1962. Abnormally large numbers of small brown shrimp, according to reports of fishermen, were discarded at sea off the Texas and Louisiana coasts during this period. Over a 10-day period in August, 1962, observations aboard a commercial trawler operating off Aransas Pass, Texas, revealed that approximately 26 percent by weight (30 percent by number) of its shrimp catch was being discarded because it failed to meet the minimum legal size. Texas law forbids the commercial fleet to land shrimp of 50 headless-count size or smaller. If we assume that shrimp at this life history stage grow in length about 15 mm per month, the discard rate a month earlier (July) would have been about 50 percent by weight (60-70 percent by number).

SUMMARY

To determine their possible use in predicting catch potential for the commercially important brown shrimp, indices derived from the results of 3 years' postlarvae sampling inside Galveston Entrance are correlated with corresponding measures of juvenile abundance on the nursery grounds and, in turn, with appropriate measures of adult abundance on offshore fishing grounds. Although further work is necessary in order to establish its reliability, it is apparent that the postlarval index forecasts quite well the relative magnitude of subsequent juvenile abundance in estuarine areas, as well as the ultimate quantity of commercial-size shrimp available offshore.

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A Biological Study and Some Economic Aspects of Squid in Tampa Bay, Florida

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Abstract

Distribution of the squid *Lolliguncula brevis* by time and area is described for Tampa Bay and its adjacent waters. Tolerances of *L. brevis* to salinity and temperature are discussed. Particular emphasis is placed upon size at which sexual maturity occurs. A discussion of the economics of the squid fishery is given.

INTRODUCTION

SQUID ARE HEAVILY EXPLOITED for human consumption in many parts of the world (Voss, 1959). Only in recent years has the squid fishery in Florida begun to attract attention. Present catch statistics show evidence of a progressive increase in annual squid landings. In addition to the Florida squid, consisting principally of *Loligo pealeii* and *Lolliguncula brevis,* the fish markets in this state regularly sell *Illex illecebrosus* and *Loligo opalescens,* which are imported from Newfoundland and California, respectively.

Prior to this investigation all published work on squid in the Gulf of Mexico pertained to systematics and geographic distribution (Voss, 1950, 1954, 1955, 1956a and 1956b). Most of Voss' information was based upon material collected by the United States Fish and Wildlife Service Vessel, OREGON. In addition, Gunter (1950) and Tabb and Manning (1961) recorded salinity and temperature ranges and distribution of *Lollinguncula brevis* in the northern Gulf and the waters of Cape Sable, Florida.

Research described in this report was accomplished in connection with an estuarine study of Tampa Bay and adjacent waters. The purpose of this study was to examine the biological, ecological and economic aspects of an animal which appears to be an important member of the estuarine community.

The authors wish to express their appreciation to Dr. Gilbert L. Voss, Institute of Marine Science, University of Miami, for the verification of our taxonomic identifications, advice throughout the course of the study, and review of the manuscript. Randall C. Teague, a summer employee, provided technical assistance and James E. Sykes, Chief of this station, developed portions of the manuscript.

Economic Aspects of Squid Fisheries

While the squid fishery in the Gulf of Mexico is still in its infancy, the annual world catch of all cephalopods is approximately one million tons, or the equivalent of about one pound per man, woman, and child on earth (Lane, 1960). During the period 1953 to 1960, squid represented 6.3 to 9.1% of the reported world landings of mollusks. Japan, South Korea, the United States, Spain, China (Taiwan), Canada, Italy, and Greece are the leading nations in squid catches, in that order. Japan and South Korea land about 75% of the world catch. During the period 1953 to 1960, United States fishermen landed 6.1% of the world catch (FAO, 1960).

The oldest and the most productive squid fishery in the United States was established near a Chinese village in Monterey, California (Fields, 1950). The squid fishery in Monterey reached the proportions of a major fishery in 1942. The product is sold within the United States and is also exported to foreign Pacific markets. In 1946 this fishery was valued at $1,214,091, exceeding the value of the sardine catch of the same region. The price of squid varied from $33 to $63 per ton during the period 1935 to 1948. The introduction of lampara nets and modern purse seines, freezing and canning of the catch, and the presence of rich fishing grounds were primary factors in the development of the squid fishery in California.

Although squid are among the most numerous and seemingly inexhaustible animals in the sea, the squid fishery in Florida is still incidental to those for other species. Squid are taken in fish and shrimp trawls. The Florida shrimp fleet takes them in large numbers off Campeche, on the Dry Tortugas grounds,

