may result in cellular lysis and muscle disfunction. The muscle tissue of heavily infected crabs has an opaque chalky appearance. Overstreet (1978) diagrammed the life cycle and documented the occurrence of this parasite in blue crabs from lakes Pontchartrain and Borgne, and from Mississippi Sound. The drug buquinolate has been used to treat blue crabs for microsporidosis caused by A. michaelis (Overstreet 1975, 1977). Additional information on this parasite can be found in Bond (1967), Davenport (1968), Weidner (1970), Weidner and Trager (1973) and Findley et al. (1981).

Heavy infestations by ectocommensal ciliate protozoans of the genera Lagenophrys and Epistylis have been associated with mortalities of blue crabs held in confinement. Heavy infestation of gill lamellae by these ciliates may interfere with respiration, resulting in mortality of crabs in shedding or holding tanks (Couch 1966, 1967). Couch (1971, 1973) studied the form, morphogenesis, ultrastructure, and host relationship of Lagenophrys callinectes. The incidence of infection by L. callinectes in natural populations of blue crabs in Chesapeake Bay was highest in spring and summer, with a peak in August (Couch and Martin 1982); the authors suggested that this ciliate may seasonally affect survival of blue crabs when oxygen levels are minimal.

2.11.5 Nemertean, Trematode and Annelid Infestations

Documented records of nemertean, trematode, and annelid infestations of blue crabs are listed in Table 2.8.

The parasitic nemertean Carcinonemertes carcinophila infests gills and eggs of adult female blue crabs in high salinity regions (Millikin and Williams 1984), while gills of male crabs are seldom infested. Hopkins (1947) discussed the use of this worm as a spawning history indicator in blue crabs.

Leeches (Myzobdella lugubris) are common on blue crabs from low salinity waters (Sawyer et al. 1975). Perry (1975) and Overstreet (1978) found no evidence of detrimental relationship of this leech with blue crabs but Hutton and Songandares-Bernal (1959) suggested that it may have been responsible for blue crab mortalities in Florida. The biology and anatomy of this species was investigated by Daniels (1973) and Daniels and Sawyer (1975).

The branchiobdellid annelid Cambarincola vitreus also infests blue crabs from freshwater and low salinity habitats (Overstreet 1978). These small worms (2-3 mm) inhabit the gill chambers and shell surfaces of blue crabs but apparently cause no harm to the crab. The ecology and morphology of branchiobdellid epizoics of blue crabs were studied by Blackford (1966).

Digenetic trematodes of the family Microphallidae often have a crustacean as a second intermediate host (Millikin and Williams 1984). In species infecting the blue crab, a snail usually serves as the first intermediate host with a fish, bird, or mammal as the definitive host. Cecariae shed from the snail enter the branchial chamber of the crab, attach to the gills, and enter the gill lumen. Cecariae enter the circulatory system and encyst in various locations throughout the body. Very heavy infestations may cause a localized, weakened condition in crabs. Visibility of the encysted or metacecarial stage depends on the species. Metacecariae of Levinseniella capitanea are very large and easily seen, whereas the metacecariae of Microphallus basodactylophallus are not visible unless hyperparasitized by Urosporidium crescens. Metacecariae of L. capitanea were isolated from the hepatopancreas and gonads of adult blue crabs (Overstreet and Perry 1972). Perry (1975) found metacecariae of M. basodactylophallus infested with U. crescens in the hepatopancreas, musculature, and gills of blue crabs from Mississippi Sound.

2.11.6 Cirripedia

Blue crabs are host to external and internal barnacles (Table 2.8). External barnacles include Chelonibia patula and Balanus venustus niveus that attach to the outer surface of the carapace and appendages (Williams and Porter 1964; Adkins 1972b; Perry 1975; Overstreet 1978, 1982; Babinchak et al. 1982). Barnacle fouling of mature female blue crabs is common; large numbers of heavily fouled, spent females occasionally litter beaches in the northern Gulf of Mexico (Adkins 1972a; Perry 1975). The gooseneck barnacle (Octolasmis muelleri) is found on gills and in gill chambers (Humes 1941) and may impede respiration (Walker 1974; Overstreet 1978). Gannon (1990) found a 40% infestation rate by O. muelleri at Seahorse Key, Florida, with no obvious seasonality. Heavily infested crabs (>20 barnacles) may compensate for barnacle presence, but extremely heavily infested (>50 barnacles) do not survive (Gannon and Wheatly 1992); however, natural infestations levels are low.

The rhizocephalan barnacle Loxothylacus texanus, a parasite of blue crabs, is found only in the Gulf of Mexico. Cypris larvae infect juvenile crabs during early stages of the molting process (Overstreet 1978). After a brief incubation period, an extensive "root" system develops within the crab, with an externa or sac protruding between the thorax and abdomen of the host (Reinhard 1950a, 1950b). The externa contains male and female gonads and serves as a brood pouch for developing larvae. Rhizocephalan infection alters the secondary sex characteristics of the crab by causing the abdomen to appear as that of a mature female.

Controversy exists concerning growth and molting in rhizocephalan-infected blue crabs. Growth of infected blue crabs is often limited to a maximum size of 3-8 cm CW (Millikin and Williams 1984). Reinhard (1956) reported that after the externa emerges, gonadal development is suppressed, and growth and molting cease. Overstreet (1978) observed that crabs with protruding externa can molt but questioned whether this was typical.

The incidence of L. texanus infection is of particular concern in Louisiana. Over 40% of the blue crabs collected in May and June from two estuarine areas in Louisiana were infected with L. texanus (Harris and Ragan 1970). Adkins (1972b) found a direct correlation between water temperature and percentage of infected crabs; peak infections occurred from July through September, with a 17.1% incidence of infection in September. Christmas (1969) collected parasitized crabs during all months in Mississippi Sound. Occurrence of L. texanus is rare in low salinity waters (More 1969; Adkins 1972b; Ragan and Matherne 1974). Ragan and Matherne (1974) stated that adult rhizocephalans cannot tolerate low salinities; maturing externa do not emerge, and those which have emerged take on water and rupture.

Data indicate that rhizocephalan infection may be increasing in Mississippi and elsewhere. Less than 1.0% of the crabs sampled in 1971 and 1972 and 0.1% of the crabs sampled from October 1973 through September 1976 were infected (Perry 1975; Perry and Herring 1976). The incidence of infection later had risen to >4.0% (Perry and Stuck 1982), and parasitized crabs showed a wider areal distribution in Mississippi Sound (Overstreet 1978). Elsewhere, Gunter (1950), Reinhard (1951), Daugherty (1952), More (1969), Wardle and Tirpak (1991), and Hochberg et al. (1992) reported on the incidence of infection in Texas and Florida. L. texanus has not been reported from blue crabs in Chesapeake Bay (Lawler and Van Engel 1973).

Hochberg et al. (1992) concluded that L. texanus infection rates varied markedly on local and regional scales. They found that incidence of parasitized crabs was highest in water of 21-25 °C and seasonal peaks followed peaks in relative abundance of ovigerous females by 4.5 months.

Cake (1983) reported on the symbiotic association of the southern oyster drill (Thais haemastoma) with blue crabs. The crabs provide passive transport and food, while the drills prey upon acorn barnacles, oysters, and slipper shells (Crepidula sp.) that fouled crab carapaces.

2.11.7 Other

Johnson (1976a) described gas bubble disease in blue crabs caused by exposure to water supersaturated with air. Gas emboli in the hemal system caused localized ischemia which killed >33% of the exposed crabs within 2 d. Ramirez-Villarroel (1990) provided additional information on effects of gas supersaturation on molting and survival.

2.12 Environmental Tolerances

2.12.1 Temperature and Salinity

2.12.1.1 Larvae. Optimum salinities and water temperatures for hatching are between 23 and 30 ppt, and 20 and 35 °C (Sandoz and Rogers 1944; Newcomb 1945; Costlow 1967). Eggs were not hatched successfully at <18 ppt or ≥33 ppt salinity. Eggs hatched successfully only at water temperatures of 19-29 °C, with no significant variation in percent hatch within this range (Sandoz and Rogers 1944). Additional data on egg hatching in relation to water temperature was provided by Costlow and Bookhout (1959) and Davis (1965).

Early stage zoeae are good osmoregulators but lose this ability as they progress through later stages (Kalber 1970). Megalopae become good osmoregulators by the fifth day and Kalber (1970) suggested that osmoregulatory adaptations are related to the sequence of salinity stress during normal development.

Optimum salinities and water temperatures for zoeal metamorphosis during the first three stages ranged from 21 to 28 ppt and 20 to 29 °C (Sandoz and Rogers 1944). In general, zoeal survival increased with corresponding salinity increase up to about 23 ppt. The optimal salinity and temperature combination for zoeal development was 30 ppt and 25 °C (Costlow and Bookhout 1959; Sulkin and Epifanio 1975; Bookhout et al. 1976). Costlow and Bookhout (1959) found salinities of 20.1-30.1 ppt to be most conducive to larval development with metamorphosis retarded outside this range. First stage zoeae did not complete a successful ecdysis at <20 °C (Sandoz and Rogers 1944).

Costlow (1967) determined mortality rates of megalopae under 23 different combinations of salinities and water temperatures. Greatest survival occurred at salinities of 16-43 ppt and water temperatures between 21.5 and 34.5 °C. A 100% mortality rate occurred at 15 °C in salinities <8 ppt and at 11 °C in salinities >30 ppt. Megalopal development was most rapid (5-6 d) at 30 °C in salinities from 10-35 ppt. A 15 °C lower limit, independent of salinity, was identified. The optimum salinity and water temperature was 30 ppt and 25 °C.

In summary, development and hatching of eggs takes place under a relatively wide range of salinity and water temperature (Sandoz and Rogers 1944), but this range, apparently, progressively narrows in successive zoeal instars. The optimum salinity and temperature ranges for larval development and survival, as indicated by laboratory experiments, correspond closely with ranges for these factors in the lower estuary and marine waters. Costlow (1967) observed that highest mortality rates occur during the early stages of zoeal development. Costlow also postulated that survival and duration of the megalopal stage in the natural environment may be directly associated with the time at which the megalopal stage is reached in relation to seasonal changes in water temperature, as well as the salinity in which the final zoeal molt occurs.

2.12.1.2 Juvenile and Adult. Juvenile or adult blue crabs can tolerate a wide range of salinities and water temperatures in contrast to the zoeae and megalopae (Steele and Perry 1990). Juveniles and adults are exposed to a salinity range from 0 to 35 ppt. The blue crab shows good hyperosmotic regulation at low to medium salinities and regulates its hemolymph hypoosmotically at high salinities (Tan and Van Engel 1966; Tagatz 1971). The thermal tolerance limits of blue crabs are dependent on the acclimation temperature and salinity. Blue crabs are generally less tolerant of high temperatures at low salinities and low temperatures at high salinities (Millikin and Williams 1984). Hyposalinity as an upstream distributional determinant was discussed by Norse (1978).

Temperature and salinity tolerance limits of juvenile and adult blue crabs have been defined by Tagatz (1969), Holland et al. (1971), Mahood et al. (1970), McKenzie (1970) and Winget et al. (1976).

Tagatz (1969) determined the 48-h median thermal tolerance limits of adult and juvenile crabs in relation to salinity and acclimation temperature. Tolerance limits for adults and juveniles were similar, although juveniles were generally slightly more tolerant to heat and less tolerant to cold than adults. Percent survival increased as the difference between test and acclimation temperature decreased. Selected thermal tolerance limits in relation to salinity and acclimation temperature are shown below:

		Tolerance Limits (°C)			
		Adults		Juveniles	
Salinity	Temperature (°C)	Upper	Lower	Upper	Lower
35	30	38.7	--	39.0	--
7	30	37.0	--	37.2	--
35	14	--	<0.1	--	<0.1
7	14	--	0.2	--	0.7

Holland et al. (1971) maintained juvenile blue crabs at different temperatures (15-35 °C) and salinities (1-21 ppt) for 30-45 d. Above 30 °C the survival rate decreased rapidly with only 20% survival at 35 °C; they suggested that the upper incipient lethal temperature appeared to be 33 °C. Salinities of 1 ppt were apparently lethal at 29-30 °C while salinities >1 ppt had no significant effect on survival.

Winget et al. (1976) found that temperature had a pronounced effect upon mortality of juvenile blue crabs under culture situations. Mortality ranged from 37.5-62.5% and 12.5-27.5% at water temperatures of 20 °C and 30 °C, respectively.

A water temperature-salinity tolerance zone was constructed by Mahood et al. (1970) for adult blue crabs acclimated at 20 °C using 96 h TLm values. At 0 °C, 100% mortality occurred at all salinities. The thermal tolerance zone ranged from 3.2 to 22.0 °C at 8.6 ppt salinity and from 18.5-35.2 °C at 36 ppt salinity. The greatest tolerance zone extended over a 27° range at 24.2 ppt salinity.

McKenzie (1970) determined 96-h TLm values for adult blue crabs at an acclimation temperature of 20 °C. At 8 ppt salinity, the upper and lower TLm values were 22.0 °C and 3.2 °C, while at 36.0 ppt TLm values were 35.2 °C and 18.5 °C.

Tagatz (1969), Mahood et al. (1970) and McKenzie (1970) all found that crabs were less tolerant of low salinities at high temperatures and of high salinities at low water temperatures. This trend may be related to known physiological characteristics of the species. The metabolic rate of blue crabs is directly related to temperature (Laird and Haefner 1976). Low salinities have also been shown to increase blue crab metabolism (King 1965). This indicates that at low salinities and high temperatures the strain of osmoregulation would add to the stress of metabolism and decrease the upper thermal tolerance limit (Mahood et al. 1970). In contrast, low temperatures may reduce metabolic activity to such a degree that it would be difficult for crabs in high salinities to maintain a favorable gradient between external and internal salinities.

The influence of temperature or salinity on osmoregulation and other physiological processes (Gross and Marshall 1960; Gifford 1962; Haefner 1964; Tan and Van Engel 1966; Ballard and Abbott 1969; Tagatz 1971; Mangum and Amende 1972; Engel et al. 1973, 1974; Leffler 1975a; Engel 1977; Findley and Stickle 1978; Cameron 1979; Robinson 1982; Wood and Cameron 1985) and on respiration (King 1965,1966; Engel and Eggert 1974; Engel et al. 1975; Reingold 1975; Mangum et al. 1976; Findley et al. 1978; Mauro and Mangum 1982; Robinson 1982; Mason et al. 1983; Price-Sheets and Dendinger 1983; deFur 1990) has been evaluated.

2.12.2 Dissolved Oxygen

Estuarine processes including tidal flushing of the marshes, seiching of the water in deeper channels, and cyclical destratification may produce lethal hypoxia in extensive areas of shallow water. Low levels of dissolved oxygen may cause high local mortalities and influence the distribution or migration of blue crabs. Trap death due to anoxia has been reported in Mobile Bay (Tatum 1982b), Chesapeake Bay (Carpenter and Cargo 1957; Van Engel 1982b), Texas (More 1969), and Louisiana (personal observations). Tatum (1982b) reported that oxygen deficient (<3 ppm) bottom waters covered as much as 44% of Mobile Bay with some crab fisherman observing mortality rates up to 75%. In Mobile Bay, 81,000 kg of blue crabs died along Great Point Clear during a 2-d period (May 1973). Periodic kills of blue crabs following excessive freshwater runoff and subsequent oxygen depletion due to rapid decomposition of organic matter were reported by Van Engel (1982b).

Price et al. (1985) noted that crab fishermen in Chesapeake Bay have had to set traps progressively closer to shore because of hypoxic conditions in deeper water. Mobile Bay "jubilees" occur when blue crabs, and fish, are driven ashore in a moribund state because of hypoxic water (Loesch 1960). Chambers and Sparks (1959) and Ettinger and Blyle (1981) collected very few blue crabs in areas of low oxygen in Galveston Bay, Texas. Sharp reductions in abundance (Pavella et al. 1983) or mortalities (Harper and Guillen 1989) of blue crabs have been associated with hypoxic Gulf waters off Texas.

Experiments by Carpenter and Cargo (1957) evaluated the effects of low dissolved oxygen on crabs in Chesapeake Bay. They concluded that, at 28-30 °C, mortalities $\geq$ 25% occurred over 24 h at oxygen concentrations $\leq$ 0.5 mg/ml. deFur et al. (1990) investigated the respiratory response of blue crabs to long term hypoxia and observed low mortalities at pO_2 of 50mm Hg for up to 25 d. Their results indicate that both heterotropic and homotropic adaptations enhance blood oxygenation at the gill during long term hypoxia, enabling blue crabs to tolerate hypoxic conditions. Additional research on respiratory and metabolic responses to hypoxia was conducted by Batterton and Cameron (1978), Lowery and Tate (1986), deFur and Pease (1988), and Das and Stickle (1993).

2.12.3 Pollutants and Toxicants

Estuarine crabs occupy an ecological niche in the coastal environment that is susceptible to man made and natural pollutants. The coastal zone interfaces with man's activities on land and therefore is especially susceptible to exposure of acute doses of degradable pollutants and chronic doses of persistent ones. Sources of pollutants include industrial and municipal effluents in the drainage basin, pesticides transferred by agricultural runoff, pesticides directly applied to control noxious insects such as mosquitos, and atmospheric exchange. Recent surveys of pollutant residues in coastal zone organisms indicate that at least a portion of the pollutants are accumulated and often concentrated by estuarine brachyurans (Williams and Duke 1979). Mothershead and Hale (1992) exposed newly molted and intermolt blue crabs to aromatic hydrocarbons and found higher concentrations in the former; they cautioned that concentration of pollutants by soft crabs may be of concern to public health.

Research has suggested that estuarine crabs are sensitive to many forms of man made pollution, either being acutely affected or serving as indicators through sublethal effects (Duke and Dumas 1974). It is beyond the scope of this document to review toxicants in detail; however, a representative list of pollutants known to affect blue crabs is contained in Table 2.9.

2.12.4 Other

Red tides caused by Ptychodiscus breve (=Gymnodinium brevis) have resulted in blue crab mortalities (Gunter et al. 1948; Wardle et al. 1975; Gunter and Lyles 1979). Van Engel (1982b) attributed thousands of dead crabs along the shoreline in Chesapeake Bay to heavy abrasions received while they were swept along hard sand bottoms by storm currents. The reactions of blue crabs to low pH (Reynolds and Casterlin 1978) and storm water runoff (Laughlin et al. 1978) have been discussed.

2.13 Recruitment Mechanisms

Epifanio (1988a and 1988b) and McConaugha (1988) reviewed recruitment mechanisms of estuarine and coastal crabs. Most crab species include several planktonic zoeal stages and a planktonic or benthic megalopal stage. Most estuarine crabs are incapable of maintaining viable populations on the continental shelf; therefore zoeae are either retained within the estuary or possess means of returning to the estuary after undergoing development in continental shelf waters.

Various species of estuarine crabs have been grouped by the degree their larvae are retained within the estuary (Nichols and Keney 1963; Dudley and Judy 1971; Sandifer 1975; Dittel and Epifanio 1982; Epifanio et al. 1984; Johnson, D. R. 1985; Brookins and Epifanio 1985). Species whose larvae are retained within estuaries are prevalent in families such as Xanthidae, whose adults are incapable of swimming. Portunid crabs such as C. sapidus are at the other extreme, where larvae are normally exported from the estuary.

Female C. sapidus spawn near the mouths of estuaries. After eggs hatch, first stage zoeae swim toward the surface and into the neuston layer (McConaugha et al. 1981; Provenzano et al. 1983; Johnson, D. R. 1985). Field observations of zoeae in surface waters are consistent with laboratory data indicating that first stage zoeae are positively phototactic and negatively geotactic, while displaying a high degree of barokinesis (Sulkin et al. 1980; Sulkin and Van Heukelem 1982). Circumstantial evidence implies a synchronized egg hatch coinciding with night ebb tides (Provenzano et al. 1983) that facilitate tidal transport onto the continental shelf. Larval development occurs offshore and megalopae are assumed to reinvade estuaries (Epifanio 1988a and 1988b; Smith and Knappenberger 1989).

Advantages of planktonic larvae listed by McConaugha (1988) include increased dispersal, colonization of new habitats, gene flow between populations, and reduced maternal energy expenditure for production of individual eggs. On the negative side, planktonic larvae may be advected away from suitable habitat.

Epifanio (1988a and 1988b) discussed several recruitment models that would result in a return of exported crab larvae back into Atlantic Coast estuaries. In the first model, larvae swim actively back to the estuaries. However, Epifanio (1988a) noted that measured larval swimming speeds negate the use of this model. Crab zoeae are generally capable of directional swimming at speeds about an order of magnitude slower than the subtidal movement of surface water in many estuaries (Pape and Garvine 1982; Sulkin 1984).

In the second model, crab larvae take up a deeper position in the water column as ontogenetic development proceeds and are subsequently transported back to the estuary in tidally driven, deep water currents. Sulkin et al. (1980), Sulkin and Van Heukelem (1982) and Sulkin (1984) suggested larvae of C. sapidus can take advantage of this type of circulation through behavioral traits. To take advantage of tidal, landward currents, megalopae would have to swim up in the water column during flood tides and sink in the water column on ebb tides (Epifanio et al. 1984). Available field data indicates that in offshore waters megalopae, like the zoeae, are found in the neuston or surface layer (Johnson, D. R. 1985; McConaugha 1988) while samples taken near or in estuaries indicate significant variation over time in the vertical position of the megalopae (Meredith, 1982; Olmi 1986; McConaugha 1988).

Utilization of internal waves as a mechanism for rapid inshore transport of crab larvae is the third model. As a result of the tidal motion dynamics at the edge of the continental shelf, packets of shoreward propagating internal waves are generated with each change from ebb to flood tide (Osbone and Burch 1980; Chereskin 1983). This phenomenon may be an important transport mechanism for crab zoeae and megalopae (Shanks 1983). Epifanio (1988a) cautioned that internal wave transport requires that larvae occupy the surface film regardless of developmental stage.

The final model utilizes episodic, wind induced water exchange on the continental shelf (D. R. Johnson, et al. 1984; D. R. Johnson 1985; Goodrich et al. 1989) to transport surface dwelling megalopae shoreward. This model requires that larvae occupy surface waters, but not necessarily the neuston layer (Epifanio 1988a). However, according to Epifanio (1988a) and Smith and Knappenberger (1989) this hypothesis has yet to be adequately documented. In a positive estuary, the net flow of water is out of the estuary and surface megalopal advection into estuaries by this mechanism could occur only during major atmospheric disturbances. Goodrich et al. (1989), however, presented evidence for a wind-driven mechanism for megalopal influx into Chesapeake Bay. They suggested that megalopal recruitment into the estuary is predominantly an episodic process where a few events with the right timing can bring the majority of that year's megalopae into the bay. They determined that, based upon analysis of 28 yr of subtidal volume data, an average of 10 major inflow events occur annually during the period of megalopal occurrences. Once inside the estuary, the thigmotactic behavior of the megalopae may prevent them from being swept back to offshore waters by residing storm surges.

