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ON THE BIOLOGY AND CULTURE OF SHRIMPS AND PRAWNS

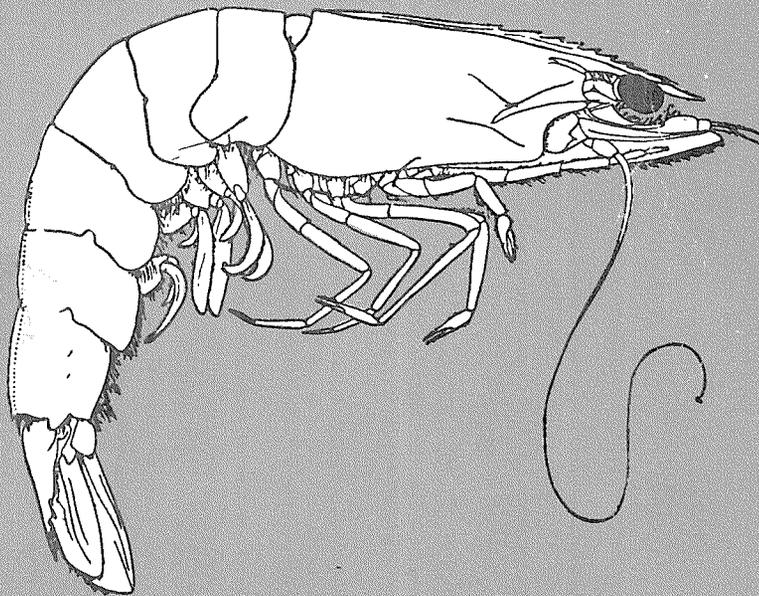
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SYNOPSIS OF BIOLOGICAL DATA ON THE PINK SHRIMP
Penaeus duorarum duorarum Burkenroad, 1939

Exposé synoptique sur la biologie de
Penaeus duorarum duorarum Burkenroad, 1939

Sinopsis sobre la biología del
Penaeus duorarum duorarum Burkenroad, 1939

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^{1/} This synopsis has been prepared according to Outline Version No. 2 (H. Rosa Jr., FAO Fish.Synops., (1) Rev.1, 1965).

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*As no information was available to the authors, these subjects are not listed in the text.

1 IDENTITY

1.1 Nomenclature

1.11 Valid name

Penaeus duorarum duorarum Burkenroad, 1939

1.12 Objective synonymy

Penaeus duorarum "Form A", Burkenroad, 1939, Bull. Bingham oceanogr. Coll., Vol. 6, p. 1-62, 36 text-figs.

1.2 Taxonomy

1.21 Affinities

Suprageneric (to family after Waterman and Chace, 1960)

- Phylum Arthropoda
- Class Crustacea
- Subclass Malacostraca
- Series Eumalacostraca
- Superorder Eucarida
- Order Decapoda
- Suborder Natantia
- Section Penaeidea
- Family Penaeidae
- Subfamily Penaeinae

Generic

Genus Penaeus Fabricius, 1798, Suppl. Ent. Syst.: 385, 408. Type species, by selection by Latreille, 1810, Consid. gén. Anim. Crust. Arachn. Ins.: 102, 422; Penaeus monodon Fabricius, 1798, Suppl. Ent. Syst.: 408. Gender: masculine.

Definition

Rostrum toothed dorsally and ventrally. Carapace without longitudinal or transverse sutures; cervical and orbito-antennal sulci and antennal carinae always present. Hepatic and antennal spines pronounced, pterygostomial angle rounded. Telson with deep median sulcus, without fixed subapical spines, with or without lateral movable spines. First antennular segment without a spine on ventral distomedian border. Antennular flagella shorter than carapace. Maxillular palp with 2 or 3 segments, usually 3. Basial spines on 1st and 2nd pereopods; exopods on 1st 4 pereopods, usually present on 5th. Petasma symmetrical, pod-like with thin median lobes with or without distal protuberances; lateral lobes often with thickened ventral margin. Appendix masculina with distal segment subtriangular or ovoid, bearing numerous spines. Thelycum usually with an anterior process, variable in shape, lying between the coxae of 4th pereopods; with or without lateral plates on sternite XIV. Pleurobranchiae on somites IX to XIV: a rudimentary arthrobranch on somite VII, and a posterior

arthrobranch on somite XIII; mastigobranchiae on somites VII to XII. Zygo-cardiac ossicle consisting of a principal tooth followed by a longitudinal row of smaller teeth which often end in a cluster of minute teeth. Body glabrous. (After Dall, 1957, slightly modified by Pérez-Farfante.)

Specific

The holotype and syntypes of Penaeus duorarum (1 male and 2 females) are in the Bingham Oceanographic Collection of Yale University, New Haven, Connecticut, U.S.A., catalogued B.O.C. 255 and 256. These specimens were taken off Alabama, U.S.A., ATLANTIS Station 2813 in 37 m of water on March 20, 1937 (Pérez-Farfante, 1969).

The following diagnosis of P. duorarum is from Williams (1965): "Female with thelycum composed of two broad lateral plates, and a median plate. Posteromedian part of median plate of adult with a well-developed, short, longitudinal carina extending anteriorly toward roughly semicircular, concave anterior portion. Lateral plates produced medially to meet in midline, except variably divergent at anteromedian corners, thus exposing carina of median plate.

"...Petasma of male with distal ends of distoventral lobes curved medially, not projecting free of distolateral lobes; external edge of distoventral lobes with a series of 2 to 12, usually 4 to 7, small spinules; median or attached edge of distoventral lobes with a compact group of 6 to 16 large, long, sharp, curved spines; fold of distolateral lobe rather small and armed inconspicuously if at all."

For a key to the western Atlantic species of the genus Penaeus, see Pérez-Farfante (1969).

1.22 Taxonomic status

Penaeus duorarum is one of about 28 species of the genus Penaeus. P. duorarum and the closely related Penaeus brasiliensis Latreille and Penaeus aztecus Ives were considered a single species (P. brasiliensis) before the taxonomic revision based on morphological differences by Burkenroad (1939).

1.23 Subspecies

Pérez-Farfante (1967) divided P. duorarum into the subspecies P. duorarum duorarum and P. duorarum notialis. The basis for the division was given by Pérez-Farfante (1969) as follows: "P. duorarum duorarum /from the northwestern Atlantic and the Gulf of Mexico/ has the dorsolateral sulcus narrower than P. duorarum notialis from the Caribbean Sea, the Atlantic Coast of South America, and Africa. Burkenroad (1939) was the first to point out this difference between the two and called the former 'Form A',

and the latter 'Form B'. Biometric studies have indicated a statistically significant difference in the ratio (K/S) of K (height of the keel) to S (width of the sulcus) between those populations." K/S ranges from about 2.5 to 15.5 (mode 4.5) in *P.d.duorarum*, and from 0.25 to 3.0 (mode 1.75) in *P.d.notialis*. In addition, the third pereopod "is proportionately shorter in *P. d. duorarum* than in *P. d. notialis*" (Pérez-Farfante, 1969). She noted further that "overlapping is very limited" and the two subspecies "do not seem to mix across the Gulf Stream" (Pérez-Farfante, 1967).

Pérez-Farfante, therefore, equated *P.d. duorarum* with Form A and *P.d.notialis* with Form B. In this synopsis, the discussion is restricted to *P.d.duorarum* of the northwestern Atlantic and Gulf of Mexico. Information concerning *P. duorarum*, or Form A, from these geographic areas is considered referable to *P.d. duorarum*.

1.24 Standard common names, vernacular names

Standard common names: U.S.A.: pink shrimp
Mexico: camarón rosado

Vernacular names: blue-tailed shrimp, brown spotted shrimp, channel shrimp, grass shrimp, green shrimp, grooved shrimp, hopper, jumbo hopper, pink grooved shrimp, pink night shrimp, pink spotted shrimp, red shrimp, spot shrimp, spotted shrimp, skipper (U.S.A.).

The common name "pink shrimp" in this synopsis refers only to the subspecies *P.d.duorarum*.

1.3 Morphology

1.3.1 External morphology

Figure 1 is a lateral view of an adult pink shrimp. The following description is from Williams (1965). "Integument thin, polished, translucent. Carapace with a median carina continuous anteriorly with rostrum and extending nearly to posterior border of carapace flanked on each side by a broad, rounded groove; posterior half of carina with a median longitudinal groove; anterior half arcuate, highest above orbit and with 9 or 10 sharp teeth; posterior tooth remote from others, anterior 6 or 7 on rostrum proper. Lower margin of rostrum with 2 to 3 teeth (occasionally 1); tip slender, horizontal or directed slightly downward, unarmed. Anterior margin of carapace with strong antennal spine on carina extending backward nearly to well-developed hepatic spine. Cervical groove extending halfway from hepatic spine to dorsal carina. A subhorizontal suture below hepatic spine, and a groove extending from near hepatic spine to near base of ocular peduncle. An orbital ridge behind eye.

"Abdomen with segments four to six carinate, carina of sixth ending posteriorly in a spine and flanked on each side by a narrow groove. Telson with deep median groove and acuminate tip."

The color of pink shrimp varies with locality, diel period and age. Shrimp in coastal areas of Florida are green, brown, or reddish; on the offshore Tortugas (Florida) and Campeche (Mexico) grounds, colors range from pale rose to deep pink (Idyll, 1964). Along the northern coast of the Gulf of Mexico, lemon yellow is common (Anderson, 1962). Day-night color differences were observed in south Texas; at sunset, shrimp became bright red (Hoese et al., 1968). Juveniles and young adults are gray, reddish brown, or bluish gray, and older individuals are red, pinkish, blue gray, or almost white (Williams, 1965). A spot (gray, blue, purple, red, or brown) may or may not be present at the pleural juncture of the third and fourth abdominal segments (Anderson, 1962; Williams, 1965).

The morphology of pink shrimp changes during growth. Several parts and appendages become shorter in proportion to the carapace length;¹ this break is distinct in females at about 108 mm total length² and in males at about 96 mm total length (Drucker, 1960).

Williams (1965) reported the rostrum to be "relatively shorter and deeper in old individuals than in young ones. It extends to the end of the basal antennular article in average-sized adults."

(See also 1.21, 1.23, and 3.11.)

1.33 Protein specificity

Leone and Pryor (1952), who made serological comparisons of the blood proteins of three species of shrimp - pink, brown (*Penaeus aztecus* Ives), and white (*Penaeus setiferus* (Linnaeus)) - from North Carolina, placed pink and brown shrimp closer to each other than either is to the white shrimp. Serological differences support the theory that these three species are distinct but closely related.