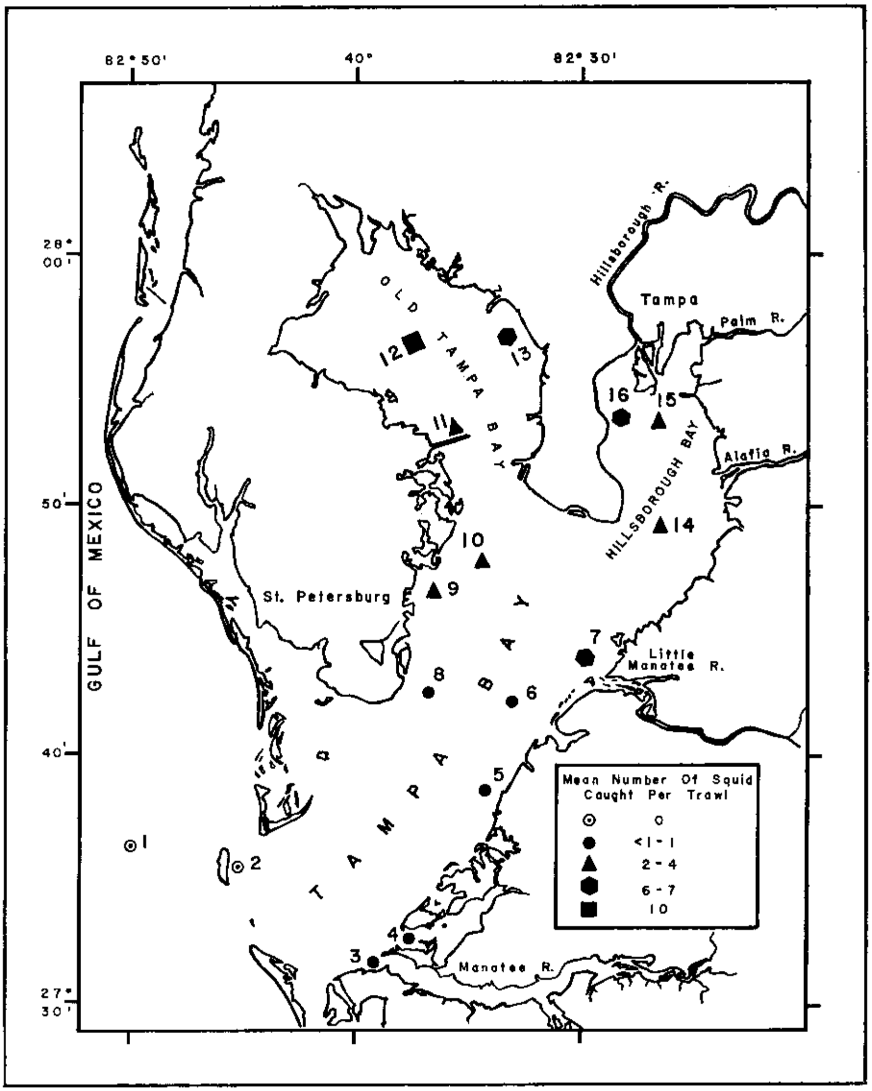

FIG. 1. Tampa Bay sampling stations and distribution of *L. brevis*.

and off Honduras; but they are usually considered trash and thrown overboard (Voss, 1959). Some squid are caught by Tampa Bay fishermen for bait purposes. Despite a progressive trend in squid landings during the past decade, the squid fishery in the Gulf of Mexico still amounts to only $2,000 with a maximum annual landing of 32,000 pounds (U. S. Fish and Wildlife Service, 1960). Florida and Texas are the leading states in squid catches among Gulf

States. The first official squid landings by Alabama and Louisiana were recorded in 1960. At present Mississippi is the only State in the Gulf not reporting squid landings.

These statistics are no reflection of the consumption and market demand for squid and perhaps not even of availability. The annual consumption of squid in the Tampa Bay region alone far exceeds the entire annual landings by the Gulf States. Most of these squid are imported from California and from Atlantic coast states. Squid are retailed in markets at 29 to 39 cents per pound. A single fish market on the Gulf beaches of St. Petersburg, Florida, buys 100,000 pounds of squid annually. This is more than the combined annual landings by all Gulf States. In addition to utilization as fish bait, squid are consumed in the Tampa Bay area for human food. They taste somewhat like scallops or abalone and besides being nutritional are a gastronomic delicacy. The food value of the common Japanese squid when seasoned and canned (Tanikawa, 1952) is as follows: food energy, 117 cal/100 g; crude protein, 17.3%; fat, 1.83%; and carbohydrates, 7.11%.

Squid is a food of many commercially important fishes. In a study of bigeye and yellowfin tuna in the Pacific Ocean, King and Ikehara (1956) found that the food of these fish by volume consisted of 29% squid for yellowfin tuna and 33% squid for bigeye tuna. Squid consumed by these fish were of the families Loliginidae and Ommastrephidae.

There are about 57 species of squid in the Gulf of Mexico (Voss, 1956b). *Loligo pealei,* the common squid, and *Lolliguncula brevis,* the brief or thumstall squid, have potential commercial importance in the Gulf area. The geographic distribution of *L. brevis* includes the Gulf of Mexico; the Atlantic coast of the United States from Maryland to Florida; the Caribbean Seas; and the Atlantic coast of South America to Rio de Plata. Distribution of *L. pealei* is similar except that on the Atlantic coast it extends from New England to Florida.

Field Procedure

Biological Study

Sixteen stations, located in Tampa Bay and adjacent waters, were sampled with a ten-foot shrimp try-net (Fig. 1). Sampling was conducted from the research vessel, KINGFISH, a 43-foot, twin-screw, diesel cruiser, and from a sixteen-foot outboard motor boat.

Sampling was scheduled on a weekly basis during September, October, and November, 1961. From December, 1961, through August, 1962, all trawls were made on a bi-weekly basis. Trawling speed was maintained at 3-4 knots for a 10 minute period at each station. All field collections of squid were preserved in 10% formalin. Subsequently, the specimens were soaked in tap water and then transferred to 70% alcohol.

Concurrent with biological collections, temperature and salinity determinations were made. Water samples for salinity determinations were collected with Van Dorn bottles (Van Dorn, 1957) or weighted polyethylene containers. All containers used for storage of samples were chemically cleaned prior to use. Water temperature was obtained with a Whitney underwater thermometer (model T65) and recorded to the nearest tenth of a degree Celsius. Salinity was determined by the Mohr-Knudsen method as described by Knudsen (1901) and recorded to the nearest hundredth of a part per thousand.