Sulkin and Epifanio (1986) proposed a recruitment model for megalopal invasion that incorporated active (i.e., conservative mechanisms resulting from behavioral adaptations of megalopae that exploit residual circulation) and passive (i.e., mechanisms resulting in passive transport dependent upon fortuitous wind events) processes. This hypothesis assumes that megalopae move deeper in the water column as they near metamorphosis and utilize the deeper, shoreward movement of bottom waters to overcome the net seaward flow of surface waters from the estuary.

Johnson and Hess (1990) utilized numerical simulation models to examine the relationship between larval recruitment and environmental forcing in Chesapeake Bay and found two primary modes of recruitment. Most larvae are exported into adjacent coastal waters and subsequently returned by wind driven, surface layers while a smaller percentage of larvae are retained in the bay throughout the period of larval development. They suggested that recruitment by migration of megalopae to bottom waters is not effective.

Smith and Knappenberger (1989), in their review of blue crab recruitment dynamics in Chesapeake Bay, concluded that recruitment strength is determined by the behavior and survival of the pelagic zoeal and postlarval stages and physical circulation at the bay's mouth and on the adjacent continental shelf. Sulkin and Epifanio (1986) suggested that vagaries of juvenile and adult abundance in estuaries of the Middle Atlantic Bight are related to hydrographic processes that regulate larval transport. Many researchers along the Atlantic Coast have related distribution and abundance of larval C. sapidus to various climatic and hydrographic factors, or evaluated larval transport and recruitment mechanisms (Nichols and Keney 1963; Pinschmidt 1963; Dudley and Judy 1971; Williams 1971; Naylor and Isaac 1973; Sandifer 1973, 1975; Scheltema 1975; Goy 1976; Sulkin et al. 1979, 1980; Smyth 1980; Boicourt 1982; Dittel and Epifanio 1982; Epifanio and Dittel 1982; D. F. Johnson 1982; Meredith 1982; Sulkin et al. 1982; Sulkin and Van Heukelman 1982; Hester 1983; McConaugha 1983, 1988; McConaugha et al. 1983; Provenzano et al. 1983; Sulkin et al. 1983; Epifanio et al. 1984; D. R. Johnson et al. 1984; McConnaughey and Sulkin 1984; Sulkin 1984; D. F. Johnson 1985; D. R. Johnson 1985; Leming and Johnson 1985; Maris 1986; Sulkin and Epifanio 1986; Sulkin and Van Heukelman 1986; Epifanio 1987; Epifanio 1988a, 1988b, 1988c; Clancy and Epifanio 1989; Epifanio et al. 1989; Goodrich et al. 1989; Johnson and Hess 1990; Lipcius et al. 1990; Olmi et al. 1990; Van Montfrans et al. 1990; Little and Epifanio 1991).

Recent research efforts on blue crab recruitment processes along the Atlantic Coast have been directed towards settlement of megalopae as quantified by artificial settlement substrates. A recent consensus by researchers was that settlement of megalopae on artificial collectors is greatest near mouths of estuaries, declining up-estuary (Smith et al. 1989). Mense and Wenner (1989) sampled planktonic megalopae along a salinity gradient in South Carolina and found decreasing abundance from the polyhaline (75% of total abundance), mesohaline (23% of total abundance), and oligohaline (2% of total abundance) zones. Seasonal and spatial patterns in megalopal settlement in Atlantic Coast estuaries were documented by Lipcius et al. (1990), Olmi et al. (1990), Van Montfrans et al. (1990), Metcalf and Lipcius (1992), and Boylan and Wenner (1993). There presently exists a cooperative regional megalopal settlement monitoring program by various researchers that includes sample sites in Louisiana and other northern Gulf states.

Little is known concerning the physical and behavioral mechanisms that allow for seaward and subsequent shoreward transport of blue crab larvae in the Gulf of Mexico. Steele and Perry (1990), however, suggested that short-term, small scale, episodic events are the primary recruitment mechanism in the Gulf. Oesterling and Evink (1977) proposed a general transport mechanism for blue crabs along the southwest Florida coast. They presented tagging data suggesting that ovigerous blue crabs concentrate in the Apalachicola Bay region of Florida and that larval dispersal from this area provides recruitment into southwest Florida. Surface current patterns in the eastern Gulf of Mexico support Oesterling and Evink's hypothesis of recruitment into southwest Florida. These researchers suggested that zoeae in Apalachicola Bay would become entrained in the Apalachicola River discharge, carried offshore, and transported southward by Gulf surface currents. Larvae would be separated out by eddy currents and transported nearer to shore. Oesterling and Evink (1977) assumed, based on the period of larval development to the megalops stage (31-49 days) (Costlow and Bookhout 1959) and drift bottle recovery patterns (Gaul and Boykin 1964; Ichiye et al. 1973), that zoeae would subsequently be spread along the entire coast.

Survey data on the occurrence of various larval developmental stages in the northern Gulf have provided important information. Based on the data of Menzel (1964), Andryszak (1979) and Perry and Stuck (1982), it appears that development through the late zoeal stages (III through VII) takes place in offshore Gulf waters and recruitment back to estuaries occurs in the megalopal stage (More 1969; King 1971; Perry 1975). Spawning may occur year round (Daugherty 1952; Adkins 1972a) and megalopae have been verified in all months except January and February (Stuck and Perry 1982). According to surveys in the northern Gulf of Mexico utilizing quantitative drop net samplers, the abundance of small juvenile blue crabs (recent recruits) peaks in fall (Williams et al. 1990; Zimmerman et al. 1990a) or summer-fall (Thomas et al. 1990).

Documented blue crab recruitment processes along the mid-Atlantic Bight may not be applicable to Louisiana. General recruitment mechanisms proposed by Shaw et al. (1985), Boesch and Dagg (1986) and Lyczkowski-Shultz et al. (1990), however, provide valuable insight on estuarine recruitment of C. sapidus megalopae. Boesch and Dagg (1986), in a summary of a workshop on recruitment processes specifically pertinent to the Gulf of Mexico, concluded that relevant features of the Gulf that affect recruitment of environmentally transgressive species (i.e., those previously classified as estuarine dependent, including blue crab) are in many instances unique. Weak seasonal cycles coupled with the low tidal amplitude in conjunction with the broad shallow continental shelf, creates a situation in which meteorological forcing dominates coastal processes. Other unique features of the Gulf includes tremendous inputs of nutrient rich, sediment laden, fresh water from the Mississippi-Atchafalaya River system, and the presence of a well developed, broad, coastal boundary layer (CBL) and the occurrence of eddies, or rings, formed at the shelf-slope interface.

Lyczkowski-Shultz et al. (1990) contrasted hydrological and larval fish transport mechanisms in Mississippi Sound with those in Atlantic Coast estuaries. The latter are typically vertically stratified, drowned river estuaries with semidiurnal tides, whereas the former is well mixed (although stratification of tidal flow may occur in passes), with a peculiar cycling of diurnal tides, leading to a disparity in the relationship between tidal and diel cycles. They suggested that the generalized larval fish transport model for the Atlantic Coast, based upon vertical migrations to and from upper and lower water column strata where residual, nontidal drift is seaward and landward, respectively, may not be applicable to Mississippi Sound. Strong northwesterly or southeasterly winds can reverse or accentuate the effect of tides (Eleuterius 1976; Seim et al. 1987). Wind effects were shown to have a considerable influence on exchanges between inner shelf and estuarine waters in other northern Gulf of Mexico estuaries where tidal amplitudes are low (Smith 1977 and 1979; Swenson and Chuang 1983; Schroeder and Wiseman 1985; Wiseman et al. 1988). Consequently, a non-tidal, episodic mechanism caused by meteorological forcing during frontal passage has been postulated by Lyczkowski-Schultz et al. (1990) as transport mechanism for larval fishes in shallow Gulf estuaries.

Shaw et al. (1985) proposed a transport mechanism for larval gulf menhaden entering Louisiana estuaries. Offshore-onshore advective transport was small in comparison with mean longshore advective transport. Episodic events (i.e., atmospheric frontal passages and reversing wind fields) were postulated as the major mechanism transporting larvae to nursery grounds.

Year class strength of estuarine organisms is ultimately determined by larval recruitment and juvenile survival in estuaries (Steele and Perry 1990). Density independent, physical mechanisms apparently influence larval recruitment of blue crabs. Based upon megalopal data obtained from artificial settlement substrates in Mississippi Sound, recruitment into the estuaries does not appear to be a limiting factor in abundance of adult crabs along the Gulf coast (Harriet Perry, pers. comm.). Year class strength may ultimately be determined by carrying capacity of the estuary and survival of juveniles (Steele and Perry 1990).

The effect of specific environmental variables known to affect juvenile blue crab abundance have not been adequately quantified. Variations in abiotic factors such as salinity, water temperature, and pollutants, may affect juvenile blue crab survival (Perry et al. 1984); however, the diversity of these parameters and their possible synergistic effects make precise identification of the influence of specific variables difficult. Additionally, the effect of abiotic variables may be intrinsic (i.e., physiological), extrinsic (i.e., affecting composition of the surrounding biotic environment), or a combination of the two.

Livingston et al. (1976) and Orth and Van Montfrans (1990) suggested that trophic phenomena and predation rates strongly influence survival of juvenile blue crabs. Steele and Perry (1990) suggested that short term, small scale episodic events thought to govern recruitment processes in the Gulf, and the long protracted spawning season (9-12 months) resulting in a continual recruitment to the juvenile population, complicates studies of recruitment success and abiotic variables affecting recruitment.

Several studies have elaborated on the relationship between environmental conditions and either commercial landings or abundance of juvenile crabs in the northern Gulf of Mexico. In Texas, periods of low salinity, high rainfall, and high river discharge rates were associated with high abundance of blue crabs (More 1969). A significant positive relationship between a heat index value during the egg and larval stages and commercial harvest of blue crabs from Barataria Bay, Louisiana, was demonstrated by Turner (1979). Walther (1989) found an inverse relationship between abundance of juvenile blue crabs in Barataria Bay and salinity for a 7-yr period. West (1981) compared commercial catches of blue crab in five northern Gulf estuaries and concluded that there were two dominant environmental influences: the positive influence of summer-fall water temperatures; and, river flows in the second half of the year. Laughlin (1979), however, concluded that recruitment levels of blue crabs in Apalachicola Bay, Florida, were unpredictable based on physio-chemical variability. On the Atlantic coast, Pearson (1948), Van Engel (1978), Van Engel and Harris (1979), Hester (1983), and Summers (1987) contrasted crab abundance with environmental factors, while Applegate (1983) and Tang (1985) utilized stock-recruitment models that incorporated environmental parameters.

Conflicting views exist regarding the presence or absence of a spawning stock-recruitment relationship for blue crabs in Chesapeake Bay. Pearson (1948) analyzed dredge fishery landings from 1930-1944 and found no significant correlation between landings in year t-2 (stock) and year t (recruitment). Sulkin et al. (1983) argued that a stock-recruitment relationship was improbable due to density-dependent mortality of offspring and dominance of abiotic factors on recruitment success. They also stated that "...there obviously must exist a theoretical threshold of spawning stock size below which inadequate numbers of larvae will be produced". Van Engel (1987) suggested that a stock-recruitment model was unlikely to be density dependent given the various "r-selected" life history characteristics of the blue crab, particularly the high fecundity, high interannual variation in production, rapid growth, early reproductive maturity, high mortality, and relatively short life span. Species such as blue crab are strongly affected by environmental factors. The evidence for a stock-recruitment relationship was provided by Applegate (1983), Tang (1985), and Lipcius and Van Engel (1990). Applegate (1983) used a multiplicative model composed of the simple Ricker model times a linear sum of environmental variables affecting recruit survival -- streamflow, incidence of light, and wind magnitude and direction. Tang (1985) incorporated environmental factors into the simple Ricker model by substituting a linear sum of environmental variables (radiant energy, streamflow, salinity, and water temperature) for the density-independent parameter. Lipcius and Van Engel (1990) reanalyzed Pearson's (1948) data utilizing a curvilinear model rather than simple correlation analysis and found a significant Ricker stock-recruitment relationship with the same data. A significant Ricker stock-recruitment relationship was also identified between juvenile abundance, as determined by trawl surveys and winter dredge landings.

In the regional blue crab fisheries management plan for the Gulf of Mexico, Steele and Perry (1990) noted the lack of correlation between spawning stock size and subsequent recruitment in many marine species (Grice et al. 1984). Steele and Perry (1990) concluded that "recruitment for most species is now considered to be the result of a synergistic combination of biological and physical factors that occur through the first year of life with density independent factors of primary importance during the larval stage and density dependent factors more important for juvenile survivorship".

2.14 Mortality

One of the critical problems in the study of population dynamics of decapods is the estimation of mortality rates. Mortality in an exploited population is due either to natural causes or harvest by man. Coefficients of fishing (F), natural (M) and total (Z) mortality are defined as instantaneous death rates for a cohort of "N" individuals over a short time, designated as "dt".

Cobb and Caddy (1989) discussed the concept of mortality in decapod crustaceans and noted that estimation of mortality rates in crustaceans is compounded by the lack of age based data. Fishery dependent data is utilized in calculation of mortality rates, and consequently migration is a frequent source of bias.

Steele and Perry (1990) noted that population models were initially developed for multiple year class vertebrate fisheries and concluded that their use to describe population characteristics of invertebrates has often not taken into consideration the difficulty of age determination, discontinuous growth, intensive seasonal fishing effort, seasonal variation in catchability, annual nature of the fishery, and difficulty in effort standardization. The lack of quantitative and qualitative data on population dynamics of crustacean fisheries and the environmental forces affecting recruitment hamper the use of traditional fishery models.

Hester (1983) and Rotschild et al. (1991) calculated instantaneous mortality rates for blue crabs in Chesapeake Bay. However, both Hester and Rotschild expressed reservations about data entered into their models.

Van Engel (1987) reviewed blue crab mortality in Chesapeake Bay. He assumed that the commercial fishery annually removes 75%-90% of the adult stock, the fecundity rate varies from 0.75 - 2.0 X 10^6 ,and the commercial fishery landings range from 46-90 million lb. His estimate of total annual mortality ranged from 0.9999725 to 0.9999959 while fishing mortality varied from 0.0000031 to 0.0000251. Small changes in survivorship of planktonic larvae of marine invertebrates are exceedingly difficult to measure; however, such changes can have major effects on juvenile recruitment (Hines 1986). For example, a decrease in larval mortality from 99.99% to 99.98% would result in a 100% increase in newly metamorphosed juveniles.

Factors affecting natural mortality rates of blue crabs (i.e., predation, disease, parasites, environmental contaminants, extreme hydrological and climatological conditions, and food availability) were reviewed by Van Engel (1982b, 1987), Millikin and Williams (1984) and Steele and Perry (1990).

Table 2.1. Selected characteristics of blue crab larval development.

Developmental stage	mean total length (mm)[1]	Characteristics[2]
zoea I	1.0	Five abdominal segments plus telson. Eyes are not stalked.
II	1.3	Eyes stalked. Third segment of endopodite of first maxilliped with one additional spine.
III	1.4	Mandible with several small teeth in addition to broad cutting surface. Sixth abdominal segment is present.
IV	1.7	Slight swelling in basal region of antenna indicates beginning of endopodite bud.
V	2.2	Developing endopodite larger than in stage IV. Buds of 3rd maxilliped, chela, and pereiopods visible beneath carapace.
VI	2.3	Pleopod buds appear on abdominal segments 2 through 6 for first time.
VII	2.8	Terminal aesthetes of antennule increase to 7; 5 subterminal aesthetes added. Basal portion of antennule swollen.
megalopa	3.0	Rostrum pointed, longer than anntennule, but shorter than antenna. Dactylopod of first pereiopod chelate.

[1] From Bookhout and Costlow (1977).

[2] From Costlow and Bookhout (1959).

Table 2.2. Catch per effort of blue crabs in 16-foot trawl samples by salinity intervals in the northern Gulf of Mexico [taken from Steele and Perry (1990)].

	Salinity (ppt)							
Modified from:	0.0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	20.0-24.9	25.0-29.9	30+	Total
Swingle (1971)	6.0	4.7	2.6	2.3	3.1	3.3	4.4	3.9
Perret et al. (1971)	12.0	6.0	6.0	6.0	6.0	5.0	5.0	7.0
Christmas and Langley (1973)	1.2	2.7	3.8	3.2	4.1	2.2	0.9	2.6
Perry and Stuck (1982)	7.6	7.8	7.1	8.3	5.9	3.0	2.7	6.3

Table 2.3. Percentages of female blue crabs in various stages of the spawning cycle in lower Galveston Bay, Texas according to More (1969) (stages 2 - 4 = preceding first ovulation; stage 5 = first sponge; stage 6 = between sponges; stage 7 = second sponge; stage 8 = spent).

Month	Stage of Development (%)				
	2-4	5	6	7	8
January	99	0	0	0	0
February	100	0	0	0	0
March-April	4	95	1	0	0
May	36	36	26	2	0
June	47	28	18	1	6
July	58	37	4	1	0
August	86	14	0	0	0
September	95	2	2	0	1

Table 2.4. Intermolt stages of the blue crab [adapted from Millikin and Williams (1984) and Mangum (1985)].

Stage	Name	Characteristics
Stage A		
A_1	Newly molted softshell	Continued water absorption and initial mineralization; carapace, including chelae, with no tangible rigidity; little or no locomotor activity; chelae not functional; body turgid; < 5-6 hr following exuviation
A_2	Softshell	Exocuticle mineralization; chelae still soft and not functional; limited locomotor activity; 5-24 hr following exuviation
Stage B	Papershell	
B_1		Endocuticle secretion begins; carapace crinkly; chelae beginning to harden but hardening incomplete; chelae functional; considerable locomotor activity; 1-2 days following exuviation
B_2		Active endocuticle formation, chelae hard; tissue growth begins; carapace hard at margins but perceptibly soft overmost of dorsal surface; locomotor activity normal
Stage C	Hardshell or green	
C_1		Main tissue growth

Table 2.4. Cont'd.

Stage	Name	Characteristics
C_2		Tissue growth continues
C_3		Completion of exoskeleton; membranous layer formed
C_4		"Intermolt"; major accumulation of organic reserves
or		
C_4T		Permanent anecdysis, no further growth; terminal stage in adult female
Stage D	Proecdysis	
D_0		Epidermal and hepatopancreas activation
D_1	White sign	Epicuticle formed and spine formation begins; clear space between epidermis and exoskeleton at ventral rim of dactylopodite of fifth pereopod but no pigment mobilization
D_2	Pink sign or peeler	Exocuticle secretion begins; incipient carotenoid mobilization in epidermis of dactylopodite of fifth pereiopod
D_3	Red sign or peeler	Major portion of skeletal resorption; maximum concentration of carotenoids in dactylopodite of fifth pereiopod, but ecdysial sutures still closed
D_4	Buster	About to molt; ecdysial sutures open; immediately central and anteroventral to lateral spines; locomotor activity ceased
Stage E	Shedder	Molt; rapid water uptake and exuviation; animal emerging; > 1 cm of new cuticle visible at posteior margin

Table 2.5. Intermolt periods of laboratory reared juvenile blue crabs[1] [taken from Millikin and Williams (1984)].

Instar numbers of juvenile stage	Mean intermolt period (days)[2]
1-2	7.2 ± 2.7 (104)
2-3	7.6 ± 3.0 (157)
3-4	8.0 ± 2.5 (157)
4-5	9.2 ± 3.8 (157)
5-6	11.1 ± 4.2 (157)
6-7	12.6 ± 2.8 (157)
7-8	14.7 ± 5.1 (156)
8-9	16.6 ± 4.6 (156)
9-10	19.7 ± 7.1 (143)
10-11	22.9 ± 8.0 (119)
11-12	27.6 ± 7.7 (75)
12-13	27.7 ± 7.1 (38)
13-14	27.7 ± 6.1 (32)

[1] Temperature = 23.5 ± 1.5°C, salinity = 25 ppt with gradual reduction to 20 ppt after 160 days, photoperiod = 8 hrs light/16 hrs dark.

[2] Mean ± standard deviation of number of days between molt instars of juvenile development. Number of crabs for each intermolt period are in parentheses.

Table 2.6. Organisms documented in the diet of blue crabs [adapted from Norse (1975)].

Species	Source
Plants	
Ulva spp.	Tagatz (1968a)
Diatoms	Tagatz (1968a)
Filamentous algae	Tagatz (1968a); Alexander (1986)
Ceratophyllum spp.	Tagatz (1968a)
Vallisneria spp.	Tagatz (1968a)
Vascular plants	Darnell (1958)
Sargassum spp.	Alexander (1986)
Animals	
Hydroids	Darnell (1958)
Bryozoans	Tagatz (1968a)
Annelids	
Nereis pelagica	Tagatz (1968a)
Bivalves	
Mercenaria mercenaria	Van Engel (1958)
Mya arenaria	Hines, Wolcott, and Haddon (1987b)
Crassostrea virginica	Laughlin (1979)
Rangia cuneata	Darnell (1958)
Mulina lateralis	Tagatz (1968a)
Brachidontes	Laughlin (1979); Odum (1971)
Macoma spp.	Laughlin (1979)
Mactra spp.	Laughlin (1979)
Tellina spp.	Laughlin (1979)
Geukensia demissa	Seed (1980)
Congeria leucophaeta	Darnell (1958); Tagatz (1968a); Odum (1971)
Modiolus demissus	Tagatz (1968a)
Musculus niger	Tagatz (1968a)
Barnacles	
Balanus eburneus	Tagatz (1968a)
Amphipods	
Gammarus fasciatus	Tagatz (1968a)
Corophium spp.	Laughlin (1979)
Ampelisca spp.	Laughlin (1979)
Polychaetes	
Neanthes succinea	Laughlin (1979)
Laeonereis culveri	Laughlin (1979)
Gastropods	
Neritina reclivata	Laughlin (1979); Tagatz (1968a)
Odostomia spp.	Laughlin (1979)
Bittium spp.	Laughlin (1979)
Nassarius obsoletus	Tagatz (1968a)
Littorina irrorata	Hamilton (1976)

Table 2.6. Cont'd.

