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A Thesis

SPECIES COMPOSITION AND RECRUITMENT SEASONALITY OF PENAEOID SHRIMPS AT BEAR CUT, BISCAYNE BAY, FLORIDA

by

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BELLO, MARIA J. (M.A., Marine Affairs)

Species composition and seasonality of recruitment of penaeoid shrimps at Bear Cut, Biscayne Bay, Florida.

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Supervised by Dr. María M. Criales

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Penaeoid shrimps were collected at Bear Cut, a tidal pass between the Atlantic and Biscayne Bay, Florida from January to December 1994. One surface net (0-1 m depth) and one moored subsurface net (1.0-3 m depth) each with 2 mm mesh were set to capture shrimp during the night-time flood tides of the new moon period monthly. These nets sampled from postlarvae (1.2 mm Carapace Length, CL) to subadult (34 mm CL). Species composition was 34.7% were *Metapenaeopsis spp.,* 32.4% *Penaeus spp.* postlarvae, 8.9% *Penaeus spp.* juveniles, *19% Penaeus spp.* subadult, 4.3% *Sicyonia spp.*, and 1.2%*Trachypenaeus constrictus*. Five species of *Metapenaeopsis* were found at Bear Cut (*M. martinella*, *M. goodei*, *M. hobssi*, *M. gerardoi*, *M. smithi*) of which *M. martinella* and *M. hobbsi* constitued new records for Florida coast. The genus *Penaeus* was represented by *P. duorarum* and *P. brasiliensis* , ocurred in a proportion of 2:1. Three species of *Sicyonia* represented by *S. typica*, *S. laevigata*, and *S. parri*, were captured.

Total catches of juveniles and subadult for the different species were higher during winter months than any other season. Influx of *Penaeus spp.* postlarvae to Biscayne Bay showed recruitment pulses during the fall in November (135

postlarvae/100 m^3). Postlarvae recruited from stages two to five, with an average size of 1.9 mm CL. The highest concentrations of *Penaeus spp*. postlarvae were found at flood tides and were most abundant in the subsurface net. Postlarvae of *Metapenaeopsis spp*., *Sicyonia spp.* and *Trachypenaeus constrictus* were not captured at this tidal pass. Juveniles of *Penaeus spp.* and subadult *P. duorarum* and *P. brasiliensis* were most abundant at ebb/flow on the surface net.

The average carapace length for *P. duorarum* males was 16.7 mm and 13.2 mm for females. For *P. brasiliensis* a greater average carapace length was found, 18. 5 mm for males and 17 mm for females . Predominant size class frequency of CL for *Penaeus spp.* juveniles was 10 mm. For *P. duorarum* subadult were 10 and 15 mm, and for *P. brasiliensis* were 15.2 and 25 mm. *M. goodei* range from 2 mm CL to 12 mm CL and *M. martinella* from 2.7 mm CL to 13.7 mm CL.

Environmental conditions including rainfall, salinity, water temperature and winds were analyzed. No strong relation was found between these factors and migration movements in or out of Biscayne Bay, except for a postlarvae recruitment pulse and a consistent wind pattern in November.

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Introduction

Penaeoid shrimps (order Decapoda, suborder Dendrobranchiata, superfamily Penaeoidea) are the most primitive group of the order Decapoda (Calman, 1909). They are one of the predominant marine groups of animals in many tropical and subtropical shallow-water and estuarine environments (Bauer, 1991).

Penaeoid shrimps are well represented in the Western Atlantic with four of the six families including the Dendobranchiata; Aristaeidae, Penaeidae, Sicyoniidae, and Solenoceridae (Pérez Farfante, 1988; Williams, 1984; Abele and Kim, 1986). They represent a valuable economic resource that support fisheries from North Carolina to Argentina (Pérez Farfante, 1988).

In South Florida exploitation of the shrimp population of the family Penaeidae have been recorded as far back as 1915 (Iversen et al., 1993). Fisheries of the pink shrimp *Penaeus duorarum* of the Dry Tortugas produced an annual average of 4, 525 mt tons during 1960-1980 (Nance and Patella, 1989). An estimated income of 22 million dollars from these fisheries was reported in 1983 (Costello et al., 1986). However a drastic decline in the mid - 1980's, reaching the lowest point during 1988-1991 when 2,000 metric tons were landed, has not yet been explained. Sheridan, (1996) reports a recovery of these fisheries to over 4,000 metric tons in 1994. Other penaeoid shrimps such as *Trachypenaeus* spp.

and *Sicyonia* spp. are also abundant, but they have little or no economic value (Eldred, 1960). In addition a live bait fishery from Florida Bay and Biscayne Bay supports a growing recreational fishing industry that reached a value of $4.7 million in 1990 (Coleman et al., 1992).

Two species of the family Penaeidae, *Penaeus duorarum* and *Penaeus brasiliensis* juveniles and subadults have supported a valuable live bait shrimp fishery in Biscayne Bay since the early 50's (Berkeley et al., 1985). In 1983 the estimated total commercial bait shrimp harvest from Biscayne Bay was $ 3.0 million at retail (Berkeley et al., 1985) and 1.7 million in 1993 (Coleman et al., 1993). Besides the economic value this population represents an important link to the food chain at different levels, from postlarvae through adult stages. Divita et al. (1983) identified penaeid shrimps as an important food item for many species of fish, crabs and birds which are significant fauna associated with Biscayne Bay.

Fluctuations in catches of penaoeid shrimps in Biscayne Bay depend on larval transport and survival. In addition to prediction the recruitment in the bay is mainly affected by tides, currents, winds and other environmental events (Berkeley et al., 1985). Most penaeoid shrimps spawn in the open sea and after a short period of complex planktonic larval development phases, postlarvae migrate inshore invading the estuarine areas. Sandifer (1975), Goy (1976), Rothlisberg et al. (1995), and Forbes and Benfield (1986) showed that penaeid larvae living offshore are commonly transported into estuaries by tidal currents and winds.

For species in which the estuary is an obligatory stage in their life cycle, a convenient measure of the survival of off-shore larval stages and juveniles can be obtained from quantitative sampling of postlarval immigration and juvenile emigration respectively (Staples and Vance, 1985; Baxter, 1963). The interpretation of the recruitment pattern of postlarvae can be very useful in understanding the spawning strategy of different species and determining the exact season and time of seed collection for culture purposes. *Penaeus* duorarum spawns off shore of Dry Tortugas (Jones et al., 1970; Munro et al., 1968; Costello and Allen, 1966) where females lay demersal eggs. After hatching, the larvae become planktonic and develop through three larval stages (nauplius, zoea or protozoea and mysis) followed by several postlarval stages (Temple et al., 1967; Dobkin, 1961; Ewald, 1965). After the third postlarval stage the postlarvae begin a vertical migration to become benthonic organisms (Ewald, 1965). Studies of the migration route of *Penaeus duorarum* larvae suggested that in southeast Florida waters they are carried northeast by the Florida Current from Dry Tortugas to the Florida Keys entering the nursery grounds of Florida Bay and Biscayne Bay throughout passes in the Middle and Upper Florida Keys (Munro et al., 1968; Jones et al., 1970). However Criales and Lee (1995) showed retention of larvae at the spawning area for a period of approximately two weeks by the cyclonic circulation of the Tortugas Gyre, followed by displacements to the southwest Florida shelf and Florida Bay by winds and tidal currents. The probability that larvae recruitment from different populations other than those of Dry Tortugas has been suggested by (Allen and Costello 1966), (Berkely et al. 1985) and

(Iversen et al. 1993). However, there is still much evidence needed before this assertion can be refuted or accepted.

Besides the genus *Penaeus* only occasionally members of the other genera have been reported from Biscayne Bay, in particular *Metapenaeopsis* goodei, *M. smithi*, *M . gerardoi*, *Sicyonia typica*, *S. laevicata* and *S. parri* (Voss et al., 1969; Pérez Farfante, 1970, 1971a; and Biosystems Research, Inc. 1984). These reports are only species inventories, not quantitative studies. Most of the information related to *Penaeus* spp. in Biscayne Bay has been obtained from the commercial bait shrimper activity. *P. duorarum, P. brasiliensis*, and *P. aztecus* have been reported for Biscayne Bay, (Saloman et al., 1968 and Eldred, 1960), but the exact species composition has not been yet described. Difficulties in finding distinguishing specific characters in juvenile stages are due to there great morphological variability (Pérez Farfante, 1971b). The fact that those latter species are very closely taxonomically related (Eldred, 1965) and the large degree of overlap on both meristic and morphometric characters are the main reasons the shrimp population of Biscayne Bay has been treated as one species. Misidentification of species and treating the shrimp population as one species (assuming that one is more representative than the other) can lead to confusing conclusions. The differences between species ecology and behavior make it difficult to establish an efficient harvesting strategies and fishery management plans.

This research is part of the Southeast Florida and Caribbean Recruitment Project (SEFCAR), a multidisciplinary project of the University of Miami, financed by National Oceanographic and Atmospheric Administration (NOAA), to examine the physical factors affecting larval and postlarval transport of fishes and invertebrates in Southeast Florida. The objectives of the research are: to identify the species composition of penaeoid shrimps migrating in and out of Biscayne Bay through Bear Cut and to examine the temporal patterns of abundance of postlarvae and juvenile penaeoid shrimps in relation to environmental variables.

Study site { TC "Study site " \l 1 }

Bear Cut is a narrow tidal pass between the Atlantic Ocean and Biscayne Bay. (Fig. 1). It is approximately 570 m wide and 4.6 m deep (Fig. 2). This tidal pass allows a direct exchange between ocean offshore waters and those of the bay which play a significant roll in the migration of penaeoid shrimps that use Biscayne Bay as a nursery ground.

Biscayne Bay is a shallow subtropical lagoon approximately 90 Km long oriented North - South with widths ranging from 6 to 16 Km. Water depths in the interior of the basins vary from 2 to 4 m. Contact with continental shelf waters takes place through a complicated network of tidal inlets between Miami Beach, Fisher island, Virginia key, Key Biscayne and Elliot Key (Lee and Rooth, 1972). Biscayne Bay has been identified as an important nursery area for postlarvae, juveniles and subadults of penaeoids (Mclaughlin et al., 1983). Different sea grass communities represented by *Thalassia testudinum, Syringodium filiformes, Halodule wrightii*, *Diplantherea wrightii*, and *Halophila baillonis* are abundant (Fig. 1). *Thalassia* is the most representative sea grass community in Biscayne Bay (Thorhaug, 1976). Mclaughlin et al. (1983) reported *Thalassia* communities in Biscayne Bay as selected habitats for commercial pink shrimp, caridean shrimps, and juvenile fishes. In other estuarine environments penaeoid shrimp have been identified as an important component of the motile epifauna in

Thalassia (Greening and Livingston, 1982; Gore et al., 1981; Heck, 1976, 1977; Dall, 1968; and Bauer, 1985).

Tides in the bay are semidiurnal and the amplitudes range from 1 to 2 feet, within a period of 12.4 hours (Van De Kreeke, 1976). The oscillatory nature of the tidal shear flow combined with vertical and transverse mixing leads to a horizontal constituent transport; consequently a transport mechanism for organisms is generated (Lee, 1975). This tidal flow at Bear Cut influences the circulation in the central part of the bay. Since Biscayne Bay is shallow, there is virtually no stratification of the water column and the water is readily mixed by wind events. Wind forces are the primary mixing and renewing mechanism for the bay (Lee and Rooth ,1972 , Lee, 1975 , Johnson and Lee, 1977, and Swankon and Wang , 1977). The major wind events occur during the passage of the winter cold-fronts which cause sudden increases in wind speed and rapid change in wind direction. During the rest of the year, the winds are generally from the East or Southeast at much lower velocities (Lee, 1975).

Methods and Materials{ TC "Methods and Materials" \l 1 }

The sampling procedure was done using a surface and a subsurface channel net suspended in the Bear Cut tidal pass between the Atlantic and Biscayne Bay during the new moon period from January to December 1994. The two channel nets were maintained on separate moorings at a single station. Nets could swing freely with tidal changes. One net 2 m wide x 1 m deep of mouth area was suspended at the surface, and fished the 0-1 m deep stratum. Buoys were used to suspended the second net (mouth area = 2 m wide x 2 m deep) below the surface to fish the 2 to 4 m deep stratum. The nets have a 2 mm mesh size with a 3 m long PVC pipe attached along the upper side to prevent the net from collapsing during slack tide and fouling on the mooring line (Fig. 3). For more details see Schenker et al. (1993). Each net was equipped with a General Oceanic Flow Meter. A high-speed rotor blade flowmeter was used during the first four months of the sampling and later replaced by a low-speed blade.

Samples typically were removed from nets shortly after dawn and again before dusk. This design includes for each new Moon period five samples collected on flood and five on ebb/flood period for each net, which made a total of about twenty samples for each month. To examine transport on discrete flood and ebb tides, samples collected during flood were sampled at each high slack tide during 5 nights on the surface and subsurface.

Samples were washed; the debris removed; then fixed in 95% ethanol solution for 24 hour; and finally transferred to 75% ethanol for subsequent identification. Later each sample was sorted and penaeoid shrimps (juveniles, subadults and postlarvae) removed.

Due to difficulties in identification (thelyca and petasma were not completely developed), postlarvae and juveniles were classified as *Penaeus* spp. Only subadults were identified to species according to the criteria of Abele and Kim (1986), Pérez Farfante (1969, 1970, 1971a, 1971b, 1980, 1988), Chase (1972) and Williams (1984).

The total length (TL, from tip of rostrum to tip of telson) and carapace length (CL, from the posterior orbital margin to the posterior border of the carapace) were measured to the nearest mm with an ocular micrometer or a ruler for postlarvae, juveniles and subadults respectively. Ten postlarvae were selected at random from each sample for measurements while juveniles and subadults were all measured. The number of spines in the rostrum for all postlarvae were counted.