¹Carapace length is a head-length measurement taken from the orbital notch inside the orbital spine, in a line parallel to the lateral rostral sulcus, to the posterior margin of the cephalothorax.

²Total length is measurement taken from the tip of the rostrum to the tip of the telson with abdominal segments extended in a straight line.

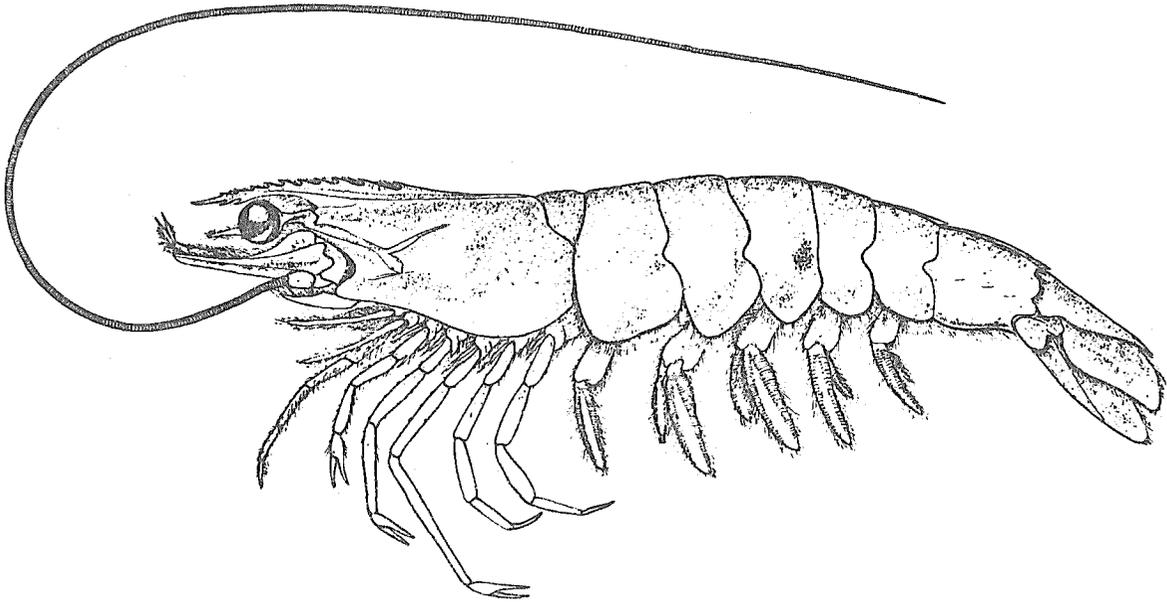


Fig. 1. *Penaeus duorarum duorarum* Burkenroad, 1939.

2 DISTRIBUTION

2.1 Total area

The world distribution of P.d.duorarum (Fig.2) is restricted to the northwestern Atlantic and the Gulf of Mexico (Atlantic, N.W. - ANW; Atlantic S.W. - ASW) - see Pérez-Farfante (1969). This subspecies inhabits coastal waters of land areas 240, 230, and 311 of the FAO distribution code (Holthuis and Rosa, 1965). P.d.duorarum is found in Bermuda and along the Atlantic coast of North America from lower Chesapeake Bay to southern Florida, and into the Gulf of Mexico. The range extends along the Gulf coast into Mexican coastal waters and terminates slightly south of Cabo Catoche at Isla Mujeres (Pérez-Farfante, 1969). P.d.duorarum, as Form A, was also found at the Doubleheaded Shot Cays in the Straits of Florida (Burkenroad, 1939).

P.d.duorarum is most plentiful where the Continental Shelf is broad and shallow, and where coastlines are characterized by shallow bays and estuaries. Highest concentrations are in the eastern and southeastern Gulf of Mexico, adjacent to the Florida and Yucatán Peninsulas.

2.2 Differential distribution

2.21 Spawn, larvae and juveniles

Pink shrimp spawn offshore. The demersal eggs were found from about 10 to 64 km off the west coast of Florida in 4- to 38- m depths (Eldred et al., 1965). The distribution of eggs on the Tortugas Shelf (Florida) was not observed directly, but the spawning grounds, determined from larval distribution, ranged from 15 to 48 m in depth (Jones et al., in press). Spawning was year around and the center of activity and intensity varied seasonally.

After hatching, the larvae are planktonic and move shoreward, apparently following an indirect route determined by currents (Munro, Jones and Dimitriou, 1968). Newly hatched larvae had their greatest abundance in the spawning area on the Tortugas Shelf, whereas postlarvae were abundant near the coast (Jones et al., in press). Postlarvae enter south Florida estuaries throughout the year; the greatest numbers were taken in spring, summer, and autumn (Roessler, Jones and Munro, 1969; Allen, Hudson and Costello, MS). In other areas studied, the annual influx of postlarvae was similar to that in south Florida, but generally more restricted (Bearden, 1961; Joyoe, 1965; Eldred et al.,

1965; Copeland and Truitt, 1966; Christmas, Gunter and Misgrave, 1966; Williams, 1969). In North Carolina, for example, Williams found that postlarvae usually enter the estuaries from May through November.

Juvenile pink shrimp inhabit coastal bays and also estuaries that penetrate deeply into the mainland (Williams, 1955a; Tabb, Dubrow and Jones, 1962; Joyoe, 1965). They also have been found in the Gulf of Mexico west of Key West, Florida, in the grassy shallows near the Marquesas Keys (Ingle et al., 1959). According to Eldred (1962), "Very small individuals prefer the very shallow, protected, relatively oalm areas near the shore..." They occur year around in Tampa Bay, Florida, where numbers are greatest in the summer and autumn (Eldred et al., 1961). A similar seasonal distribution was noted in Florida Bay (Costello, Allen and Hudson, MS), and in North Carolina estuaries (Williams, 1955a).

As juvenile pink shrimp grow, they move gradually into deep water (Iversen and Idyll, 1960). Juveniles and young adults (58 to 101 mm total length) marked and released in northeastern Florida Bay in 2 m of water appeared, within a few months, as adults (87 to 155 mm total length) on the Tortugas grounds in depths of 17 to 44 m (Allen and Costello, 1966).

(See also 3.23.)

2.22 Adults

A few pink shrimp remain in south Florida estuaries after they become adults, but most move offshore (Iversen and Idyll, 1960; Allen and Costello, 1966). The size of shrimp on the Tortugas grounds increases with depth (Iversen, Jones and Idyll, 1960) and the greatest concentrations are between 9 and 45 m (Kutkuhn, 1962a). These shrimp are rare at depths greater than 51 m (Hildebrand, 1955), but a few have been taken at depths to at least 110 m and specimens of P. duorarum, subspecies unknown, were caught at depths as great as 366 m off the western edge of the Great Bahama Bank (Anon., 1961; 1962).

The biomass of Tortugas pink shrimp, generally, is least in the spring and summer and greatest in the autumn and early winter (Kutkuhn, 1962a). Annual fishable biomass from 1956 to 1959 was fairly uniform, but with a slight downward trend.

(See also 4.22, 4.24, and 5.31)

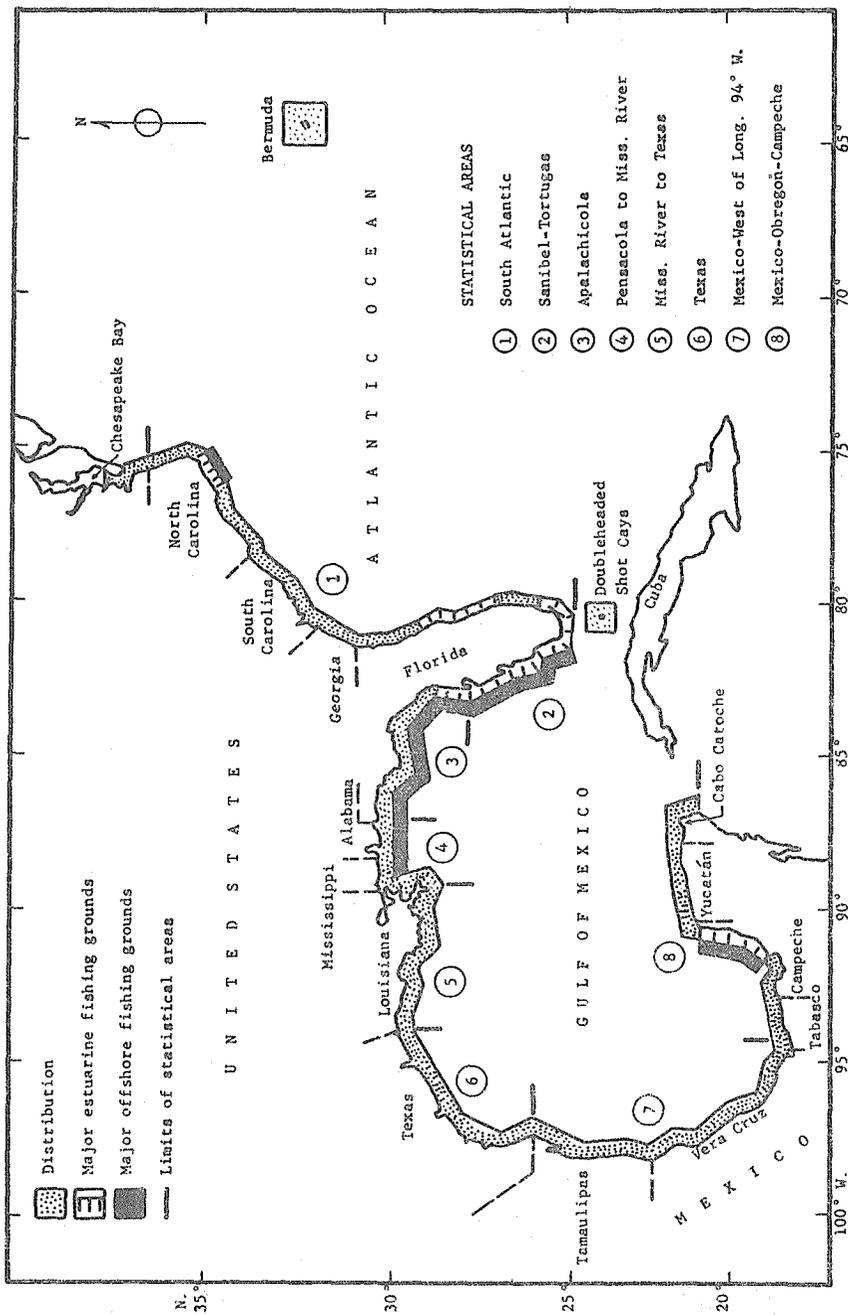


Fig. 2 Distribution and fishing areas for *Penaeus duorarum duorarum*.