Species	Source
Shrimp	
Penaeus spp.	Laughlin (1979)
Palaemonetes spp.	Laughlin (1979)
Mysids	
Mysidopsis spp.	Laughlin (1979)
Neomysis americana	Tagatz (1968a)
Crabs	
Rhithropanopeus harrisi	Laughlin (1979); Darnell (1958); Tagatz (1968a)
Callinectes sapidus	Laughlin (1979); Darnell (1958)
Neopanope spp.	Laughlin (1979)
Clibanarius spp.	Laughlin (1979)
Arenaeus cribrarins	Alexander (1986)
Fishes	
Anchoa mitchilli	Laughlin (1979)
Micropogonias undulatus	Laughlin (1979)
Microgobius spp.	Laughlin (1979)
Etropus spp.	Laughlin (1979)
Trinectes spp.	Laughlin (1979)
Fundulus spp.	Kneib (1982)
Insects	
Dicrontendipes	Laughlin (1979)
Coleoptera	Tagatz (1968a)
Diptera	Tagatz (1968a)
Hemiptera	Tagatz (1968a)
Hymenoptera	Tagatz (1968a)
Odonata	Tagatz (1968a)
Birds	
Anas strepera	Milne (1965)

Table 2.7. Documented predators of *C. sapidus* [adapted from Norse (1975) and Van Engel (1987)].

Predators	Source
Fishes	
Carcharhinus leucas	Sadowsky (1971)
Sphyrna tiburo	Gunter (1945); Hoese and Moore (1958)
Dasyatis sabina	Darnell (1958)
Dasyatis sayi	Hess (1961)
Dasyatis centroura	Hess (1961)
Dasyatis americana	Dahlberg and Heard (1969)
Lepisosteus spatula	Darnell (1958); Lambou (1961)
Lepisosteus osseus	Suttkus (1963)
Lepisosteus oculatus	Lambou (1961); Suttkus (1963); Goodyear (1967)
Elops saurus	Austin and Austin (1971)
Megalops atlanticus	Hildebrand (1963)
Albula vulpes	Bruger (1974)
Brevoortia tyrannus	McHugh (1967)
Anguilla rostrata	Wenner and Musick (1975)
Bagre marinus	Gunter (1945); Odum (1971)
Galeichthys felis	Gunter (1945); Darnell (1958)
Ictalurus furcatus	Darnell (1958); Lambou (1961)
Ictalurus catus	Heard (1973)
Urophycis regius	Sikora and Heard (1972)
Micropterus salmoides	Darnell (1958); Lambou (1961)
Morone interrupta	Darnell (1958); Lambou (1961)
Morone saxatilis	Truitt and Vladykov (1937); Hollis (1952); Manooch (1973)
Epinephelus itajara	Pew (1954)
Epinephelus nigritus	Pew (1954)
Lobotes surinamensis	Gunter (1945)
Rachycentron canadum	Gunter (1950)
Lutjanus griseus	Starck (1971)
Lutjanus apodus	Austin and Austin (1971)
Lutjanus campechanus	Felder (1971)
Orthopristis chrysoptera	Moffett (1975)
Archosargus probatocephalus	Gunter (1945); Moffett (1975)
Lagodon rhomboides	Darnell (1958); Moffett (1975)
Menticirrhus americanus	Darnell (1958)
Aplodinotus grunniens	Darnell (1958)
Bairdiella chrysura	Darnell (1958); Moffett (1975)
Cynoscion nebulosus	Gunter (1945); Tabb (1961)
Cynoscion regalis	Merriner (1975)
Pogonias cromis	Gunter (1945); Moffett (1975)
Sciaenops ocellatus	Gunter (1945); Simmons (1957); Boothby and Avault (1971); Moffett (1975)
Micropogonias undulatus	Darnell (1958)
Opsanus tau	Verrill (1873)
Opsanus pardus	Moffett (1975)
Paralichthys lethostigma	Moffett (1975)
Birds	
Somateria mollissima	Burnett and Snyder (1954)
Casmerodius albus	Bailey (1971)
Ajaia ajaia	Green (1968)
Grus americana	Stevenson and Griffith (1946); Hedgpeth (1950)
Rallus longirostris	Bateman (1965)
Ardea herodias	Steele and Perry (1990)
Mergus merganser	Steele and Perry (1990)
Lophodytes cucullatus	Steele and Perry (1990)

Table 2.7. Cont'd.

Predators	Source
Reptiles	
Alligator mississippiensis	Valentine et al. (1972)
Caretta caretta	Van Engel (1987)
Lepidochely kempi	Van Engel (1987)
Mammals	
Procyon lotor	Hedgpeth (1950)
Lutra canadensis	Wilson (1955); Chabreck et al. (1982)

Table 2.8. Symbionts of the blue crab, including viruses, bacteria, and parasites [adapted from Van Engel (1987), Millikin and Williams (1984), and Messick and Sindermann (1992)].

NAME	TYPE OF ORGANISM	HISTOPATHY	SOURCE
FOULING ORGANISMS			
Algae	Algae	Exoskeleton (carapace)	Overstreet (1982)
Amphipods	Metazoan; ectoconsorte	Exoskeleton (carapace)	Overstreet (1982); Pearse (1947)
Annelids			
Calliobdella vivida	Leech	Carapace; gills	Overstreet (1982)
Myzobdella lugubris	Leech	Carapace; gills	Hutton and Songandares-Bernel (1959)
Cambrincola vitreus	Branchiobdellid annelid	Carapace; gills	Overstreet (1978)
Barnacles			
Balanus eburneus	Cirripede, ectocommensal fouling organism	Carapace	Adkins (1972a), Perry (1975), and Overstreet (1978)
Balanus improvisus	Cirripede, ectocommensal fouling organism	Carapace	Adkins (1972a), Perry (1975), and Overstreet (1978)
Balanus venustus nivens	Cirripede, ectocommensal fouling organism	Carapace	Overstreet (1982), Babinchak et al. (1982)
Chelonibia patula	Cirripede, ectocommensal fouling organism	Gills and egg mass	Adkins (1972a), Perry (1975), Overstreet (1978)
Loxothylacus texanus	Rhizocephalan barnacle	Gonads	Adkins (1972b), Perry (1975), Overstreet (1982), Hochberg et al. (1992)
Octolasmis mulleri	Pedunculate barnacle	Gill chamber	Perry (1975), Overstreet (1978)
Bacteria			
Coliforms	Bacterial flora	Exoskeleton and gills	Sizemore et al. (1975)
Bryozoans			
Acanthodesia tenuis	Bryozoan symbionts	Exoskeleton	Osburn (1944), Overstreet (1982)
Alcyonidium mytil	Bryozoan symbionts	Exoskeleton	Osburn (1944), Overstreet (1982)
Alcyonidium verrelli	Bryozoan symbionts	Exoskeleton	Osburn (1944), Overstreet (1982)
Canopeum tenuissium	Bryozoan symbionts	Exoskeleton	Overstreet (1982)
Membranipord crustulenta	Bryozoan	Exoskeleton	Osburn (1944)
Membranipora tenuis	Bryozoan	Exoskeleton	Overstreet (1982)
Triticellaeu longata	Etenostomate ectoproct	Branchial chamber	Osburn (1944), Overstreet (1982)
Coelenterates			
Obelia bidentata	Coelenterate	Carapace and gills	Overstreet (1982)
Bougainvillia sp.	Coelenterate		
Isopods	Metazoan, ectoconsorte	Gill chamber	Van Engel (1987)
Mollusks			
Crassostrea virginica	American oyster	Carapace	Overstreet (1982)
Mytilis edulis	Mussel	Carapace	Cargo (1959)
Porifera	Sponges and corals	Carapace	Pearse (1947)

Table 2.8. Cont'd.

NAME	TYPE OF ORGANISM	HISTOPATHY	SOURCE
Tunicates			
Molgula manhattensis	Ectoconsorte	Exoskeleton	Pearse (1947)
PARASITES (Species lethal to the host are marked with *)			
Viruses			
Baculovirus A	Bacilliform virus	Epithelium of hepatopancreas	Johnson (1978)
Baculovirus B	Bacilliform virus	Hemocytes	Johnson (1983)
EHV (enveloped helical virus)	Bacilliform, elongate virus	Hemocytes, hemopoietic tissues	Johnson and Farley (1980)
Enterovirus	Icosohedral O-shaped		Babinchak et al. (1982)
*HLV (herpes-like virus)	Icosohedral O-shaped virus	Hemocytes	Johnson (1976b)
*CBV (Chesapeake Bay Virus)	Icosohedral O-shaped virus	Ectodermally derived, especially nervous tissue; hemocytes	Johnson (1978)
*RLV (Reo-like virus)	Icosohedral O-shaped virus	Many types, especially hemocytes, hemopoietic tissue, and epidermis	Johnson and Bodammer (1975)
*RhvA (Rhabdo-like virus A)	Bacilliform, elongate virus	Mesodermal and ectodermal tissues	Jahromi (1977), Yudin and Clark (1978, 1979)
*RhvB (Rhabdo-like virus B)	Bacilliform virus	Mandibular organ	Yudin and Clark (1978)
Bacteria			
Chitinoclastic	Infectious bacteria naturally occurring on the exoskeleton	Carapace, hemolymph, and tissues	Johnson (1983), Cook and Lofton (1973), Sindermann (1989)
Acinetobacter sp.	Gram negative coccobacilli	Carapace, hemolymph, and tissues	Colwell et al. (1975)
Aeromonas sp.	Gram negative rod	Carapace, hemolymph, and tissues	Sizemore et al. (1975)
Bacillus sp.	Gram negative rod	Carapace, hemolymph, and tissues	Colwell et al. (1975)
Benekea sp.	Gram negative rod associated with "shell disease"	Carapace, hemolymph, and tissues	Sandifer and Eldrige (1974)
Clostridium perfringes	Endospore-forming rod	Carapace, hemolymph, and tissures	Elliot (1984)
Clostridium botulinum	Endospore-forming rod	Carapace, hemolymph, and tissues	William-Walls (1968)
Enterobacter aerogenes	Gram negative rod	Carapace, hemolymph, and tissues	Babinchak et al. (1982)
Escherichia coli	Gram negative rod	Carapace, hemolymph, and tissues	Sizemore et al. (1975)
Flavobacterium sp.	Gram negative rod	Carapace, hemolymph, and tissues	Johnson (1983)
Leucothrix mucor	Septate filamentous bacterium	Carapace, hemolymph, and tissues	Bland and Amerson (1974)
Pseudomonas sp.	Gram negative rod associated with "shell disease"	Carapace, hemolymph, and tissues	Cook and Lofton (1973)
Staphyloccoccus aureus	Gram positive cocci	Carapace, hemolymph, and tissues	Elliot (1984)
Vibrio sp.	Gram negative rod associated with "shell disease"	May penetrate the carapace to enter hemolymph and various tissues	Cook and Lofton (1973)
Vibrio alginolyticus	Gram negative rod	Carapace, hemolymph, and tissues	Elliot (1984)
Vibrio fischeri	Gram negative rod	Carapace, hemolymph, and tissues	Sizemore et al. (1975)
Vibrio cholerae	Gram negative rod	Carapace, hemolymph, and tissues	Moody (1982)
*Vibrio parahaemolyticus	Gram negative rod	Carapace, hemolymph, and tissues	Davis and Sizemore (1982)
Vibrio vulnificus	Gram negative rod	Carapace, hemolymph, and tissues	Davis and Sizemore (1982)
Fungi			
*Lagenidium callinectes	Marine phycomycete	Eggs and gills	Couch and Martin (1982)
Thraustochytrium sp.	Fungi	Exoskeleton	Bland and Amerson (1974)

Table 2.8. Cont'd.

NAME	TYPE OF ORGANISM	HISTOPATHY	SOURCE
Protozoans			
Dinoflagellates			
*Hematodinium spp	Dinoflagellate protozoan	Hemolymph and various tissues	Newman and Johnson (1975), Couch and Martin (1982)
Amoebae			
*Paramoeba pernicosa	Pathogenic amoeba	Many tissues, blood cells, gills, muscles, gonads, and hepatopancreas	Newman and Ward (1973a) Couch and Martin (1982)
Microsporidians			
*Ameson (Nosema) michaelis	Microsporidian parasite	In muscles, causing cysts and a chalky appearance	Sprague (1977), Overstreet (1978), Findley et al. (1981) Couch and Martin (1982)
Ameson sapedi	Microsporidian parasite	In muscles, causing cysts and a chalky appearance	Sprague (1977), Overstreet (1978), Couch and Martin (1982)
Ameson sp.	Microsporidian parasite	In muscles, causing cysts and a chalky appearance	Sprague (1977), Overstreet (1978), Couch and Martin (1982)
Pleistophora cargoi	Microsporidian parasite	In muscles, causing cysts and a chalky appearance	Sprague (1966 and 1977), Overstreet (1978), Couch and Martin (1982)
Thelohania sp.	Microsporidian parasite	In muscles, causing cysts and a chalky appearance	Sprague (1977), Overstreet (1978), Couch and Martin (1982)
Haplosporidians			
*Haplosporidium sp. (Minchinia-like)	Histozoic intercellular parasite	Hemolymph and various tissues	Newman et al. (1976)
Urosporidium crescens	Haplosporidian hyper-parasite	Spores develop in host trematode metacercariae causing cysts in muscles, hepatopancreas, and gills	Perry (1975), Overstreet (1978)
Peritrichs			
*Lagenophrys callinectes	Pertrichous ciliate	Gills	Couch (1966 and 1967)
Lagenophrys epistylus	Ecto-commensal peritrichous ciliate	On eggs and gills	Couch and Martin (1982)
Cestodes			
Echinobothrium affine	Larval diphyllidean cestode (tapeworm)	Internal (body cavity)	Dollfus (1964)
Digeneans (Flukes)			
Microphallus basodactylophallus	Trematode metacercariae	Host to U. crescens in crab muscles and hepatopancreas	Perry (1975), Overstreet (1978) and Heard (1976)
Microphallus nicolli	Trematode metacercariae	Host to U. crescens in crab muscles and hepatopancreas	Cable and Hunnien (1938 and 1940), Perry (1975), Overstreet (1978) and Heard (1976)
Levinseniella capitanea	Trematode metacercariae	Host to U. crescens in crab muscles and hepatopancreas	Perry (1975), Overstreet (1978) and Heard (1976)
Megaphallus diodontis	Trematode metacercariae	In gill chambers	Perry (1975), Overstreet (1978) and Heard (1976)

Table 2.8. Cont'd.

NAME	TYPE OF ORGANISM	HISTOPATHY	SOURCE
Microphallus diodontis	Microscopic digenean (Fluke)	Thoracic muscles hepatopancreas and ventral ganglion	Overstreet (1982)
Microphallus pygmaeus	Microscopic digenean (Fluke)	Thoracic muscles hepatopancreas and ventral ganglion	Overstreet (1982)
Microphallus carcini	Microscopic digenean (Fluke)	Thoracic muscles heptopancreas and ventral ganglion	Overstreet (1982)
Microphallus similis	Microscopic digenean (Fluke)	Thoracic muscles hepatopancreas and ventral ganglion	Overstreet (1982)
Nemertean			
Carcinonemertes carcinophila	Ribbon worm	Gills and eggs	Hopkins (1947), Overstreet (1982)

Table 2.9. Documented field and laboratory surveys of contaminants affecting blue crabs [adapted from Williams and Duke (1979)].

Contaminant	Source
	<u>Larvae</u>
Cadmium	Rosenberg and Costlow (1976)
Mercury	McKenney and Costlow (1981)
Methoxychlor	Bookhout et al. (1976)
Malathion	Bookhout and Monroe (1977)
Mirex	Bookhout and Costlow (1975)
Kepone	Bookhout et al. (1980)
MONO-585	Costlow and Bookhout (1979)
Dimilin	Costlow (1979)
	<u>Juvenile/Adult</u>
Cadmium	Hutcheson (1974); Rosenberg and Costlow (1976); Frank and Robertson (1979); Wiedow et al. (1982); Engel et al. (1985)
Chromium	Frank and Robertson (1979)
Mercury	McKenney and Costlow (1981)
Zinc	Engel et al. (1985)
Copper	Engel et al. (1985)
Chlorine	Burton et al. (1980); Hall et al. (1979)
Flouride	Moore (1971)
Bromine Chloride	Burton and Margrey (1978)
Pentron D-90 {Reg TM}	Burton (1980)

Table 2.9. Cont'd.

Contaminant	Source
HcB	Murray et al. (1992)
Diflubenzuron	Walker and Horst (1992)
PAH, PCB, and organochlorine pesticides	Mothershead et al. (1991)
Petroleum hydrocarbons	Connell and Miller (1981a); Connell and Miller (1981b)
No. 2 fuel oil	Melzian (1977)
Aromatic hydrocarbons	Lee et al. (1976)
Benzene	Cantelmo et al. (1981)
Chlorinated hydrocarbons	Mahood et al. (1970)
Pentachlorophenol	Cantelmo and Ranga Rao (1978); Rao et al. (1979); Coglianese and Neff (1982)
2, 4-dinitrophenol	Cantelmo and Ranga Rao (1978)
DDT	Sheridan (1975); Koenig et al. (1976); Petrocelli et al. (1974); Lowe (1965); Leffler (1975b); Butler and Springer (1963); Sandholzer (1945); Cottam and Higgins (1946); Springer and Webster (1951); Tiller and Cory (1947)
3-chloro-4-methyl benzenamine hydrochloride	Walker et al. (1979)
2,4-D	Beaven, et al. (1962); Rawls (1965); Steenis (1968)
Kepone	Roberts and Leggett (1980); Roberts (1981); Schimmel and Wilson (1977); Schimmel et al. (1979)

Table 2.9. Cont'd.

Contaminant	Source
Mirex	Schoor (1974); McKenzie (1970); Borthwick et al. (1974); Mahood et al. (1970); Lowe et al. (1971); Tagatz et al. (1975); Cripe and Livingston (1977); Leffler (1975b)
Dieldrin	Petrocelli et al. (1974) and (1975); Harrington and Bidlingmayer, (1958)
Malathion	Tagatz et al. (1974)
Dibrom 14 (Naled)	Bearden (1967)
Radiation	Engel (1967); Engel et al. (1973)
Antimycin	Finucane (1969)
Dursban	Ludwig et al. (1968)

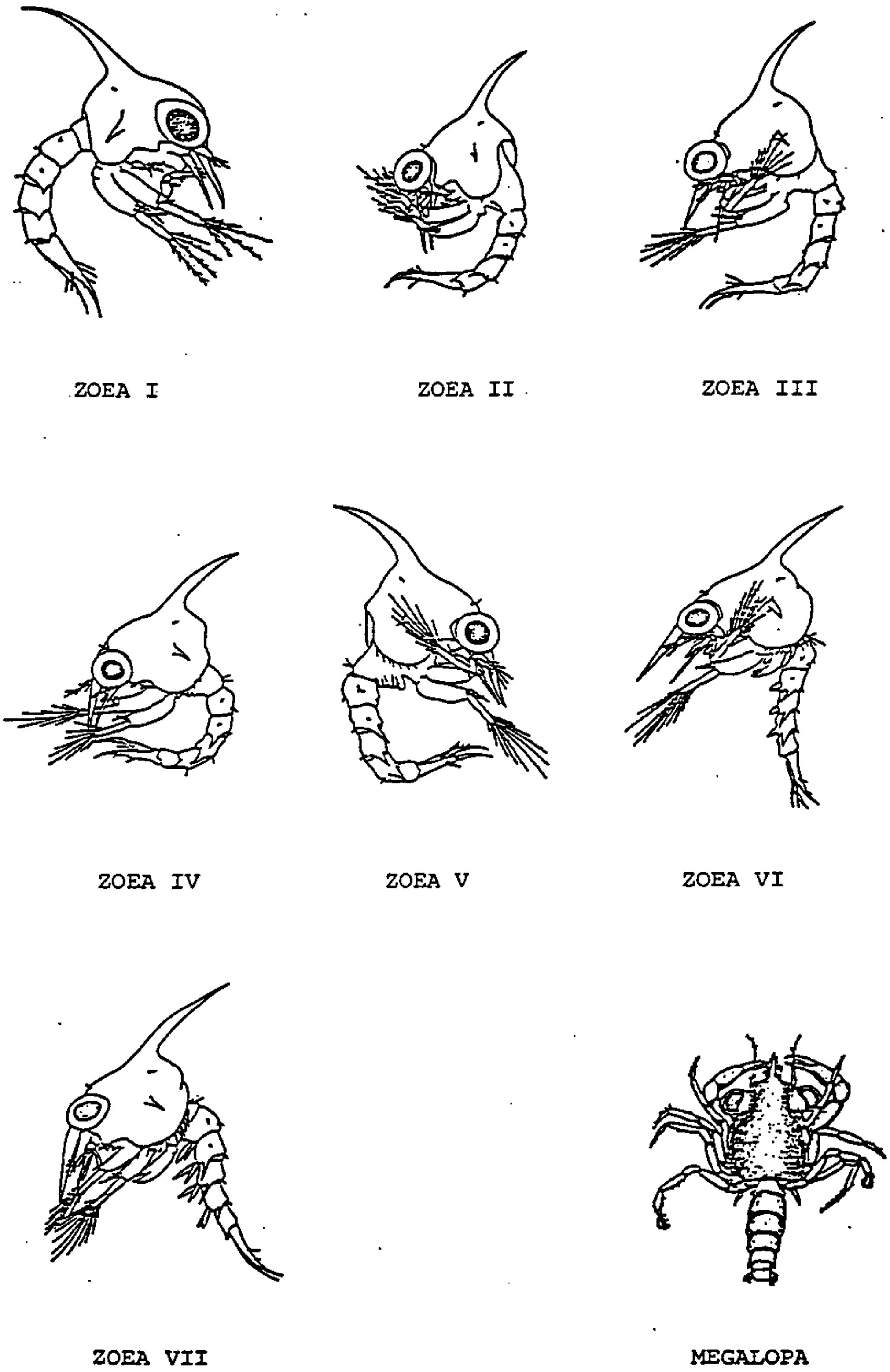

Figure 2.1. Larval stages of blue crab [taken from Costlow and Bookhout (1959)].

3.0 DESCRIPTION OF THE FISHERY

The blue crab supports one of the largest commercial and recreational fisheries in the coastal waters of Louisiana and other Gulf states (Steele and Perry 1990). Blue crabs are harvested by commercial fishermen for their value as a human food commodity and by recreational fishermen for enjoyment and their delectable flavor. Louisiana has accounted for >33% of the total Gulf blue crab harvest since 1968 and >50% since 1983 (Steele and Perry 1990).