Volume of water filtered through the plankton nets was calculated as follows:

Volume (m^3) = Mouth area net x Distance in meters

Mouth area surface net = 2 m wide x 1 m deep = 2 m^2

Mouth area subsurface net = 2 m wide x 2 m deep = 4 m^2

$$\text{Distance in meters} = \frac{\text{difference in counts x rotor constant}}{999999}$$

Rotor Constant: high speed rotor = 26,873

low speed rotor = 51,020

Data sets from low and high speed flowmeters for surface and subsurface nets were compared and correction factors were calculated as:

Correction factor for the subsurface net = 0.431336

Correction factor for the surface net = 0.3676

Concentration was defined as the standardized catch in 100 m^3 of seawater and calculated as:

$$\frac{N_i \times 100}{V_i}$$

i = net surface or subsurface fished during a night

N_i = number of shrimps (postlarvae, juveniles or subadults) caught in net i

V_i = volume filtered by net i

Data Analysis. Concentration of shrimps were used to determine differences between surface or subsurface catches per each species and between flood and ebb periods. Average monthly concentrations of shrimps also were calculated for each species to determine fluctuations along the year. To reduce the influence of occasional large peaks, concentrations were transformed by log (x + 1) to determine differences in catches between surface and subsurface samples. Size distribution averages for *Penaeus* and *Metapenaeopsis* males and females were calculated to establish ranges and average values.

Environmental Data. Tides, water temperature and wind direction and speed were collected at Virginia Key National Oceanographic Service Tide Station NOAA/NOS/NGWLS located at Bear Cut. Wind data was also obtained from Fowey Rocks C-man Station at NOAA/AOML National Data Bouy Center. Rainfall records were taken from the rain collector on the roof of the S/LAB building at University of Miami Rosenstiel School of Marine and Atmospheric Science.

Daily average of water surface temperature and rainfall averages were calculated for each month from hourly records of the sampling period. Hourly wind direction data were converted to cross-shelf and alongshelf wind stress components. Daily average wind vectors were rotated into an isobath coordinated system, such that the Y-axis is oriented along the isobath (v + downstream) and the x-axis is perpendicular cross-shore (u + offshore). Wind direction (form) was rotated 180 degrees and then resolved into alongshore (v') and cross-shore (u') components.

Results

{ TC "Results " \l 1 }

A total of 1540 juveniles and subadults penaeoid shrimps and 885 postlarvae from 247 samples were sorted for a year-long monthly sampling program. Eleven species of the superfamily Penaeoidea belonging to the families Penaeidae and Sicyonidae were identified at the study site (Fig. 4). Eight species of the family Penaeidae; *Penaeus dourarum, Penaeus brasiliensis, TrachyPenaeus constrictus, Metapenaeopsis goodei, Metapenaeopsis martinella, Metapenaeopsis hobbsi, Metapenaeopsis gerardoi,* and *Metapenaeopsis schmiti* were identified. *M. martinella* and *M. hobbsi* are are recorded in this area for the first time. Three species of the family Sicyonidae, *Sicyonia laevigata, Sicyonia parri,* and *Sicyonia typica* were also found. *Penaeus* spp. postlarvae represented the highest yearly average abundance of 14.19/100 m^3, followed by *M. goodei* 5.8/100 m^3, *M. martinella* 4.6/100 m^3, *P. duorarum* 4.2/100 m^3, *Penaeus* spp. 2.3/100 m^3 and *P. brasiliensis* 2.0/100 m^3 (Table 1).

Penaeus duorarum and *P. brasiliensis* were found all year around being abundant from December to April with a peak in January. *P. duorarum* was the predominant species of the genus *Penaeus* (Fig.5). *P. duorarum* was always more abundant than *P. brasiliensis*. A yearly proportion of 2:1 *P. duorarum*/*P. brasiliensis* was found.

Juveniles *Penaeus* spp. were caught also all year around at Bear Cut with an abundant peak in September (Fig. 5).

Penaeus spp. postlarvae were found all year around. Monthly densities were below 10 postlarvae/100 m^3 except for November where a significant peak of 135 postlarvae/100 m^3 occurred (Fig. 6).

Seasonality and abundance fluctuations for the peneaoids species identified at Bear Cut are shown in Table 1. A seasonal monthly variation was found for each group. While *Penaeus* spp. postlarvae were significantly abundant in November, juvenile *Penaeus* spp. increased their presence in September. *P. duorarum* and *P. brasiliensis* were abundant from December to April.

The genus *Metapenaeopsis* with five species was the most diverse and representative. Only *Metapenaeopsis goodei* and *M. martinella* occurred in sufficient numbers to justify further analysis. *M. goodei* and *M. martinella* showed greates concentrations during winter, and lowest during summer (Fig. 7, 8). The genus Sicyonia showed asimilar pattern to that of Meta-penaeopsiss, being scarce† during the summer (Fig. 9A). *Sicyonia typica* was the most abundant of the genus Sicyonia , with 3% of all species captured. A relative frecuency distribution of all species of genus Sicyonia is given in Fig. 9b.

Averages of CL size distribution for *Penaeus* and *Metapenaeopsis* males and females are shown in Table 2. *Penaeus brasiliensis* has greater average size than *P. duorarum*. The average size of male and females *P. brasiliensis* was similar, females 17 mm CL and males 18.45 mm CL. The average size for *P. duorarum* males (16.7mm CL) was greater than for females (13.3 mm CL). Juvenile *Penaeus* spp. were found in a size range of 5 mm CL to 12.5 mm with an average of 8 mm CL. The sizes of *Penaeus* spp. postlarvae migrating into Biscayne Bay range from 1.20 to 3.4 mm CL, with an average of 1.92 mm CL and with a total lenght (TL) range from 4.1 mm to 11.9 mm TL and average of 9.3 mm TL. The largest postlarvae entering Biscayne Bay were reported for January and March (Fig.10). The age of postlarvae range from stage II to V (two to five rostrum teeth) being predominant stages III and IV (Fig. 11).

Metapenaeopsis goodei males and females show similar average size, 7.5 mm CL for females and 7.4 mm CL for males. Size range for males was 2.0 to 12.0 mm CL and for females, 2.0 to 11.5 mm CL. Average size for *M. martinella* males was 6.7 mm CL with a range between 3.5 mm CL to 10.5 mm CL and for females 7.0 mm CL with a range of 2.7 mm CL to 13.7 mm CL.

Size class frequency distributions vary among penaeoids groups and season. *Penaeus* spp. juveniles size classes of 7.5 mm Cl and 10 mm CL were representative for the abundant season with a large peak in September (Fig.12). *P. duorarum* dominant large classes for the highest density period (December to April) were 15 and 20 mm CL. The same size classes were found during the less abundant months (May to October) (Fig.13). For *P. brasiliensis* predominant size classes during the highest abundant season (December to April) were 20 and 25 mm CL. However, during the less abundant season (May to November) the dominant size class were 15 and 20 mm CL (Fig.14). Size class distributions for juvenile *Penaeus* during the entire year are shown in Fig, 15. A different pattern of size class distributions was observed for each species. *P. brasiliensis* shows a wider range of size classes, being especially evident classes of 15, 20 and 25 mm CL. *P. duorarum* dominant classes are 10 and 15 mm CL and *Penaeus* spp. juveniles representative class is 10 mm CL.

A size class frequency distribution for genus *Metapenaeopsis* is given in Fig. 16, where for *M. goodei* two representative size class 7.5 and 10.0 mm can be identified. In contrast *M. martinella* has a wider range of size classes 5.0, 7.5 and 10.0 mm CL. *Metapenaeopsis* spp . sizes range from 5 to 7.5 CL mm. Figs. 7 and 8 show a more detailed distribution.

Penaeus spp. Juveniles tended to be more abundant during Ebb/Flow than during the Flow (Fig. 17) and more represented in the surface net throughout the sampling year (Fig. 18, 19). However *Penaeus* spp. postlarvae showed the opposite pattern being more abundant during the flood and significant abundance on the subsurface net. Figure 20 shows the caches of postlarvae on surface and subsurface during the flood in November where the intensive migration peak concentration ocurred. This figure shows an evident contrast among abundance on the surface and the subsurface net. Figure 17 shows the abundance of the five genera found at Bear Cut at different tide regimes. The remarkable high abundance of *Penaeus* spp. postlarvae during the Flood is in sharp contrast with the abundance of the other genera during the Ebb/Flow.

Statistical analysis also shows differences between catches of juvenile *Penaeus* spp., *Penaeus* spp. postlarvae and Metapeneaopsis spp. in surface and subsurface strata. Concentrations of *Penaeus* spp. postlarvae caught in the subsurface net (n = 117, $\bar{x}$ = 0.245, s = 0.23) were higher than those of post-larvae caught at the surface (n =116, $\bar{x}$ = 0.066, s = 0.08), with the difference being highly significant (t-test, t_{231} = 0.0003, $p < 0.05$). Captures of juveniles and subadults of *Penaeus* spp. and *Metapenaeopsis* spp. showed the opposite trend from that of postlarvae. *Penaeus* spp. juveniles were more abundant in the surface stratum (n = 116, $\bar{x}$ = 0.586, s = 0.78) than in the subsurface (n =117, $\bar{x}$ = 0.0302, s = 0.199). The t-test was highly significant (t-test, t_{169} = 0.002, $p > 0.05$). *Metapenaeopsis* spp. juveniles also showed higher captures at the surface (n = 101, x = 0.595, s = 0.805) than the subsurface (n = 102, $\bar{x}$ = 0.289, s = 0.183), but the test was not highly significant (t-test, t_{220} = 0.5208, $p > 0.05$).

Concentrations of *Penaeus* spp. postlarvae caught on high slack tides were higher (n = 110, $\bar{x}$ = 0.177, s = 0.178) than during ebb/flood tide (n =114, $\bar{x}$ = 0.147, s = 0.16), but the difference was not significant (t-test, t_{113} = 1.65, $p > 0.05$). Concentration of *Penaeus* spp. juveniles caught in high slack tide during flood tides (n = 110, $\bar{x}$ = 0.333, s = 0.08) were lower than during ebb/flow tide (n =114, $\bar{x}$ = 1.64, s = 2.9), but the difference was not significant (t-test, t_{171} = 1.65, $p > 0.05$). Concentrations of *Metapenaeopsis* spp. juveniles caught during flood tides(n =110, $\bar{x}$ = 0.1293, s = 0.27) were lower than during ebb/flood tide (n = 116, $\bar{x}$ =0.74, s = 1.03, but the difference was not significant (t-test, t_{170} = 1.65, $p > 0.05$)

Monthly averages of water surface temperature oscillated between 21.2 °C and 30.58 °C with an average of 26.72 °C during the year (Table 3). The lowest water temperatures were found from October to May and the highest from June to September (Fig. 21). No relation with temperature and penaeoids movements was found at Bear Cut.

Monthly rain amounts fluctuated from 24.60 mm in November to 449 mm in September, with a yearly average of 209.1 mm (Fig. 22). The precipitation average record for the wet season was 274.13 mm and for the dry season 179.57 mm slightly higher than historical records for South Florida (National Climatic Data Center, 1994). Juvenile *Penaeus* spp. showed an abundant migration peak when precipitation records were highest during September (Fig. 23). Salinity records did not show a remarkable variation, values fluctuated from 29 ppm to 35 ppm (Table 3).

The cross-shelf component of the winds (Fig. 24) was irregular during the year, but for November the air blew consistently onshore almost the entire sampling period. The along-shelf component also was variable, but again during November was intense and consistent, reaching the highest value of the year (Fig. 25).

Discussion{ TC "Discussion" \l 1 }

Three species of the genus *Penaeus*: *P. duorarum*, *P. brasiliensis* and *P. aztecus* have been reported for Biscayne Bay (Saloman et al., 1968; Voss et al., 1969). Reports of *P. duorarum* as the dominant *Penaeus* species in Florida Bay, Biscayne Bay and in deep waters of the Florida Keys were given by Burkenroad (1939) and Costello and Allen (1966). *P. brasiliensis* distribution in North America is scarce, being limited to South Florida (Pérez Farfante, 1971c). Eldred (1960) and Iversen and Van Meter (1964) reported for the first time in Biscayne Bay P. brasiiensis juveniles. Biscayne Bay possess the greatest concentration of this species in USA continental waters. According to our results, *P. brasiliensis* represents 34% of the *Penaeus* spp. population at the entrance of Biscayne Bay. This result is different from other authors that report *P. brasiliensis* on the bay making only up to 5-15% of the population (Mckinley, 1995; Saloman et al., 1968). *P. brasiliensis* was reported by Voss et al. (1969) in the bay as abundant in the Summer where they accounted for up to 40% of the bait catch. P. *aztecus* has been reported in Florida waters by Burkenroad (1939); Tabb and Manning (1961) and Eldred et al. (1961), but always as rare and scarce. In this survey at Bear Cut, Biscayne Bay P. *aztecus* was not found.

The genus Metapeneaopsis is the largest genus of the family penaeidae (Dall et al., 1990). However in the Western Atlantic only five species have been described (Pérez Farfante, 1971a). These five species were found at Bear Cut during this 1994 survey. Little is known about the biology of the species of the genus (Dall et al., 1990). They have been poorly studied in this area in part due to its scarce distribution and nocturnal behavior. *Metapenaeopsis* goodei has been recorded in Biscayne Bay waters by Voss et al. (1969) and Biosystems Research Inc. (1984); *M. smithi* and *M. gerardoi* from Bear Cut (Pérez Farfante, 1971a). However *M. martinella* the second most abundant species of juvenile penaeoids found during the present study, and M. hobbsi have not been previously recorded in the literature for Biscayne Bay or Florida Waters.

The genera Sicyonia and *Trachypenaeus* were not abundant. *Trachypenaeus* is represented only by one species *T. Constrictus*. It accounts only for 1.2% of total catches. The genus Sicyonia, represented by the three species mentioned above accounts for the 4.3% of total catches.