2.3 Determinants of distribution changes

The distribution of pink shrimp may be limited by salinity, temperature, and substrate (Williams, 1965). Details of these and additional factors are given here.

Temperature: Spawning temperatures (see 3.16) are apparently critical and may determine area of spawning and subsequent distribution of shrimp populations (Eldred *et al.*, 1961). In North Carolina estuaries, the majority of samples containing postlarvae were collected at water temperatures between 23° and 28° C (Williams and Deubler, 1968).

Temperatures required for survival of pink shrimp may vary with locality. In North Carolina estuaries, juveniles have been collected in water temperatures ranging from 4° to 34° C (Williams, 1955a). These shrimp became narcotized by the cold at 10° C (Williams, 1955), and in severe winters most of the shrimp population in estuaries may die (Williams, 1965). Death caused by low temperatures may be relatively unimportant in the warmest parts of the species range because none has been reported. In Florida, shrimp have been collected within the range 10° to 35.5° C; they were narcotized at 13.3° C (Eldred *et al.*, 1961). These authors stated that juveniles move into deep water with the onset of cold weather.

Mortalities attributed to high temperatures have not been reported.

Salinity: Salinity requirements or preferences vary with geographic area and shrimp size. Minimum salinities associated with pink shrimp, (irrespective of size) are as follows: "no measurable salt (using standard hydrometers)" in the Florida Bay area (Tabb, Dubrow and Jones, 1962); less than 1.0°/oo in the Caloosahatchee Estuary, Florida (Gunter and Hall, 1965); 0.64°/oo in a north-east Florida estuary (Joyce, 1965); and 2.7°/oo in Mesquite Bay, Texas (Hoese, 1960). Maximum salinities recorded for waters with pink shrimp are 60°/oo in the Upper Laguna Madre, Texas (Simmons, 1957), and 70°/oo in Florida Bay (Tabb, MS). Tabb, Dubrow and Jones (1962) caught postlarvae in the Florida Bay area at salinities ranging from 12 to 43°/oo, juveniles at salinities of about 0 to 47°/oo and adults at salinities of 25 to 45°/oo. Where adults are concentrated on the Tortugas grounds, salinities range from about 36 to 38°/oo (Iversen and Idyll, 1960).

Juvenile pink shrimp can survive in waters having a wide salinity range, although optimum salinities may be relatively high as compared with those of white and brown shrimp (Gunter, Christmas and Killebrew, 1964).

Young pink shrimp tolerate low salinities (Burkenroad, 1939) but not for extended periods of time (Joyce, 1965). They were most abundant in Texas bays at salinities higher than 18°/oo (Gunter, Christmas and Killebrew, 1964) and in Florida Bay at salinities from 30 to 50°/oo (Tabb, MS). Observations concerning distribution were summarized by Hildebrand (1955) who concluded that juvenile pink shrimp "prefer" salinities of 20°/oo or more.

Values of temperature and salinity should be considered together in evaluations of the effects of either factor on pink shrimp. Williams (1960) reported that the survival of shrimp at low temperatures is best at moderate to high salinities. Joyce (1965) noted that "The ability of shrimp to withstand low salinities appears to depend upon several factors..." which include temperature and perhaps the concentration of calcium ion.

Currents: The distribution of pink shrimp may be controlled to a great extent by currents. Concerning larvae spawned on the Tortugas grounds, Munro, Jones and Dimitriou (1968) reported: "dispersal may be effected primarily by the current which leaves the Tortugas area through Rebeoca Channel, and enters the Florida Current in the Florida Straits. Entry into the Florida Current would result in rapid transit to the area adjacent to Florida Bay." The movement of postlarvae to estuarine waters is effected by inflowing currents (Idyll and Jones, 1965; Copeland and Truitt, 1966; Hughes, 1969). Juvenile pink shrimp in North Carolina estuaries concentrate near inlets where tidal currents are moderate (Williams, 1955a). In south Florida waters, some juveniles "move seaward on the ebb tides and back into the bays on subsequent flood tides" (Tabb, Dubrow and Jones, 1962). Juveniles migrating to sea are carried by ebbing currents (Burkenroad, 1949; Copeland, 1965; Beardsley and Iversen, 1966; Hughes, 1969).

Substrate: The distribution of pink shrimp follows closely that of sand, shell-sand, or oocal mud substrate (Williams, 1965). The importance of substrate type, however, as related to food, cover, or some less obvious factor has not been established. Williams (1958) reported that young pink shrimp in North Carolina estuaries are "confined largely to areas near the sea where the bottom is composed of coarser materials." He noted that pink shrimp can burrow into extremely coarse substrates, and in laboratory experiments, learned that subadults prefer shell-sand and loose peat substrates. Adults prefer oocalareous

sediments but do occur on hard sand bottoms "particularly in non-turbid waters" (Hildebrand, 1955).

Seagrasses: The association of juvenile pink shrimp with seagrass has been noted by many investigators, including Hildebrand (1955), Woodburn *et al.* (1957), and Tabb, Dubrow and Manning (1962). Eldred (1962) reported that in inshore waters, small juveniles were near shore in beds of shoal grass, Diplanthera wrightii, and the large juveniles were in deeper waters in turtle grass, Thalassia testudinum. Moore (1963) observed that turtle grass is a suitable habitat for many organisms

that may serve as food for shrimp. The geographic distribution of pink shrimp may follow closely the distribution of seagrasses. according to Hoese and Jones (1963), who noted that there are no pink shrimp fisheries near areas where seagrasses are rare or absent.

Environmental changes can alter growth of seagrasses and affect associated organisms, which include young pink shrimp (Tabb, Dubrow and Manning, 1962). Destruction of seagrass beds by dredge-and-fill operations has eliminated nursery areas for pink shrimp in Tampa Bay, Florida (Saloman, 1965).

3 BIONOMICS AND LIFE HISTORY

3.13 Mating

3.1 Reproduction

3.11 Sexuality

Pink shrimp are dioecious. Hermaphroditism has not been reported. Males are distinguished from females by the presence of the male sex organ, the petasma, between the 1st pair of pleopods. On the female, the distinguishing external organ, the thelycum, lies between the 4th and 5th pairs of pereopods. Figure 3 illustrates the petasma and thelycum.

Female shrimp attain a greater size than males. Williams (1955) reported: "There is a sex size disparity in adult P. duorarum which is statistically significant at mean total lengths which exceed 100 mm." The largest female reported was 280 mm total length (Eldred, 1958); the largest male was 43 mm carapace length or about 197 mm total length (Iversen, Jones and Idyll, 1960). In large pink shrimp, females have a greater carapace length than males of the same total length (Kutkuhn, 1966).

3.12 Maturity

Female pink shrimp may become sexually mature at 85 mm total length and males at 74 mm (Eldred et al., 1961). At these lengths, estimated weights (Kutkuhn, 1966) are about 5.2 g for females and 3.5 g for males.

The degree of sexual maturity in female pink shrimp has been described by Cummings (1961) as follows:

- Undeveloped stage: Ovaries flaccid, small and translucent
- Developing stage: Ovaries flaccid, larger than in undeveloped stage, and white to pale orange buff colour.
- Nearly ripe stage: Ovaries slightly turgid, large, and glaucous color.
- Ripe stage: Ovaries same as nearly ripe stage, ova with peripheral rod-like bodies.

Males "with joined endopods and spermatophores with spermatozoa" are considered sexually mature (Eldred et al., 1961).

(See also section 4.12.)

No observations describing copulation are published, but it may occur several times during the life of a female (Idyll, 1964); this multiple copulation would indicate that pink shrimp are promiscuous. Sperm transfer probably is between a hard-shelled male and a recently molted female (Cummings, 1961).

3.14 Fertilization

Idyll (1964) described fertilization in pink shrimp. "Fertilization is external. The male attaches a spermatophore to the underside of the abdomen of the female....

"Females bearing spermatophores are in various stages of sexual development. The spermatophores are shed at ecdysis.

"The genital pores of the female open at the bases of the third pair of pereopods. After the eggs pass through these pores they are fertilized by the spermatozoa stored in the thelycum."

3.15 Gonads

Cummings' (1961) report that ovary weight increased with shrimp size suggests that large females produce more eggs than smaller ones. The number of eggs produced per spawning is unknown, but a female of a related species--a white shrimp 172 mm total length--contained about 860,000 eggs (Anderson, King and Lindner, 1949). Pink shrimp probably produce a similar number of eggs during one spawning, and Cummings (1961) indicated that they may spawn more than once during their lifetime.

3.16 Spawning

The ratio and distribution of sexes of adult pink shrimp on the spawning grounds may vary seasonally (Broad, 1951; Iversen, Jones and Idyll, 1960).

The location of the spawning ground on the Tortugas Shelf (Florida) was given by Jones et al. (in press). The center of spawning shifted with the movement of adult shrimp from shallow to deep water as winter approached (Munro, Jones and Dimitriou, 1968). Eldred et al. (1965) reported that offshore from Tampa Bay, Florida, the location of intensive spawning varied from one year to the next.

Several environmental factors may influence spawning. Pink shrimp spawn throughout the year on the Tortugas Shelf

but larval abundance is highest in the spring, summer and autumn and lowest in the winter (Jones *et al.*, in press). In the more northerly parts of the range, the spawning season may be shorter than in the southern portion (Williams, 1965; Joyce, 1965). Cummings (1961) noted a positive correlation between temperature of bottom water and the occurrence of ripe shrimp on the Tortugas grounds. Shrimp spawn on the Tortugas grounds between 19.6° and 30.6° C (Jones *et al.*, in press); activity is maximum during the period of highest bottom water temperatures (Munro, Jones and Dimitriou, 1968). Eldred *et al.* (1965), however, found evidence that pink shrimp spawn at temperatures as low as 16.1° C and stated that "a rising temperature is the important factor in triggering spawning" On the Tortugas grounds, most spawning was during the waning moon (Munro, Jones and Dimitriou, 1968). Spawning in the laboratory was "always in the very early hours of the morning" (Ewald, 1965).

The female shrimp releases the fertilized eggs freely into the water where they sink slowly to the bottom (Idyll, 1964).