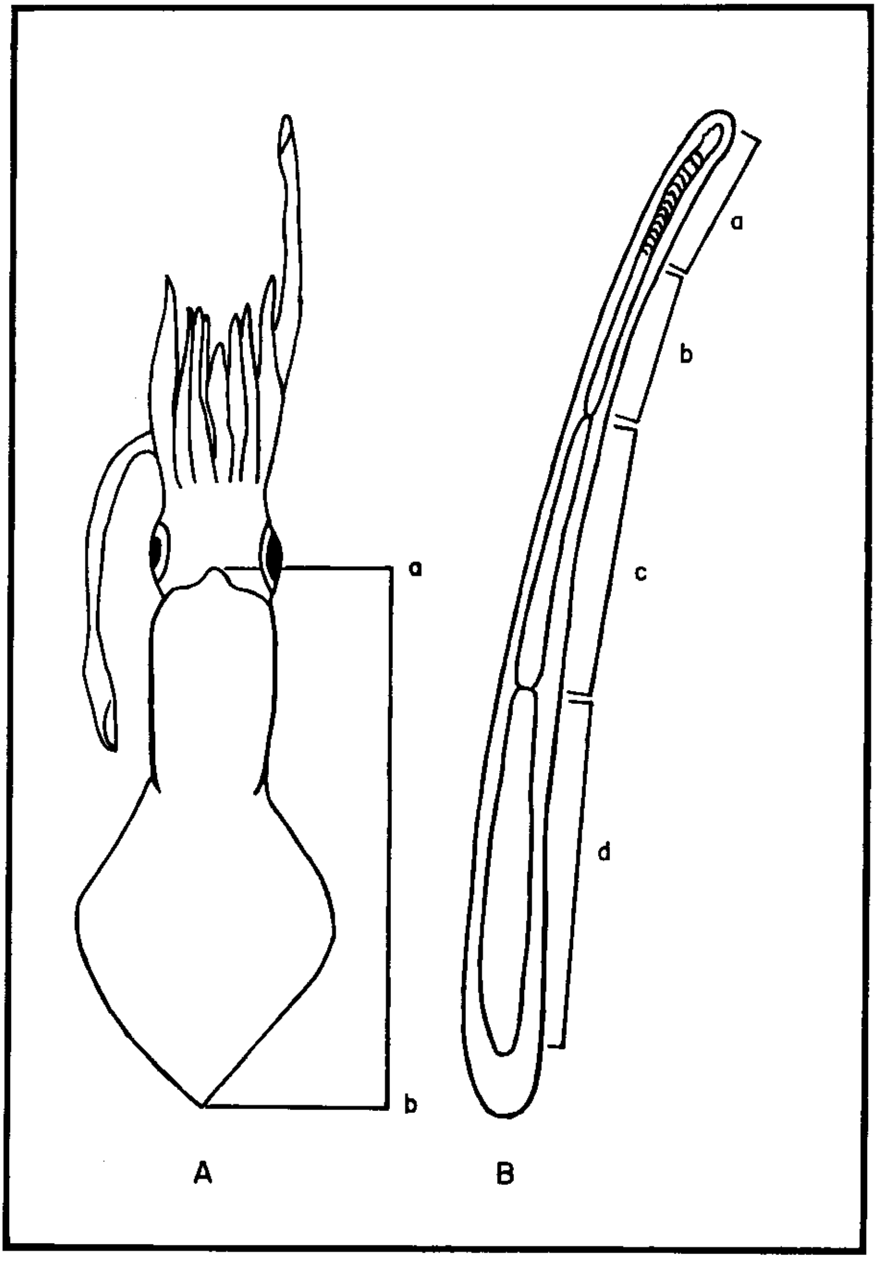

FIG. 2. A-Dorsal view of a squid illustrating the mantle length measurement, ab. B-Mature spermatophore (X 29); a-head or horn; b-tube; c-mid section or cement gland; d-sperm reservoir.

Laboratory Procedure

External Examination: The dorsal length of all animals was measured from the anterior margin of the tip of the rostrum to the posterior end of the dorsum (Fig. 2). These and all other measurements were made with the aid of Vernier calipers and recorded in millimeters. Mantle length is equivalent to standard length and was used throughout this paper simply as body length. This is considered a basic measurement for comparative purposes by all teuthologists (Voss, 1956; Fields, 1950; and Lane, 1960). The mean body length, respective standard deviation, and coefficient of variation were determined for each category of sex and maturity. Weighing of entire animals or of certain organs was made with a Mettler analytical balance. All squid were examined for the presence of a hectocotylized arm. Once this arm has been developed external identification of the male sex is possible.

Internal Examination: The maturity stage and sex were classified for each specimen by internal examination of reproductive organs. Prior to this examination, the entire ventral portion of the mantle was removed to facilitate inspection of the organs.

Each specimen was classified in one of three categories: immature-unsexed, immature-sexed (male or female), or mature (male or female). If neither penis nor nidamental glands were visible, the animal was labeled "immature-unsexed." In specimens identified as males the spermatophoric sac was dissected and spermatophores, if present, were examined under the microscope. If spermatophores possessed a distinctly developed head, spiral tube, cement gland, and sperm sac, the animal was considered mature (Fig. 2). In some males with a well developed penis, the spermatophoric sac was either empty or the spermatophores, if present, were not fully developed. These were classified as "immature-sexed (male)." Female squid were considered mature if ova approximately 2 mm in diameter were found in the oviduct (Fields, 1950). When ova approached this size, they were translucent and yellowish-orange in color. If there were no ova or if all of them were less than 2 mm in diameter, the specimen was said to be in the "immature-sexed (female)" category. Although the condition of nidamental glands was not used as a criterion of maturity, examination showed that in mature specimens the glands were large, firm, white, and occupied the entire, upper-ventral half of the mantle cavity (Fig. 3).

In examining reproductive organs, attention was focused on the macroscopic appearance of the organs and surrounding viscera. This was done to relate the macroscopic changes in reproductive organs to the body length of the organisms, and to pave the way for more detailed microscopic studies which may be accomplished at a later date. Examinations were facilitated by the fact that all collected animals were in excellent condition.