Only postlarvae of *Penaeus* spp. were found during this survey. A species differentiation of the larval and postlarvae stages of *Penaeus* spp. is extremely difficult and has not been feasible. The absence of other penaeoid postlarvae could be explained by selectivity of the sampling design or by differences in the life cycle of the species. Dall et al. (1990) established that even when the sequence of development is similar among penaeoid genera (planktonic larvae with several naupliar, protozoea, mysis, and postlarval stages followed by juvenile and adult stages) there are differences in the preferred habitats of postlarvae, juveniles and adults. *Penaeus* spp. postlarvae seek estuarine habitats for development. *Trachypenaeus* spp. and some *Metapenaeus* spp. prefer relatively high salinity, usually sheltered inshore waters. Some *Metapenaeopsis* spp. have an entirely offshore life cycle (Dall et al., 1990). This monthly variations in abundance could be explained as a result of live cycles strategies interacting with environmental conditions

Penaeus spp. postlarvae were found at Bear Cut all year around with a large peak in November (Fig. 6). Allen et al. (1980) also found postlarvae of *P. duorarum* entering Florida Bay through Whale Harbor Channel (Upper Florida Keys) all year round with an abundant period from April to September. The presence of *Penaeus* spp. postlarvae all year round could be related to year round spawning (Bielsa et al., 1983), but a seasonal trend in abundance found during November seems related to wind stress. Wind stress is an important factor in near-shore surface circulation, being related to larval transport and postlarval settlement (Caputi and Brown 1993). In the Florida Keys wind-driven Ekman transport, mesoscale gyres and meanders seem to be the most important controls in larval transport and recruitment (Yeung, 1996).

Data collected on wind speed and direction at Bear Cut (Figures 24 and 25) for November show the wind blowing intensely and consistently onshore. Examining the weather situation reported on the Daily Weather Maps (NOAA, 1994) between November 1-10, starting on November 3, the wind blew consistently from the East - Northeast direction at a relative high speed. This consistent wind pattern seems to be related to the high concentration of postlarvae found in this month (Fig. 6).

McConaugha (1988), Courtney et al. (1995) and Neal and Maris (1995) stated that decapod larval distributions and transport for species that move long distances are highly correlated with wind events. Consequently, fluctuations in environmental conditions will produce differences in postlarval recruitment year to year. This could explain the high density of *Penaeus* spp. postlarvae found during the sampling period in November.

The average sizes of *Penaeus* spp. postlarvae recruited into Bear Cut vary monthly, with a range of 1.2 to 3.4 mm CL and a yearly average of 1.9 mm CL. Total Length average for the postlarvae found was 9.31 mm in a range of 5.2 to 12.2 mm (Fig. 10). These size ranges correspond to postlarvae II to postlarvae VI, with stages III and IV predominant (Fig. 11). Similar results were found by Costello et al. (1986) who reported planktonic postlarvae of *P. duorarum* entering Florida Bay with a range size of 5-10 mm TL and stages from II to VI. Allen et al. (1980) reported most of the *P. duorarum* postlarvae sampled at Whale Harbor Channel in the Florida Keys with 3 spines and an average size of 7.5 mm TL. Postlarvae other than *P. duorarum* had 4-5 rostrum spines and were 11-12 mm TL.

Our results are also similar to othersresearches in different geographic areas. Wenner and Beatty, (1993) reported postlarvae of *Penaeus duorarum* entering three different points of the Charleston Harbor system with a TL from 7 mm to 11 mm. Bearden (1961) found white shrimp, *P. setiferus*, postlarvae entering South Carolina Sound from June to September as second stage postlarvae of about 7 mm TL. It seems that postlarvae of *Penaeus* spp. arrive at nursery areas with a similar age and size range.

The highest concentrations of *Penaeus* spp. postlarvae in this study were found during flood tides at night (Fig. 21) confirming the results of several authors that reported postlarval recruitment of *Penaeus spp*. occurring mainly at flood tides at night (Penn, 1975; Eldred et al., 1965; Young and Carpenter, 1977; Forbes and Benfield, 1986; Garcia and Le Reste's, 1981; Staples and Vance, 1985; Wenner and Beatty, 1993; and Jones et al., 1964).

Abundance of postlarvae was significantly higher in the subsurface net that in the surface net. This might indicate a vertical migration strategy for postlarvae entering the bay. Forbes and Benfield (1986) found similar results for postlarvae of two species of *Penaeus* that were significantly more abundant in bottom samples entering nursery areas. A vertical migratory behavior of *Penaeus* spp. postlarvae described as nocturnally active offshore, but becoming ephibentic as they approach the near shore nursery grounds changing from nocturnal to tidal activities has been suggested by Dall et al. (1990), Rothlisberg (1982), and Rothlisberg et al. (1995).

At Bear Cut the greatest concentrations of juvenile *Penaeus* spp. were detected at ebb/flow all year round being most abundant in September. Juveniles penaeoids tend to move into the estuary from offshore in a general pattern to deeper and more saline waters, a migration that may involve a considerable along shore movement (Dall et al., 1990). This migration has been associated with such environmental variables as rainfall (Staples and Vance, 1986), temperature and tidal currents (Hughes, 1972). The most relevant environmental variable associated to *Penaeus* spp. juveniles abundant peak at Bear Cut was the rainfall. Rainfall records reached the highest of the year when the massive migration happened in September (Fig. 23).

According to Dall et al., (1990), both the time of the day as well as the time of the lunar month when most migration takes places is controlled by both environmental factors and endogenous rhythms .

Juvenile and subadult penaeid shrimps have been found emigrating from inshore nursery areas during the ebb tide, usually with greatest catches at night during the new and full moon, (Idyll et al., 1964; Staples and Vance, 1986; and Yokel et al., 1969; Beardsley, 1970). Although penaeoids could probably emigrate merely by using environmental clues, internal circadian and tidal rhythms greatly assist the process (Dall et al, 1990). Hughes (1972) suggested that for *Penaeus duorarum*, both a circadian light rhythms and a tidal rhythms are involved in the migration pattern. New and Full Moon periods have been found by different authors as an active emigration times for *Penaeus* spp. juveniles

(Copeland, 1965; King 1971; Su and Liao,1987). Juveniles *Penaeus* spp. were found migrating on the surface as a general tendency. Staples and Vance (1986) reported for juveniles *Penaeus* merguiensis massive migration was related to the wet season with 81% of the emigrating animals being found within 0.5 m of the water surface. Beardsley (1970) and King (1971) indicate similar results for *P. dourarum* and *P. aztecus* in Florida. It seems that offshore emigration of juvenile penaeoids near the water surface is a common behavior pattern .

Subadult *P. duorarum* and juvenile *Penaeus* spp. were more abundant during the ebb/flood period in the surface net (Fig. 18,19). Figure 17 summarizes the migration behavior of the five genera of penaeoids reported at Bear Cut. It seems that except for *Penaeus* spp. postlarvae movement occurs during the ebb/flood period close to the surface.

The size and the season at which subadults of *P. duorarum*, *P. brasiliensis* and juveniles *Penaeus* spp. became more abundant at Bear Cut differs. Juveniles *Penaeus* spp. massive migration occurs during September being the size class of 1.5 mm CL the predominant one (Fig. 15). Subadults of *P. duorarum*. were found relatively abundant all year with a high abundant from December to April predominating size class of 25 mm CL (Fig. 13) . *P. brasiliensis* were abundant from January to June with size class of 30 mm CL as predominante (Fig. 14). Figure 15 shows size class distribution for juveniles and subadults *Penaeus* spp. all year in which we can easily identify the three groups. Voss et al. (1969) concluded that juvenile and subadults shrimps remain in the bay as juveniles where they attain considerable size. About the end of December, depending upon weather conditions and moon phase juveniles move out of the bay into the ocean. The movement has a northward direction in the bay since Bear Cut is one of the main passes leading into ocean waters. Records of catches for a sampling area close to Bear Cut and other areas inside the bay reported by Mckinley (1995) during 1994 indicate similar abundant season for *Penaeus* spp. migrating throughout Bear Cut.

M. martinella and *M. goodei* showed high abundance from December to April, appearing only occasionally the rest of the year. A periodicity of appearance for *M. goodei* and *M. smithi* were also reported for Bermuda waters where they appeared only during the summer (Wheeler J. 1937).

A better understanding of the dynamic migration pattern for the penaeoid shrimps in Biscayne Bay with emphasis on *P. duorarum* and *P. brasiliensis* (those species with a considerable economic value) will required a great effort and research. The development of a management policy based on modeling of a population with a large and complex life cycle, depending on annual recruitment as a consequence of environmental variables is complicated. Antrophogenic pressure on an environment such as Biscayne Bay serving as nursery grounds for *Penaeus* spp. populations, needs to be monitored carefully. Our results are only a small contribution to future projects with a more broad perspective and more sampling points at Biscayne Bay.

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{ TC "References" \l 1 }

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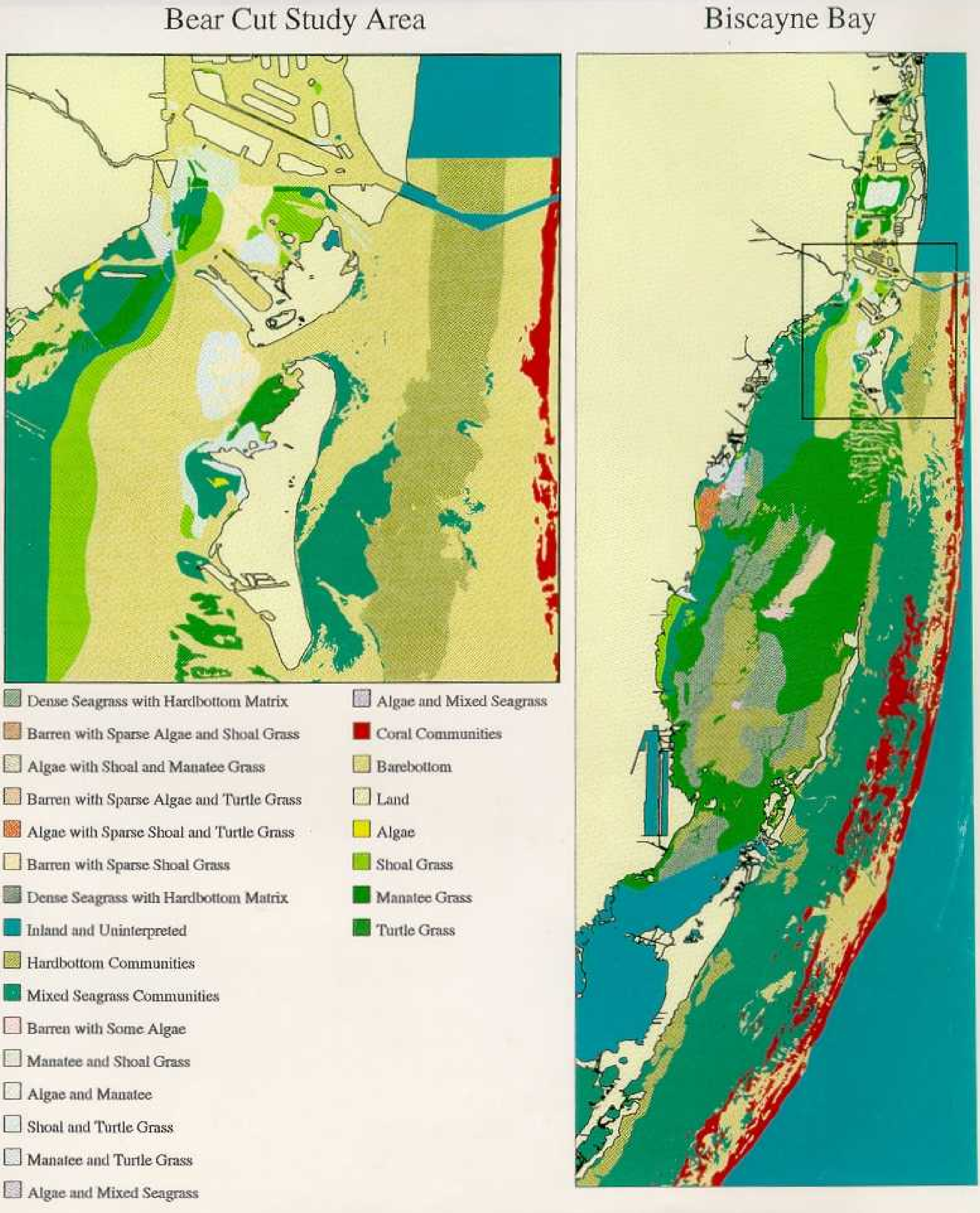

Figure 1. Bottom communities of Biscayne Bay (DERM, 1988).