Joyce (1965) showed that where pink, white and brown shrimp occurred together off the northeast coast of Florida, spawning times overlapped during the warm months of the year. Brown shrimp begin to spawn in February, white shrimp in April, and pink shrimp in May.

3.17 Spawn

Viable eggs measure from 0.31 to 0.33 mm in diameter (Dobkin, 1961). They are opaque and yellow-brown and the chorion shows a blue hue under certain light reflections.

The specific gravity of fertilized eggs is slightly greater than water (Idyll, 1964).

3.2 Pre-adult phase

3.21 Embryonic phase

The embryos develop in the fertilized eggs that are extruded in the water. There is no parental care.

Dobkin (1961) provided a photomicrograph of eggs in several stages of development, and noted that development of pink shrimp may be similar to that of *Penaeus japonicus* as summarized by Pearson (1939).

Dobkin (1961) described hatching as follows: "Prior to its emergence, the nauplius moves its appendages convulsively at short intervals. After the furcal spines puncture the egg membrane, the nauplius emerges, posterior half first, by pushing

against the membrane with the first antennae. Emergence from the egg requires 2 to 3 minutes."

3.22 Larval phase

The larvae of pink shrimp were described by Dobkin (1961) who noted 5 naupliar stages, 3 protozoal stages, and 3 mysis stages. Figure 4, taken from Dobkin, shows a 4th nauplius. He reported size of larvae in total length as follows: nauplii, 0.35 to 0.61 mm; protozoae, 0.86 to 2.7 mm; and mysids, 2.9 to 4.4 mm.

Development time of the various stages in the laboratory was reported by Ewald (1965). He noted that the number of mysis stages and the length of larval life varied with water temperature and observed that "Pink shrimp reared at 26° C took a minimum of 15 days to metamorphose whereas those at 21° C took 25 days...."

Nauplii subsist on yolk granules in their bodies, and active feeding begins in the 1st protozoal stage (Dobkin, 1961; Ewald, 1965). In the laboratory, larvae were fed a mixture of unicellular algae and marine yeast supplemented, in the 3rd mysis stage, with nauplii of brine shrimp (*Artemia*).

Larvae reared in the laboratory survived better in Gulf Stream water than in water from Biscayne Bay, Florida (Ewald, 1965). Survival rates of larvae on the Tortugas Shelf vary little and average 83 percent per day (Munro, Jones and Dimitriou, 1968).

3.23 Adolescent phase

The postlarvae of pink shrimp were described by Dobkin (1961); methods for their identification were provided by Williams (1959), Ringo and Zamora (1968), and Chuensri (1968). The smallest postlarva reported from plankton by Dobkin was 3.8 mm total length; the smallest reared in the laboratory by Ewald (1965) was 2.9 mm. Ewald reported that the postlarvae reared at the lowest temperatures were smallest.

Early postlarvae are planktonic in offshore waters (Jones *et al.*, in press). The more advanced ones enter the estuaries at about 8 mm total length (Copeland and Truitt, 1966; Allen, Hudson and Costello, MS), although size at entrance varies with season (Matias, 1966) and area (Tabb, Dubrow and Jones, 1962). They become benthic at about 10 mm and concentrate in shallow water where cover is adequate. Here, they develop into juveniles, and density of

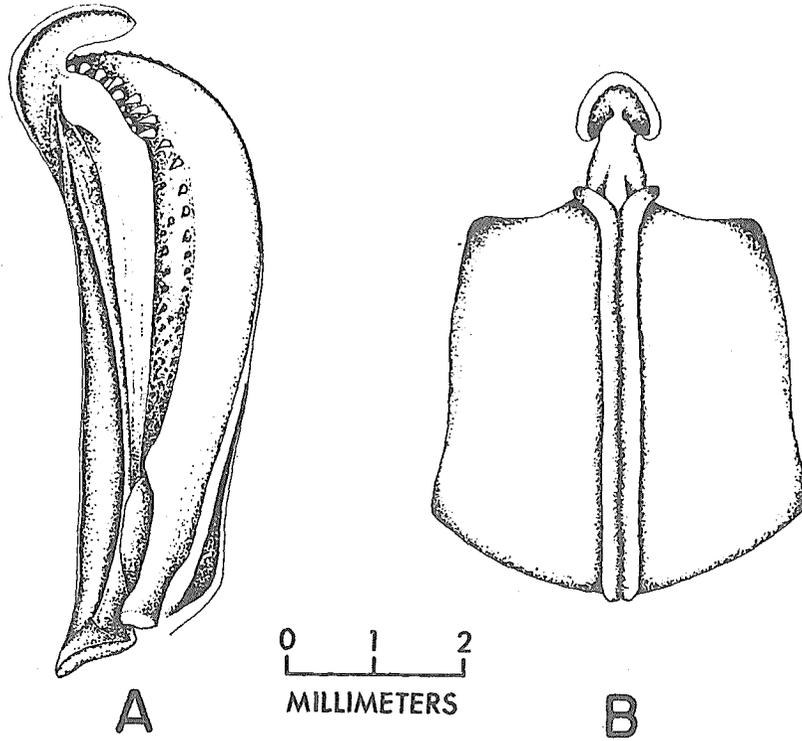


Fig. 3 Sex organs of Penaeus duorarum duorarum.
A. Pataema of male, 125 mm total length (right lateral view)
B. Thelycum of female, 125 mm total length (ventral view)

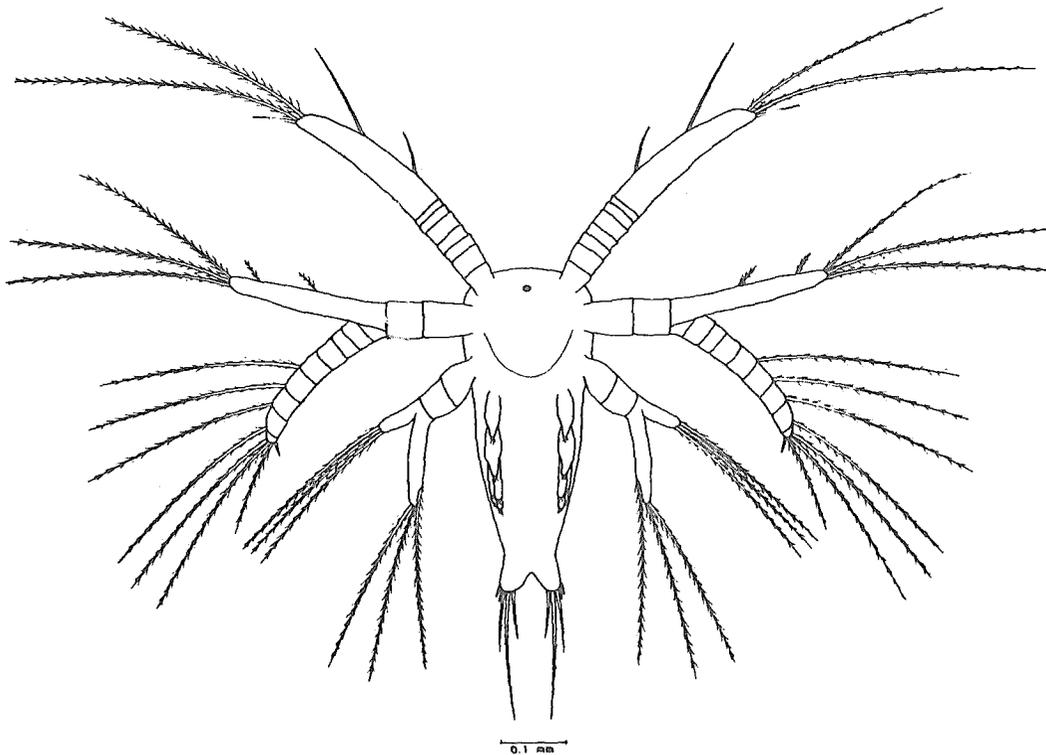


Fig. 4 A ventral view of a 4th nauplius of Penaeus duorarum duorarum.
(From Dobkin, 1961)

individuals may exceed 32 per m² (Costello, Allen and Hudson, MS).

Juvenile shrimp are more robust than postlarvae and have proportionately shorter 6th abdominal segments. Methods for identifying juveniles were given by Williams (1953).

Pink shrimp, as juveniles and adults, may spend from about 2 to at least 6 mo in the shallow nursery areas (Costello and Allen, 1966), but as size increases, they move gradually toward deep waters. When shrimp migrate from the estuaries to the offshore waters, they average about 95 to 100 mm total length (Joyce, 1965). Size at emigration, however, varies with season and area (Iversen and Idyll, 1960; Eldred et al., 1961; Tabb, Dubrow and Jones, 1962; Copeland, 1965).

(See also 2.3.)

3.3 Adult phase

3.31 Longevity

(See 4.12.)

3.32 Hardiness

Juvenile and adult pink shrimp are hardy animals capable of tolerating rough handling without excessive mortality (Costello and Allen, personal observations). They may be taken in trawls from depths of 9 to 35 m, held in tanks at the surface, and returned to the bottom without undue loss. Costello (1964) noted, however, the importance of maintaining water temperatures below about 24.0° C when holding them in tanks.

When pink shrimp are transported in trucks in the live bait industry, large volumes of air are pumped into the water. Under these conditions, they do not perish from air embolism due to excess bubbles in the water. When held in bait tanks, pink shrimp are more hardy than white shrimp and less hardy than brown shrimp (De Sylva, 1954).

Like other crustaceans, pink shrimp are delicate immediately following ecdysis.

3.33 Competitors

Burkenroad (1939) suggested that pink shrimp are in interspecific competition with brown shrimp and Caribbean brown shrimp, Penaeus brasiliensis. He proposed that juveniles of these species had optimum salinity requirements which determined species dominance by area.

Competition between pink shrimp and other penaeid species has been discussed by Williams (1955), Hildebrand (1955), and Joyce (1965). These investigators concluded that in the estuaries, variations in habitats occupied

by the different species in respect to size and season probably reduce competition. Offshore, pink and white shrimp sometimes occur at the same depths. Differences in substrate preference, food, and diel behaviour, however, probably reduce competition there also (Hildebrand, 1955).