RESULTS

Distribution: All squid collected during this investigation were of the same species, *Lolliguncula brevis*. Numerically, *L. brevis* was the second most abundant invertebrate observed in trawl collections, and represented 13.4% of all collected organisms. From September, 1961, through August, 1962, 378 trawls were made in Tampa Bay and adjacent neritic waters. The average number of squid per trawl varied from 0 to 9.7.

Squid abundance as measured by catch per trawl was greater in the upper

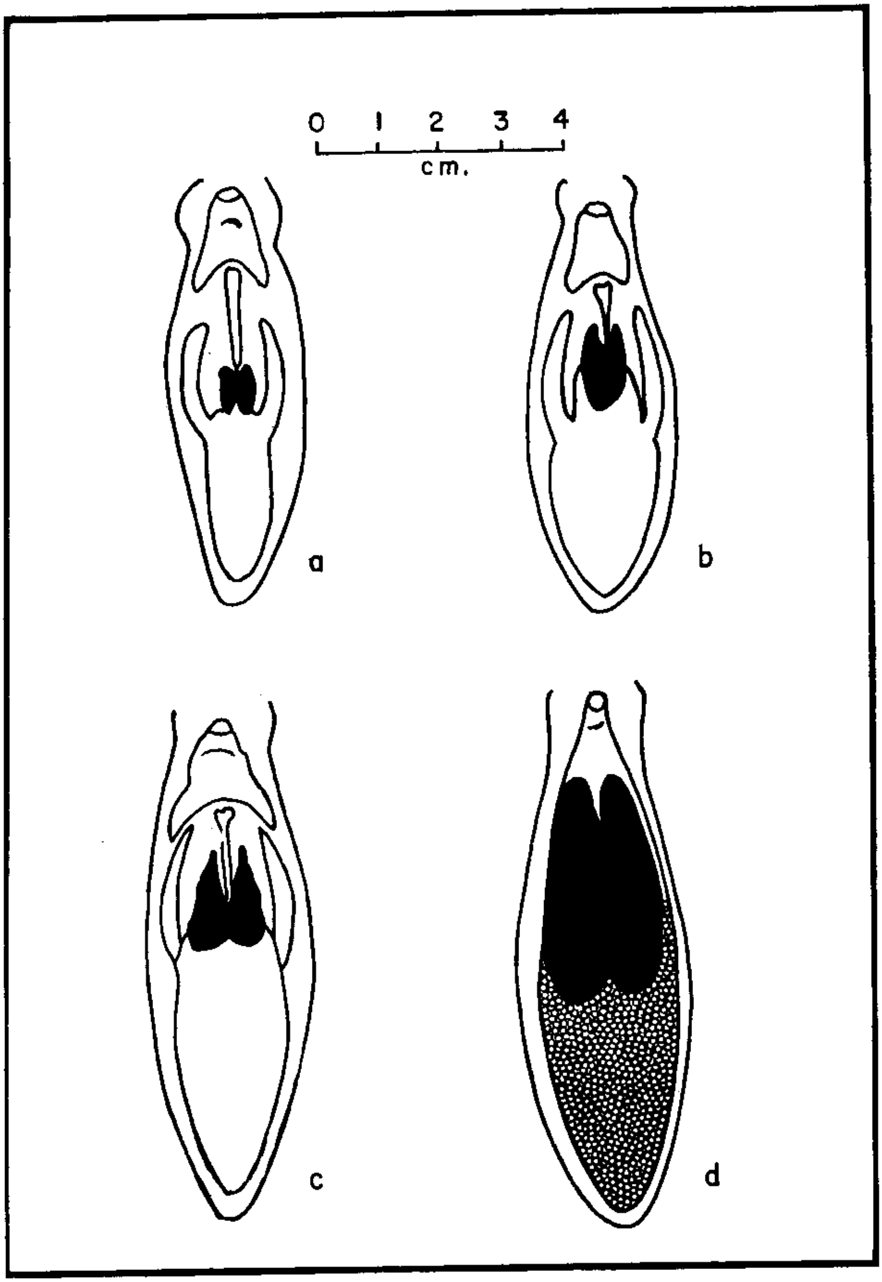

FIG. 3. Nidamental glands increasing toward maturation. The dark central region shows nidamental glands; a- and b- immature specimens; c- approaching maturity or in puberty stage; d- nidamental glands and eggs in mature specimen.