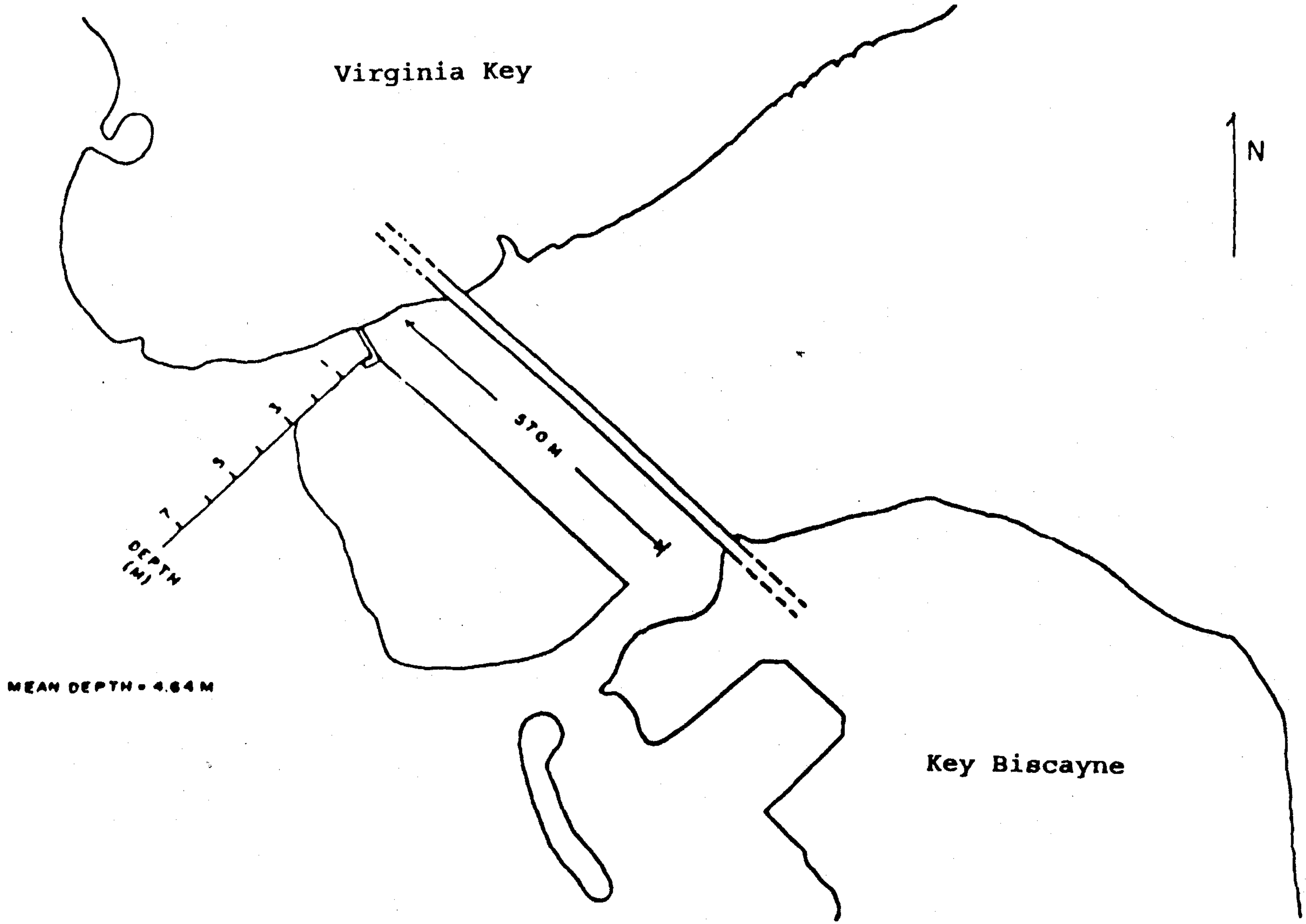

Figure 2. Bear Cut bottom profile (Meyer, 1970).

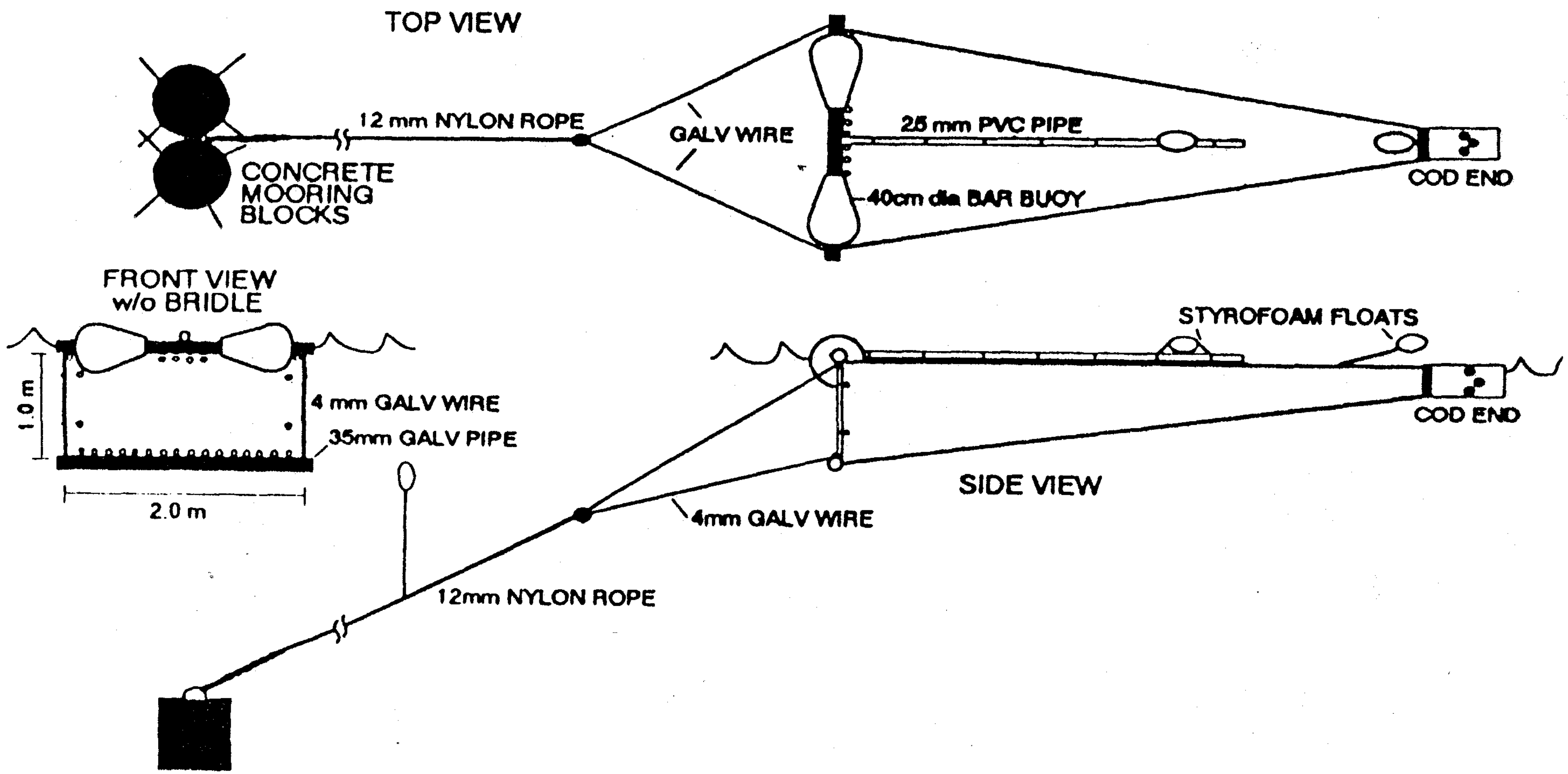

Figure 3. Schematic diagram of the surface and subsurface channel net and their mooring (Shenker et al., 1993).

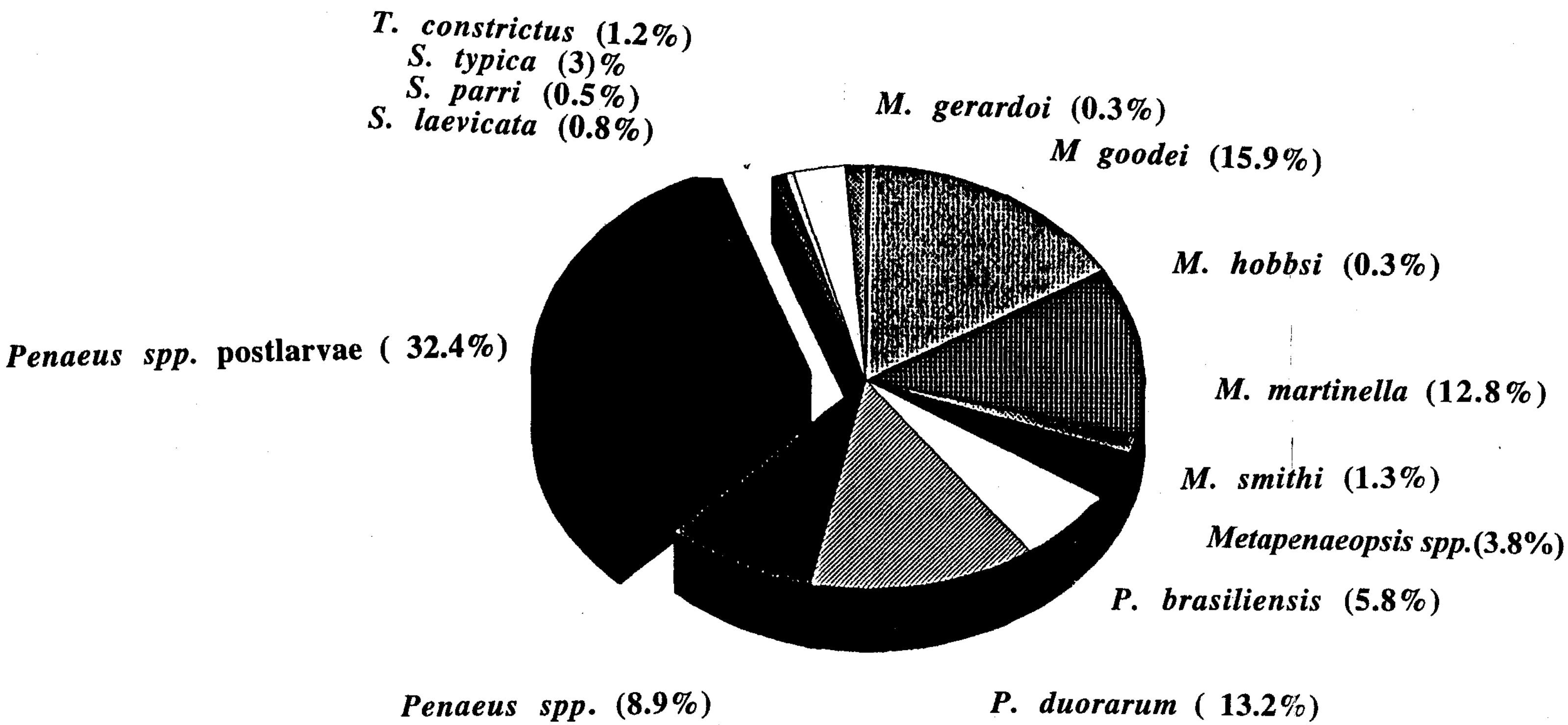

Figure 4. Species composition (%) of penaeoid shrimps identified at Bear Cut, January - December 1994.

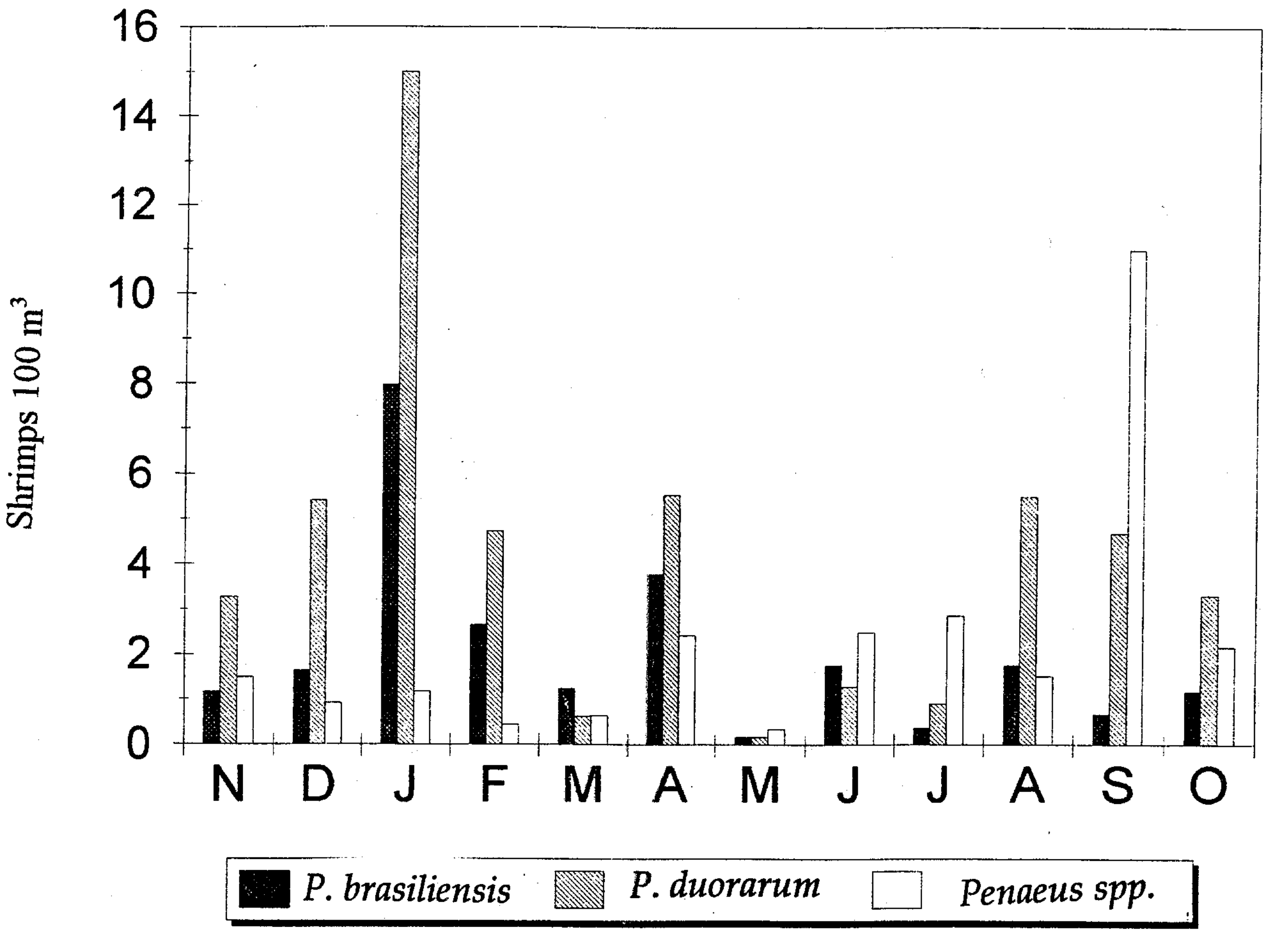

Figure 5. Monthly concentration of juvenile *Penaeus* at Bear Cut, January - December 1994.