3.34 Predators

Fishes that prey upon pink shrimp under natural conditions include: snook, Centropomus undecimalis (Marshall, 1958); spotted seatrout, Cynoscion nebulosus (Moody, 1950; Tabb, 1961; Stewart, 1961); mangrove or gray snapper, Lutjanus griseus (Croker, 1962); toadfish, Opsanus beta (Woodburn et al., 1957); red drum, Sciaenops ocellata (Yokel, 1966); and blue oyster, Bairdiella chabana (Robins and Tabb, 1965). We have found pink shrimp in the stomachs of king mackerel, Scomberomorus cavalla, and mutton snapper, Lutjanus analis (unpublished observations). Costello and Allen (1962), in tank experiments, found mangrove snapper, red grouper (Epinephelus morio), and black grouper (Mycteroperca bonaci) predacious on pink shrimp. Undoubtedly, many fish not listed here prey upon pink shrimp.

Birds, mammals, and reptiles that inhabit shallow estuaries are probably predators of pink shrimp, but this matter is poorly documented.

We have observed that pink shrimp react in two ways when attacked by predators: (1) backward movement to avoid contact is accomplished by rapid contractions of the abdominal muscles and sweeping of the uropods and (2) the shrimp seek shelter of any kind.

3.35 Parasites, diseases, injuries and abnormalities

The following parasites and diseases have been recorded in pink shrimp:

Class Eubacteriae: Pseudomonas sp. Pseudomonas was listed by Hutton (1964) as a parasite in shrimp along the Florida west coast.

Class Telosporidae: Cephalolobus penaeus Kruse, 1959. This gregarine was isolated from the digestive tract of shrimp (Kruse, 1959). Kruse found 20.8 percent of a sample infected with this parasite. It is found in numerous Florida localities (Hutton, 1964).

Nematopsis penaeus Sprague, 1954. The young forms of this gregarine were isolated from the intestines of shrimp (Kruse, 1959). It occurs in numerous Florida localities (Hutton, 1964).

Class Cnidosporidea: Thelohania sp. This parasite occurs in muscles and body organs. Kruse (1959) reported 1.9 percent infection in 784 pink shrimp examined, and considered this organism to be a cause of the "cotton" or "milk" condition which makes shrimp unacceptable for marketing in the United States. Found in Alligator Harbor and Apalachicola Bay, Florida.

Thelohania duorara Iversen and Manning, 1959. Body muscle fibers and legs of shrimp are infected by this organism which causes a milky color. The incidence of infection is low (Iversen and Manning, 1959), but it is found in numerous Florida localities (Hutton, 1964).

Nosema nelsoni Sprague, 1950. This organism, isolated from the body muscle tissue, causes a cotton or milky appearance of shrimp flesh. It has been reported in shrimp from Boca Ciega Bay, Florida (Hutton et al., 1959).

Epistylis sp. This oiliate was isolated from shrimp in numerous Florida localities (Hutton, 1964).

Class Trematoda: Parorchis sp. (tentative identification). A metacercaria was taken from one shrimp from Tampa Bay, Florida (Hutton et al., 1959).

Microphallus pygmaeus (Levinsen, 1881) Baer, 1943. Metacercariae of this trematode were found in shrimp from numerous Florida localities (Hutton, 1964).

Opecoelodes fimbriatus (Linton, 1934). Metacercariae were found in the hepato-pancreas, gonads and other soft tissues of shrimp (Hutton et al., 1959). This trematode occurs in numerous Florida localities (Hutton, 1964).

Class Cestoda: Polypocephalus sp. (=Parataenia sp.). This cestode is found in shrimp from numerous Florida localities (Hutton, 1964).

Prochristianella penaei Kruse, 1959. This organism was isolated from the digestive gland and tissues that surround the digestive gland and stomach. This is probably the most common helminth parasite of pink shrimp. In a sample of 137 shrimp, Kruse (1959) reported 97 percent infected. It is found in numerous Florida localities (Hutton, 1964).

Parachristianella monomegantha Kruse, 1959. This parasite was isolated from the digestive gland. The incidence of infection is extremely low (Kruse, 1959), but it is found in numerous Florida localities (Hutton, 1964).

Parachristianella dimegantha Kruse, 1959. This parasite, recovered from the digestive gland, occurs infrequently (Kruse, 1959), but it is found in numerous Florida localities (Hutton, 1964).

Class Nematoda: Contracaecum habena (Linton, 1900) Linton, 1934. Immature forms were taken from the hepato-pancreas, pyloric gland, cephalothoracic musculature, testes, and ovaries. Incidence of infection was 11 percent (Hutton, Ball and Eldred, 1962). It is found in numerous Florida localities (Hutton, 1964).

Pink shrimp are intermediate hosts for the trematodes, cestodes, and nematodes listed above.

Class Hexapoda (Insecta): An unidentified larva of the family Sarcophagidae was noted in the terminal ampoule of one specimen caught in Tampa Bay, Florida (Hutton and Eldred, 1958).

3.4 Nutrition and growth

3.41 Feeding

Feeding habits of pink shrimp were determined from analyses of stomach contents by Eldred et al. (1961). Pink shrimp are bottom feeders, and juveniles and young adults feed primarily in shallow waters where marine plants grow. Although most feeding is at night, shrimp may feed in the daytime when the water is turbid.

Feeding varies seasonally. Sastrakusumah (1970) reported that feeding activity of juveniles in south Florida was minimal in the late winter and summer, and highest in September. Eldred et al. (1961) suggested that shrimp feed more in the summer than in the winter.

3.42 Food

Idyll (1964) reported that pink shrimp are omnivorous and also ingest inorganic detritus.

Ewald (1965) found that microplankton was suitable food for early larval stages reared in the laboratory. Advanced larval stages and postlarvae were fed nauplii of brine shrimp (Artemia), and microplankton.

Sastrakusumah (1970) reported that crustaceans and polychaetes are the main foods of juvenile pink shrimp in south Florida waters. He detected no difference in diet seasonally, or between small and large specimens.

Eldred *et al.* (1961) recorded the following items from stomachs of juvenile and adult shrimp from the Tampa Bay, Florida, area: sand, debris, algae, diatoms, seagrass particulates, dinoflagellates, foraminiferans, nematodes, polychaetes, ostracods, copepods, mysids, isopods, amphipods, caridean shrimps, caridean eggs, mollusks and fish scales.

Williams (1955) and Broad (1965) listed foods in shrimp stomachs, but these lists include items ingested by several species of Penaeus.

3.43 Growth rate

Growth rates have been calculated or estimated by a number of authors. These rates are reported as increases in weight or length per unit time. Length frequently is given as either carapace length or total length. Growth of larvae and postlarvae was observed under laboratory conditions. Estimates of growth rates for juvenile and adult shrimp are based on marking (release-recovery) data, and on length-frequency distributions. For conversions of various size measurements, see 4.13.

Rates of growth, as measured by length increases, vary with size and sex (Iversen and Jones, 1961) and water temperature (Williams, 1955; Teinsongrasmee, 1965). As larvae, pink shrimp increase their total length from about 0.38 mm (nauplii) to 4.1 mm (postlarvae) in 2 to 3 wk (Dobkin, 1961; Ewald, 1965). Estimates of juvenile growth range from about 7 to 52 mm total length per mo (Williams, 1955; Costello and Allen, 1959; Costello and Allen, 1961; Eldred *et al.*, 1961; Tabb, Dubrow and Jones, 1962), whereas monthly increments of subadult and adult shrimp range from 0 to about 22 mm (Costello and Allen, 1960; Iversen and Idyll, 1960; Iversen and Jones, 1961; Costello, 1963; Kutkuhn, 1966; Knight, 1966; McCoy and Brown, 1967).

3.44 Metabolism

Steed and Copeland (1967) reported that the metabolic rate of pink shrimp in sea water, as measured by oxygen consumption, is lower than that of brown shrimp. When the animals were exposed to petrochemical waste, however, the metabolic rate of pink shrimp increased, and that of brown shrimp decreased.

Osmotic regulation in pink shrimp is influenced by temperature (Williams, 1960). Pink shrimp adjust rapidly to salinity changes in a normal range of temperatures, but at lower temperatures, regulation is more difficult.

3.5 Behaviour

3.51 Migrations and local movements

The larvae of pink shrimp are planktonic and move vertically in the water column, generally ascending at night and descending in the daytime (Jones *et al.*, in press). As age increases, the larvae move farther from the bottom.

For migrations of larvae as related to currents, see section 2.3.

Migrations of postlarvae also are effected by currents. In south Texas, most postlarvae migrate into the bays "when the bays are being refilled after previous seasons of low water" (Copeland and Truitt, 1966). Migration into the nursery grounds of south Florida is on the flood tides (Tabb, Dubrow and Jones, 1962; Idyll and Jones, 1965). According to Hughes (1969a), tidal transport of postlarvae may be initiated by the organisms' response to tidal salinity changes.

In the Everglades National Park, juveniles migrate usually at night on the ebbing tides (Idyll, Iversen and Yokel, 1964). Further observations in the same area were made by Idyll, Iversen and Yokel (1966), who reported, "periods of high relative abundance occur in spring, summer and early fall, but ... inter-year variation is considerable." These authors noted that the smallest shrimp usually appear when relative abundance is highest.

Several factors may cause migration of pink shrimp. Tabb, Dubrow and Jones (1962) suggested that juveniles move to escape unfavourable conditions such as sudden reductions in water temperature and salinity. Extensive movements from the estuaries to the offshore grounds take place as maturity approaches. These movements apparently are breeding migrations (Broad, 1951; Allen, 1966). Tabb and Jones (1962) suggested that a hurricane caused shrimp to move from south Florida estuaries to the offshore grounds earlier and at a smaller size than usual.

Juvenile shrimp from the Everglades National Park migrate to the offshore Tortugas grounds (Iversen and Idyll, 1960; Costello and Allen, 1966). Observations on the timing and direction of pink shrimp migrations from south Florida estuaries to the Tortugas and Sanibel grounds were made by Costello and Allen (1966), who reported

that juveniles spend from 2 to 6 mo in the nursery areas before migrating offshore. These investigators noted that some marked shrimp traveled at least 277 km before recovery on the offshore grounds, and although migration routes were broad, shrimp that left particular sections of the nursery grounds demonstrated distinct distributional patterns on the offshore grounds. Once they reached the offshore grounds, the shrimp generally continued to move into deep water (Iversen and Idyll, 1960; Costello and Allen, 1966).

Migration of pink shrimp in North Carolina waters was reported by McCoy and Brown (1967). Movement out of the estuaries apparently was influenced by tide. In the ocean, migration was southward along the coast.

(See also 2.21 and 3.23.)

3.52 Schooling

The movements and catches of the shrimping fleet indicate that, at times, pink shrimp may school; schooling may be by size.