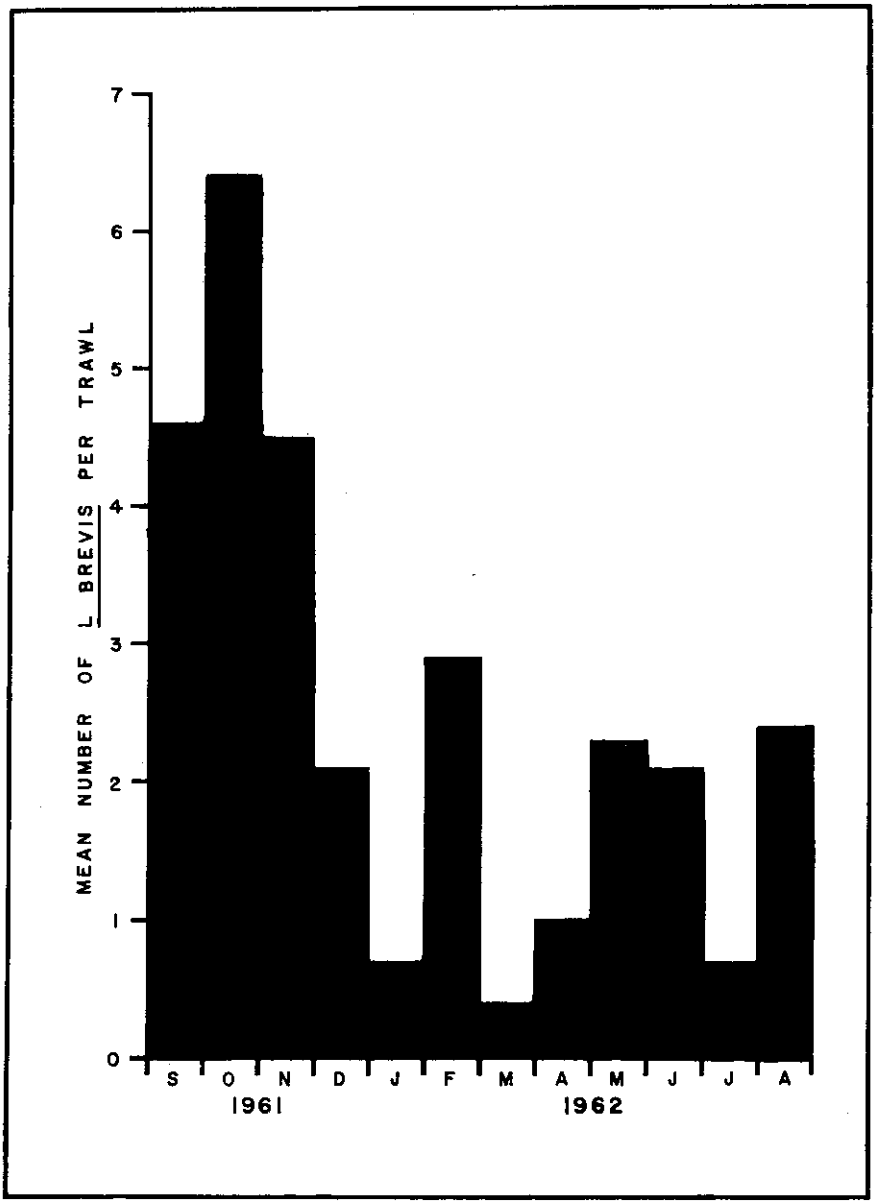

FIG. 4. Monthly occurrence of *Lolliguncula brevis* in Tampa Bay, September, 1961 - August, 1962.

estuary than in the lower estuary (Fig. 1). Old Tampa Bay was the most productive subarea, contributing 42.8% of the combined catch. Percentages of the total catch by other areas were 25.3% in Hillsborough Bay, 30.4% in central Tampa Bay, and 1.5% in lower Tampa Bay. At all sampling stations *L. brevis* was dominated by immature organisms. Squid were not caught at the mouth of Tampa Bay or in adjacent Gulf of Mexico waters.

The seasonal occurrence of squid was characterized by maximum trawl catches in late summer and early fall and irregular catches during the remaining portion of the observation period (Fig. 4). Both mature and immature squid occurred throughout the study except during the month of July when mature animals were absent.

The maximum water temperature (32C) during the sampling period was observed in July in central Tampa Bay and the minimum (12.6C) was recorded in January in Old Tampa Bay. During the summer and early fall months, temperature variations seldom exceeded IC. Cooling during the fall months proceeded slowly (Table 1). The monthly mean temperature did not fall below 20C until December. The water warmed progressively from February to July when the maximum was reached. Monthly water temperature was closely associated with air temperature.

The range of salinity measured concurrently with squid sampling extended from 17.32‰ during August in Hillsborough Bay to 35.66‰ in July, 3½ miles offshore in the Gulf. A horizontal gradient was present throughout the observation period with the maximum zone in the adjacent Gulf waters and minimum zone in the upper portion of the estuary (Table 1). Monthly salinity changes were associated with fluctuations in rainfall. A reduction in salinity was particularly noticeable from June through August during the period of high rainfall. The monthly salinity variations in offshore waters did not parallel those in Tampa Bay.

SEX AND MATURITY: The sex ratio of total squid collected was 1.12 males per female; of mature squid, 7.1 males per female; and of immature squid, 1.1 females per male. Male squid were more abundant than females at a majority of stations.

A large portion (36.3%) of specimens were in the immature-unsexed category. The organisms in this group varied in body length from 8.0 mm to 40.0 mm with a mean of 18 ± 4.7 mm. The body length of the majority (87.5%) of unsexed squid was found to vary between 8 mm and 28 mm (Fig. 5).

Fifty-six percent of all examined organisms were in the immature-sexed category. The body length of immature males varied from 16 mm to 75 mm (Fig. 5). The majority of immature males (83.7%) were within the narrow range in body length of 18 mm or between 21 mm and 38 mm. Only 3.5% of the specimens were less than 21 mm in body length while 12.8% were larger than 38 mm. The mean length of all immature males was 30.1±7.5 mm. Immature females had the widest range in size. The body length in this group varied from 17 mm to 86 mm with a mean of 34.7±12.1 mm. The largest portion of immature females was between 22 mm and 41 mm in body length and constituted 78.3 percent of all immature females. Only 4.5% were smaller and 17.2% were larger than the extremes in this range.