Blue crabs are taken year-round in coastal Louisiana in a variety of habitats including fresh, brackish, and shallow oceanic waters (Adkins 1972a). The fishery takes place almost exclusively in state waters (Lindall and Hall 1970).

3.1 History of Exploitation (Hard Crabs)

Little is known of the early history of the commercial blue crab fishery in Louisiana (Steele and Perry 1990). Commercial landing statistics were first collected in 1880. The uniqueness of the product probably prevented early development of the fishery (Perry et al. 1984). One of the first crab commercial fisheries in the Gulf developed near New Orleans to supply the French Market and local restaurants (Perry et al. 1984). The first processing plant for Louisiana crab meat was constructed in 1924 at Morgan City, and by 1931 there were seven additional plants in the Morgan City-Berwick area. This period also saw the onset of crab processing operations in other Gulf States. Jaworski (1972) traced the development of the hard-crab fishery in Barataria Bay. Hard-crab fishing for commercial processing did not become significant until WWII.

The first documented gear used to commercially harvest hard crabs in Louisiana was the trotline (Rathbun 1884). Gowanloch (1952) described the crab trap used in Chesapeake Bay and encouraged Louisiana fishermen to adopt this gear, because it was efficient and economical; however, the crab pot did not become popular until the mid-1960s.

Commercial landing statistics have been recorded in the Gulf of Mexico since 1880, although the data are not continuous prior to 1948 (Table 3.1). Commercial blue crab landings in Louisiana are probably less accurate than similar data for other fisheries (Perry et al. 1984; Steele and Perry 1990) but they can depict long-term trends. Annual commercial landings in Louisiana gradually increased from 1.4 million lb in the late 1880s to 14 million lb in 1940; the average for this period was 4.6 million lb. Recorded annual landings peaked at 31.2 million lb in 1945, corresponding with curtailment of gasoline and commodity rationing, and possible reentry of WWII veterans into the fishery (Steele and Perry 1990). Annual landings averaged 11.0 million lb from 1945 to 1968, increased gradually during the 1960s, 1970s, and 1980s, and then peaked at 53.5 million lb in 1988.

No long term recreational fishery data for blue crabs in Louisiana is available, although one-time surveys were conducted by the U. S. Department of Commerce (1977), Titre et al. (1988) and Guillory (1990b).

3.2 Commercial Fishery (Hard Crabs)

3.2.1 Description of Fishing Activities

The primary commercial gears used since the 1970s in recent years to harvest blue crabs in Louisiana include wire traps, otter trawls, and trotlines. Wingnets, handlines, drop nets, and hoop nets have also been used at various times in the fishery. Crabs are frequently taken as incidental catch (bycatch) in other fisheries and often traded, sold locally, or simply discarded (Carver 1965; Davis et al. 1970; Adkins 1972a; Steele and Perry 1990).

The units of gear, number of fishermen, and landings by selected gear type in the Louisiana commercial hard crab fishery are shown in Tables 3.2 and 3.3. The fishery gradually evolved from a trotline and drop net based fishery to one predominated by traps. By 1967, landings from trap fishermen exceeded landings from all other gears combined, and by the 1990s drop nets and trot lines were rarely used. All gears used historically will be discussed in the following paragraphs.

In the 1800s, crabbers waded in shallow water at night and used hand held dip nets, with lanterns or torches to harvest crabs. Dip nets were long handled and fashioned with a metal ring to which shallow webbing was attached to facilitate removal of the crabs with a quick shake (Perry et al. 1984). Crabs were scooped up and dropped into towed skiffs, tubs, half-barrels or burlap sacks.

In waters too deep for wading, crab fishermen used drop nets consisting of a net covered iron frame of 18 in^2, with bait fastened in the middle, attached to a buoy line. Nets were periodically raised. Benedict (1940) made reference to thick wire (single loop), shallow drop nets used by Lake Pontchartrain crab fishermen. Prior to 1965, drop nets accounted for the second highest percentage of blue crab landings among all gears used in the Louisiana fishery (Table 3.3).

Baited hoop nets, often connected together with a longline, were used to harvest blue crabs in lakes Pontchartrain and Maurepas (Steele and Perry 1990).

Trotlines were the primary method of harvesting crabs in Louisiana during the early years of the fishery (Rathbun 1884; Stearns 1887; Wilkinson 1892) . Louisiana has consistently yielded more trotline caught crabs than any other Gulf state. Annual landings with trotlines was greater than with other gears through 1966 (Table 3.3) when crab pots became popular (Table 3.2). Trotline use declined thereafter until they were nonexistent in the early 1990s.

Trotlines were described in detail by Andrews (1948) and Floyd (1968). A trotline consisted of a length of rope or mainline, short (10 in) drop lines (called snoods, drops, stagings, or gangions) placed at approximately 2-ft intervals, and bait. Beef lips, ears, and tripe were preferred baits because they were tough and durable. Other baits, such as salted eels, were favored by some crabbers because they were reportedly more effective at catching male crabs. Trotlines were run immediately after setting. Fishermen pulled their skiff downwind, or downcurrent, along the trotline and netted the feeding crabs with a long handled dip net. Most trotline fishing was done at night under lanterns or in the early morning, because crabs were easily spooked during daylight by shadows created by the skiffs. Trotline orientation within the estuary was dependent upon tide, season, and geographic location (Van Engel 1962; Jaworski 1972).

After motorized vessels were adopted, the trotline was lifted from the water by rollers or spools extending outward from the vessel side. Drop lines were abandoned because they became easily entangled in the spool as the line passed over the roller. Instead, baits were attached directly to the mainline by a slip knot or by tucking the bait between rope strands. Trotlines were fished by placing the line over the spool or roller and maneuvering the boat along the line. Crabs were dipped when the bait was lifted from the water.

Wing nets or butterfly nets used in the shrimp fishery incidentally catch blue crabs. Documented landings of blue crabs taken in wing nets are scarce and typically make up a very small proportion of annual harvests (Table 3.3). Wing nets are large funnel shaped nets with webbing attached to a rectangular metal frame, attached to a pivot point, and which is raised and lowered from a vertical boom and tethered front and rear for stability. Wing nets are fished from a vessel or stationary platform, primarily on falling tides, and may capture large numbers of crabs, especially during or immediately following a cold front.

Otter trawls, the most common gear used in the shrimp fishery, accounted for <0.5% of the total blue crab catch between 1980 and 1989 with reported landings fluctuating widely (Table 3.3). Blue crabs are usually not targeted with this gear; however, large numbers of crabs are often taken and a limited, seasonal trawl fishery does exist during late fall and early winter. Trawl blue crab landings are directly related to economic conditions in other fisheries, particularly the shrimp fishery (Adkins 1972a). Adkins (1972a) reported that one shrimper trawling in the mouth of a deep bayou following a strong cold front caught 8,000 to 9,000 lb of crabs in a single day. The blue crab trawl fishery in Georgia was described by Cummins and Rivers (1962). The effects of tow length and tickler chain on blue crab catches in Chesapeake Bay were evaluated by Chittenden and Van Engel (1972).

Crab traps, the dominant gear used in the Louisiana fishery today, were first introduced into the Chesapeake Bay blue crab fishery in 1927. Traps were later introduced into Louisiana but did not gain wide spread popularity until the 1960s (Table 3.2). A wide variety of trap sizes and designs are presently used. Traps used prior to the early 1970s were similar to the early Chesapeake Bay design (Adkins 1972a) described by Andrews (1947), Van Engel (1962), Green (1952), Isaacson (1962) and Steele and Perry (1990).

Traps constructed of vinyl coated wire became widely adopted by the mid-1970s because of their resistance to corrosion.

Although size varies, most traps measure 24 in long and 14.5 in high and are usually constructed of 1.5 in hexagonal, black vinyl coated mesh. However, traps constructed of 1.5 in square mesh have become increasingly popular. Different colors (e.g., green, black, orange, red) of wire have also been used in recent years. Traps consist of the following: a floor and ceiling; two to four tapered conical entrance funnels located one mesh above the floor; an arched or gull wing shaped apron, which separates the inner and outer chambers and serves as an effective means of crab retention; and an inner cylindrical shaped bait chamber fastened to the center of the floor and containing an exterior door. Bait chambers are usually constructed of smaller 0.5 in x 1.0 in vinyl coated mesh. Trap size, number of funnels, size of inner chamber relative to outer chamber and bait chamber (presence or absence) can be adjusted to produce a wide variety of traps. Construction techniques vary although hog rings are usually utilized to fasten components together.

Some blue crab fishermen weight their traps by attaching 0.5- 0.75 in diameter reinforcing iron bars (re-bar) or bricks to the trap base. Lines of varying length, depending upon water depth, are attached to the top of the trap and lead to a buoy, generally made of polystyrene or plastic. Traps are usually set in a line and baited with fish; the preferred bait is gulf menhaden (Brevoortia patronus).

Vessels engaged in the trap fishery range from small outboard powered flats to large inboard powered skiffs. Fishermen fish alone or may have one to two deck hands, depending upon the number of traps fished, the proportion of undersized crabs, and whether or not premolt crabs are separated from the catch.

Larger skiffs engaged in the trap fishery may utilize a "rake", a rectangular metal (usually aluminum) frame or boom to assist in retrieving buoys and cages. Rakes are generally mounted to the starboard aft one-third of the vessel and tethered to the bow and a short mast. Rakes are deployed to allow the bottom toothed bar to fall just below the water surface. The vessel is guided toward the buoy and the buoy line is snared between the teeth of the rake, which carries the trap to the surface by the vessel's momentum. The fisherman then reaches overboard with his hand or boat hook to retrieve, empty, and rebait the trap. A pulley system rigged to the mast and boom is used to raise or lower the tooth bar, allowing the snared buoy to drop. Shallow pieces of webbing or wire are stretched across the metal frames to prevent buoy lines from wrapping around tooth bars.

Traps retrieved with rakes must have specially reinforced corners where the buoy lines are tied. Metal bars or strong wooden sticks are inserted at these corners to provide support. Flat-bar or cross sections of PVC pipe are often added to the tops and bottoms of buoys to reduce their damage and loss.

The concept of self-culling crab traps to reduce the number of sublegal crabs retained in traps originated in the Atlantic Coast blue crab fishery (Steele and Perry 1990). The problem of retention of sublegal crabs has been recognized since the introduction of crab traps (Green 1952). Large mesh panels (Cronin 1950), traps made of larger mesh (Van Engel 1962) and escape rings (Eldrige et al. 1979) have been evaluated. In Louisiana, Guillory and Merrell (1993) assessed size, number, and location of escape rings in blue crab traps. Three 6.03 cm (2.38 inch) diameter rings located flush with the floor and apron with at least two located in the outer chamber were recommended. Guillory (1989) later compared square (5.08 cm side) and circular (6.03 cm diameter) escape vents. Although both performed adequately and equally well, square vents were more economical, and easier to construct and apply than circular vents. Guillory (1990a) evaluated the effects of escape vents on catch rates of premolt blue crabs. On a percentage basis, rank peeler (i.e., pink-line and red-line molt stages) catches were reduced about 70% in traps with escape vents when compared to unvented traps. Consequently, the use of escape vents could affect the soft crab fishery by reducing the supply of premolt crabs.

The influence of various factors on blue crab catch rates in traps was documented by Green (1952), Isaacson (1962), and Castro and DeAlteris (1990). Miller (1986, 1990) and Krouse (1989) discussed and reviewed performance and selectivity of decapod traps.

The impact of ghost fishing in blue crab traps was evaluated by Guillory (1993). He reported that large numbers of traps are lost annually by commercial crab fishermen and concluded that substantial numbers (25/trap-yr) of crabs died in each trap and that unbaited traps continued to attract crabs (35/trap-yr). Arcement and Guillory (1993) found that blue crab mortality in unvented ghost traps was 3.2 times greater than in vented traps. General reviews of ghost fishing by crab traps were provided by Smolowitz (1978a, 1978b) and Breen (1990). Several authors have developed and recommended the use of time release mechanisms or biodegradable panels in other trap fisheries to reduce ghost fishing mortality. Blott (1978) evaluated several time release mechanisms in lobster traps and recommended the use of hinged doors with a biodegradable attachment. Square or triangular escape panels with cotton butcher twine as a binding material for use in sablefish (Anoplopoma fimbria) traps were recommended by Scarsbrook et al. (1988).

Bycatch in hard crab traps has been documented in several studies: diamondback terrapins (Malaclemys terrapin) (Bishop 1983), several species of fishes (Guillory 1993), and premolt crabs utilized in shedding operations (Bishop et al. 1983, 1984; Christian et al. 1987).

Crab dredges, a controversial gear used in the Chesapeake Bay fishery since 1900, were introduced in Louisiana in late 1990 and used by a few fishermen in nearshore Gulf waters (Caillou Bay) and in Vermilion Bay. At that time dredges were not defined as a legal method of taking blue crabs in Louisiana. Legislation introduced during the 1991 legislative session has specifically prohibited the use of dredges to harvest blue crabs in

Louisiana. A "Concurrent Resolution" requesting an investigation into the effects of crab dredges was also passed.

Commercial oyster luggers or Lafitte skiffs equipped with one to two dredges were typically used. Crab dredges had essentially the same structural design as the oyster dredge, with slight modification. Dredges consisted of a rectangular iron frame up to 5 ft wide, a metal bridle to which a hauling chain was attached, and a bag of 2 in square mesh. Unlike dredges used in the Chesapeake Bay, these dredges had a nontoothed drag bar. Crab dredges used in Chesapeake Bay were described by Cargo (1954) and Van Engel (1958). Sulkin and Miller (1975) evaluated a modified oyster dredge for sampling blue crabs.

Commercial fishermen typically made "spot checks" with one of the dredges in order to locate harvestable concentrations of blue crabs. Tow chain length was generally determined by depth, vessel speed, and substrate type. Tow time varied from 3-5 min.

The commercial fishery for hard blue crabs in various parts of the country has been described or summarized in numerous other studies: Gulf of Mexico (Moss 1982; Perry et al. 1984; Perry and McIlwain 1986; Steele and Perry 1990); Texas (Leary 1967; More 1969; Miller and Nichols 1986); Mississippi (Perry 1975); Alabama (Tatum 1980, 1982b; Florida (Steele 1982); South and Middle Atlantic Coast (Cummins and Rivers 1962; Tagatz 1965; Eldrige and Waltz 1977; Sholar 1982; Van den Avyle and Fowler 1984; Low et al. 1987; Maiiolo et al. 1986); and, Chesapeake Bay (Newcombe and Gray 1941; Tang 1983; Cronin 1987). The overall fishery was addressed by Rhodes and Van Engel (1978), Millikin and Williams (1984) and Haefner (1985). Descriptions of surveys which gathered fishery dependent data were described in South Carolina (Rhodes 1973) and Maryland (Summers et al. 1983a and 1983b). Overall surveys, and descriptions of blue crab commercial gear were presented in Cargo (1954), Van Engel (1958), Perry et al. (1984) and Steele and Perry (1990).

3.2.2 Effort and Harvest

Annual landings of blue crabs in the Gulf of Mexico have ranged from 0.32 millon lb in 1880 to 79.1 million lb in 1988, averaged 27.3 million lb from 1880-1992, and accounted for 26.0% of the total U.S. hard blue crab landings since 1960 (Tables 3.1 and 3.4). The annual percentage has fluctuated from peaks of 34.5% in 1977 and 38.9% in 1987 to a low of 18.8% in 1982. Gulf blue crab landings in 1992 contributed 36.2% of the nation's total.

The annual percent contribution of individual Gulf States to total Gulf landings from 1960 through 1993 is shown in Table 3.4. Historically, Louisiana landings were predominate among Gulf States. However, beginning in the late 1950s and through the 1960s, Florida displaced Louisiana as the leading producer of blue crabs in the Gulf of Mexico. Since the 1970s, Louisiana has led all Gulf States in reported landings (Table 3.1) and yielded at least 70.0% of the total Gulf catch since 1991 (Table 3.4).

As stated earlier, reported blue crab commercial landings are probably not as accurate as landings reported for other fisheries. Landings underestimate actual production because some dealers may not report all landings and not all market channels were included in the NMFS statistical surveys (Lindall and Hall 1970; Jaworski 1971; Adkins 1972a; U. S. Army Corps of Engineers 1974; Moss 1982; Roberts and Thompson 1982; Keithly et al. 1988b). However, landings do illustrate trends and cycles over time.

Blue crab fisheries are characterized by seasonal, annual, and geographic fluctuations in harvest. Lyles (1976) and Moss (1982) suggested these harvest fluctuations appear to be influenced more by economic conditions than by blue crab population levels. Environmental factors, conditions in other fisheries, variations in fishing effort, and increased gear efficiency have also contributed to annual fluctuations in crab production.

In Louisiana, reported commercial blue crab landings, while exhibiting year-to-year fluctuations, gradually increased until the 1980s. A dramatic increase in landings occurred after 1983 when several successive harvest records were set. This increase in landings was largely due to increased fishing effort. The number of fishermen, by gear type (Table 3.2), showed a significant increase during the 1980s. The number of trap fishermen prior to 1978 was obtained from NMFS data (three part time fishermen were considered equal to one full time fishermen); after 1977 the number of commercial trap licenses sold by the Louisiana Department of Wildlife and Fisheries (LDWF) was used (Table 3.5). From 1979 to 1989, the number of commercial trap licenses increased from 751 to 3,019, an increase of almost 300%. The increased fishing effort has been attributed to several interrelated factors: relatively low fixed investment requirements and high resource abundance, economic difficulties of individuals previously employed in the recently depressed oil and gas industry, economic overfishing in interdependent fisheries, stock reduction in oyster resources, and a sudden influx of Indochinese into the fishery (Roberts and Thompson 1982; Keithly et al. 1988b; Steele and Perry 1990).

In the 1990s the number of crab trap licenses declined to a low of 2,503 in 1994. An improving economy, increased operating costs, increased number of traps per fishermen, declining catch rates, and other factors may have provided incentives for fishermen to leave the fishery. These factors may also make the fishery less attractive to newcomers.

The average number of traps per fisherman estimated by NMFS increased, particularly during the 1980s, but declined abruptly following 1988 (Table 3.5). Annual catch per fishermen declined from 28,210 lb in 1979 to 11,044 lb in 1989, a period of dramatic increase in fishing effort (Table 3.5). Catch per trap declined from 190 lb in 1979 to 74 lb in 1989 (Table 3.5).

Dominant gears used to commercially harvest blue crabs in Louisiana have changed over time. Until the mid-1960s, trotlines, drop nets, and trawls were the most popular gears and accounted for 80.0%, 11.6%, and 6.5%, respectively, of total crab landings from 1948-1966 (Table 3.3). Trotline catches declined gradually from 1948 while trawl catches gradually increased. Drop net catch fluctuated widely from 1948-1955, increased significantly from 1956-1965, and then drastically declined. After 1966, traps displaced trotlines, drop nets, and trawls as the most popular gear used in the fishery (Tables 3.2 and 3.3).

Trends in monthly blue crab landings for 1979-1985 and 1986-1992 are depicted in Figure 3.1. Landings gradually increased through late winter, spring, and early summer, peaked in June and July, then gradually declined until a secondary peak was reached in October, and then abruptly declined.

Figure 3.2 depicts Louisiana commercial blue crab landings by region for 1979-1985 and 1986-1992. Region I consists of those parishes bordering lakes Pontchartrain and Maurepas and includes Orleans, St. Tammany, East Baton Rouge, Ascension, Livingston, and Tangipahoa parishes. The coastal area east of the Mississippi River, Plaquemines and St. Bernard parishes, makes up Region II. Region III is located between the Mississippi and Atchafalaya Rivers and includes St. Charles, Jefferson, Lafourche, Assumption, Terrebonne, St. James, St. John and St. Mary parishes. Region IV, the area west of the Atchafalaya River, includes the parishes of Lafayette, Iberia, Jefferson Davis, Acadia, Evangeline, St. Landry, St. Martin, Calcasieu, Vermilion, and Cameron. Region III has contributed 67.9% of Louisiana's blue crab landings since 1979 and since 1986 has experienced a 55.8% increase in landings. Regions I and II accounted for 8.0% and 13.7%, respectively, of total Louisiana blue crab landings since 1979 and have experienced landings increases of 36.4% and 57.9%, respectively. Landings from region IV have remained fairly static, as illustrated by an increase of only 23.2% since 1986.

3.2.3 Economics

In addition to information presented in the following sections that relate specifically to the Louisiana commercial hard crab fishery, other data can be found in the literature that may also be pertinent to Louisiana. Economic surveys were conducted in Texas (Miller and Nichols 1986), Florida (Landrum and Prochaska 1980), Georgia (Carley and Frisbe 1968), South Carolina (Rhodes and Bishop 1979; Low et al. 1987), North Carolina (Maiiolo et al. 1986) and the Gulf of Mexico (Perry et al. 1984; Moss 1982; Steele and Perry 1990). Ex-vessel prices were analyzed by Prochaska and Taylor (1982), Prochaska et al. (1982) and Rhodes (1982). Economic trends (Strand 1978) and markets (Vondruska 1986) in the industry were described. Dressel et al. (1983) compiled an economic profile of the blue crab industry.

The blue crab fishery, in view of its dockside value, is becoming an increasingly important component of the Louisiana commercial fishing sector (Keithly et al. 1988b). For instance, the dockside value of $17.5 million for the 1987 Louisiana commercial blue crab fishery was exceeded only by the shrimp ($153.6 million), menhaden ($48.2 million) and oyster ($19.2 million) fisheries.

The blue crab fishery also provides an important source of employment in some regions of the state. The number of commercial crab trap licenses ranged from 2,500-3,000 during 1987-1991. Employment in the harvesting sector creates additional employment in wholesaling and processing activities (Keithly et al. 1988b).

3.2.3.1 Markets. Marketing and procurement of crabs in Louisiana and other Gulf states was reviewed by Perry et al. (1984), Steele and Perry (1990) and Keithly et al. (1988b). Louisiana blue crabs are bought by Louisiana wholesalers, processors, restaurants or retail outlets, and nonresident buyers. Wholesalers do not process crabs and usually purchase their crabs directly from local crabbers. Processors purchase their crabs from wholesalers or directly from fishermen. Restaurants or retail outlets may purchase crabs from wholesalers, processors, or fishermen. A substantial volume of Louisiana crabs is also purchased directly by nonresidents without entering Louisiana marketing channels. Keithly et al. (1988b) reported that in 1986, 27.3 million lb of blue crabs were handled by processors, 14.3 million lb by wholesalers, and 6.6 million lb by nonresidents. They presented no information on direct purchases from crab fishermen by individuals, restaurants, or retail outlets.