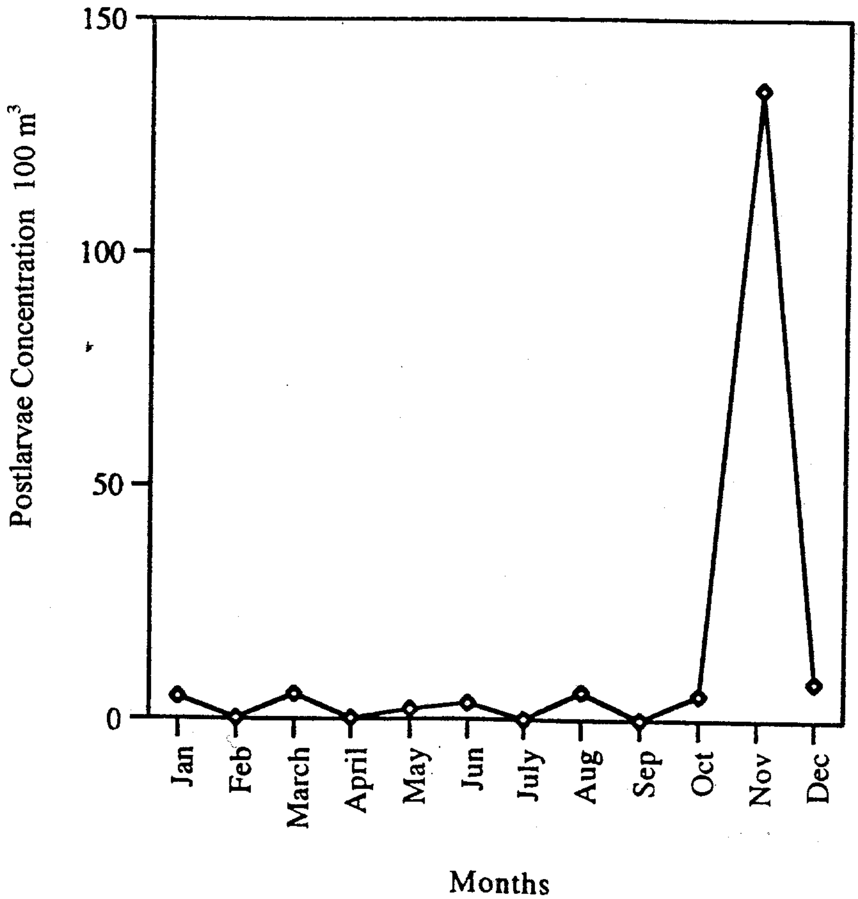

Figure 6. Monthly densities (100 m^3) of *Penaeus spp*. postlarvae at Bear Cut, January - December 1994

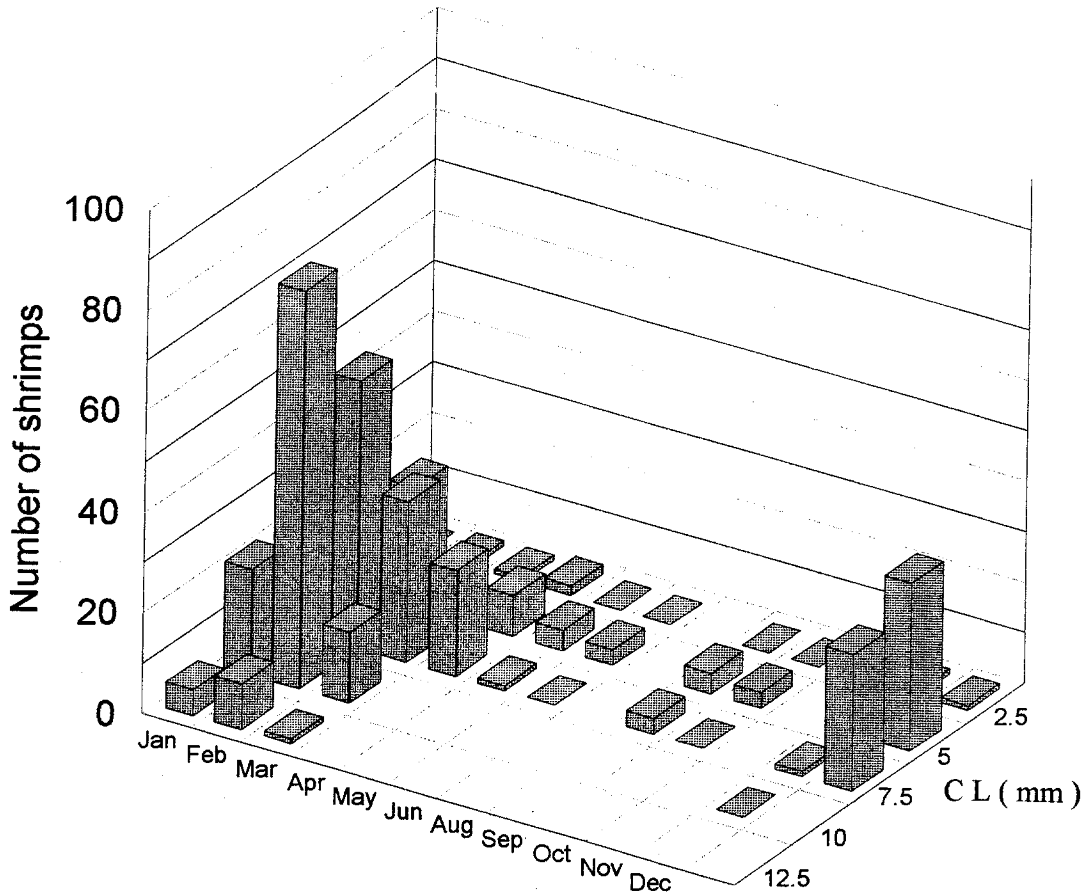

Figure 7. Monthly carapace length frequency distributions of *Metapenaeopsis goodei* at Bear Cut, January - December 1994.

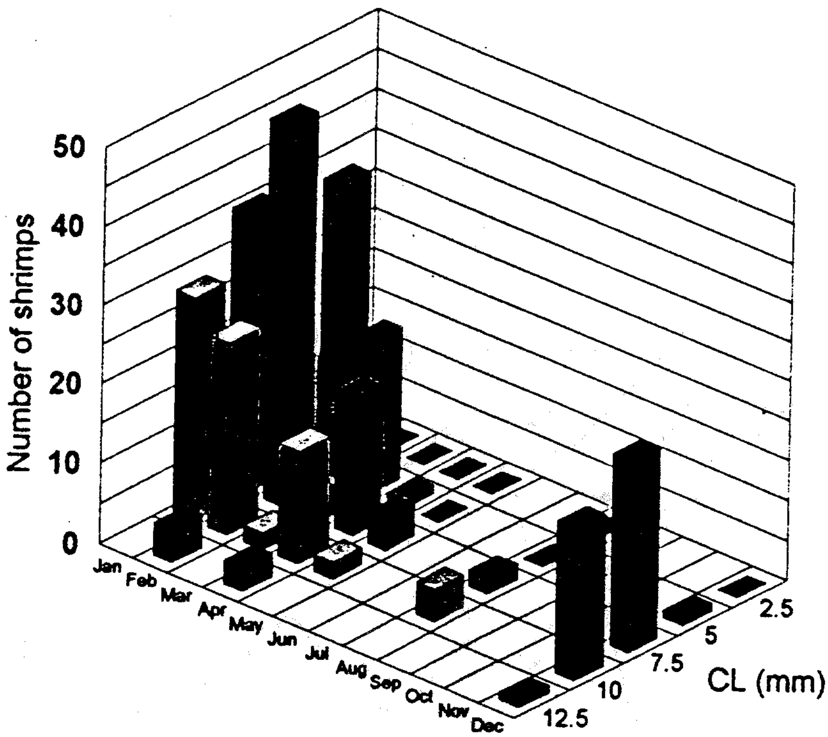

Figure 8. Monthly carapace length frequency distributions of *Metapenaeopsis martinella* at Bear Cut, January - December 1994.

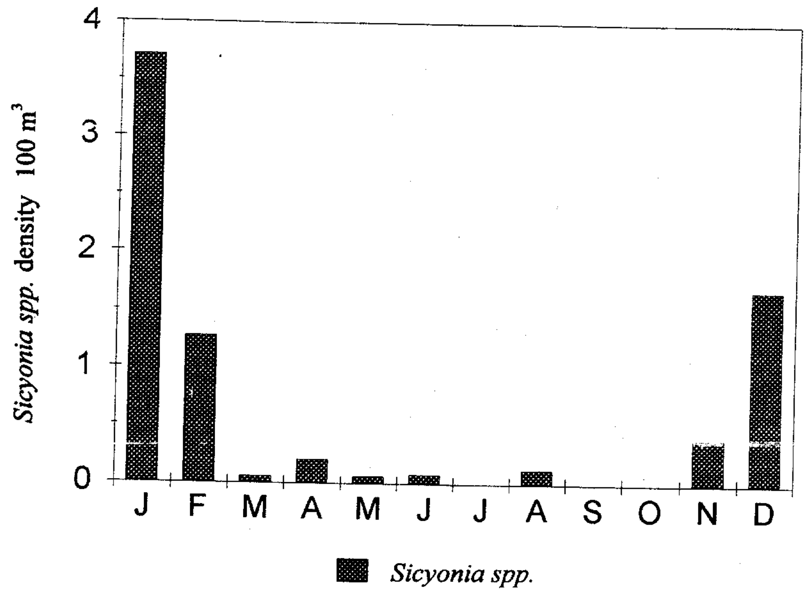

Figure 9a. Monthly concentrations (100 m^3) of genus *Sicyonia* at Bear Cut, January - December 1994.

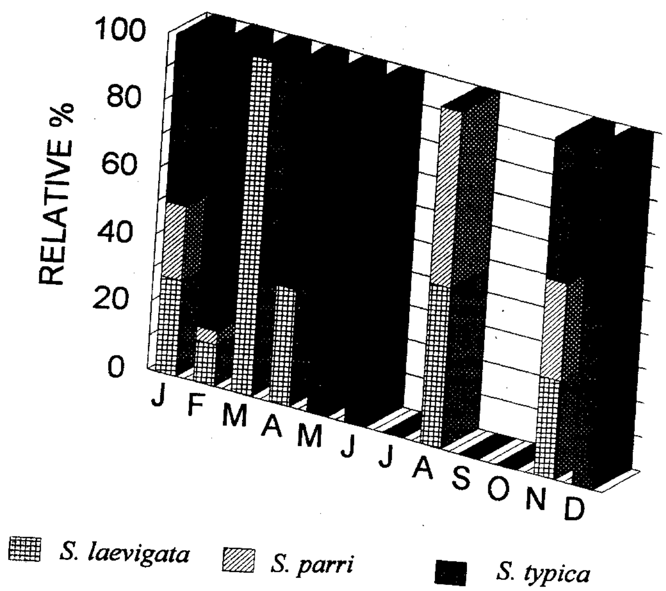

Figure 9b. Relative frequency distribution of *Sicyonia spp.* at Bear Cut, January - December 1994.

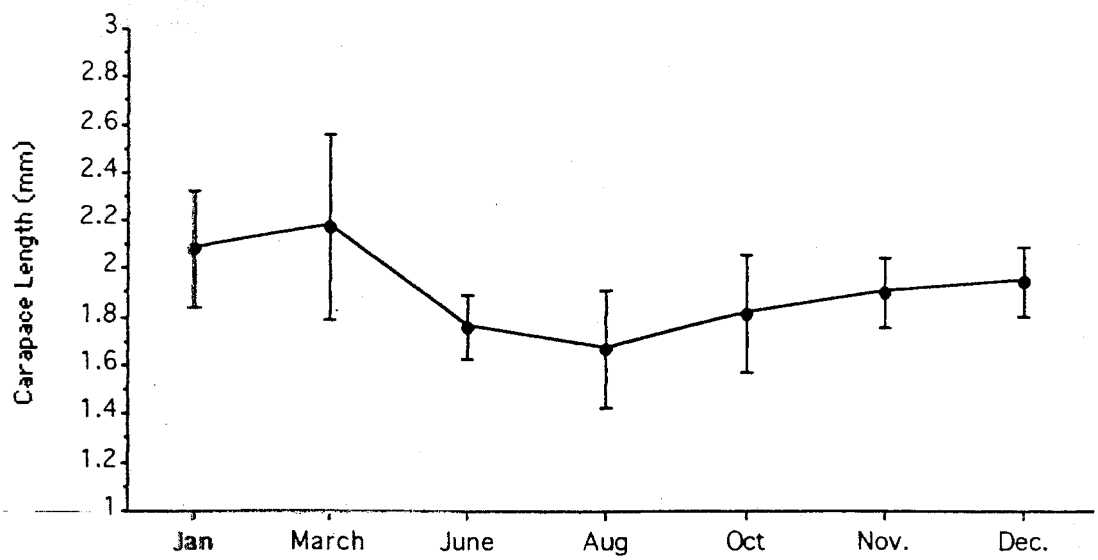

Figure 10. Monthly carapace length average of *Penaeus spp.* postlarvae entering Bear Cut, January - December, 1994

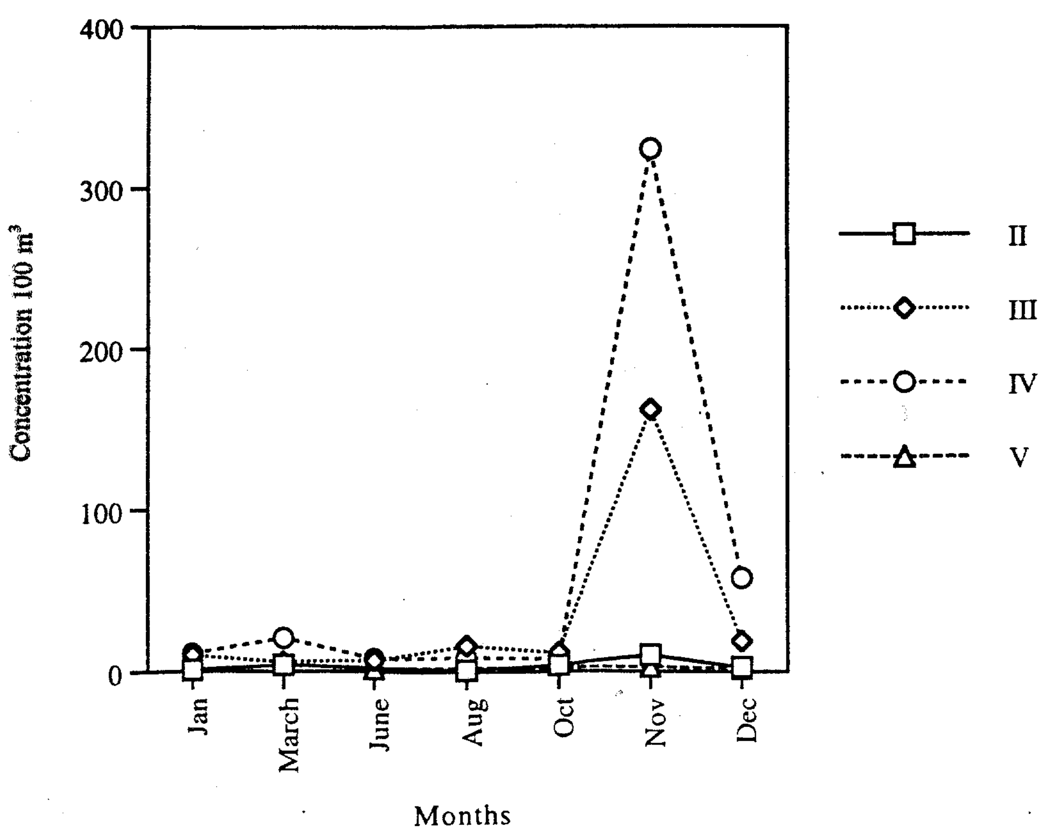

Figure 11. Monthly average densities of *Penaeus spp.* postlarvae at different stages entering Bear Cut, January - December 1994.