The smallest proportion (7.7%) of males and females was observed in the mature category. The frequency distribution of these specimens was irregular (Fig. 5). Mature males ranged in body length from 32 mm to 83 mm and the

TABLE 1

MEAN TEMPERATURES, RAINFALL AND SALINITIES IN TAMPA BAY, FLORIDA
SEPTEMBER, 1961 - AUGUST, 1962

Location	Water Temperature (°C)											
	1961				1962							
	S	O	N	D	J	F	M	A	M	J	J	A
Hillsborough Bay	27.9	24.7	22.0	19.2	16.7	18.2	19.4	22.0	26.8	28.5	30.2	29.0
Old Tampa Bay	27.1	24.2	21.9	18.2	16.4	19.9	17.0	23.2	26.7	29.1	30.5	29.4
Central Tampa Bay	27.9	24.7	22.7	18.9	16.0	18.1	18.2	20.2	26.4	28.8	30.6	30.1
Lower Tampa Bay	27.3	24.3	22.5	18.2	16.4	19.7	17.5	20.8	24.7	28.8	30.5	30.5
3½ miles offshore	27.7	24.6	22.8	19.0	15.6	-	19.0	19.7	23.8	28.8	30.7	30.5
	Air Temperature (°C)											
Old Tampa Bay	27.7	23.6	21.0	17.9	15.8	19.3	17.7	20.8	25.5	26.6	28.3	27.7
	Rainfall in Inches											
Old Tampa Bay	2.43	0.25	0.94	3.80	1.40	0.40	4.26	1.43	2.76	6.34	2.31	10.14
	Salinity (‰)											
Hillsborough Bay	24.88	27.07	28.91	28.50	27.75	27.68	27.87	27.57	28.78	28.84	25.32	23.92
Old Tampa Bay	24.24	25.28	26.92	28.24	27.75	27.99	28.43	28.41	29.92	29.53	28.87	26.91
Central Tampa Bay	27.63	29.13	30.56	30.60	29.89	28.53	29.90	29.90	30.99	30.58	29.29	28.35
Lower Tampa Bay	30.92	31.92	32.59	32.76	31.86	-	32.31	31.82	34.10	33.07	32.12	29.99
3½ miles offshore	34.96	34.45	33.84	33.96	33.36	-	34.29	34.07	35.59	35.39	35.76	35.01

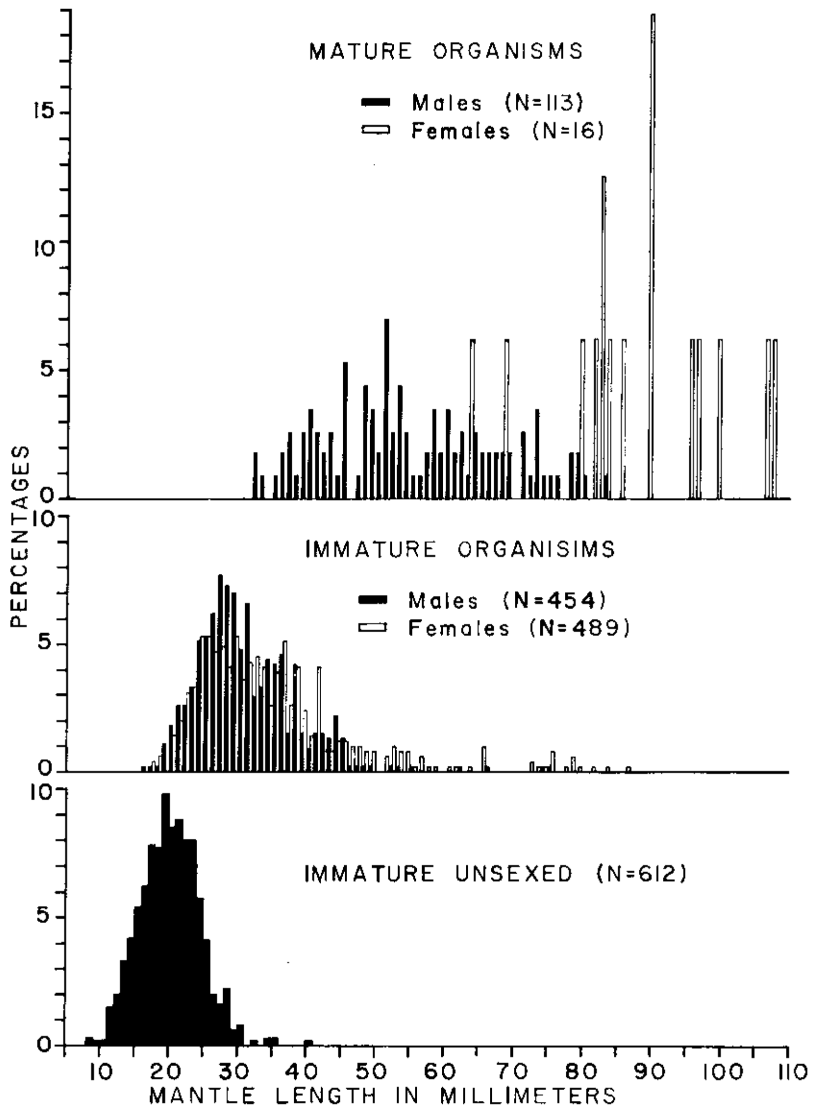

FIG. 5. Frequency distribution of mature and immature *Lolliguncula brevis* in each millimeter range of mantle length, shown as percentage of the total number of squid in each stage of maturity (Tampa Bay, September, 1961 - August, 1962).

mean was 54.4 ± 12.4 mm. The body length of mature females ranged from 63 mm to 107 mm and the mean length was 87.1 ± 5 mm.