Louisiana crabs are sold either live or processed. The volume of crabs sold live or for processing in 1986 made up 36.5% and 63.4%, respectively, of the total (Keithly et al. 1988b). Reported live crab sales by dealers and processors were almost exclusively (98.2%) out-of-state. Processed product sales to resident and out-of-state buyers were 35.3% and 64.7%, respectively. These sale percentages of live and processed crabs did not reflect the direct sale of whole crabs by Louisiana restaurants or retail outlets.

Crabs are sold in various forms and grades (Keithly et al. 1988b). Live crabs are often graded by sex and size when sold in restaurants and retail outlets. Processed crab meat grades include several body (jumbo, lump or backfin, and special white) and claw (claw, cocktail claw, and fingers) meat categories. On a percentage basis, processed crab meat is marketed fresh (87.8%), frozen (7.6%), or pasteurized (4.6%).

3.2.3.2 Value. Data on commercial hard crab landings, and current and deflated price per pound and overall value are tabulated in Table 3.6. Total dockside value, gradually increased during the 1960s but began to fluctuate more as landings exhibited greater oscillations. Overall dockside values ranged from $14.8 million to $26.7 million for 1987-1992. Dockside prices, likewise, increased, particularly after 1986. Prices ranged from $0.342 to $0.524/lb pound during 1987-1992. Dockside prices in Louisiana are slightly higher than the national average (Keithly et al. 1988b).

Average annual dockside prices in the fishery during the 1970s and 1980s were relatively unresponsive to changes in landings (Steele and Perry 1990). Keithly et al. (1988b) attributed the increase in dockside prices to inflation. Prochaska et al. (1982) and Rhodes (1982) statistically examined the relationships among dockside prices, landings, and other factors, and found that disposable income of consumers was the largest determinant of blue crab dockside price. The deflated value of blue crabs increased only marginally for the 27 yr period prior to 1987 (Steele and Perry 1990).

While average annual dockside prices are affected significantly by factors other than supply, average monthly prices appear to be influenced by landings. Average Louisiana monthly landings and dockside prices for 1979-1989 are illustrated in Figure 3.3. Average monthly price per pound ranged from $0.35 to $0.39 from December through April and from $0.26 to $0.33 from May through November; average monthly landings ranged from 1.1 to 2.3 million lb for the former period and from 2.5 to 3.8 million lb for the latter period.

Applying an economic multiplier of three (Cody et al. 1992) to the 1984-1993 values of the Louisiana hard crab fishery yields expanded values ranging from $44.4 million to $64.3 million and an average of $55.4 million. These values for the hard crab fishery are probably actually greater because landings are under reported or marketed through channels not incorporated in statistical surveys (Lindall and Hall 1970; Jaworski 1971; Adkins 1972a; U. S. Army Corps of Engineers 1974; Moss 1982; Roberts and Thompson 1982; Keithly et al. 1988b).

Keithly et al. (1988b) documented the value of live crab and processed crab meat sales by Louisiana dealers for 1986. Live crab and processed meat sales totalled $6.5 million and $8.9 million, respectively.

Perry et al. (1984) plotted the distribution of the consumer dollar spent for crabs and crab products. The largest share accrues to processors (48%), while fishermen, retail stores, and wholesalers receive 28%, 19%, and 5%, respectively.

3.2.3.3 Processing. The processing sector is not reviewed in detail, but several recent pertinent references are cited here. Comprehensive reviews of blue crab processing throughout the Gulf of Mexico include Perry et al. (1984), Keithly et al. (1988a), Steele and Perry (1990), and Keithly et al. (1992). Keithly et al. (1988b) and Perkins (1982) provided data on the economics of the crab processing industry in Louisiana and Mississippi, respectively. Technical aspects of processing were addressed by Miller et al. (1974), Duersch et al. (1981) and Moody et al. (1982). de la Bretonne et al. (undated) compiled workshop proceedings into a processing manual for the crab industry

3.2.3.4 Fishing Income. Steele and Perry (1990) estimated the current gross income per crab fisherman (average annual income for the period) in Louisiana for 1971-1975, 1976-1980, and 1981-1985 as $2,567, $3,737 and $6,600, respectively. Increased gross income was not attributed solely to inflation; Steele and Perry found that the 1986 deflated gross income exceeded the 1971-1975 average by almost 50%. They further suggested that, while gross income appears to be relatively constant when evaluated on a deflated basis, profitability may be declining because of increased costs associated with the increased number of traps per fisherman.

Earlier cost and return profiles, while outdated, do provide insight into the economics of individual Louisiana and Texas crab fishermen (Table 3.7). In both budgets, variable costs exceeded fixed costs with bait, boat fuel, and traps being the major expense.

3.2.4 Mariculture

No commercially successful aquaculture operation for hard blue crabs is presently found in Louisiana. Although considerable information about the biology and life history of the blue crab is available, total culture from egg to adult hard crab has not been practiced commercially. While blue crabs can reach maturity and market size in < 1yr under optimal rearing conditions, factors such as high mortality rates, high labor demands to raise larvae, a prolonged larval life, cannibalism, and high trophic level (i.e., carnivory) are primary reasons why total commercial culture from egg to market size has not been attempted (Oesterling and Provenzano 1985). Probably the major factor in the failure of most early attempts to rear blue crabs in mass culture in artificial environments has been cannibalism. Relatively low market value for hard crabs also discourages their mariculture (Lunz 1968).

Proven laboratory methods for successful hatching of blue crab eggs were described by Lockhead and Newcombe (1942), Sandoz and Rogers (1944), Costlow and Bookhout (1960), Bookhout and Costlow (1977) and Sulkin et al. (1980). Studies describing the effects of various live food organisms separately or in combination on survival rate and duration of larval development were reported by Bookhout and Costlow (1970), Sulkin (1978) and Millikin et al. (1980).

Larvae reared in mass culture by W. T. Yang (personal communication, cited in Provenzano 1985) obtained marketable size in 6 mo. Laboratory culture of juvenile blue crabs reared from larvae has been successful only when individuals are isolated in compartments to prevent cannibalism. Millikin (1978) and Millikin et al. (1980) reported a dramatic increase in survival rates of the first crab stage in the laboratory compared with larval stages. Bookhout and Costlow (1977) and Millikin et al. (1980) reported on the influence of salinity, water temperature, photoperiod, and nutrition on blue crabs. Holland et al. (1971) reported maximum weight gain of blue crabs at 29-30 °C in the laboratory.

Adults are easily cultured in the laboratory in either filtered or artificial seawater when reared individually to prevent cannibalism (Oesterling and Provenzano 1985). Additional research on excretion rates, nutrient requirements, and respiration rates are needed to improve design of closed systems for rearing both juveniles and adults.

Attempts at artificial stocking near Chrisfield, Maryland, with ovigerous females held in shedding floats failed due to low survival rates of adults (Graham and Beaven 1942). Leary (1967) suggested that blue crabs could be raised in ponds or artificial impoundments; however, he provided no documentation. In saltwater ponds used for mariculture experiments, blue crabs yielded about 112 kg/ha in South Carolina (Lunz 1968) and 79.1 kg/ha in Louisiana (Rose et al. 1975). Lunz (1968) commented on the large size of crabs in mariculture ponds.

3.3 Recreational Fishery (Hard Crabs)

3.3.1 Description of Fishing Activities

Blue crabs provide a popular and important source of recreation for many families and coastal residents, especially in warmer months. Approximately one-third of Louisiana's recreational saltwater license holders participate in recreational crabbing with the average number of directed and undirected (i.e., as incidental trawling catch) trips being high (Guillory 1990b). Although the recreational blue crab fishery is less prominent than the recreational finfish fishery and equals only a small percentage of the commercial catch, it is nevertheless an important recreational fishery.

Estimates of recreational fishing pressure and harvest vary widely among different locations and studies (Perry et al. 1984). The recreational catch of blue crabs in Louisiana was estimated to be almost 11 million lb in 1975 or 64% of the reported commercial catch (U. S. Department of Commerce 1977). This figure is now considered by Gulf of Mexico crab biologists to be greatly overestimated. The recreational catch was estimated to make up a much smaller percentage of the total commercial catch in other studies: 20% in Alabama (Tatum 1982b); <4% in Mississippi (Herring and Christmas 1974); 5.9% in Galveston Bay, Texas (Benefield 1968); and 4.1% in Terrebonne Parish, Louisiana, in a year when Terrebonne Parish contributed 28.8% of the total Louisiana commercial blue crab harvest (Guillory 1990b).

Recreational crabbing is a relatively inexpensive, low key, family oriented activity. It occurs year-round, but peaks in late spring and summer when crabs migrate into more accessible habitats and become more active. Recreational fishermen harvest crabs with a variety of gears including crab traps, hand lines, trotlines, drop nets, dip nets, bait seines, and rods and reels. Additionally, large numbers of crabs are taken as incidental bycatch by recreational fishermen using shrimp trawls. Fishing modes vary and include land-based or boat-based fishermen using gear other than traps; those using traps; and those retaining crabs incidentally caught while trawling shrimp (Guillory 1990b). The greatest effort is expended in areas accessible by roads (Adkins 1972a) such as canals, bays, bayous, beaches, jetties, seawalls, piers, wharfs, docks, and bridges. Crabs are harvested from boats in lakes, bays, bayous, and canals, as well as behind dams, weirs, and water control structures. Favorite baits include beef, fish, and chicken and turkey necks.

Creel surveys of recreational crabbing have also been conducted in Texas (Benefield 1968), Mississippi (Herring and Christmas 1974), Maryland (Maryland Department of Natural Resources 1989), and Florida (Anderson and Gehringer 1965).

3.3.2 Effort and Harvest

Marine recreational fishing in general has increased at an unprecedented rate in recent years. The increased recreational demand has largely stemmed from a marked increase in mobility of coastal residents and from attendant increases in leisure time and discretionary income. Shifts in population from inland to coastal areas has occurred; approximately two thirds of Louisiana's population resides within a 2-h drive of the coastal zone (Davis 1982). The sale of recreational saltwater angling licenses (Table 3.8) illustrates the recent increase in marine fishing activities. License sales increased from 102,125 during license year 1984-1985 to 265,759 in license year 1993-1994. While the increased number of saltwater angling licenses may not necessarily reflect an attendant increase in recreational crabbing, the latter may have also increased in recent years. The sale of recreational crab trap licenses increased from 1,200 in 1987-1988 to 3,130 in 1994-1995 (Table 3.9). Emphasis on recreational crabbing may continue to increase in the future.

Although data on long term trends of the recreational harvest of blue crabs in Louisiana is lacking, several marine recreational surveys have been completed and include Stern and Schafer (1966), Adkins (1972a), Davidson and Chabreck (1983), Titre et al. (1988), and Guillory (1990b). These studies differed in both scope and methodology; consequently, temporal trends in the recreational fishery cannot be depicted. Survey data, however, will be presented for each study.

During a 10-wk survey (June 29 - September 6, 1964) Stern and Schafer (1966) estimated that recreational fishermen harvested 5,661 lb of crabs from Biloxi Marsh, Louisiana. This figure represented 2.8% of the total recreational harvest of all species.

Adkins (1972a) interviewed recreational shrimp trawlers during a 1-d survey and reported that sport trawlers captured and retained their entire catch of 42 bushels of crabs. Davidson and Chabreck (1983) surveyed recreational activities during 1981 at the Rockefeller Wildlife Refuge in southwest Louisiana. They estimated the recreational harvest of blue crabs at 51,077 lb, of which 55.2% was taken from impoundments and weir areas.

Titre et al. (1988) surveyed outdoor recreational activities in the deltaic wetlands of eastern Louisiana from December 1985 to December 1986. They reported that 42.7% of interviewed boaters participated in recreational crabbing during the year. Fewer than 1% considered recreational crabbing as their most preferred activity and slightly more than 5% considered it their second most preferred activity. During the 12-mo survey, respondents averaged 1.29 trips/yr in the west portion of the study area and 1.69 trips/yr in the east portion.

Guillory (1990b) quantified effort, catch per effort, harvest, and other associated parameters in the major segments of the Louisiana blue crab recreational fishery in Terrebonne Parish: land based and boat based crabbers using gear other than crab traps;

shrimp trawlers retaining incidental catch of crabs; and crabbers using crab traps. This study consisted of a roving clerk intercept survey of land based crabbers, an access point intercept survey of recreational shrimp trawlers, a mail survey of individuals purchasing a saltwater fishing license in Terrebonne Parish, and a mail survey of individuals purchasing a Louisiana recreational crab trap license.

Results from the access point trawler survey indicated that trawlers averaged 7.9 trips/yr, retained crabs 75.5% of the time, and caught 11.9 crabs/trip of which males made up 61.9% of the total. Annual incidental harvest averaged 71.4 crabs/fisherman. Total estimated 1989 crab harvest by recreational shrimp trawlers in Terrebonne Parish was 108,250 lb.

Land based recreational crabbers averaged 7.9 trips/yr and an overall harvest of 83.8 crabs/d, with 30% of the catch discarded because of small size. Approximately 70% of the harvest were males. Drop nets (25.2%) and hand lines (71.3%) were utilized most frequently by crabbers, with no other gear utilized by >2.5% of the crabbers. Average number of dropnets and handlines used were 6.0 and 8.0, respectively. Catch per hour (CPHR) was highest with handlines (22.9) and drop nets (12.4). Chicken and turkey necks were the most popular bait types and were the most efficient (CPHR of 22.5). Fish was the second most popular bait, but ranked next to last in CPHR. Effort peaked in September and catch rates increased throughout the spring, peaked from June to August and then steadily declined during the fall. Estimated harvest by land based recreational crabbers in Terrebonne Parish was 84,558 lb. In Mississippi, Herring and Christmas (1974) reported that recreational crabbers overwhelmingly used drop nets, preferred poultry parts for bait, crabbed an average of 17.7 d/yr and kept an average of 9.5 crabs.

Nearly 33% of the respondents from the mail survey of saltwater fishing license holders crabbed recreationally in Terrebonne Parish; 73.3% were involved in boat based crabbing; 72.6% were involved in land based crabbing, and 54.8% crabbed from both land and boat. Almost 50% of the respondents indicated that they had experienced decreases in crab catches, and crab size over the last 5 yr. Estimated total boat based and total land based harvest in Terrebonne Parish was 139,860 and 122,800 lb, respectively. Although participation in crabbing in Terrebonne Parish by saltwater fishermen (32.3%) was lower than that (42.7%) estimated by Titre et al. (1988), average crabbing effort (3.2-4.1 land based crabbing trips plus 4.6-4.8 boat based trips) was considerably higher than effort estimates of Titre et al. (1988).

Responses from recreational crab trap license holders indicate that >85% of trap fishermen either owned or had unlimited access to a camp and that these fishermen averaged more trap sets than occasional or noncampers. Additionally, 80% of the trap fishermen utilized gear other than traps to catch crabs. Trap fishermen averaged 7.2 traps each 11.6 trap sets a year, 60.7 crabs/set, and an annual harvest of 704 crabs. Almost 50% of these respondents reported decreases in crab catches and crab size over the last 5 yr. Total recreational trap harvest in Terrebonne Parish was estimated at 27,590 lb.

Harvest by weight by all fishing modes totaled 4.1% of the reported 1989 Terrebonne Parish commercial crab catch of 9.6 million lb (Lee Usie, NMFS; New Orleans, La.; pers. comm.).

3.3.3 Economics

Measures of fishing effort and average expenditures per trip for crab fishermen are needed to estimate the economic value of the Louisiana blue crab recreational fishery. Two surveys (Titre et al. 1988; Guillory 1990b) provided information on the Louisiana recreational crab fishery. Titre et al. (1988) surveyed characteristics of recreational marine anglers, including those targeting blue crab, in the deltaic wetlands of southeastern Louisiana. Guillory (1990b) quantified various parameters in the major segments of the Louisiana blue crab recreational fishery in Terrebonne Parish.

Effort in a recreational fishery is a direct function of expenses incurred and perceived benefits of the activity. As costs rise (in relation to other leisure activities or as a fraction of disposable income) effort declines. Effort is also directly related to both tangible and intangible benefits such as gustatory value of the catch, enjoyment of the outdoors, change in daily routine, or other unquantifiable benefits.

Titre et al. (1988) reported that 42.7% of interviewed boaters participated in recreational crabbing during a 12-mo survey. Respondents averaged approximately 1.5 crabbing trips/yr.

Guillory (1990b) determined the average number of annual recreational crabbing trips by fishing mode: a) land based, nontrap fishermen -- 5.8 or 7.9 trips, depending upon survey approach; b) boat based, nontrap fishermen -- 7.6 trips; and c) trap fishermen -- 11.6 trips. Nearly 33% of respondents from the mail survey of saltwater fishing license holders crabbed recreationally; of these, approximately 73% were involved in either land or boat based crabbing and 55% crabbed from both land and boats. Interviewed recreational shrimp trawlers averaged 7.9 trips/yr, with crabs retained as bycatch in 6.0 trips.

The gross economic value of a recreational fishery is comprises total angler expenditures plus value in excess of actual expenditures that fishermen would be willing to spend to continue fishing (Malvestuto 1983). Actual expenditures fall into two general categories: (1) variable or fishing trip costs, which includes expenditures for items such as fuel, food, bait, and lodging incurred while traveling and during a fishing trip; and (2) fixed or durable costs for fishing equipment (boat, motor, trailer, gear, special clothing) which can be used over a number of years (Gordon et al. 1973).

Direct expenses (fuel, bait, food, drinks, ice) of interviewed land based crabbers in Terrebonne Parish averaged $22.30/party-d (Guillory 1990b). This estimate is conservative because expenditures such as tackle and lodging were excluded. Expenses incurred from boat based crabbers would be greater because of boat fuel and launching costs.

Recreational trawlers retaining crabs as bycatch estimated average expenses of approximately $40/trip. Titre et al. (1988) determined that overall expenditures (including lodging and tackle) averaged $91.27/trip among all recreational user groups. Combined direct and indirect (equipment, lodging) expenditures for all recreational crab fishing modes would therefore probably range between $22.30 (Guillory 1990b) for land based crabbers and $91.27 (Titre et al. 1988) for all recreational user groups.

Available data is insufficient to accurately assess total statewide fishing effort and expenditures by Louisiana recreational crab fishermen. However, rough estimates by fishing mode (i.e., trap fishermen, nontrap fisherman, shrimp trawlers) can be generated if the data of Titre et al. (1988) and Guillory (1990b) are assumed applicable to the entire Louisiana coast. Input data utilized in calculation of effort and expenditures were conservatively derived.

Total statewide expenditures for nontrap fishermen can be derived from the product of average expenses per trip, number of recreational crabbers and average number of crabbing trips divided by the average party size. Average expenses per party-day were estimated at $22.30 and party size, 3.3 persons (Guillory 1990b). The number of recreational crabbers was obtained from the sum of licensed (an average of 206,000 since 1989) and unlicensed (assumed to equal license total) saltwater anglers times the proportion (1/3) of saltwater anglers who recreationally crab (Guillory 1990b). Approximately 75% of land based crabbers interviewed by Guillory (1990b) did not possess a saltwater fishing license. The average number of crabbing trips was estimated at four, midway between the estimates of Titre et al. (1988) and Guillory (1990b). Annual statewide estimates for nontrap fishermen include 135,960 participants who made 164,800 crabbing trips and had actual expenditures of aproximately $3.68 million.

Expenditures for recreational trap fishermen were quantified by the product of the number of licensed recreational crab trap fishermen (2,270 1991-92 LDWF license records), average number of crabbing trips (11.6, Guillory 1990b) and average per trip expenses. Determination of per trip expenses is difficult because approximately 85% of recreational trap fishermen either own or have access to camps (Guillory 1990b); purposes of camping trips may include combinations of fishing, hunting, crabbing, or just camping. Therefore, per trip expenses allocated to trap crabbing were assumed to equal that of land based crabbers ($22.30). Annual estimates for trap fishermen are 26,330 trips and expenses of $587,205.

Interviewed recreational shrimp trawlers who incidentally harvested crabs averaged $40 of expenses/trip and 6 trips/yr (Guillory 1990b). The number of recreational trawlers was estimated at 14,000; this approximation was based on 1985-86 LDWF license sales, the last year that recreational trawl licenses were available for trawls larger than 16 ft. Extrapolated over an annual statewide basis, estimated recreational effort and expenditures where crabs were harvested as incidental trawl catch totalled 84,000 trips and $3.36 million.

These estimates have probably declined in recent years because of a decline in recreational trawlers.

While direct expenditures represent an important facet in evaluation of recreational crabbing, they do not fully describe the economic value of a fishery because the perceived value is disregarded. "Willingness to pay" in excess of actual expenditures measures the profit, rent, and net value attributable to the fishery, a value theoretically collectable if anglers could be induced to pay this excess amount (Malvestuto 1983). Titre et al. (1988) found that the average user would be willing to pay approximately $320-$360 annually for the right to recreate in Louisiana wetlands under current conditions of harvest, catch, and amenities. This value is in addition to current expenditures and represents all recreational pursuits, such as hunting, angling, shrimping, and crabbing.

3.4 History of Exploitation (Soft Crabs)

Louisiana, unlike the other Gulf states, has a long and successful history of commercial soft crab production. Due to market demands generated by the city of New Orleans, the Louisiana soft crab fishery initially developed along the northern shore of Lake Pontchartrain and the Rigolets in the late 1800s (Jaworski 1972 and 1982). Terminology and shedding techniques were borrowed from Chesapeake Bay, where the United States soft crab fishery began. Fishermen commonly held peelers in wooden floats that were tethered along shorelines. With the discovery that peeler or premolt crabs could be harvested using fresh willow (Salix nigra) and wax myrtle (Myrica cerifera) branches, the fishery later expanded in the 1930s into the Barataria estuary around Lafitte, Bayou Des Allemands, Lake Salvador, and Bayou Barataria. Crabbers in these areas also utilized open "live cars" to shed peelers.

Soft crab production prior to the 1980s was essentially restricted to the eastern portion of the Mississippi River delta (Jaworski 1982), especially the upper Barataria Bay estuary and lakes Pontchartrain and Borgne. Crab shedding houses with flow through circulating systems were introduced during the 1960s to replace passive float or live car operations (Jaworski 1971), and fishermen from parishes bordering Lake Pontchartrain began to increasingly rely on these systems. More advanced, closed recirculating systems were introduced in the early 1980s and by 1985 (Horst 1985) became increasingly important because of deteriorating water quality, expensive waterfront property, and the desire to move shedding operations close to home. Approximately 50% of Lake Pontchartrain crab shedders abandoned float cars by 1985, with the fishermen choosing closed and open systems in equal numbers. With the development of the closed recirculating system, the soft crab industry expanded geographically to the central coast of the state and eventually expanded to areas west of the Atchafalaya River; however, the majority of producers are still located in parishes bordering Lake Pontchartrain and within 50 mi of New Orleans (Caffey et al. 1993).