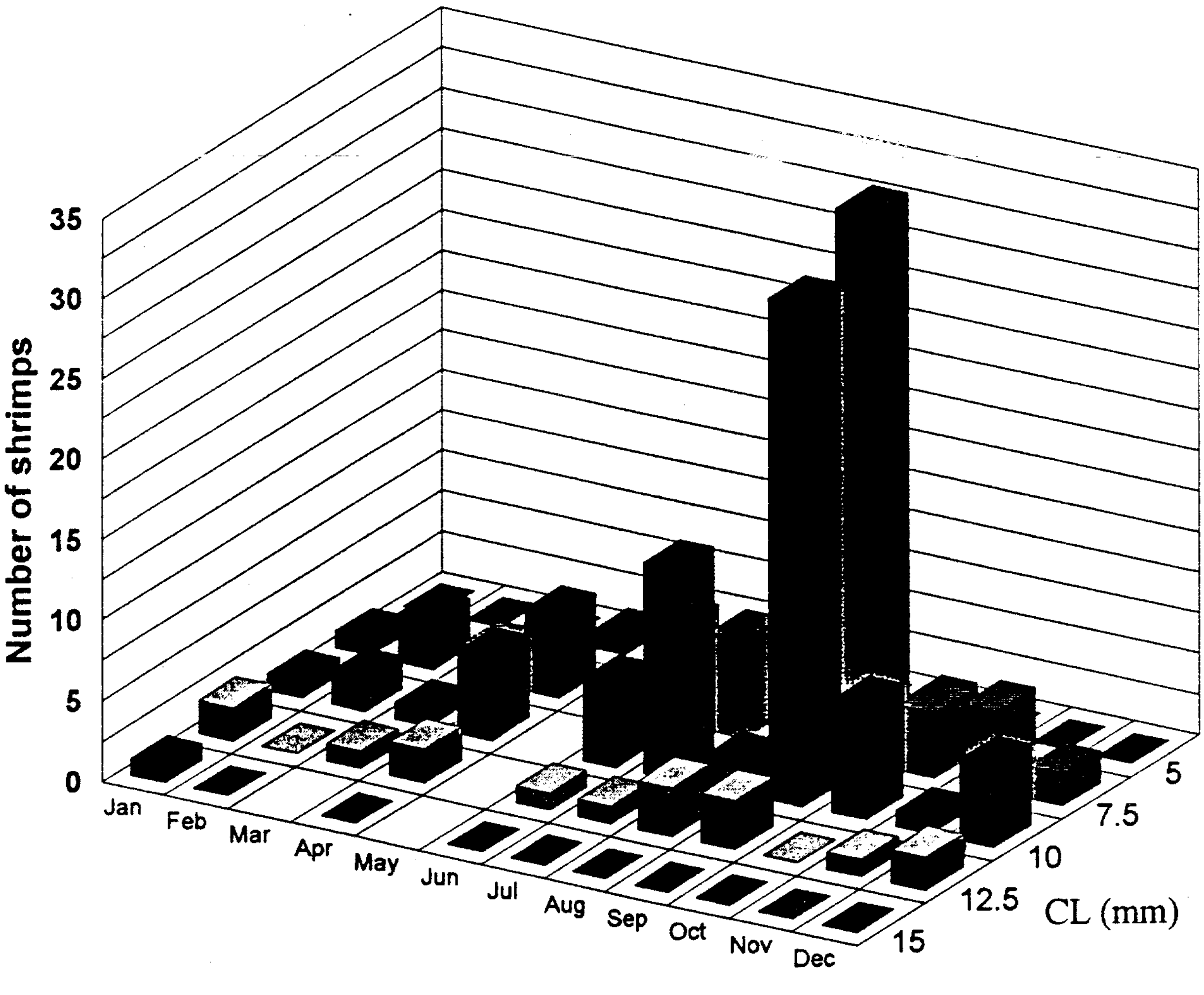

Figure 12. Monthly carapace length frequency distribution of juveniles *Penaeus spp.* at Bear Cut, January - December 1994.

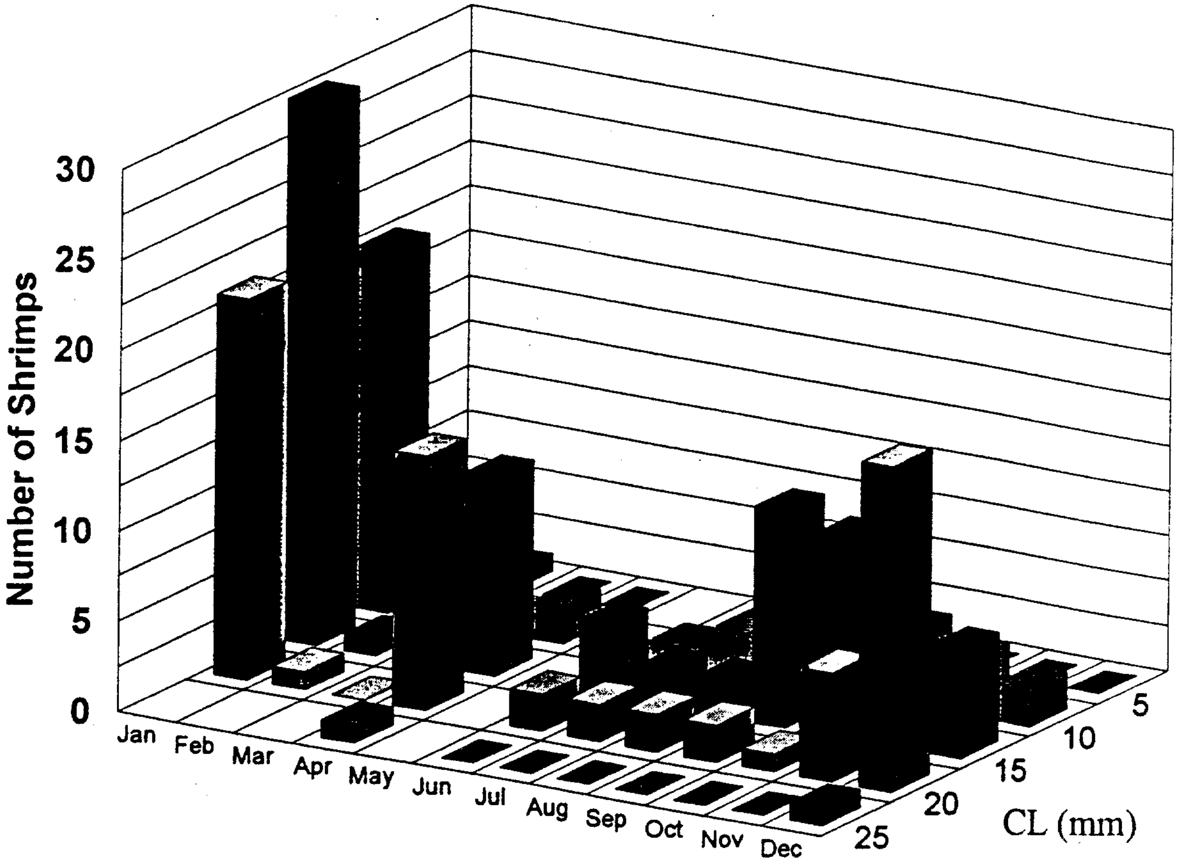

Figure 13. Monthly carapace length frequency distribution of *Penaeus duorarum* at Bear Cut, January - December 1994.

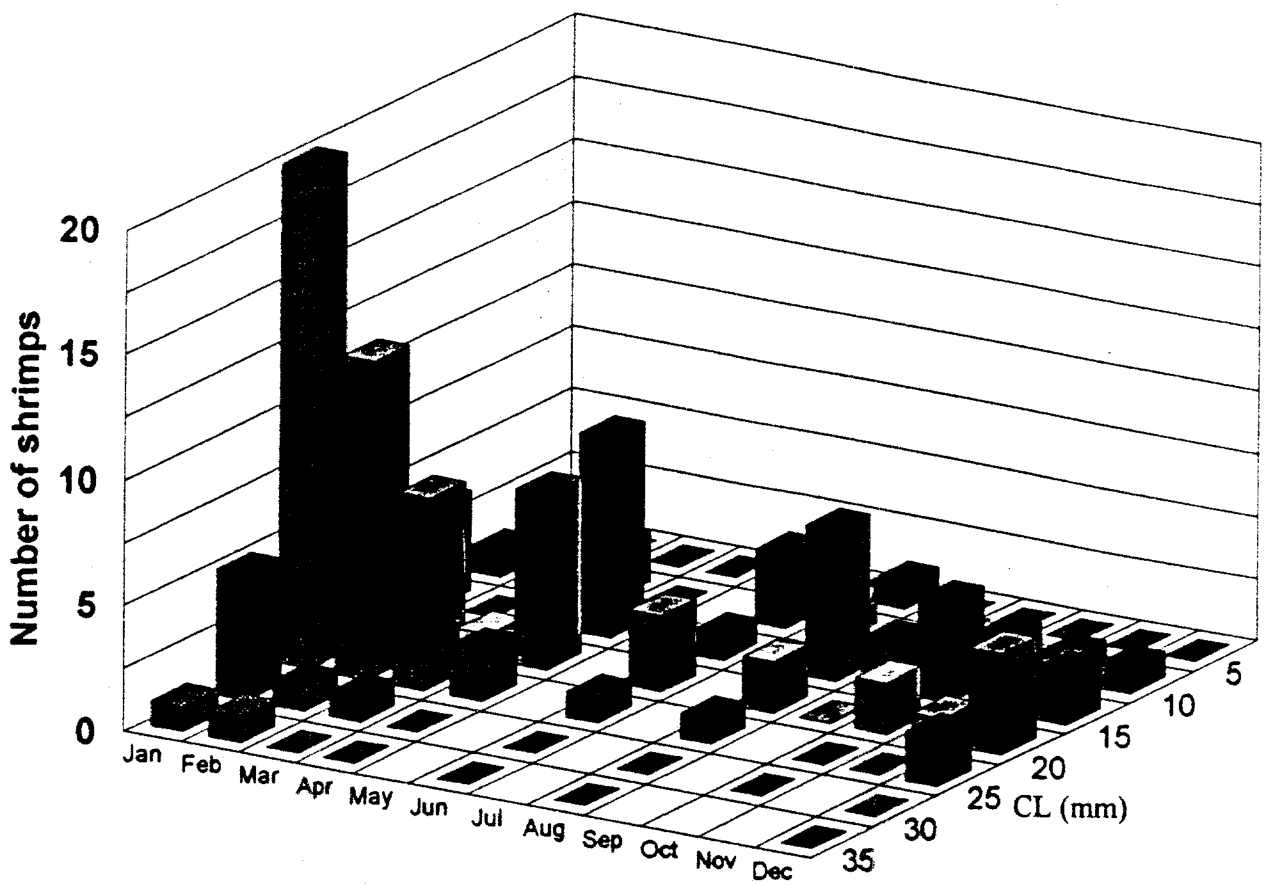

Figure 14. Monthly carapace length frequency distribution of *Penaeus brasiliensis* at Bear Cut, January - December 1994.