CONDITION OF REPRODUCTIVE ORGANS IN RELATION TO BODY LENGTH: The first sexual manifestation in males is the development of a penis. Smallest specimen having a penis was 18 mm in body length. The length of the penis varied from 1 mm to 14 mm. The second observed sexual manifestation in males is the development of spermatophores. Immature males in the puberty stage ranged from 20 mm to 74 mm body length. This stage was characterized by the presence of immature spermatophores and included 15.6% of the males examined. The majority (76%) of squid in this stage was found within a range of 24 mm to 38 mm body length, while 8.4% and 15.5% were below and above this range, respectively. The number of spermatophores in the puberty stage varied from one to six. The size of the spermatophoric sac in this stage is relatively small, usually 5 mm to 10 mm in length. Following puberty the spermatophores mature and at this time squid reach their full reproductive capacity. The size of the spermatophoric sac becomes relatively large and is filled with spermatophores stored neatly in spaghetti-like fashion. Counts among ten, randomly selected, mature males showed that the number of spermatophores was not related to size of the animal. The length of mature spermatophores varied from 4.9 mm to 7.1 mm. The weight of the entire reproductive system accounted for 1.4 to 1.5% of the total body weight. Body length of the ten randomly selected animals varied from 65 mm to 75 mm.

The first external appearance of secondary male characteristics was evident at 20 mm body length. In 97% of the specimens, development of the hectocotylized arm was observed at sizes about 30 mm. In 84% of the animals with the hectocotylized arm, mature spermatophores were present. In the remaining 15.6%, spermatophores were immature or absent.

Although nidamental glands were not used as indicators of maturity, the dissection of females revealed that sexual development is accompanied by a distinct increase in size of the glands (Fig. 3). The earliest macroscopic evidence of a nidamental gland was noted in a specimen 17 mm in body length. In most squid ranging from 20 to 60 mm body length, the development of nidamental glands appeared to be a gradual process. From 60 mm to 86 mm this development occurred rapidly. Above 86 mm all specimens were fully mature.

The nidamental glands in immature specimens varied in length from 1.0 mm to 17 mm. Comparable dimensions for the mature females were 22.8 mm and 36.5 mm. In mature specimens the whole reproductive system, including ova, extended from the anterior to the posterior end of the mantle cavity (Fig. 3). The weight of the reproductive organs in five fully mature females accounted for 23-26% of the total body weight.

Egg counts were made in three randomly selected mature females. Egg counts and body lengths were 1,400; 1,700; 3,900 and 63, 85, and 107 mm respectively. The largest eggs averaged 2 mm in diameter, while the smallest in the same organism averaged 1 mm in diameter. In the female with 3,900 eggs, there were 750 eggs averaging 2 mm in diameter and 3,180 eggs averaging 1 mm in diameter. The proportion between the two sizes of eggs was specific for each observed specimen.

STOMACH CONTENTS: Examination of stomachs revealed that 80% of them were empty. The highest percentage (94%) of empty stomachs occurred in organisms less than 40 mm in body length. In the remaining 6%, the stomach contents consisted of mud particles only. In organisms larger than 40 mm body length, 54% of the stomachs were empty. Taxonomic identification of stomach contents was not possible in most instances, because the material was severely mutilated and fragmented. Even though the squid is carnivorous, small fragments of *Gracilaria verrucosa, Thalassia testudinum,* and *Spyridia* sp. were identified. The anterior half of a *Limulus polyphemus* larva was also observed in one of the stomachs. The remaining material was taxonomically unidentifiable and consisted of various parts of planktonic crustaceans, fish scales, fish eggs, bits of flesh, and sand or mud particles.

DISCUSSION

The examination of macroscopic changes in reproductive organs disclosed the sizes of *L. brevis* at which maturity occurred. It was shown that males mature at smaller sizes than females. The male may become mature at a length of 32 mm or may remain immature until it reaches 75 mm in body length. Comparable sizes for females are 63 mm and 86 mm respectively. The largest immature female (86 mm) was 3 mm longer than the largest mature male. The range of body length in the group of unsexed specimens indicates that the development of reproductive organs does not occur at any particular size. In all specimens less than 17 mm in body length, the macroscopic identification of sex was impossible.

The largest specimen of *L. brevis* observed during this study was about one third shorter than the maximum size (150 mm) observed by Tabb and Manning (1961). Since 1.6% of all collected squid were greater in length than 75 mm, we doubt that our collecting gear was adequate in capturing the fast-swimming, larger specimens. The findings with regard to the larger specimens should, therefore, be considered preliminary.

The dispersion of body length in relation to its mean, measured as the coefficient of variation, was greatest in immature females (34.9%). The coefficient of variation for immature males was 10% lower than that for immature females. In organisms with undetermined sex the coefficient of variation was 26%. The least variation in body length was observed in mature organisms. The variation in mature females (5.7%) was smaller than in males (22.8%).

The first macroscopic appearance of primary sexual characteristics, penis in the male and nidamental glands in the female, occurred in both sexes at about the same body length. The secondary sexual characteristics were observed only in males. The presence of the hectocotylized arm in males was an indication of sex only, not of maturity. Simultaneous presence of mature and immature eggs in mature organisms indicated that the maturation of eggs is a gradual and continuous process, once the organism reaches maturity (Clark, 1962).

The stomach analysis revealed that *L. brevis* exceeding 40 mm body length feed upon planktonic crustaceans and fish. The data also suggest that organisms smaller than 40 mm may utilize mud particles as a source of food.

To compare the possible influence of temperature and salinity on the occurrence of *L. brevis,* both were subdivided into three ranges, each of which included about one third of the total number of observations (Fig. 6).