The first record of soft crab production in Louisiana dates back to 1887 when 133,000 lb valued at $7,000 were harvested. Although year to year fluctuations were prevalent, Louisiana became the center for soft crab production in the Gulf of Mexico and a major supplier of soft crabs to the southern states (Perry et al. 1982). However, the Chesapeake Bay region remains the major producer of soft crabs.

Documented soft crab production is only a small percentage of the total Louisiana blue crab fishery in terms of volume, although soft crabs are more valuable on a per unit basis. Prices for soft crabs produced in Louisiana and other Gulf states have traditionally exceeded prices paid for soft crabs from the Chesapeake and South Atlantic, possibly due to a larger crab size (Lee and Stanford 1962), excessive demand, and the practice of direct sales to retailers (Horst 1982).

Soft crab production, like hard crab landings, is underestimated. Jaworski (1971) estimated that actual soft crab landings were 2 times those reported and Roberts and Thompson (1982) estimated actual landings in the Lake Pontchartrain-Lake Borgne area were 6 times those reported. Underestimation of landings may be even higher in recent years because of the proliferation of "mom-and-pop" operations using closed recirculating seawater systems and utilizing marketing channels not incorporated into statistical reporting systems. Horst (1985) reported that virtually all production from one area was marketed directly by the producer to consumers or restaurants and not documented by NMFS reporting systems. Supan (In press) estimated the 1986 Louisiana harvest at 1.3 million lb or nearly 16.5 times greater than reported landings. Caffey et al. (1993) suggested that total 1991 production was valued between $4.3 and $5.6 million in a year reported landings were valued at only $298,000.

3.5 Commercial Fishery (Soft Crabs)

3.5.1 Description of Fishing Activities

Soft and peeler (premolt) crabs have been harvested historically in Louisiana with a variety of gears including bush lines, standard hard crab traps, dirty traps, scrapes, push nets, dip nets, trotlines, shrimp trawls, and wing nets. Although a directed but very limited fishery for peeler crabs presently exists in Louisiana, the capture of premolt crabs occurs typically as incidental catch.

The standard hard crab trap or pot is the most important gear type used in obtaining peeler crabs for soft crab shedding operations. Some processors may sort through hard crab purchases for peelers, although most peeler crabs are obtained from hard crab fishermen who sell directly to soft crab shedders. Fishermen shedding soft crabs generally prefer to fish standard traps near shorelines or grass beds (Horst 1982). "Dirty traps", which attract premolt crabs in much the same fashion as the artificial habitat pot described by Bishop et al. (1982 1983, and 1984) and Christian et al. (1987), are also used. "Dirty traps" are standard unbaited crab traps fouled with marine growth that are used to target premolts near grass beds and shorelines by providing dark havens for shedding crabs. These traps are left unbaited intentionally to decrease catch of intermolt hard crabs whose presence may repel peeler crabs.

Bush lines became popular in the early 1930s after fishermen in upper Barataria Bay discovered that peeler crabs were attracted to fresh willow branches used to catch river shrimp (Macrobrachium ohione) and eels (Anguilla rostrata) (Jaworski 1982). Bush lines are typically anchored between large poles in waters 3-6 ft deep and suspended just above the water's surface, with 10-100 bundles of brush, preferably wax myrtle, tied to the line with snoods (Horst 1982). Lines are set in areas of gentle tidal flow. Bush lines are periodically checked in a downwind direction by gently lifting the bushes and shaking them over a net or boat. During peak runs, in April, catches of 4-5 premolts (busters, cracked busters) may be taken from each bush. Bush lines are currently used very little. Significant numbers of soft crabs are also harvested from bushes (Horst 1982).

Hand held crab scrapes consisting of a metal frame, plastic handle, and fiberglass blade are used to harvest premolt and soft crabs. This method is traditionally restricted to the northshore of Lake Pontchartrain where firm bottomed eelgrass (Vallisneria spiralis) beds are found. Scrapes are pushed through eelgrass beds to flush shedding crabs which are then captured with dipnets. Push nets, a large mouth net with a flat wooden blade or metal roller attached to a 2-in mesh bag, are used in a similar manner.

Shrimp trawls and wing nets are other gears that may be used to harvest soft and premolt crabs, although crabs are of generally poorer quality for shedding because of injuries received during capture. Large numbers of premolt and soft crabs may be taken seasonally by shrimpers. In most cases these crabs are discarded due to limited space; however, some fishermen shed cracked busters in pails of water. Horst (1982) and Supan et al. (1986) described the use and effectiveness of flow through shedding systems onboard large trawl vessels operating on a 7- or 8-d trip schedule.

A method used in the past to harvest premolt crabs was the "tapaderos" or seine stretched loosely across the mouth of a bayou (Benedict 1940). Crabs following the tide would cling to the webbing. Trotlines were also used in the past to harvest premolt crabs; however, their use was labor intensive and is no longer popular.

3.5.2 Effort and Harvest

The commercial soft crab fishery in Louisiana began during the late 1800s. Landings averaged nearly 117,000 lb annually from 1880 through 1933. A significant increase to 651,000 lb in 1934 was associated with the development of the bush line technique in the Barataria estuary (Jaworski 1971). Landings peaked in 1945 at nearly 2.4 million lb (Table 3.10), when food demands during WWII greatly accelerated crabbing effort. Production varied between 0.35 and 0.88 million lb through the late 1940s and 1950s. However, during the 1960s, 1970s, and early 1980s production steadily declined to a low of 0.08 million lb in

1984. The downward trend in soft crab production was probably due to the continued decline in estuarine water quality and the lack of a reliable source of peeler crabs (Jaworski 1971 1972 and 1982; Perry et al. 1982). After 1984 production increased annually until 0.25 million lb was reached in 1990; this increase was associated with the development and wide spread adoption of advanced, closed recirculating systems and the recognition by hard crab fishermen that peeler crabs are a valuable bycatch. Increased fishing effort (both number of fishermen and average number of traps per fishermen) probably also contributed to an increased supply of peeler crabs. Caffey et al. (1993) estimated that there were approximately 300 Louisiana soft crab producers in 1991.

Approximately 66.5% of Louisiana's soft crab production historically came from Orleans, St. Tammany, and northern Jefferson parishes which border Lake Pontchartrain and the remaining 33.5% from lower Jefferson in the Barataria estuary (Horst 1985). Production spread into the parishes of Lafourche, Terrebonne, St. Mary, and St. Charles in the 1980s with the widespread adoption of closed recirculating systems. The soft crab fishery eventually spread to areas west of the Atchafalaya River; however, while the parishes of Iberia, Lafayette, Vermilion, and Cameron include over 25% of the Louisiana coast, this area accounts for only 3% of average annual production (Caffey et al. 1993).

Table 3.11 shows the catch of soft and peeler crabs by gear in the Louisiana fishery from 1946 to 1989. Brush traps have accounted for the highest catches in most years, followed through 1969 by drop net and trotline catches 1969. Catch from crab traps has become increasingly important since 1964 and now accounts for the greatest portion of annual catches among all gears used in the fishery. With the adoption of both open and closed shedding systems, the directed harvest of soft crabs with bush lines, dirty traps, scrapes, push nets, dip nets, trawls, traps, and wing nets has been virtually nonexistent.

According to Horst (1985), 50% of commercial soft crab shedders abandoned the use of float cars as their primary means of shedding crabs in the early 1980s, with approximately 50% of these adopting closed recirculating systems and the other 50% adopting open systems. Between 1979 and 1985, workshops and extension efforts conducted by the Louisiana Sea Grant College Program and Louisiana Cooperative Extension Service resulted in a 300% increase in closed systems (Manthe 1985). Some shedders have reported a 25% decrease in mortality after switching from float cars to closed systems, which do not use the poor quality water often found in lakes and bayous. Crab shedding onboard shrimp vessels also increased in popularity. Caffey et al. (1993) reported that in 1991, 44.6% of producers used a closed recirculating system with basic shell filters; 32.2%, flow through systems; 15.4%, float cars; and 6.2% used closed systems with recently developed, pressurized sand filter systems. However, some producers operate more than one type of system, including holding busters in float cars during periods when busters are abundant and space limited.

Harvest rates are affected by season, lunar stage, water conditions, and availability of peeler crabs. Premolt crabs are more abundant during new and full moon. Shedding season generally extends from March to October, but crabs usually shed most rapidly in May

(Horst 1982). Production slows in July and August, increases again in October, and sometimes extends into December. Caffey et al. (1993) noted two monthly peaks in 1991 production, April and September, with the April or "spring run" more predictive and characterized by 97% producer participation levels.

The Louisiana soft crab fishery is characterized by high producer annual turnover rates and seasonal operations. A 50% turnover rate between 1985 and 1991 was documented by Caffey et al. (1993). They further reported that nearly 50% of all producers surveyed had been in soft crab production for only 1-5 yr; 34% were full time or operated for >6 mo/yr; and 80% were commercial crab fishermen, with 53% of these also commercial shrimpers.

3.5.3 Economics

Data on commercial soft crab landings, current and deflated price per pound, and overall value are tabulated in Table 3.12. While displaying year-to- year fluctuations, production steadily declined from peaks in the early 1960s to a low of 0.08 million lb in 1984 and then increased annually beginning in 1987 until a peak of 0.25 million lb was reached in 1990. Current dockside values did not decline with landings, but fluctuated erratically. Peaks in dockside values for 1977, 1990, and 1993 were associated with peaks in price per pound.

Applying an economic multiplier of three (Cody et al. 1992) to the value of the Louisiana soft crab fishery for the 1987 to 1993 period yields expanded values ranging from \$0.83 million to \$1.86 million, with an average of \$1.3 million.

Otwell and Cato (1982) noted that the use of weight to express the dollar value of soft crabs is inconsistent with commercial practices and complicates the interpretation of production data. Soft crabs are usually sold by the dozen and are graded by width. Soft market grades used for East Coast suppliers include: medium (3.5-4.0 in CW) hotel (4.0-4.5 in CW), prime (4.5-5.0 in CW), jumbo (5.0-5.5 in CW) and whale (≥5.5 in CW). Soft crabs are graded by three methods in Louisiana (Roberts 1985): 1) the east coast method; 2) a three-grade method based on weight: small (2-4 oz), medium (4-6.5 oz), and large (>6.5 oz); and, 3) a series of grades based on a 'counter' soft crab.

According to documented production the soft crab fishery is relatively insignificant when compared to the hard crab fishery. For instance, the 1990 dockside value of \$0.62 million for the soft crab fishery is contrasted with a value for the hard crab fishery of \$14.83 million. Soft crabs, however, are more valuable on a per unit basis than hard crabs. In 1990, soft crab production was 0.64% that of the hard crab fishery, but value of the soft crab fishery was 4.2% that of the hard crab.

Production may be underestimated even more in soft crabs than in hard crabs because of the proliferation of "mom-and-pop" operations utilizing market channels not covered in statistical surveys. Surveys by Jaworski (1971), Roberts and Thompson (1982), Horst (1985), Caffey et al. (1993), and Supan (In press), documented the underestimation of soft-crab landings. Caffey et al. (1993) and Supan (In press) estimated that actual Louisiana soft crab harvest was 14.4 to 18.8 times greater than reported landings.

Roberts (1985) analyzed profitability components of closed shedding systems for blue crabs, and concluded that profits were determined by at least five major factors:) 1) the number of times the system can complete the shedding cycle during the season of peeler availability; 2) the survival of crabs from the time of stocking until removal as a successfully shed crab; 3) the relationship between the owner's success in supplying peeler crabs to the system and the system's capacity from an engineering viewpoint; 4) market prices, which vary by size of crab; and, 5) system size.

Roberts (1985) concluded that soft-shelled crab shedding systems have many attractive business attributes compared to other aquaculture systems: 1) animals are managed through direct observation; 2) no feeding costs; 3) the short holding time minimizes disease problems; 4) minimum investment requirements; and, 5) good opportunities for local sales and direct marketing. Roberts indicated that these attributes will stimulate expansion as individuals become more knowledgeable about shedding operations and management. Thomasson and Malone (1989) designed a computer program for closed shedding system economics.

Other literature contains information on soft crab economics that may be pertinent to the Louisiana fishery. Constraints and considerations in marketing soft crabs were discussed by Conway (In press). DuPaul (1985) elaborated on the development of export markets for soft crabs. Economics of the United States soft crab fishery were reviewed by Otwell and Cato (1982).

3.5.4 Mariculture

Currently there exists three fundamental types of systems used to culture and produce soft crabs in Louisiana. These include float (also referred to as floating box or live car), flow through and closed recirculating systems.

Historically, the most common type of system used in Louisiana to culture soft crabs has been the float system described by Haefner and Garten (1974), Horst (1982), Otwell et al. (1980), Jaworski (1982), and Perry et al. (1982). Floats are of two basic shapes, trapezoid or square, and generally made of hard cypress. Floats are passive shedding systems that have been continually modified to suit the specific requirements of individual producers. Trapezoid shaped floats are designed to be anchored in lakes or bays and to remain pointed into the wind in rough weather. These floats are generally worked while wading. Dimensions of trapezoid-shaped floats vary but are typically 1.0-1.2 ft deep, 3.0-5.5 ft long, and at their widest point, 2.0-3.5 ft. Rectangular boxes are generally anchored in bayous and are worked from small boats or attached to docks. Windlasses are used to raise and lower the boxes during grading operations. Although dimensions of square boxes vary, most are usually 8.0 ft long, 4 ft wide, and 2.0-3.0 ft deep. Floats are solid on the ends with no openings, have slat board bottoms, and holes in the sides to aid water circulation. Crabs are graded, removed carefully, and placed in floats according to stage of development. Green crabs are often separated out or have their claws clipped to prevent them damaging or killing the more ripe shedders. As many as 500 shedding crabs may be placed in a single car. Float culture is currently one of the least favored methods used due to periodic rapid changes in water quality, susceptibility to predation, and labor intensity. Caffey et al. (1993) noted that float cars ranked third in terms of annual productivity among the four systems utilized by surveyed producers, averaging 29.4 soft crabs/ft^2/yr; however, float cars had the highest average levels of mortality (29.5%).

Land based, open, flow through shedding systems were developed later for convenient access and the increased ability to check and harvest soft crabs any time of the day. Flow through systems have been described by numerous authors including Horst (1982), Otwell and Cato (1982), Jaworski (1982), and Perry et al. (1982). Flow through systems are of all shapes and sizes, and take advantage of the ability to circulate water from a natural waterbody through trays or troughs. Covered enclosures may be built to provide shade and protection from predators. The size of the system varies, with most 8 to 12 ft long. Water is usually drawn from the bottom of the waterbody to avoid polluted surface water and circulated through the system by means of an electric pump and PVC piping. PVC piping in the tray containing a series of small diameter holes creates a powerful spray which aerates the water and promotes better circulation. The size and number of holes used in the pipe is dependent on pump size and number of trays to be aerated. Trays, either lined in a series or stacked, are typically constructed of unpainted plywood with fiberglassed seams and corners and mounted on wooden frames. Water levels are generally maintained at about 4 in with drains located in corners. Horst (1982) described the use of self-cleaning drains which were developed to remove solid waste products. These drains are constructed of a 4-in tall section of PVC pipe mounted to the bottom of the tray, and an outer, section of PVC pipe, of larger diameter, 6-in tall and notched or serrated completely along its bottom. Water and dirt is sucked through the notches of the outer tube, uplifted, and carried out through the smaller inner pipe. Individual trays may be subdivided into three compartments to isolate and maintain different stages of premolt crabs. Although flow through systems suffer from many of the same environmental problems as those of float systems, they are still favored by a number of soft crab producers. Flow through systems were found to be the most productive system averaging 48.2 soft crabs/ft^2/yr, yet ranked second (27.6%) in highest average levels of mortality (Caffey et al. 1993).

Closed recirculating shedding systems first described by Overstreet and Cook (1972) have been responsible for recent growth in the industry. A detailed account of the physical set up, maintenance, and water quality management is not an objective of this document. Therefore a brief description will follow, along with references for additional information. Recirculating systems eliminate the need for access to natural water of good quality by reusing synthetically mixed seawater. Proper management generally results in increased water quality. However, since water is recirculated and reused indefinitely, water quality deteriorates as increased levels of carbon dioxide, nitrogenous compounds, phosphates, and dissolved and particulate organic substances occur. Additionally, pH in the system declines over time, and accumulation of metabolic wastes from crabs may reach lethal levels. Therefore, water treatment is of primary importance to stabilize water quality of the system within the optimum range of the crabs (Perry et al. 1982). Recirculating shedding systems consist of five distinct functional elements: pump, sump, reservoir, biological filter, and holding trays. The pump and sump provide circulation and aeration of the system's water; the reservoir and filter work to maintain suitable water quality in the system, and the trays hold the peeler crabs through the shedding process. Caffey et al. (1993) reported that 50% of interviewed producers utilized closed (recirculating) systems and that the great majority of these relied on basic shell filter systems, although 10% relied on pressurized sand filter systems. The authors further noted that closed systems with shell filters ranked second in annual production averaging 46.2 soft crabs/ft^2 per year while closed systems with pressurized sand filters ranked last, averaging 25.1 soft crabs/ft^2/yr. However, closed systems with sand filters had the lowest average mortality, 17.7%, while shell filter systems had 19.6%.

Early researchers of shedding systems (Epifanio et al. 1973; Winget et al. 1973; Haefner and Garten 1974) developed elaborate closed recirculating systems that controlled such factors as water temperature, salinity, and oxygen which could, theoretically, enhance molting and extend the molting season. Perry et al. (1982) described the development and theory of operation of a closed recirculating shedding system. Further review, development, and design of closed recirculating shedding systems was outlined by Malone and Burden (1988), Perry and Malone (1989), Hochheimer (in press), and Oesterling (1988 and in press). Malone and Burden (1988) provided the most current design recommendations in blue crab recirculating shedding systems and identified, discussed, and presented the rationale for component design including comparisons among submerged rock, upflow sand, and fluidized bed biological filters. The flow through sand filter was described by North Carolina Sea Grant (1991).

Research has been conducted on evaluating various aspects of water quality management on specific system design. Lakshmi et al. (1984) performed bioassays with ammonia and determined sublethal, lethal, and incipient lethal ranges of unionized and total ammonia on intermolt and molting blue crabs held in closed systems. Ary and Porrier (1989) and Porrier et al. (In press) evaluated nitrite toxicity to soft crabs. Manthe et al. (1983) established production levels and described water quality operating parameters in commercial closed recirculating seawater systems. Comparisons of media type and design and comparison of various biological filters in recirculating shedding systems were discussed by Gates et al. (1985), Manthe and Malone (1987), and Malone and Burden (1987). Johnson and Sieburth (1974) developed a process of selective ion exchange as an alternative to the biological oxidation of ammonia with filters in closed system aquaculture. A protein skimmer to replace the algal filter and marine activated carbon used to absorb dissolved organic material in closed shedding systems was illustrated by Paparella (1979). Additional research on evaluation of system design and management was accomplished by Manthe et al. (1984 and 1985), Malone et al. (In press), Malone and Manthe (1985), Wheaton (1985), and Poirrier et al. (In press).

On a practical basis for public education purposes, water quality concerns (Perry and Wallace 1985), conversion tables (Hochheimer 1985), and methodology for artificial seawater preparation (Perry 1983) have been published. Oesterling (1982) and Manthe et al. (1984) reported on sources of crab mortality and their elimination and examined the carrying capacity in closed shedding systems that used various filter systems.

Literature concerning soft crab production under restricted conditions or techniques include: in heated power plant effluents (Reimer and Strawn 1973; Parker et al. 1976; Biever 1981; Wang 1982); on vessels (Supan et al. 1986; Hines, In press); in artificially heated systems (Oesterling 1990); in fresh (Wescott, In press) or low salinity waters (Bridges, In press); in ponds (Springborn 1984); in low calcium water (Freeman et al. 1986 and In press); through the use of hormones (Gillies 1975; Freeman and Perry 1985; Schoettker and Gist, In press) or eyestalk ablation (Wang 1982) to initiate ecdysis.

Fishing methods, identification of peelers, and techniques for handling soft crabs were described by Haefner and Garten (1974), Bearden et al. (1979), Cupka and Van Engel (1979), Otwell (1980), Otwell et al. (1980), Ogle et al. (1982), Perry et al. (1982), Springborn (1984), Oesterling (1984 and 1988), Wescott (1984), Oesterling and Provenzano (1985), Whitaker et al. (1987), Hines (1991), Supan (In press), and Whittaker (In press). Bishop et al. (1983 and 1984), and Christian et al. (1987) evaluated the efficiency and compared design techniques of various gears used to harvest premolt crabs. Springborn (1984) reported on the production and harvest of peeler and soft crabs in ponds. The biological (Van Engel 1982a) and physiological (Mangum et al. 1985a) aspects of crab shedding were summarized. Perry et al. (1988) discussed the potential of a soft crab fishery in the Caribbean region.

3.6 Recreational Fishery (Soft Crabs)

3.6.1 Description of Fishing Activities

The recreational fishery for soft crabs is very limited in Louisiana. Fishermen wading in shallows at night along vegetated shorelines or along beaches may occasionally harvest soft crabs with dip nets or flounder gigs. Some fishermen may also dip soft crabs while wading in shallow grass beds in Lake Pontchartrain. Soft crabs are harvested incidentally with hard crabs by crab traps, shrimp trawls, hand lines, trotlines, and drop nets. Shrimp trawls probably account for the greatest percentage of soft crabs harvested by recreational fishermen, followed by crab traps, dip nets, and flounder gigs.

3.6.2 Effort and Harvest

No data on the recreational harvest of soft crabs is available. Although recreational catch data for blue crabs is lacking and, was defined as a major management problem by Perry et al., (1984), harvest of soft crabs has been ignored in most recreational surveys. In a survey of recreational effort, catch per effort, and harvest in the Louisiana blue crab fishery in Terrebonne Parish, Guillory (1990b) reported that recreational shrimp trawlers averaged 7.9 trips/yr and incidentally harvested an average of 0.2 soft crabs/trip.

Table 3.1.Historical hard blue crab landings (thousands of pounds) and value (thousands of dollars) in each Gulf state, 1880-1994*.