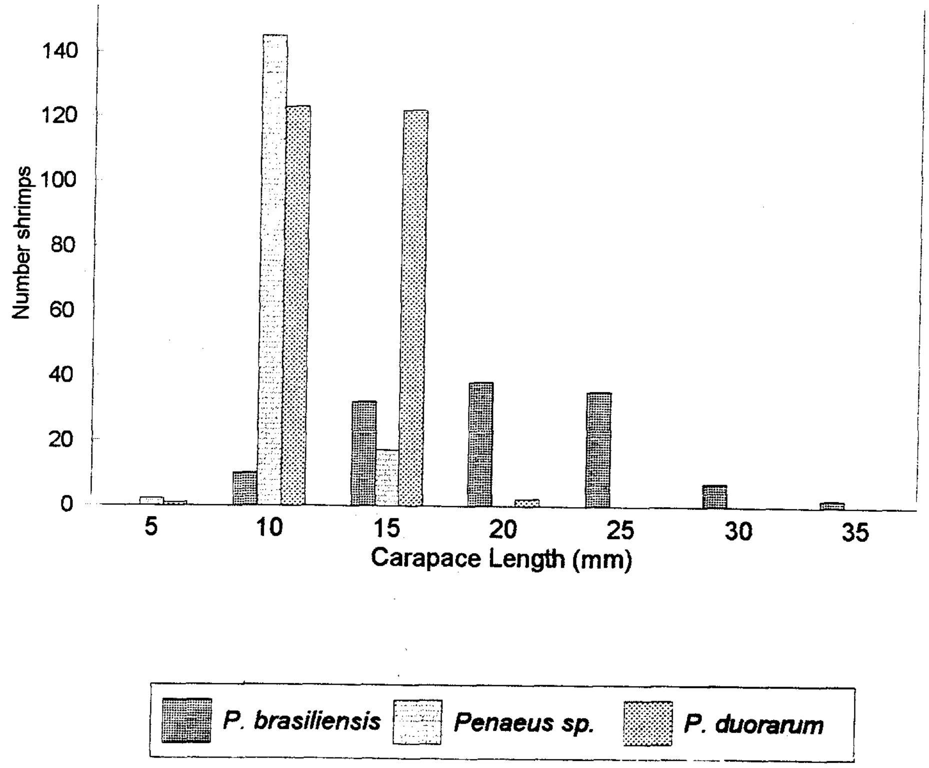

Figure 15. Size class distribution (CL cm) of juveniles *Penaeus spp.* at Bear Cut, January - December 1994.

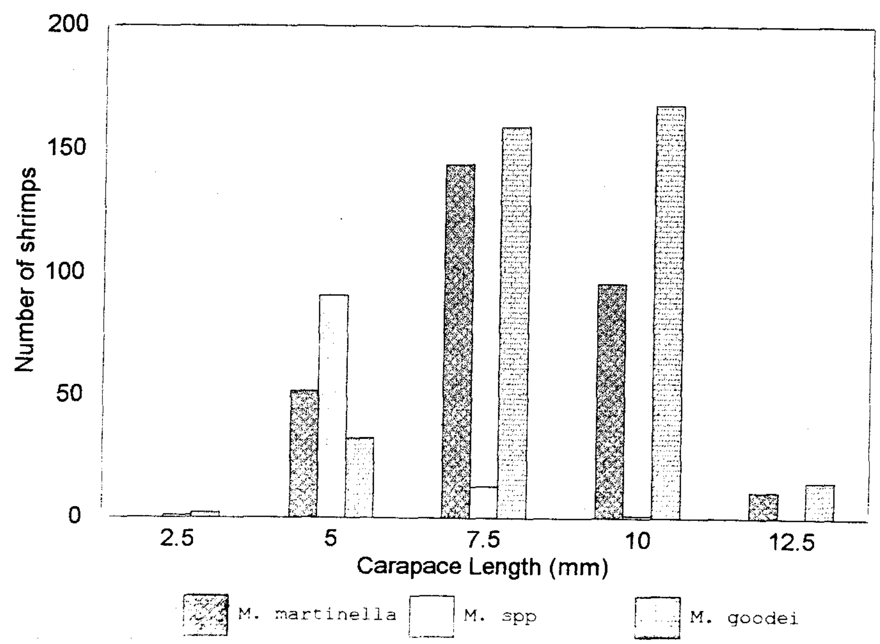

Figure 16. Size class distribution (CL cm) of *M. goodei* and *M. martinella* at Bear Cut, January - December 1994.

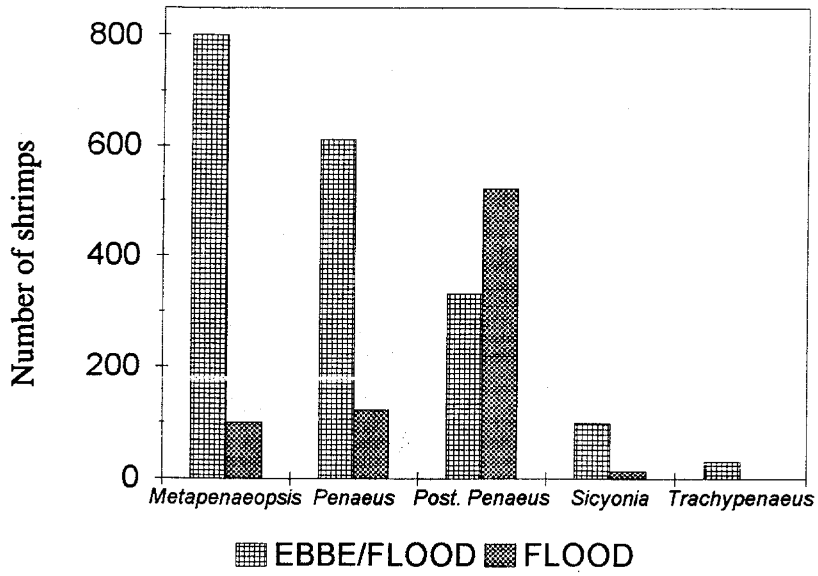

Figure 17. Distribution of Penaeoids shrimps found at Bear Cut on ebb/flood tides during 1994.

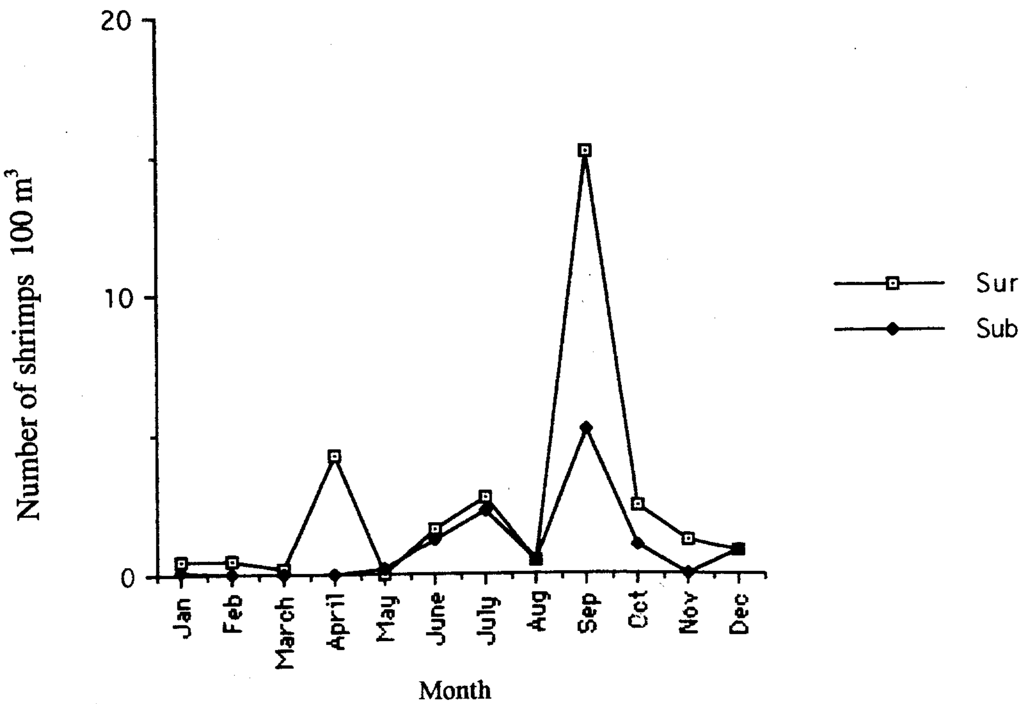

Figure 18. Monthly concentration of juveniles *Penaeus spp.* /100 m^3 on Surface and Subsurface net at Bear Cut, January - December - 1994.

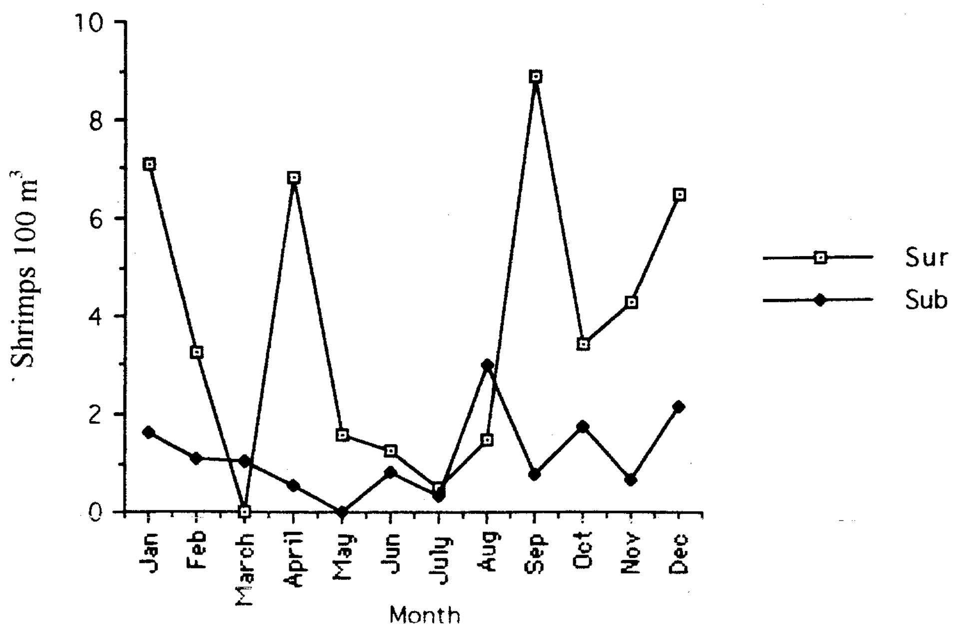

Figure 19. Monthly concentration (100 m^3) of *P. duorarum* on flood and ebb/flood at Bear Cut, January - December 1994.

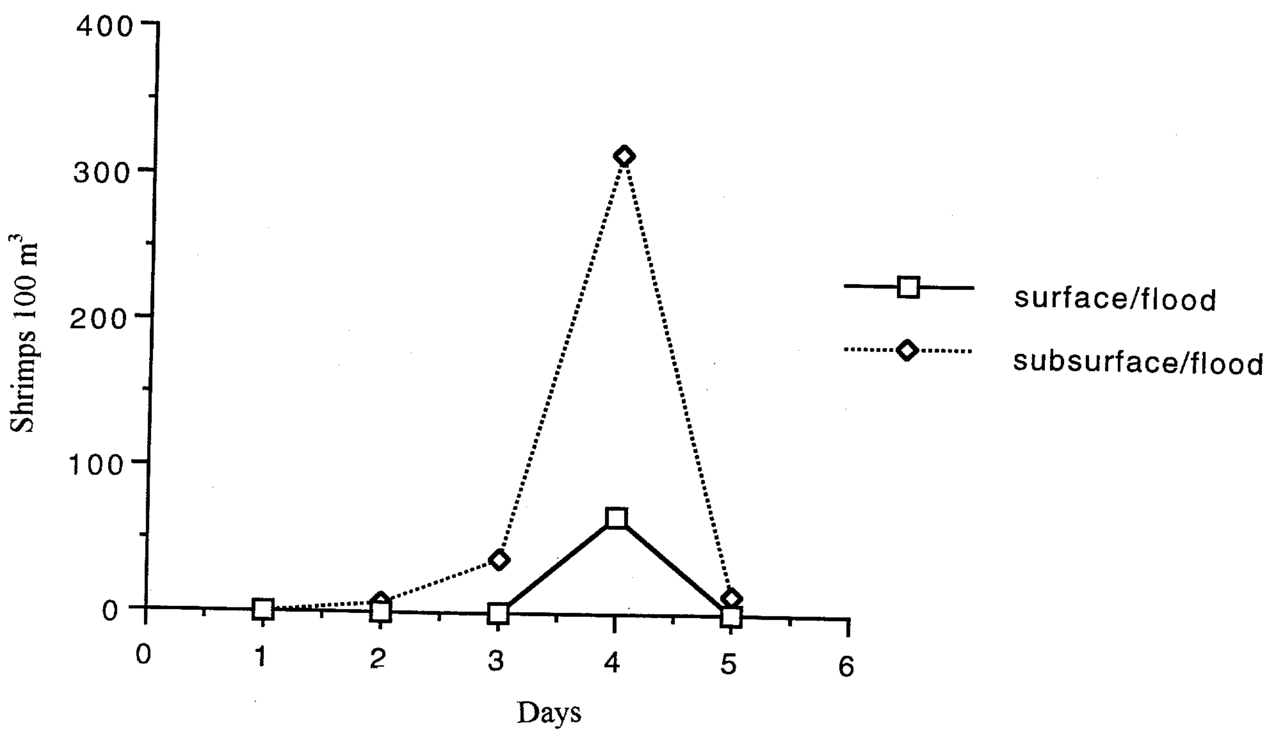

Figure 20. Abundant of *Penaeus spp.* postlarvae (100 m^3) during the sampling days on November 1994 at Bear Cut.