L. brevis occurred with greatest frequency in the lower portion of the salinity range and decreased in frequency as salinity increased. To check the occurrence of *L. brevis* in extremely low salinities, trawl activity was extended

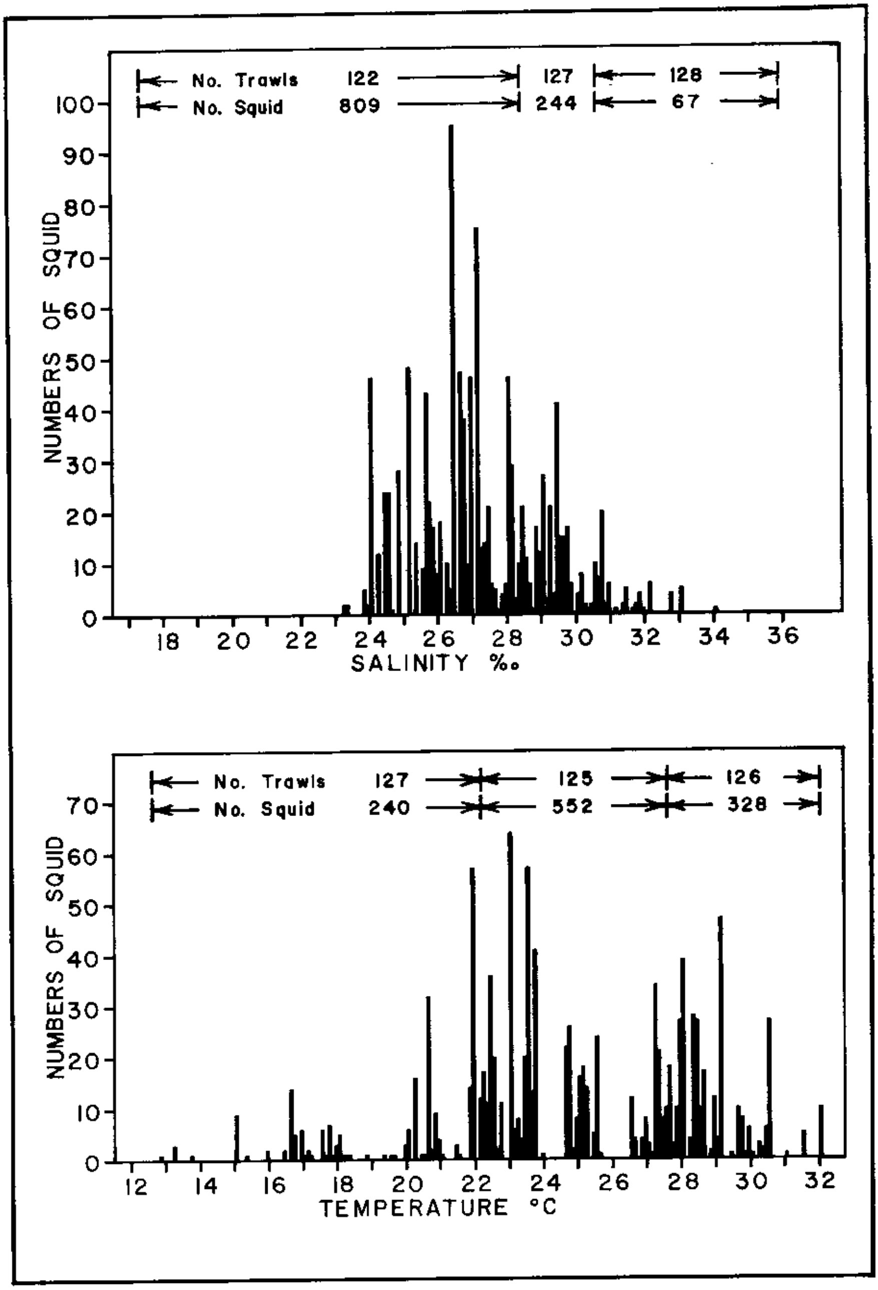

FIG. 6. Incidence of *Lolliguncula brevis* in Tampa Bay at three salinity and temperature intervals, each of which includes a comparable number of observations, September, 1961 - August, 1962.

during August to the mouth of the Alafia River, a tributary of Tampa Bay. One immature specimen was found at a salinity of 2.40‰, the lowest at which a squid was recorded. Salinities at which squid were observed by Gunter (1950), Tabb and Manning (1961), and Haefner (1959) were 17.7‰, 22‰ to 38‰, 28.6‰, and 29.4‰. Thus, *L. brevis* may be considered a euryhaline organism at least in immature stages. The data do not permit determination of whether salinity, *per se,* is the decisive factor in areal and seasonal distribution of squid. However, the ability of *L. brevis* to tolerate low salinities enables them to inhabit upper and lower portions of the estuary. Thus, *L. brevis* is available as food to other animals with great salinity tolerances as well as to those restricted to a narrow range in salinity. The estuarine nature of *L. brevis* is unique since most of the cephalopods are exclusively marine.

In relating temperature to the occurrence of *L. brevis,* it was noted that the animal occurred most frequently at the intermediate temperature range and less frequently at the lower end of the temperature scale than at the higher end. These observations are in general agreement with those of Tabb and Manning (1961).

The numerical dominance of immature-unsexed squid over those that were mature suggested local spawning. In one instance, newly hatched squid were observed during September in Old Tampa Bay.

The best tangible evidence of spawning time is the occurrence of ripe egg masses and the developmental stages of newly hatched organisms. Fields (1950) found that in *Loligo opalescens* large reserves of spermatophores and ova were found throughout the year and, with the exception of freshly exhausted organisms, the accessory organs were maintained in potential spawning conditions at all times. He reported further that squid spawned on every occasion when introduced into an aquarium at Hopkins Marine Station, California. Since our collections included some ripe organisms throughout the most of the year, no specific spawning season was indicated. The findings, therefore, are in general agreement with those of Fields (1950).

At present there is no estimate of the availability of squid stocks to the commercial fishery industry of the Gulf States. Furthermore, this is an incidental fishery and little attention has been paid to its development. It appears that the domestic market is ready to absorb much larger quantities of squid than the amount being produced by local fishermen. The foreign market has a pressing demand for protein and appears capable of increasing its consumption of squid. In consideration of these potential markets, experimentation with fishery methods seems advisable and could result in increased efficiency of exploitation.

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