Stocks of pink shrimp probably mix frequently. Costello and Allen (1966) reported some overlap between stocks of the Tortugas and Sanibel grounds, Florida. They stated, however, that "Apparently, Tortugas shrimp do not migrate to the Sanibel grounds and migration from the Sanibel to the Tortugas grounds is minimal."

Pink shrimp are taken frequently in trawl catches with several other species of shrimp. Williams (1955) observed that in North Carolina, the seasons during which white shrimp, brown shrimp and pink shrimp appear in the nursery grounds are fairly distinct; however, there is some mixing of postlarvae. Adults mix wherever they occur in the same general area.

Vertical movements of pink shrimp were reported by Costello and Allen (1968), who observed shrimp in dense schools "near the surface at night." Concerning night-time vertical movements of migrating juveniles, Beardsley and Iversen (1966) stated: "An average of about 91% of the shrimp caught on full moon tides were taken on or close to the surface; only about 75% were caught in the surface layers during new and quarter moon tides."

3.53 Responses to stimuli

Environmental stimuli

Pink shrimp burrow into the substrate as "a protective measure against predators and adverse environmental conditions" (Fuss and

Ogren, 1966). In the laboratory, they have buried in sand to a depth of 15.3 cm (Eldred *et al.*, 1961). The depth of burrowing may be influenced by shrimp size (Fuss, 1964), and bottom type (Williams, 1958).

The response of pink shrimp to light may vary with shrimp size or with light intensity (Fuss and Ogren, 1966). Larvae held in aquaria are positively phototrophic (Ewald, 1965). In a natural environment, however, the larvae migrate vertically away from the water surface during the day (see 3.51). Juveniles respond positively to moonlight by moving to the water surface on the ebb tide (Beardsley, *in press*). Ordinarily, adults are buried in the substrate during daylight and are active at night (various authors), but juveniles and adults may be active by day under conditions of low light level (Eldred *et al.*, 1961). Juveniles, moreover, tend to be more active than adults in the daytime (Eldred *et al.*, 1961; Fuss and Ogren, 1966; Hughes, 1968). Fuss and Ogren (1966) considered burrowing activity a direct effect of light at the time of the burrowing. Wickham (1967) and Hughes (1968), however, presented evidence that diurnal activity of juveniles and young adults is influenced partly by previous light-intensity experience.

Under laboratory conditions, juvenile shrimp showed nocturnal activity peaks that probably were related to tidal rhythm (Wickham, 1967). Activity of juveniles also may be affected by water movement and water height (Wickham, 1967), and that of juveniles and adults by feeding (Hughes, 1968). Hughes (1969a) found that salinity affected the tide-associated movements of postlarval and juvenile pink shrimp.

Tabb, Dubrow and Jones (1962) observed that the oxygen depletion and buildup of hydrogen sulphide that followed a hurricane caused pink shrimp to swim at the water surface in full sunlight.

See 2.3 for responses to salinity and currents, and 2.3 and 3.16 for effects of temperature.

Artificial stimuli

Burrowed pink shrimp responded to mechanical stimulation of their dorsal body surfaces by burrowing deeper into the substrate (Fuss, 1964). Continued agitation of the dorsal surfaces or stimulation of the animals' sides caused the shrimp to hop vertically out of the substrate.

Photo-orientation of juvenile and young

adult shrimp was studied by Jachowski and Myrberg (1968). The shrimp were attracted more frequently toward light than toward darkness, and toward higher intensities and longer wavelengths than toward lower intensities and shorter wavelengths. Maximum artificial photoactivation of juveniles and young adults was during the full moon, minimum during the new moon (Aaron and Wisby, 1964). Photoactivation and phototactic drive varied with shrimp size but not with sex.

Electrical stimuli

Pink shrimp, mostly adult, subjected to interrupted direct current, responded by flipping, tail first, toward the anode (Higman, 1956). This galvanotaxic reaction, affected by shrimp size and position, pulse width and water temperature, causes pink shrimp to hop from their burrows (Kessler, 1965). The intensity of the response lessens when the shrimp is shocked repeatedly (Nelson, 1962).

4 POPULATION

April and the largest ones (about 140 mm total length) in September.

4.1 Structure

The size composition of captured pink shrimp is affected by the time of day that fishing is done. In Tampa Bay, the largest shrimp were caught at night (Eldred et al., 1961; Saloman, 1968).

4.1.1 Sex ratio

Saloman (1965) reported a sex ratio of about 1:1 after examining 11,695 juvenile pink shrimp from Tampa Bay, Florida. Idyll (1964) also reported a sex ratio of about 1:1, but he noted (as did Broad, 1951) that the ratio may vary with season and size of shrimp.

Conversions of size measurements were given by Kutkuhn (1962), Kutkuhn (1966), and Fontaine and Neal (1968). Formulas for the total length-total weight relationship in pink shrimp are as follows:

4.1.2 Age composition

female, $w = 5.06 \times 10^{-6} L^{3.12}$,
male, $w = 4.49 \times 10^{-6} L^{3.13}$ (Kutkuhn, 1966).
(see 3.11, 3.12 and 4.12)

Age composition of the commercial catch varies with recruitment, migration, mortality and practices of the fishing fleet.

4.2 Abundance and density of population

Age at various life stages can be estimated with size-age conversions provided by Kutkuhn (1966). The youngest pink shrimp for commercial use are captured in the bait shrimp industry. These shrimp are about 6 wk old, since Saloman (1965) has reported bait shrimp marketed as small as 47 mm total length. Male and female shrimp that reach sexual maturity at 75 and 85 mm total length, respectively (Eldred et al., 1961), may be 9 or 10 wk old. Kutkuhn (1966) gave 15 wk (107 mm total length) as the age when shrimp are first recruited to the Tortugas fishery, where they have a fishable life span of about 68 wk. He also estimated 83 wk as the average maximum age. Absolute maximum age is not known, but Eldred et al. (1961) suggested that specimens 200 mm total length may be 2 yr old or more.

4.2.2 Changes in abundance

4.1.3 Size composition

Fishing effort and practices are variable, but in certain areas, such as the Tortugas grounds, landings may reflect actual changes in abundance. Monthly changes in abundance by area (Fig. 5), were compiled from Fishery Statistics of the United States (United States Bureau of Commercial Fisheries) and Kutkuhn, 1962a. Annual landings by United States vessels are listed in Table I. For areas of capture, see Fig. 2.

Size composition varies similarly to age composition. (See 4.1.2.)

Seasonal and geographic changes in abundance as well as annual fluctuations may result from varying oceanographic conditions. (See 2.3, 3.16 and 4.33.)

It is generally true that small, immature pink shrimp live near shore, and large, mature individuals offshore. Size increases with depth of water (Iversen, Jones, and Idyll, 1960). Shrimp caught in Tampa Bay, Florida, ranged from 11 (Eldred et al., 1961) to 144 mm total length (Saloman, 1965). On the Tortugas grounds, however, shrimp ranged from about 49 to 230 mm total length (Iversen, Jones and Idyll, 1960).

The exploitation of newly recruited shrimp may affect annual yields in the Tortugas fishery (Kutkuhn, 1962a).

Annual landings from the Tortugas grounds showed "No marked changes or trends ..." from 1951 to 1965, although they fluctuated from year to year (Berry, 1966).

4.2.4 Changes in density

Size composition also varies seasonally. In Tampa Bay, the smallest average size (about 31 mm total length) was in the summer and the largest (about 82 mm total length) in the late spring (Eldred et al., 1961). Length-frequency data from the Tortugas fishery (Wheeler, Benton and Hudson, 1965) showed that shrimp with the smallest average sizes (about 95 mm total length) were caught in

Kutkuhn (1962a) found that catch-per-unit intensity values were highest in the Tortugas fishery in the late autumn and lowest in the spring. He noted a downward trend in the Tortugas annual population from 1956 to 1959, but a population buildup from 1956 to 1958 for the Apalachicola (Florida) area, followed by a decline in 1959.

On the Tortugas grounds, shrimp are most dense in the shallowest waters and least dense in the deepest waters (Lindner, 1966).

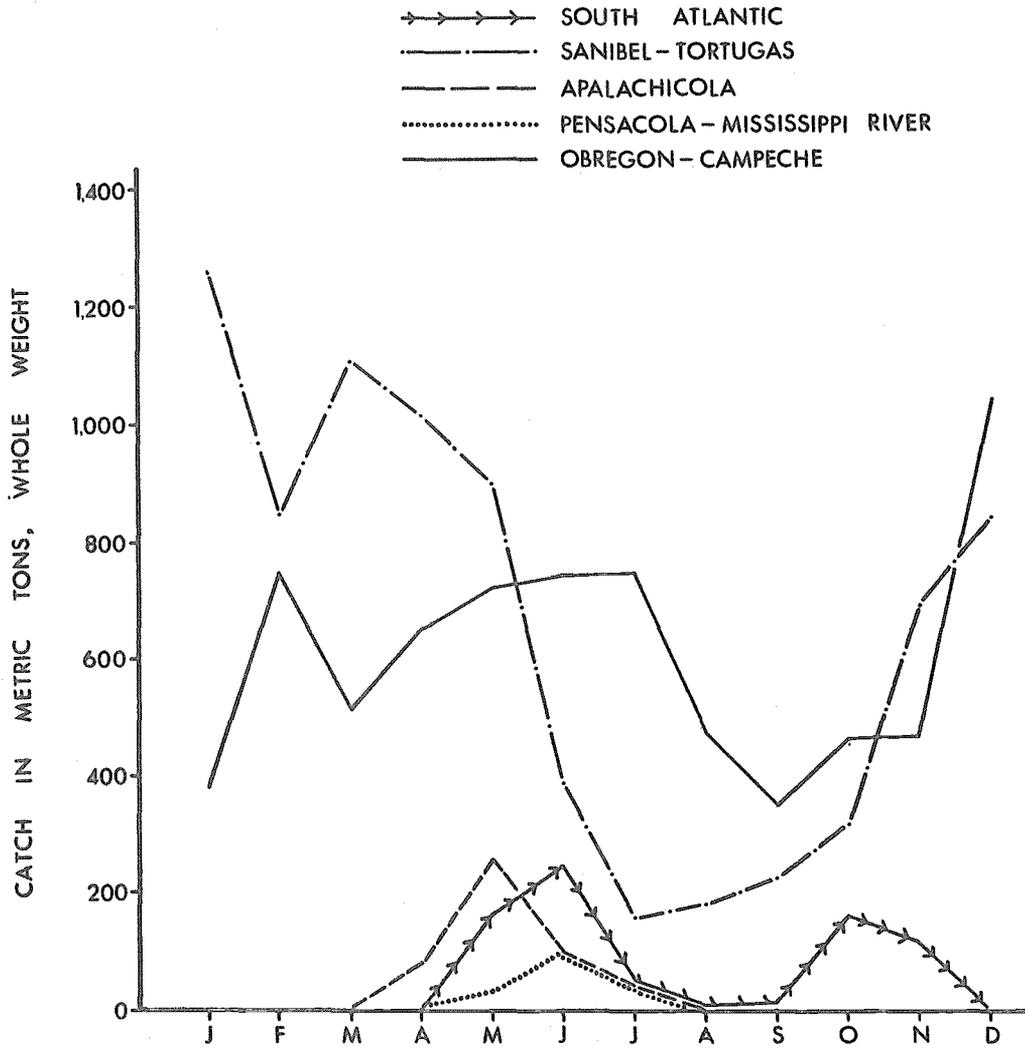


Fig. 5 Major United States pink shrimp fisheries (seasonal abundance as indicated by average monthly landings 1957-59).