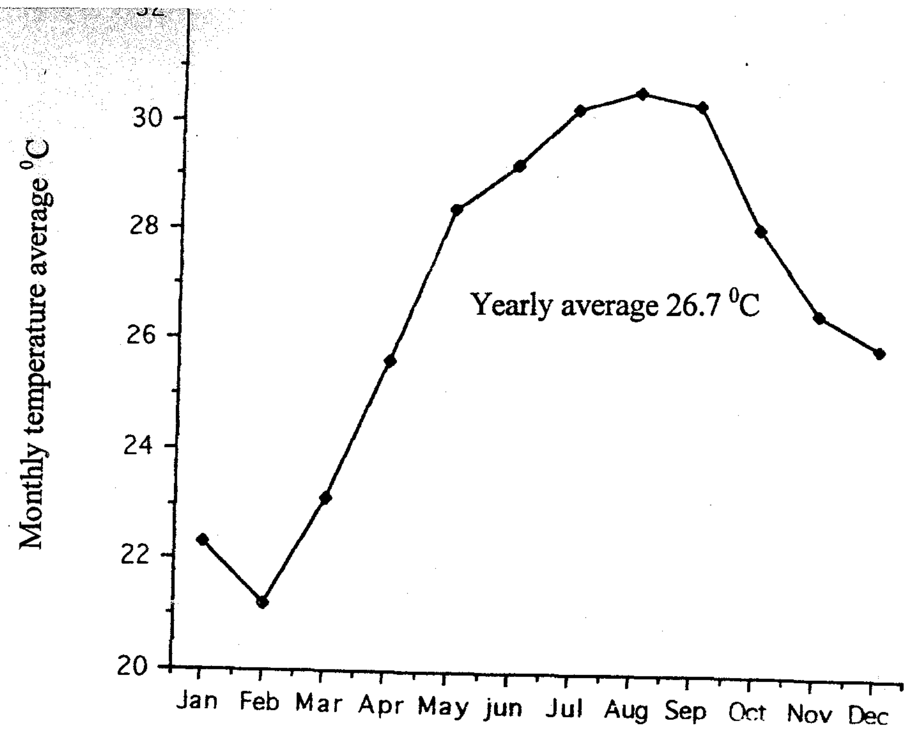

Figure 21. Monthly average water surface temperature at Bear Cut January - December 1994.

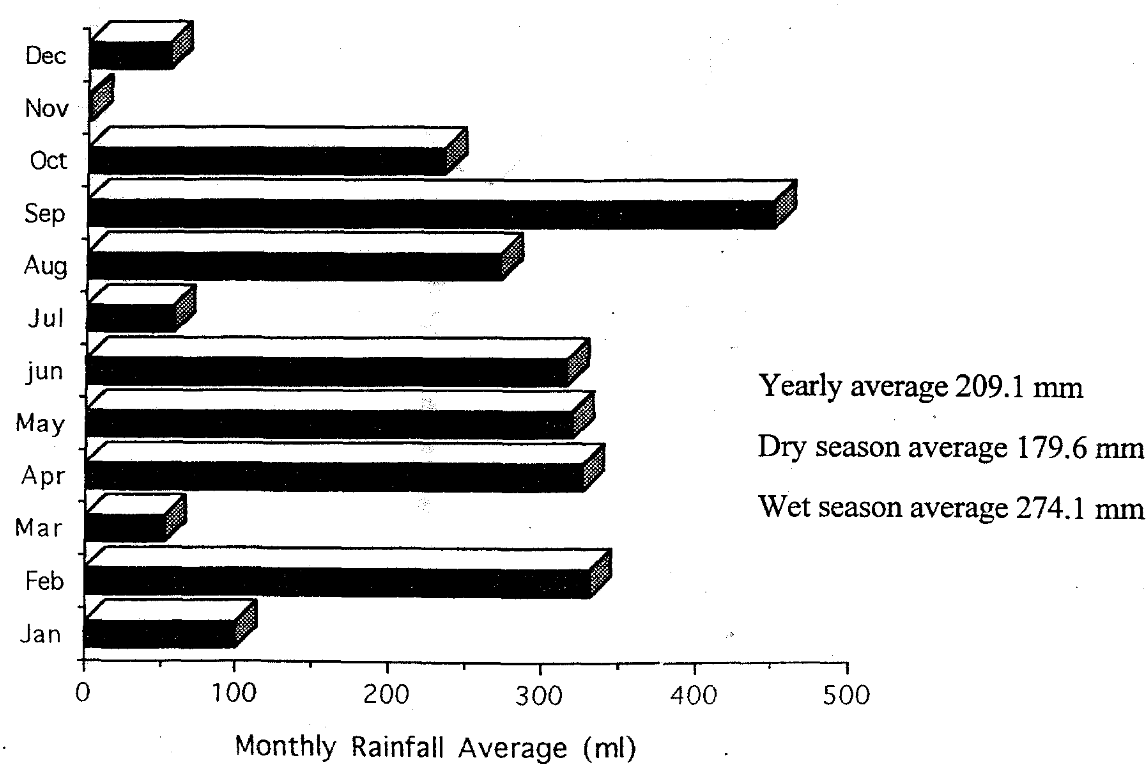

Figure 22. Monthly average precipitation in mm at Bear Cut January - December 1994.

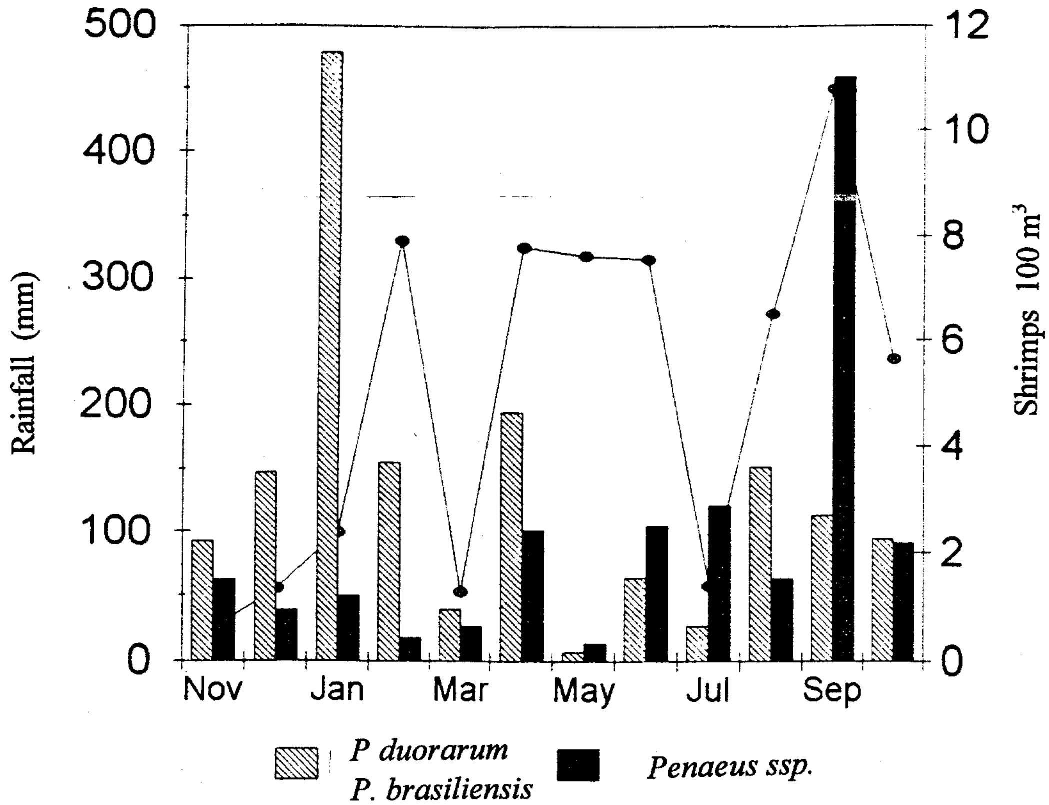

Figure 23. Monthly concentration of juvenil *Penaeus* at Bear Cut, January - December 1994 relate to rainfall monthly average.

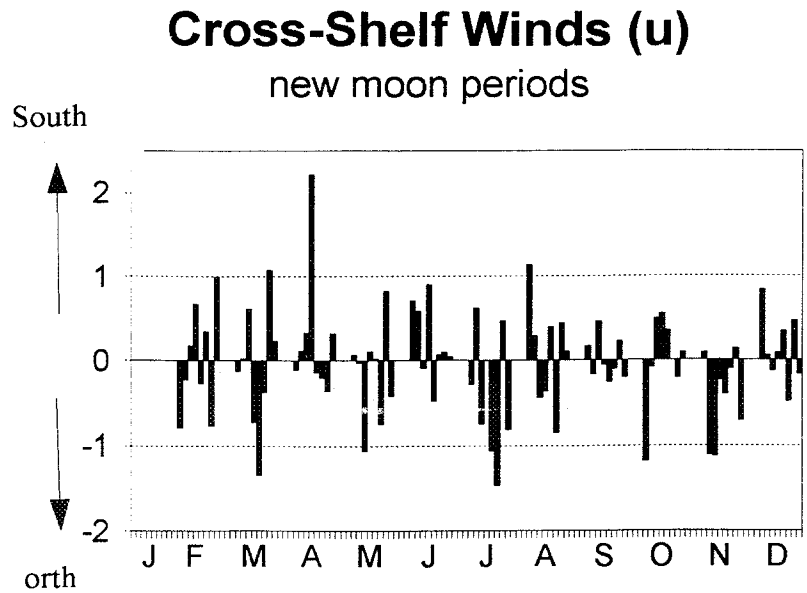

Figure 24. Cross-shelf wind component during the new Moon period at Bear Cut, January - December 1994.

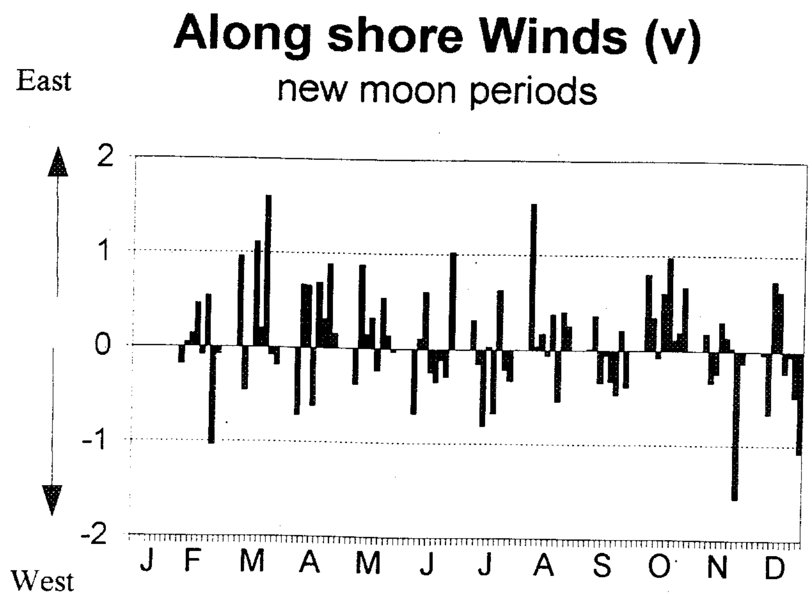

Figure 25. Along-shelf wind component during the new Moon period at Bear Cut, January - December 1994.

Sampling period (New moon)	Number of samples	Net Surface/Sub surface	Tide Ebb/Flood	*Penaeus spp.*	*Penaeus spp.* Postlarvae	*Penaeus duorarum*	*Penaeus brasiliensis*
01/09/94-01/13/94	15	7/8	8/7	1.19	4.72	15.01	7.98
02/08/94-01/12/94	20	10/10	10/10	0.43	0.19	4.74	2.66
03/10/94-03/14/94	14	7/7	6/8	0.64	5.29	0.63	1.25
04/09/94-04/13/94	20	10/10	10/10	2.42	0.21	5.53	3.77
05/08/94-05/12/94	20	10/10	10/10	0.33	2.10	0.16	0.17
06/07/94-06/11/94	18	9/9	9/9	2.49	3.39	1.28	1.76
07/06/94-07/10/94	20	10/10	1010	2.88	0.00	0.92	0.36
08/05/94-08/09/94	20	1010	10/10	1.51	5.90	5.50	1.76
09/03/94-09/09/94	22	11/11	10/12	11.01	0.00	4.69	0.67
10/03/94-10/07/94	20	10/10	10/10	2.16	5.28	3.32	1.17
11/01/94-11/05/94	20	10/10	10/10	1.49	135.01	3.28	1.16
11/30/94-12/04/94	20	10/10	10/10	0.92	8.18	5.40	1.65
Total	229			27.48	170.28	50.48	24.36
Monthly Average				2.29	14.19	4.21	2.03

Sampling period (New moon)	Number of samples	Net Surface/Sub surface	Tide Ebb/Flood	*M. goodei*	*M. martinella*	*Metapeneaopsis spp.*
01/09/94-01/13/94	15	7/8	8/7	8.22	13.90	1.79
02/08/94-01/12/94	20	10/10	10/10	27.7	18.44	9.90
03/10/94-03/14/94	14	7/7	6/8	8.42	3.96	1.93
04/09/94-04/13/94	20	10/10	10/10	6.40	6.86	1.82
05/08/94-05/12/94	20	10/10	10/10	0.83	1.04	0.16
06/07/94-06/11/94	18	9/9	9/9	0.56	0.26	0.00
07/06/94-07/10/94	20	10/10	1010	0.18	0.00	0.00
08/05/94-08/09/94	20	1010	10/10	1.02	1.04	0.00
09/03/94-09/09/94	22	11/11	10/12	0.92	0.00	0.28
10/03/94-10/07/94	20	10/10	10/10	0.20	0.00	0.00
11/01/94-11/05/94	20	10/10	10/10	1.65	0.64	2.91
11/30/94-12/04/94	20	10/10	10/10	13.53	9.81	0.92
Total	229			69.61	55.65	19.72
Monthly Average				5.80	4.64	1.64

Table 1. Monthly concentration average (100 m^3) of penaeoids shrimps postlarvae and juveniles captured during the sampling at Bear Cut, Biscayne Bay, Florida, 1994.

Species	Sex	Avg. Length (CL mm)	Standar deviation	Range (CL mm)	n
Penaeus duorarum	m	16.7	5.2	9.9-25.4	144
	f	13.3	4.3	7-23.5	120
Penaeus brasiliensis	m	18.5	5.3	11-23.7	51
	f	17	6.2	7-3.4	77
Penaeus spp.		8	2.4	5-12.5	94
Metapenaeopsis goodei	m	7.4	2.1	2.0-12	124
	f	7.5	2	2-11.5	254
Metapenaeopsis martinella	m	6.7	2	3.5-10.5	82
	f	7	2.3	2.7-13.7	216

Table 2. Carapace Length (average and standard deviation) of five penaoid shrimps identify at Bear Cut with their respective ranges .