Year	Florida West Coast		Alabama		Mississippi		Louisiana		Texas		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1880	--	--	--	--	--	--	288	7	36	1	324	8
1887	(2)	(2)	(2)	(2)	38	1	837	13	111	4	(2)	(2)
1888	3	(1)	96	6	16	(1)	851	13	115	4	1,081	23
1889	--	--	--	--	48	1	842	14	189	5	1,079	20
1890	--	--	--	--	33	1	851	13	191	5	1,075	19
1891	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1892	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1895	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1897	6	(1)	24	1	132	3	1,459	13	138	4	1,759	21
1898	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1899	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1901	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1902	1	(1)	75	2	235	5	312	16	43	2	666	25
1904	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1905	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1908	2	(1)	246	6	380	10	244	8	199	5	1,071	29
1915	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1918	--	--	96	3	216	6	282	10	193	11	787	30
1919	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1920	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1921	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1922	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1923	--	--	84	3	435	11	312	8	109	9	940	31
1924	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1925	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1926	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1927	12	1	32	1	2,426	62	1,091	51	121	9	3,682	124
1928	7	1	102	4	1,518	40	2,320	78	300	12	4,247	135
1929	2	(1)	103	3	1,247	33	2,675	78	163	11	4,190	125
1930	4	(1)	80	1	673	11	4,186	63	29	1	4,972	76
1931	4	(1)	78	1	454	7	4,985	53	49	1	5,570	62
1932	4	(1)	70	1	320	5	5,878	57	45	1	6,317	64
1933	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1934	49	1	257	4	603	7	11,676	164	258	13	12,843	189
1935	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1936	821	12	997	14	2,011	30	12,576	168	320	8	16,725	232
1937	775	12	756	11	1,435	25	14,717	195	922	24	18,605	267
1938	1,104	16	511	8	1,016	17	10,533	106	971	24	14,135	171
1939	722	11	558	8	1,469	25	11,228	129	406	8	14,383	181
1940	1,170	16	1,381	28	1,488	26	14,062	172	252	6	18,353	248
1941	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1942	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1943	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1944	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1945	1,092	54	2,207	110	5,639	282	31,280	1,418	339	39	40,557	1,903
1946	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1947	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1948	(2)	(2)	2,373	119	5,503	275	21,110	608	526	34	(2)	(2)
1949	2,056	91	2,128	106	4,163	208	17,874	555	374	22	26,595	982
1950	684	27	599	26	4,040	202	13,106	599	387	30	18,816	884
1951	2,076	83	1,109	46	1,623	82	8,710	461	280	24	13,798	696
1952	1,984	89	655	39	1,726	86	7,334	314	338	24	12,037	552
1953	3,153	126	1,087	54	1,412	71	8,131	333	432	39	14,215	623
1954	2,903	145	972	49	1,256	68	7,085	294	379	26	12,595	582
1955	4,954	248	1,613	81	1,763	88	10,811	449	356	29	19,497	895
1956	3,728	180	725	36	1,979	99	9,402	433	195	20	16,029	768
1957	5,302	318	1,462	73	2,400	144	8,559	419	201	11	17,924	965
1958	8,693	461	1,182	56	2,124	123	9,336	402	570	51	21,905	1,093
1959	13,895	681	1,093	57	3,003	165	9,570	461	1,192	75	28,753	1,439
1960	18,648	895	499	26	2,812	169	10,050	497	2,867	177	34,876	1,764
1961	17,130	736	838	46	2,505	143	11,910	514	2,875	178	35,258	1,617
1962	10,356	487	634	35	907	55	9,523	463	4,473	289	25,893	1,329
1963	13,148	644	1,297	75	1,112	64	7,982	447	2,980	199	26,519	1,429
1964	14,068	843	1,762	110	1,286	82	5,692	379	2,484	175	25,292	1,589
1965	20,598	1,185	1,812	153	1,692	131	9,284	635	3,622	286	37,008	2,390
1966	16,547	912	2,183	182	1,457	105	7,986	537	2,778	228	30,951	1,964
1967	13,976	817	2,353	188	1,015	79	7,559	520	2,625	222	27,528	1,826
1968	9,008	674	1,980	159	1,136	108	9,551	807	4,084	329	25,759	2,077
1969	11,584	1,074	1,920	223	1,740	177	11,602	1,072	6,343	599	33,189	3,145
1970	14,786	1,073	1,407	144	2,027	193	10,254	928	5,525	509	33,999	2,847
1971	12,279	952	1,997	212	1,259	126	12,186	1,256	5,810	567	33,531	3,113
1972	10,673	959	1,612	195	1,362	169	15,083	1,777	6,464	653	35,194	3,753
1973	9,599	1,147	2,098	294	1,814	231	23,080	2,811	6,881	830	43,472	5,313
1974	10,134	1,280	1,826	284	1,667	227	20,639	2,701	6,088	832	40,354	5,324
1975	12,807	1,585	1,639	283	1,137	177	17,144	2,510	5,992	948	38,719	5,503
1976	12,049	1,966	1,299	281	1,334	268	15,211	3,061	6,668	1,179	36,561	6,755
1977	15,832	3,119	2,174	548	1,919	473	16,154	3,765	8,249	1,947	44,328	9,852
1978	11,679	2,256	2,009	458	1,940	422	15,074	3,189	7,470	2,004	38,172	8,331
1979	11,198	2,235	1,341	400	1,313	316	21,334	4,776	8,312	2,146	43,498	9,873
1980	11,276	2,387	1,557	465	2,760	693	18,183	4,327	8,953	2,456	42,729	10,328

Table 3.1. Cont'd.

	Florida West Coast		Alabama		Mississippi		Louisiana		Texas		Total	
Year	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1981	14,788	3,327	2,462	850	1,867	519	16,237	4,469	6,952	1,928	42,306	11,093
1982	8,871	2,209	1,266	479	1,297	348	17,284	4,843	8,010	2,375	36,728	10,254
1983	9,337	2,524	1,412	514	1,140	332	19,616	6,366	8,829	3,250	40,334	12,986
1984	12,912	3,197	4,216	1,374	2,250	640	29,617	8,192	7,229	2,252	56,224	15,655
1985	12,273	3,113	2,261	830	1,649	538	29,848	8,387	9,722	3,309	55,753	16,177
1986	7,644	2,981	2,886	950	1,303	470	31,611	9,295	9,482	3,170	52,926	16,866
1987	10,413	3,332	2,496	1,005	1,374	480	52,345	20,134	11,688	4,763	78,316	29,714
1988	10,385	3,750	3,869	1,551	862	327	53,554	21,447	10,428	4,325	79,100	31,402
1989	8,158	3,182	4,090	1,735	650	287	33,390	14,781	9,123	3,972	55,412	23,959
1990	6,886	3,222	3,302	1,264	390	169	39,135	14,830	8,598	3,305	58,311	22,790
1991	4,996	2,715	2,731	942	453	160	51,087	17,467	6,123	2,271	65,390	23,555
1992	7,899	4,065	3,550	1,465	443	207	51,744	26,666	6,151	2,784	69,787	35,187
1993	8,661	3,836	2,554	1,186	230	120	45,847	24,039	8,242	3,932	65,534	33,113
1994	8,458	5,394	2,744	1,518	168	90	36,765	22,526	5,094	3,006	53,229	32,534

(1) Less than 500 pounds
(2) Data not available
* Partial surveys were done prior to 1912 and in 1934, 1936-1940, 1945, 1948, 1949, and 1951.
-- No survey

Table 3.2. Number of fishermen and units by gear type in the Louisiana hard crab fishery.

Year	Trap[1]		Trap[2] Licenses	Avg #[1] Traps	Trotline[1]		Avg #[1] Baits	Drop Net[1]	
	Full-Time	Part-Time			Full-Time	Part-Time		Full-Time	Part-Time
1952	49	28	---	NA	555	148	449	50	96
1953	40	25	---	NA	562	154	438	74	152
1954	0	0	---	0	506	89	447	102	118
1955	0	0	---	0	495	108	450	58	76
1956	0	0	---	0	429	109	469	109	69
1957	3	10	---	25	409	98	395	119	65
1958	3	8	---	25	451	73	512	141	58
1959	3	8	---	25	443	87	512	143	60
1960	5	7	---	25	492	95	548	143	61
1961	5	7	---	25	498	132	607	230	51
1962	13	12	---	80	496	147	660	300	44
1963	21	12	---	91	587	122	644	285	59
1964	25	9	---	96	590	104	615	388	32
1965	101	21	---	94	578	122	592	357	46
1966	321	76	---	101	524	125	596	106	21
1967	470	89	---	104	388	120	641	94	34
1968	474	103	---	114	416	146	624	94	38
1969	489	105	---	114	412	159	658	78	55
1970	490	67	---	136	308	34	632	58	84
1971	530	136	---	126	292	49	NA	30	50
1972	571	123	---	126	289	44	NA	14	27
1973	609	148	---	124	151	50	NA	0	0
1974	630	179	---	134	132	30	NA	0	0
1975	687	212	---	137	102	30	NA	0	0
1976	789	226	---	142	75	20	NA	0	0
1977	728	233	---	140	55	10	--	0	0
1978	1,067		832	142	0	0	--	0	0
1979	1,085		751	148	0	0	--	0	0
1980	885		827	175	0	0	--	0	0
1981	891		810	166	0	0	--	0	0
1982	975		981	156	0	0	--	0	0

Table 3.2. Cont'd.

Year	Trap[1]		Trap[2] Licenses	Avg #[1] Traps	Trotline[1]		Avg #[1] Baits	Drop Net[1]	
	Full-Time	Part-Time			Full-Time	Part-Time		Full-Time	Part-Time
1983	952		1,296	152	0	0	--	0	0
1984	1,010		1,337	169	0	0	--	0	0
1985	1,030		1,600	185	0	0	--	0	0
1986	1,046		1,985	189	0	0	--	0	0
1987	1,231		2,927	227	0	0	--	0	0
1988	1,343		2,809	218	0	0	--	0	0
1989	1,892		3,019	149	0	0	--	0	0
1990	2,303		2,807	129	0	0	--	0	0
1991	3,020		2,571	130	0	0	--	0	0
1992	2,602		2,734	141	0	0	--	0	0
1993	2,711		2,854	163	0	0	--	0	0
1994	NA		2,503	NA	0	0	--	0	0

1 = NMFS estimates
2 = Louisiana Department of Wildlife and Fisheries
NA = Not Available

Table 3.3. Louisiana annual hard crab landings (thousands of pounds) by gear type, 1948-1989.

Year	Trawls	Traps	Trotlines	Drop Nets	Misc. Gears[1]
1948	32	110	20,545	415	0
1949	37	85	17,274	466	0
1950	26	60	12,739	282	0
1951	1	706	7,654	330	0
1952	37	550	6,402	345	0
1953	34	517	7,243	338	0
1954	120	0	6,387	578	0
1955	55	0	9,827	930	0
1956	41	0	7,331	2,031	0
1957	73	17	6,795	1,675	0
1958	98	13	7,390	1,835	0
1959	137	19	7,414	2,000	0
1960	140	38	7,557	2,315	0
1961	904	38	8,613	2,354	0
1962	709	57	6,812	1,946	0
1963	568	82	5,902	1,431	0
1964	649	297	3,368	1,378	0
1965	1,953	1,119	4,640	1,573	0
1966	669	3,126	3,476	716	0
1967	464	4,279	2,263	553	0
1968	449	5,414	2,869	819	0
1969	945	6,686	3,199	772	0
1970	1,181	5,728	2,568	778	0
1971	1,065	9,386	1,734	2	0
1972	692	11,307	2,916	167	0
1973	1,301	19,157	2,622	0	0
1974	206	19,601	833	0	0
1975	266	17,788	1,089	0	0
1976	354	14,713	130	0	0
1977	153	15,794	202	0	6
1978	212	14,824	38	0	0
1979	148	21,186	0	0	0
1980	474	17,709	0	0	0
1981	203	16,033	0	0	0
1982	160	17,125	0	0	0
1983	130	19,486	0	0	0
1984	145	29,458	14	0	0
1985	23	29,825	0	0	0
1986	37	31,574	0	0	0
1987	81	52,263	0	0	0
1988	76	53,478	0	0	0
1989	44	33,341	0	0	3

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[1] Includes handlines, hoop nets, and wing nets.

Table 3.4. Percent contribution by state to total Gulf of Mexico hard crab landings and percent contribution of Gulf of Mexico to total U. S. hard crab landings, 1960-1994.

Year	Florida West Coast	Ala.	Miss.	La.	Texas	Gulf of Mexico
1960	53.5	1.4	8.1	28.8	8.2	23.3
1961	48.6	2.4	7.1	33.8	8.2	23.9
1962	40.0	2.4	3.5	36.8	17.3	17.3
1963	49.6	4.9	4.2	30.1	11.2	18.7
1964	55.6	7.0	5.1	22.5	9.8	16.6
1965	55.7	4.9	4.6	25.1	9.8	22.2
1966	53.5	7.1	4.7	25.8	9.0	18.6
1967	50.8	8.5	3.7	27.5	9.5	19.0
1968	35.0	7.7	4.4	37.1	15.9	22.7
1969	34.9	5.8	5.2	35.0	19.1	25.1
1970	43.5	4.1	6.0	30.2	16.3	23.4
1971	36.6	6.0	3.8	36.3	17.3	22.5
1972	30.3	4.6	3.9	42.9	18.4	23.9
1973	22.1	4.8	4.2	53.1	15.8	31.8
1974	25.1	4.5	4.1	51.1	15.1	27.1
1975	33.1	4.2	2.9	44.3	15.5	28.7
1976	33.0	3.6	3.6	41.6	18.2	31.7
1977	35.7	4.9	4.3	36.4	18.6	34.5
1978	30.6	5.3	5.1	39.5	19.6	27.6
1979	25.7	3.1	3.0	49.0	19.1	28.5
1980	26.4	3.6	6.5	42.6	21.0	26.2
1981	35.0	5.8	4.4	38.4	16.4	21.7
1982	24.2	3.4	3.5	47.1	21.8	18.8
1983	23.1	3.5	2.8	48.6	21.9	21.0
1984	23.0	7.5	4.0	52.7	12.9	27.9
1985	22.0	4.1	3.0	53.5	17.4	29.3
1986	14.4	5.5	2.5	59.7	17.9	31.0
1987	13.3	3.2	1.8	66.8	14.9	38.9
1988	13.1	4.9	1.1	67.7	13.2	36.2
1989	14.7	7.4	1.2	60.2	16.5	26.8
1990	11.8	5.7	0.7	67.1	14.7	28.9
1991	7.6	4.2	0.7	78.2	9.3	29.5
1992	11.3	5.1	0.6	74.2	8.8	36.2
1993	13.2	3.9	0.4	70.0	12.6	26.2
1994	16.6	5.3	0.3	72.1	5.7	24.3

Table 3.5. Landings, efort, and catch per effort in the Louisiana hard crab fishery, 1970-1994.

Year	Landings (1000 lbs)	Number[1] of Fishermen	Pounds Per Fishermen	Number of Traps	Traps/ Fishermen	Pounds Per Trap
1970	5,728	512	11,187	69,632	136	82
1971	9,386	575	16,323	72,450	126	129
1972	11,307	612	18,475	77,112	126	147
1973	19,157	658	29,114	81,592	124	235
1974	19,601	690	28,407	92,460	134	212
1975	17,788	758	23,467	103,846	137	171
1976	14,713	864	17,029	122,688	142	120
1977	15,794	806	19,595	112,840	140	140
1978	14,824	832	17,817	118,144	142	125
1979	21,186	751	28,210	111,148	148	190
1980	17,709	827	21,413	144,725	175	122
1981	16,033	810	19,794	134,460	166	119
1982	17,125	981	17,457	153,036	156	112
1983	19,486	1,296	15,035	217,728	168	89
1984	29,458	1,337	22,033	224,616	168	131
1985	29,825	1,600	18,641	296,000	185	101
1986	31,574	1,985	15,906	428,760	216	74
1987	52,263	2,927	17,855	667,356	228	78
1988	53,478	2,809	19,038	615,171	219	87
1989	33,341	3,019	11,044	449,831	149	74
1990	39,135	2,801	13,971	361,329	129	108
1991	51,087	2,571	19,948	334,230	130	153
1992	51,744	2,734	18,926	385,494	141	135
1993	45,847	2,854	16,064	456,664	163	100
1994	36,765	2,503	14,680	NA	NA	NA

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[1] From 1970-1977 NMFS data on number of fishermen was used (3 part time fishermen = 1 full time fisherman) while from 1978-1992 LDWF license records were used

NA - not available

Table 3.6. Historical commercial Louisiana hard crab landings and current and deflated price per pound and total dockside value (deflated values based on the 1982-84 base period consumer price index).

Year	Landings (1000 lbs)	Price/pound(¢) Current	Price/pound(¢) Deflated	Value ($1000) Current	Value ($1000) Deflated
1960	10,050	4.9	16.5	497	1,679
1961	11,910	4.3	14.4	514	1,719
1962	9,523	4.9	16.2	463	1,528
1963	7,982	5.6	18.3	447	1,461
1964	5,692	6.7	21.5	379	1,219
1965	9,284	6.8	21.5	635	2,009
1966	7,906	6.7	20.6	537	1,652
1967	7,559	6.9	20.6	520	1,557
1968	9,551	8.4	24.1	807	2,319
1969	11,602	9.2	25.1	1,072	2,921
1970	10,254	9.1	23.3	928	2,386
1971	12,186	10.3	25.4	1,256	3,094
1972	15,083	11.8	28.2	1,777	4,251
1973	23,080	12.2	27.5	2,811	6,331
1974	20,639	13.1	26.6	2,701	5,479
1975	17,144	14.6	27.1	2,510	4,665
1976	15,211	20.1	35.3	3,061	5,380
1977	16,154	23.0	37.9	3,765	6,213
1978	15,074	21.0	32.1	3,189	4,884
1979	21,334	22.4	30.9	3,885	5,359
1980	18,183	23.7	28.8	3,874	4,707
1981	16,237	27.5	30.2	4,468	4,904
1982	17,284	28.0	29.0	4,843	5,013
1983	19,616	32.5	32.5	6,366	6,385
1984	29,617	27.7	26.6	8,191	7,868
1985	29,848	28.1	26.1	8,386	7,779
1986	31,611	28.9	26.4	9,310	8,502
1987	52,345	38.1	33.5	20,134	17,724
1988	53,554	40.0	33.8	21,447	18,145
1989	33,390	44.3	35.8	14,781	11,930
1990	39,135	37.9	29.0	14,830	11,364
1991	51,987	34.2	25.1	17,467	12,824
1992	51,744	51.5	36.7	26,666	19,006
1993	45,847	52.4	36.2	24,039	16,636

Table 3.7. A cost and return budget for Louisiana [Roberts and Thompson (1982)] and Texas [Miller and Nichols (1986)] commercial crabbers.

	Louisiana		Texas	
Gross Returns		$28,496		$17,981
Variable Costs				
Bait	$ 6,562		$ 6,264	
Boat Fuel	3,632		3,935	
Truck Operation	2,985		---	
Traps	1,939		1,500	
Repairs	1,142		756	
Oil	63		72	
Subtotal	$16,323		$12,527	
Overhead Costs				
Depreciation	$ 984		$ 656	
Interest	864		371	
Licenses	95		15	
Dock Fees	--		240	
Insurance	180		--	
Subtotal	$ 2,123		$ 1,282	
Self Employment Tax	$814		$381	
Total Costs		$19,260		$14,190
Net Return		$ 9,236		$ 3,791

Table 3.8. Number of resident Louisiana recreational saltwater fishing licenses from 1984-85 to 1993-94.

Season	Number of Licenses
1984-1985	102,125
1985-1986	169,149
1986-1987	198,852
1987-1988	195,099
1988-1989	204,686
1989-1990	208,292
1990-1991	206,088
1991-1992	229,805
1992-1993	245,942
1993-1994	265,759

Table 3.9. Number of resident and nonresident Louisiana recreational crab trap licenses from 1987-88 to 1994-95.

Year	Resident	Nonresident	Total
1987-1988	1,189	11	1,200
1988-1989	223	1	224
1989-1990	1,589	10	1,599
1990-1991	1,946	9	1,955
1991-1992	2,270	105	2,375
1992-1993	2,270	17	2,287
1993-1994	2,018	17	2,835
1994-1995	NA	NA	3,130

NA=Not Available

Table 3.10. Historical soft crab landings (thousands of pounds) and value (thousands of dollars), in each Gulf state 1880-1994.