TABLE I

Annual landings (metric tons, whole weight) of pink shrimp by United States vessels and area of capture, 1951-66^{1/}. Data for earlier years not available for all areas

Year	North Carolina	South Carolina Georgia-Florida east coast	Sanibel-Tortugas	Apalachicola	Pensacola to Mississippi River	Mississippi River to Texas	Texas	Mexico, west of long. 94°W	Mexico, Obregon-Campeche
1951	--	--	8,314.2	--	--	--	--	--	3,550.6
1952	--	--	4,952.4	--	--	--	--	--	9,931.2
1953	--	--	7,529.3	--	--	--	--	--	13,961.8
1954	--	--	7,893.9	--	--	--	--	--	10,748.6
1955	--	--	8,916.3	--	--	--	--	--	10,498.4
1956	--	--	9,246.9	577.9	345.5	1.1	26.9	2.1	10,601.5
1957	961.0	17.4	7,209.9	388.2	380.9	0.06	3.0	0	9,193.4
1958	368.8	4.7	10,665.3	1,080.5	82.0	8.2	54.6	4.3	5,806.8
1959	934.8	0.3	6,011.2	4.8	121.4	4.4	6.9	6.9	7,085.8
1960	556.3	0	10,670.1	343.0	49.1	0.03	47.3	3.1	7,998.9
1961	792.8	0	8,070.8	904.6	151.8	7.2	30.3	0	8,192.4
1962	1,018.0	1.0	6,391.9	682.9	45.6	0.04	7.7	8.0	8,753.1
1963	251.4	0	7,733.7	1,408.8	154.6	0.3	8.6	4.6	7,840.7
1964	878.5	5.2	9,013.5	1,176.8	70.0	3.5	29.4	6.2	8,361.1
1965	765.3	0	9,306.0	1,304.8	29.0	3.1	10.9	2.4	7,896.2
1966	240.1	0.8	9,649.0	453.9	36.4	1.2	23.2	2.9	2,772.6

^{1/} 1951-55 from Idyll (1964); 1956-66 compiled from Fishery Statistics of the United States, published annually by the United States Bureau of Commercial Fisheries.

4.3 Natality and recruitment

4.31 Reproduction rates

For survival rates of larvae, see 3.22 and 4.41.

4.32 Factors affecting reproduction

(See 2.3 and 3.16.)

4.33 Recruitment

For recruitment of postlarvae to the estuaries, see 2.21.

The relative abundance of juveniles emigrating from Everglades National Park can be positively correlated with the subsequent commercial catch on the Tortugas grounds (Yokel, Iversen and Idyll, 1969).

Migration studies (Costello and Allen, 1966) indicate that young adult shrimp are recruited to the Tortugas fishery year around. Maximum recruitment is in the spring and autumn (Berry, 1966). In more northerly pink shrimp fisheries, recruitment is seasonally more restricted (Fig. 5).

For factors that influence recruitment, see 2.3, 3.16, 3.34, 3.43, 3.51 and 4.42.

4.4 Mortality and morbidity

4.41 Mortality rates

Mortality rates for the larvae of pink shrimp have been estimated as a nearly constant 17 percent per day (Munro, Jones and Dimitriou, 1968). Only a small percentage of the larvae produced survive to become juveniles.

Estimates of mortality in adult populations are based on data from mark-recovery experiments and, in one study (Berry, in press), on the decline in abundance of age groups. In the estimates in Table II, derived from experiments performed in waters off south Florida, Z is the instantaneous total mortality coefficient; F is the instantaneous coefficient of mortality caused by fishing; and X is the instantaneous coefficient of other losses in the marking theory, including true natural mortality (M) plus losses of individuals which for any reason become unavailable for recapture.

4.42 Factors causing or affecting mortality

Causes of mortality are varied. Periodically, large numbers of pink shrimp perish as a result of hurricanes (Tabb and Jones, 1962). Occasionally, red tide (marine water which is toxic due to excessive concentrations of the dinoflagellate, Gymnodinium breve) causes mass mortality of pink shrimp (Gunter, Smith and Williams, 1947).

4.43 Factors affecting morbidity

(See 2.3 and 3.35.)

4.6 The population in the community and the ecosystem

The optimum habitat for pink shrimp varies with shrimp size (Eldred, 1962). Young shrimp prefer quiet, clear, shallow waters and firm substrates, with protective growth such as turtle grass (Viosca, 1957). According to Hoese and Jones (1963), characteristic associates of juvenile shrimp in a south Texas turtle grass community were: rainwater killifish, Lucania parva; mojarra, Gerres cinereus; pinfish, Lagodon rhomboides; goby, Gobiosoma robustum; mud crab, Neopanope texana; and grass shrimp, Palaemonetes pugio.

Adult shrimp typically inhabit offshore waters that have no seagrasses. The faunal associates of adult shrimp on the Campeche grounds in the 11- to 29-m depth included the following: fighting conch, Strombus alatus; West Indian chank, Xanopus angulatus; portunid crab, Portunus spinimanus; redmouthed grunt, Bathystoma aurolineatum rimator; and porgy, Stenotomus caprinus (Hildebrand, 1955). (See also 2.2 and 2.3.)

TABLE II
Estimates of mortality rates of pink shrimp in Florida waters

Source	Z	F	X	Rates of reduction per	
				1-week period	Other losses
				Fishing	
Iversen (1962)	--	0.02393	0.05998	--	--
Kutkuhn (1966)	1.51	0.96	0.55	62%	42%
Berry (1967)	0.22-0.27	0.160-0.227	0.024-0.061	14.8-20.3%	2.4-5.9%
Berry (in press)	0.10-0.16 (males)	--	--	--	--
	0.07-0.12 (females)	--	--	--	--
Gostello and Allen (1968)	0.233 0.357	0.0689 0.1385	0.1644 0.2185	6.8% 13.1%	14.8% 19.7%

5 EXPLOITATION

5.1 Fishing equipment

5.1.1 Gears

The fishing gears used in estuaries or in relatively shallow near-shore waters to capture young pink shrimp for bait or food vary regionally. In North Carolina, fishermen use otter trawls (Broad, 1951a) and channel nets (Guthrie, 1966). Another type of channel net is used in Florida (Higman, 1952). Also used in Florida are pushnets (De Sylva, 1954), dipnets (Iversen and Van Meter, 1964; Joyce, 1965), bridge nets (Higman, 1952), and roller frame trawls (Woodburn *et al.*, 1957; Tabb, 1958). On the Yucatán Peninsula, Mexican fishermen use beach seines and traps (Idyll, 1964).

In the shallow water United States fisheries, most pink shrimp are caught with roller frame trawls. These trawls usually are constructed of iron pipe and rods and have rectangular openings 1.8 to 3.0 m wide and 61 to 77 cm deep. The bottom parts of the frames serve as attachments for trawl nets that terminate in cod ends similar to those used on small otter trawls. This gear is effective in grassy areas in shallow water. The rollers (about 127 mm in diameter) move over the seagrass without uprooting it, and rakes, built on the frames, prevent large objects from entering the frame mouths. (Otter trawls used in grassy areas soon fill with uprooted grass and are ineffective.) Roller frame trawls used to catch live shrimp for bait are emptied about every 10 to 15 min.

Otter trawls are the principal gear fished in deep water. The trawls used in the United States have been described by Bullis (1951), Knake, Murdock and Cating (1958), and Robas (1959). The mesh size of the cod end of the trawling gear used inshore is typically 25.4 to 41.4 mm stretch measure, whereas the mesh size of that used offshore is usually 50.8 to 57.2 mm. Thread sizes range from about 36 to 48 in the cod ends, and from 12 to 18 in the body and wings of the trawls. Doors of the otter trawl vary with trawl size and vessel horsepower. Until about 1957, single otter trawls with openings 24 to 31 m were used in the United States, but at present, most vessels fish two otter trawls, each opening 12 to 14 m. Also, a third, small otter trawl-- the trynet-- is fished to determine the density and size of shrimp at a particular location. If it produces good catches, the large nets are lowered. Trawls are dragged about 3 h at a speed of 2 to 3 kn (3.7 to 5.5 km/h) and then taken aboard, emptied and reset.

Fishing for pink shrimp is usually at night, because these animals typically are buried in the bottom during the day. Recently, trawling gear was developed that employs an electrical field which causes pink shrimp to leave their burrows (Pease and Seidel, 1967) and enables fishermen to take shrimp in daylight.

Descriptions of various types of shrimping gear were given by Dumont and Sundstrom (1961).

5.1.2 Boats

Shrimp boats range from 4-m skiffs powered by outboard motors to 34-m vessels with a gross weight of 118 metric tons powered by 360 hp diesel engines.

Most vessels used in shallow waters have wooden hulls and shallow draft and are less than 15 m long. They are powered by engines that burn either diesel or gasoline fuel; most engines are 140 hp or less.

Typical shrimp trawlers used offshore are 18 to 21 m long, are powered by a diesel engine of 200 to 300 hp, and have a gross weight of about 61 metric tons. Hulls are usually wood, but now steel hulls are being built and are recommended especially for boats longer than about 18 m. These boats generally have a single propeller and incorporate a 3-drum winch with a power takeoff from the main engine to handle the otter trawls and trynet. The development of large vessels with more power has been necessary to accommodate the double-rig trawls and large otter trawls now in use.

Most shrimp trawlers are of conventional hull design, although at least one catamaran (double hull) shrimp trawling vessel, 21 m long, was launched and used in the Gulf of Mexico. Aluminum hulls and fibreglass reinforced hulls may be used in the near future (Captiva, 1967).

Ringhaver (1960) described the design and rigging arrangements of shrimp trawling vessels.

5.2 Fishing areas

5.2.1 General geographic distribution

Pink shrimp are fished throughout most of their range. Williams (1965) observed, however, that pink shrimp are not uniformly abundant and that fisheries are "concentrated at diverse points."

Fishing areas are shown in Fig. 2. Major fisheries for bait or food shrimp in estuaries or shallow inshore waters are in North Carolina, Florida, and Campeche, Mexico (land areas 238 and 311) (Burkenroad, 1949; Woodburn et al., 1957; Idyll, 1964; Joyoe, 1965; Costello and Allen, 1966). The major offshore fisheries are off North Carolina, the Florida west coast, Alabama, Mississippi, and Campeche (land areas 238, 235, and 311) (Broad, 1951; Kutkuhn, 1962a). By far the largest pink shrimp fisheries are the Tortugas fishery off the southwest coast of Florida and the Campeche fishery off the west coast of the Yucatán Peninsula (Kutkuhn, 1962a).

5.22 Geographic ranges

The distance of fishing areas from the coast varies throughout the pink shrimp range and with the type of fishery. Bait shrimping often takes place a few meters from shore. The Tortugas fishing grounds, however, extend from about 83 to 222 km from the mainland coast (Costello and Allen, 1968).

5.23 Depth ranges

Depths in which pink shrimp are caught vary regionally and with the type of fishery. Bait shrimp are taken in waters as shallow as 0.5 m and most adult shrimp are caught in waters between 9 and 60 m.

(See 2.22.)

5.24 Conditions of the grounds

Offshore shrimp grounds are usually areas of smooth bottom suitable for trawling. In the eastern Gulf of Mexico, they "are characterized by sand, shell and coral gravel; and by live coral overlying white, gritty, calcareous mud" (Springer and Bullis, 1954). Typically, the bottom on the Tortugas grounds is silt and mud, with 20 to 25 percent white coral sand (Idyll, 1964). The Tortugas and Campeche grounds have dead shell and patches of coral and sponge (Springer and Bullis, 1954; Hildebrand, 1955).

For conditions of the estuarine and inshore fishing grounds, see 2.3.

5.3 Fishing seasons

5.31 General pattern of seasons

Fishing seasons vary with the type of fishery and with geographic location. In North Carolina estuaries, juvenile pink shrimp are caught for food during May, June and July (Burkenroad, 1949). In south Florida estuaries, such as Biscayne Bay, juveniles are taken for live bait throughout the year (Saloman, Allen and Costello, 1968). Here, peak catches are in the winter and spring (Welch, 1965; Jones and Smith, 1966).

Seasonal variations in offshore fisheries for adult pink shrimp are shown in Fig. 5. Off North Carolina, South Carolina, Georgia, and northeast Florida (South Atlantic fishery), shrimp are taken from April to December; catches are greatest in June and October. Off southwest Florida (Sanibel-Tortugas grounds), the fishing season is year around, and catches are highest in the winter and spring. The fishery near Apalachicola, Florida, is from March to August with greatest catches made in May. In the Pensacola-Mississippi River area, shrimp are taken from April to August and peak landings are in June. The Obregon-Campeche grounds produce large quantities of shrimp throughout the year with peaks in the winter and early summer.

5.4 Fishing operations and results

5.41 Effort and intensity

The unit of effort in United States otter trawl fisheries for pink shrimp is designated "days fished". This unit, representing 24 h of fishing effort, is used by the United States Bureau of Commercial Fisheries in their statistical reports for uniformity in tabulation of data.

Fishing effort also is reported by the United States Bureau of Commercial Fisheries as the number of trips made by commercial fishing vessels in a given time period. Landings per unit of fishing effort may be calculated from U.S. statistical data because landings and effort are reported for specific areas. A few reports deal with catches per unit area, or both.

The following tabulation, abridged from Kutkuhn (1962a), shows offshore fishing effort in the Gulf of Mexico primarily for pink shrimp. The units represent the numbers of 24 h periods fished.

<u>Area</u>	<u>1956</u>	<u>1957</u>	<u>1958</u>	<u>1959</u>
Sanibel-Tortugas	17,519	17,356	20,690	17,098
Obregon-Campeche	22,236	21,491	16,899	19,709

Fishing effort and intensity vary because of shrimp availability, size of shrimp, market price, weather conditions, vessel efficiency, and regulatory measures (Iversen and Idyll, 1959; Iversen, 1962). In addition, effort is affected by: (1) seasonal changes in the number of hours of darkness; (2) changes in moon phase, i.e., fishermen report poorer catches when the moon is full than when it is waning or waxing; and (3) changes in amount of jellyfish (*Aurelia* sp.) or algae, i.e., excessive amounts clog nets (Iversen and Idyll, 1959).

During the period 1950-59, fishing effort increased on the Tortugas grounds but total catch "remained fairly constant" (Iversen and Jones, 1961). Available information suggests a decline in the catch per unit of effort during this period.

5.42 Selectivity

The selectivity of various sizes of trawl mesh in catching pink shrimp was reported by Regan, Idyll and Iversen (1957). They reported escapement of pink shrimp through cod ends of varying mesh sizes as shown in Table III.

Berry and Hervey (1965) studied the selectivity of various mesh (stretched) sizes as applied to Gulf of Mexico shrimp (species not given) and suggested that, because large mesh increases fishing power, "the catch of large shrimp by nets with 2 1/2- and 3-in [63.8- and 76.2-mm] meshes should be approximately 15 and 20 percent greater than the catch by

1 1/2- or 2- in [38.1- or 50.8-mm] mesh nets...trawls with large meshes throughout will permit some marketable shrimp to escape and therefore could profitably be used only in certain situations."

Market preference affects the sizes of pink shrimp retained by fishermen in some areas. On the Tortugas grounds in 1963, approximately 11 percent of the total catch (by weight) was not landed because the shrimp were too small for the market (Wheeler, Benton and Hudson, 1965). Discarding declined from 1963 to 1966, apparently because of the increased value of the small shrimp (Berry and Benton, 1969).

5.43 Catches

Monthly and annual records of catches of bait shrimp (mostly pink shrimp), although not complete, are given in Summary of Florida Commercial Marine Landings, which is published annually by the Florida Board of Conservation.

Total annual yields of pink shrimp in the offshore waters of the United States are given in Fishery Statistics of the United States, published by the United States Bureau of Commercial Fisheries. Table I lists annual landings of pink shrimp by United States vessels. A comparison of yields from different areas is shown in Fig. 5.

TABLE III

Escapement of pink shrimp through cod ends
of varying mesh sizes

Mesh size ¹ in cod end (mm)	Shrimp size (number of tails per pound ²)	Escapement through cod end (percent)
44.5	110	10
	83	5
	51	0
50.8	110	50
	83	10
	51	0
57.2	83	30
	51	10
	33	0
63.8	83	40
	51	15
	33	5

¹ Measurement between the midpoints of knots (stretched mesh)

² 1 pound equals 0.45 kg

6 PROTECTION AND MANAGEMENT

6.1 Regulatory (legislative) measures

6.11 Limitation or reduction of total catch

The efficiency of gear fishing for pink shrimp has been controlled in certain Florida fisheries. Limits are placed on the size of trawling gear used to take live bait shrimp. This regulation limits the total catch in some areas.

6.12 Protection of portions of population

The usefulness of certain laws to protect small shrimp is the subject of some controversy. For example, a 1956 Florida regulation placed limitations on the mesh size of ood ends of trawls used on the Tortugas grounds, but the regulation was later withdrawn (Idyll, 1957). Another Florida regulation is a "size-limit" law designed to prohibit the taking of undersized pink shrimp in the Tortugas area. Lindner (1966) reviewed the problem

of regulations applying to pink shrimp and recommended that the size-limit law be repealed. He observed that "The size distribution of our shrimp on the fishing grounds is such that size limits cause more waste than benefit."

Regulations specifying a sanctuary for small pink shrimp were applied in a section of the Tortugas grounds in 1957. The area is closed to trawling when it is determined that shrimp smaller than 50 to the pound (0.45 kg), heads off, predominate in the area.

In the United States, regulations that apply to commercial shrimp close certain areas at specified seasons in States bordering the Gulf of Mexico, and in Georgia and the Carolinas.

Generally, no restrictions are placed on the use of pink shrimp. For the fishery in Biscayne Bay, Florida, however, a regulation specifies that shrimp are to be taken only for use as live bait.

7 POND CULTURE

Pond cultivation of pink shrimp is just beginning and information on the culture of this species is scarce. Information on culture of related shrimp species is provided by Cook and Lindner (1970), and Lindner and Cook (1970).

7.1 Procurement of stocks

Ewald (1965) captured large, ripe female pink shrimp on the Tortugas grounds with a trynet to obtain spawning stock. The shrimp were transported to the laboratory in plastic garbage cans.

7.3 Spawning (artificial, induced, natural)

Laboratory spawning of shrimp captured on the Tortugas grounds was described by Ewald (1965): "At the laboratory, individual shrimp were placed in 15-gallon running seawater aquaria. Spawning, if it occurred, was within two days after return to the laboratory and always in the very early hours of the morning. Water temperature in aquaria at times of spawning was 27° and 29° C. The eggs, being demersal, settled to the bottom of the aquaria. They were present in such great numbers that they were visible to the naked eye and appeared like fine, white powder."

7.4 Holding of stock

Ewald (1965) held larval pink shrimp individually in compartmented plastic boxes. Survival was better in Gulf Stream water (oceanic) than in Biscayne Bay water (estuarine). Survival was best and development time least at a water temperature of 26° C.

Costello and Allen (1959) held pink shrimp in a small salt-water pond with a sand-mud bottom for 3½ mo while the shrimp grew from juvenile to adult size.

In a later experiment, juvenile shrimp were held in the same pond at water temperatures ranging from 26° to 33° C and salinity from 27 to 36‰ (Costello and Allen, 1961).

7.6 Foods; feeding

Ewald (1965) provided a mixture of several unicellular algae and a marine yeast as food for early larval stages of pink shrimp. The last mysis stage and early postlarvae were fed nauplii of brine shrimp (Artemia).

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