	Florida West Coast		Alabama		Mississippi		Louisiana		Texas		Total	
Year	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1880	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1887	(2)	(2)	(2)	(2)	15	1	133	7	(2)	(2)	(2)	(2)
1888	(2)	(2)	(2)	(2)	40	1	143	7	(2)	(2)	183	8
1889	(2)	(2)	(2)	(2)	19	1	147	8	(2)	(2)	166	9
1890	(2)	(2)	(2)	(2)	15	1	130	7	(2)	(2)	145	8
1891	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1892	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1895	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1897	(2)	(2)	(2)	(2)	21	2	(2)	(2)	(2)	(2)	21	2
1898	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1899	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1901	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1902	(1)	(1)	(2)	(2)	30	3	(2)	(2)	(2)	(2)	30	3
1904	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1905	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1908	(2)	(2)	(2)	(2)	47	6	78	21	1	(1)	126	27
1915	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1918	(2)	(2)	(2)	(2)	9	2	(2)	(2)	1	(1)	10	2
1919	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1920	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1921	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1922	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1923	(2)	(2)	(2)	(2)	9	2	3	1	(2)	(2)	12	3
1924	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1925	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1926	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1927	(2)	(2)	(2)	(2)	8	2	137	48	(2)	(2)	145	50
1928	(2)	(2)	3	1	67	12	183	52	(2)	(2)	253	65
1929	(2)	(2)	4	1	12	4	81	25	(2)	(2)	97	30
1930	(2)	(2)	1	(1)	6	2	146	58	(2)	(2)	153	60
1931	(2)	(2)	1	(1)	5	1	121	45	(2)	(2)	127	46
1932	(2)	(2)	1	(1)	4	1	99	25	(2)	(2)	104	26
1933	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1934	(2)	(2)	2	(1)	4	1	651	86	(2)	(2)	657	87
1935	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1936	(2)	(2)	1	(1)	3	1	365	53	(2)	(2)	369	54
1937	2	(1)	(2)	(2)	2	(1)	329	51	(2)	(2)	333	51
1938	(2)	(2)	(2)	(2)	(2)	(2)	248	37	(2)	(2)	248	37
1939	(2)	(2)	(2)	(2)	(2)	(2)	215	33	(2)	(2)	215	33
1940	(2)	(2)	(2)	(2)	(1)	(1)	252	40	(2)	(2)	252	40
1941	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1942	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1943	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1944	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1945	(2)	(2)	(2)	(2)	(2)	(2)	2,370	1,706	(2)	(2)	2,370	1,706
1946	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1947	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
1948	(2)	(2)	(2)	(2)	(2)	(2)	881	440	(2)	(2)	(2)	(2)
1949	(2)	(2)	(2)	(2)	(2)	(2)	455	192	(2)	(2)	455	192
1950	(1)	(1)	(1)	(1)	(2)	(2)	364	165	(2)	(2)	364	165
1951	4	1	(1)	(1)	6	2	350	188	(2)	(2)	360	191
1952	15	2	(2)	(2)	15	4	448	215	(2)	(2)	478	221
1953	3	(1)	(2)	(2)	(1)	(1)	488	203	(2)	(2)	491	203
1954	(1)	(1)	(2)	(2)	(2)	(2)	455	215	(2)	(2)	455	215
1955	1	(1)	(2)	(2)	7	3	581	290	(2)	(2)	589	293
1956	1	1	(2)	(2)	6	1	600	250	(2)	(2)	607	252
1957	10	5	(2)	(2)	17	3	551	192	(2)	(2)	578	200
1958	1	(1)	(2)	(2)	20	2	577	298	(2)	(2)	598	300
1959	3	2	(2)	(2)	11	1	605	302	(2)	(2)	619	305
1960	4	2	(2)	(2)	5	1	514	256	2	(1)	525	259
1961	5	3	(2)	(2)	7	1	620	310	2	1	634	315
1962	(1)	(1)	(2)	(2)	2	(1)	344	172	6	1	352	173
1963	4	2	(2)	(2)	3	1	329	164	2	(1)	338	167
1964	13	7	(2)	(2)	2	(1)	200	127	(1)	(1)	215	134
1965	12	9	(2)	(2)	1	(1)	204	141	(2)	(2)	217	150
1966	1	(1)	(2)	(2)	1	(1)	128	85	(2)	(2)	130	85
1967	7	4	(2)	(2)	1	(1)	146	121	(2)	(2)	154	125
1968	(2)	(2)	(2)	(2)	1	(1)	284	207	(2)	(2)	285	207
1969	(1)	(1)	(2)	(2)	(1)	(1)	197	161	(2)	(2)	197	161
1970	(1)	(1)	(2)	(2)	(2)	(2)	90	79	(2)	(2)	90	79
1971	(2)	(2)	(2)	(2)	(2)	(2)	127	126	(2)	(2)	127	126
1972	(1)	(1)	(2)	(2)	(2)	(2)	102	109	(2)	(2)	102	109
1973	(2)	(2)	(2)	(2)	(2)	(2)	119	132	(2)	(2)	119	132
1974	(1)	(1)	(2)	(2)	(2)	(2)	96	127	(2)	(2)	96	127
1975	2	1	(2)	(2)	(2)	(2)	111	155	(2)	(2)	112	156
1976	(2)	(2)	(2)	(2)	(1)	(1)	88	145	(2)	(2)	88	145
1977	(2)	(2)	(2)	(2)	(2)	(2)	225	570	(2)	(2)	225	570
1978	22	27	(2)	(2)	2	1	133	276	(2)	(2)	157	304
1979	9	5	(2)	(2)	(2)	(2)	147	338	(2)	(2)	156	343

Table 3.10. Cont'd.

	Florida West Coast		Alabama		Mississippi		Louisiana		Texas		Total	
Year	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1980	17	12	(2)	(2)	(2)	(2)	118	273	(2)	(2)	135	285
1981	23	15	(2)	(2)	(2)	(2)	100	238	(2)	(2)	123	253
1982	53	52	(1)	(1)	(2)	(2)	164	432	(2)	(2)	217	484
1983	36	80	(1)	(1)	(2)	(2)	101	290	(2)	(2)	137	370
1984	28	79	(1)	(1)	(1)	(1)	75	203	(2)	(2)	103	282
1985	17	47	3	4	(2)	(2)	82	200	(2)	(2)	102	251
1986	9	(3)	(1)	(1)	(2)	(2)	79	181	(2)	(2)	88	181
1987	11	39	11	3	(1)	(1)	139	371	(2)	(2)	161	413
1988	17	45	(2)	(2)	(1)	.9	162	439	(2)	(2)	179	485
1989	38	140	(2)	(2)	18	46	172	421	(2)	(2)	228	607
1990	36	98	(2)	(2)	4	7	249	621	(2)	(2)	289	726
1991	18	56	(1)	(1)	2	4	200	298	(2)	(2)	220	358
1992	33	181	.7	1.7	2	3	240	532	(2)	(2)	276	718
1993	21	63	(1)	(1)	(1)	1.3	99	426	(2)	(2)	121	491
1994	57	136	(1)	(1)	.9	2.8	100	436	(2)	(2)	159	572

(1) Less than 500 pounds or $500
(2) Data not available

Table 3.11. Catch (thousands of pounds) by gear type in the Louisiana soft and peeler crab fishery, 1946-1989.

Year	Trap	Trotline w/Bait	Otter Trawl	Brush Trap	Haul Seine	Drop Net	Dip Net
1946	NS	NS	0	NS	NS	NS	0
1947	NS	NS	0	NS	NS	NS	0
1948	0	0	0	295	184	402	0
1949	0	0	0	213	82	160	0
1950	0	0	0	188	74	102	0
1951	44	0	0	243	22	41	0
1952	75	0	0	299	23	51	0
1953	108	0	0	296	31	52	0
1954	0	138	0	247	32	39	0
1955	0	180	0	327	0	73	0
1956	0	93	0	343	0	164	0
1957	0	67	0	317	0	167	0
1958	0	59	0	338	0	180	0
1959	0	0	0	340	0	209	0
1960	0	59	0	200	0	255	0
1961	0	68	0	274	0	278	0
1962	0	46	0	107	0	192	0
1963	0	64	0	52	0	213	0
1964	23	49	0	24	0	112	0
1965	14	35	0	40	0	115	0
1966	20	33	0	37	0	37	0
1967	53	20	0	52	0	553	0
1968	88	39	0	106	0	51	0
1969	61	19	0	78	0	38	0
1970	35	5	(1)	37	0	6	5
1971	30	(1)	(1)	57	0	2	32
1972	21	(1)	3	44	0	16	17
1973	50	8	9	37	0	0	15
1974	31	0	2	57	0	0	6
1975	28	0	2	77	0	0	3
1976	25	0	0	57	0	0	6
1977	68	0	0	152	0	0	3
1978	5	0	3	125	0	0	0
1979	68	0	1	76	0	0	3
1980	55	0	(1)	62	0	0	1
1981	52	0	1	37	0	0	10
1982	61	0	(1)	97	0	0	6
1983	45	0	1	50	0	0	6
1984	21	0	2	52	0	0	0
1985	21	0	6	55	0	0	0
1986	29	0	6	45	0	0	0
1987	59	0	18	61	0	0	0
1988	130	0	5	26	0	0	0
1989	164	0	1	6	0	0	0

(1) - Less than 500 pounds
NS - No survey taken

Table 3.12. Historical commercial Louisiana soft shell crab landings, and current and deflated price per pound and total value (deflated values based on the 1982-84 base period consumer price index).

Year	Landings (1000 lbs)	Price/pound($) Current	Price/pound($) Deflated	Value ($1000) Current	Value ($1000) Deflated
1960	514	.50	1.69	256	865
1961	620	.50	1.69	310	1037
1962	344	.50	1.65	172	568
1963	329	.50	1.63	164	536
1964	200	.64	2.06	127	408
1965	204	.69	2.18	141	446
1966	128	.66	2.03	85	262
1967	146	.83	2.48	121	362
1968	284	.73	2.10	207	595
1969	197	.82	2.23	161	439
1970	90	.88	2.26	79	203
1971	127	.99	2.44	126	310
1972	102	1.07	2.56	109	261
1973	119	1.11	2.50	132	297
1974	96	1.32	2.68	127	258
1975	111	1.40	2.60	155	288
1976	88	1.65	2.90	145	255
1977	225	2.53	4.17	570	940
1978	133	2.07	3.17	276	423
1979	147	2.30	3.17	338	466
1980	118	2.32	2.82	273	332
1981	100	2.38	2.61	238	261
1982	164	2.63	2.72	432	447
1983	101	2.87	2.88	290	291
1984	75	2.71	2.60	203	195
1985	82	2.44	2.26	200	362
1986	79	2.29	2.09	181	165
1987	139	2.67	2.35	371	326
1988	162	2.71	2.29	439	371
1989	172	2.45	1.98	421	340
1990	249	2.51	1.92	621	476
1991	200	1.49	1.09	298	219
1992	240	2.22	1.58	532	379
1993	99	4.30	2.98	426	295

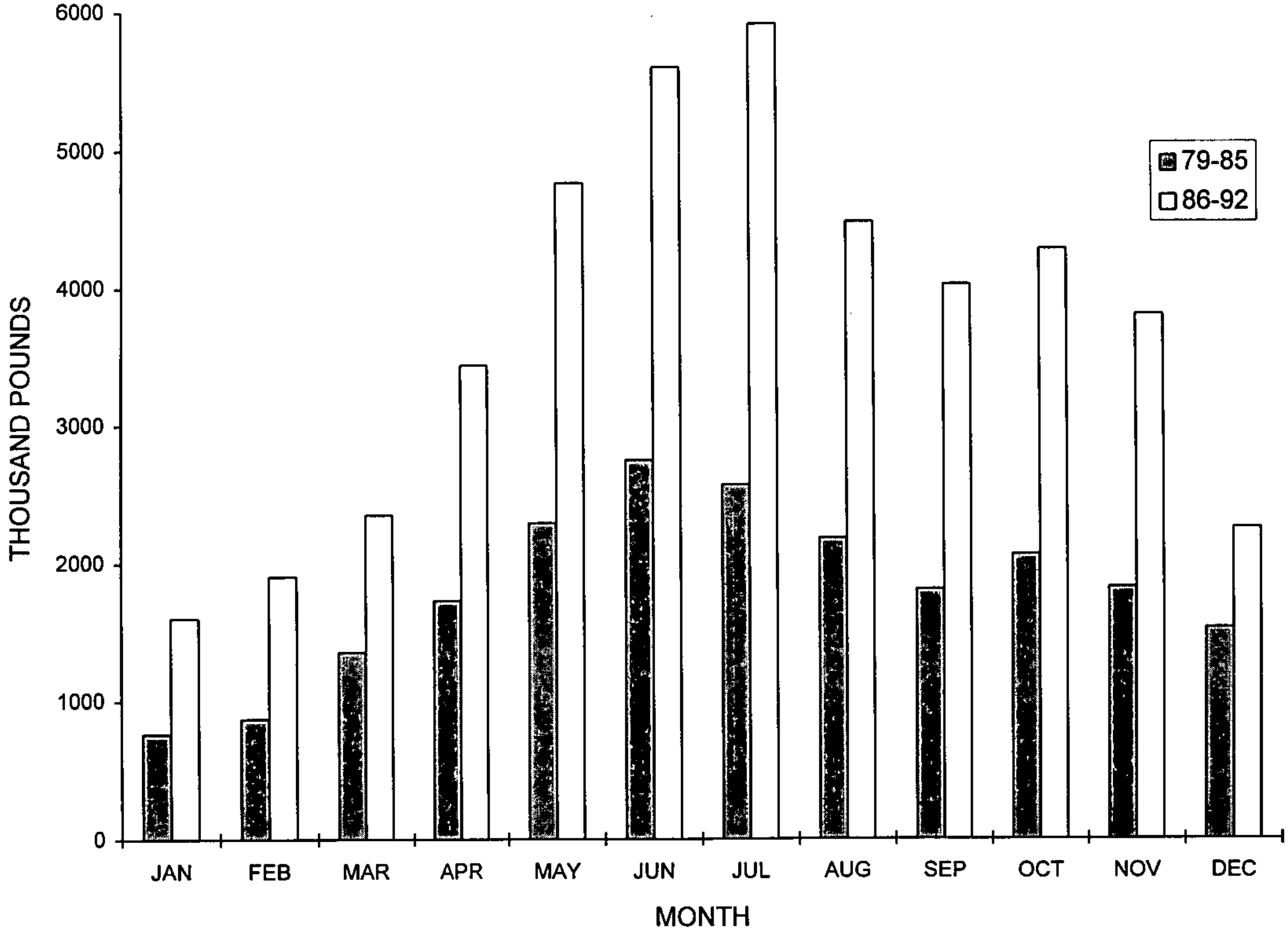

Figure 3.1. Average monthly Louisiana hard crab landings for time periods 1979-1985 and 1986-1992.

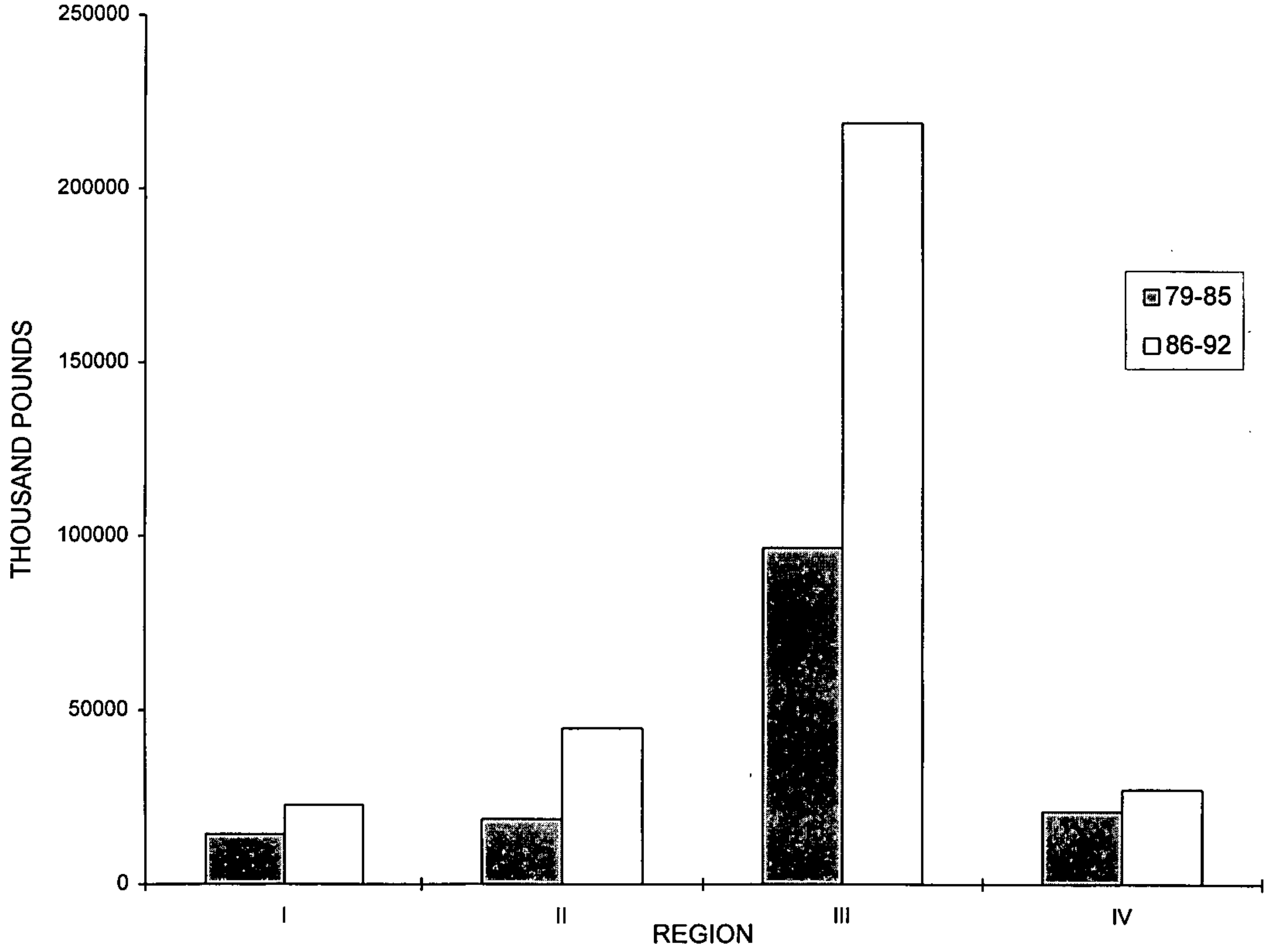

Figure 3.2. Louisiana hard crab landings by region for time periods 1979-1985 and 1986-1992.

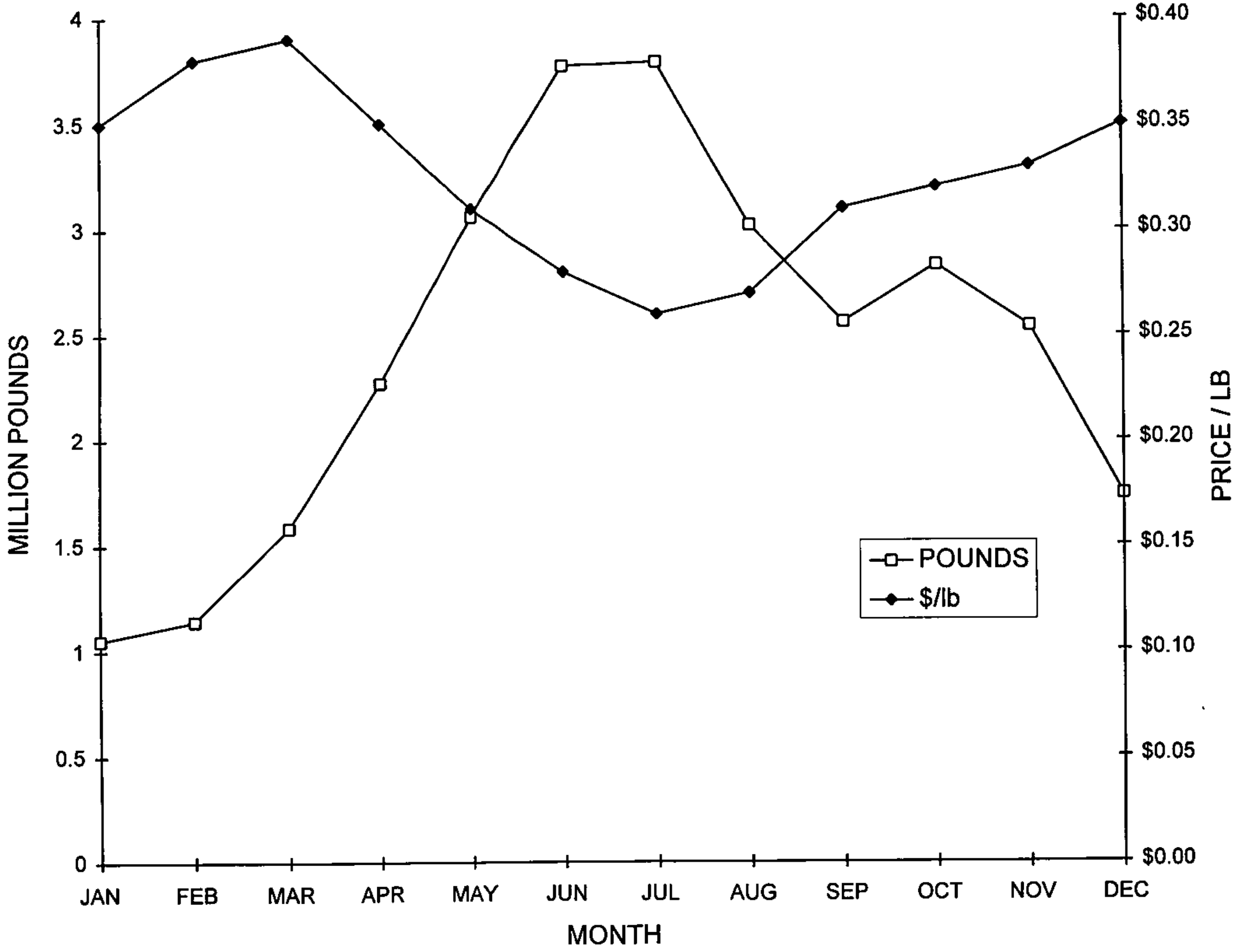

Figure 3.3. Average monthly commercial hard crab landings (million lb) and price per pound.

4.0 RESEARCH NEEDS

The blue crab and its fishery in Chesapeake Bay has received considerable attention since the 1940s, and during the 1980s and 1990s research efforts greatly expanded. In contrast, the Gulf of Mexico blue crab fishery has been one of "low priority" in terms of funded research (Steele and Perry 1990). Emphasis on the Louisiana blue crab fishery, the largest crab fishery in the United States, has not been commensurate with the value of the fishery. Since a large portion of the data on Atlantic Coast populations of blue crab is not applicable to the Gulf of Mexico, data gaps exist in the biology and fishery of the blue crab in Louisiana.

Suggested research topics would fill some of the critical gaps in the blue crab life history, fishery, and industry.

4.1 Biological

1. Influence of environmental factors on blue crab recruitment.
2. A mark-recapture study to determine migration patterns and fishing mortality.
3. Predator-prey relationships between crabs and other estuarine organisms.
4. Characterization of long term trends in blue crab abundance.
5. Impact of salinity intrusion and freshwater inflow on blue crab nursery grounds.
6. Impact of marsh and wetland loss and "marsh management" on blue crab populations.
7. Blue crab population dynamics.
8. Effects of capture and handling.

4.2 Fisheries/Economics

1. Development of predictive models for commercial harvest or crab availability.
2. Influence of factors such as trap type, mesh size and type, and funnel size and number on trap catches.
3. Economic impact of existing and proposed management regulations.
4. Economic and fishery surveys of the recreational fishery.
5. Sociological and cultural impacts of ethnic diversity on all sectors of the fishery.

6. Seasonal distribution and abundance of premolt crabs.
7. Development of alternative methods or gears for harvesting premolt crabs.
8. Influence of bait type and quantity, and soak time on trap catches.
9. Accumulation of accurate soft and hard crab production data.
10. A general survey of commercial crab fishermen.

4.3 Industrial/Technological

1. Utilization of crab processing wastes.
2. Influence of season, area, sex, and crab size on meat yield.
3. Evaluation of feeding of hard crabs held for shedding.
4. Increasing the shock-loading capacity of closed shedding systems.
5. Development of methodology to induce molting of hard crabs.
6. Development of an artificial crab bait.

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