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Distribution of Migrating Juvenile Pink Shrimp, *Penaeus duorarum duorarum* Burkenroad, in Buttonwood Canal, Everglades National Park, Florida[1]

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ABSTRACT

The vertical and horizontal distribution of migrating juvenile pink shrimp, *Penaeus d. duorarum* Burkenroad, in Buttonwood Canal, Everglades National Park, Florida, was studied by sampling with 13 small, conical nets. Samples were taken during darkness on the ebb tide, and were scheduled thrice monthly for 13 months to coincide with the full moon, new moon, and either the last- or first-quarter moon.

Juvenile pink shrimp responded positively to moonlight by moving to the surface of the canal during the ebb tide. They probably stayed on the bottom or along the sides of the canal during flood tides.

Changes in lateral distribution also were attributable to moonlight. More shrimp were caught on the western side of the canal than on the eastern side during the full- and last-quarter-moon phases because the eastern side of the canal is in shadow for the early part of the ebb tide on these moon phases. On new and first-quarter moons the shrimp were usually distributed evenly across the center of the canal.

INTRODUCTION

The pink shrimp, *Penaeus duorarum duorarum*, is the most valuable commercial marine resource of Florida. Landings of pink shrimp from the Tortugas-Sanibel grounds averaged over 18 million pounds (heads-on weight) yearly from 1951 through 1967; the annual value to fishermen averaged more than $5.5 million. Yearly landings ranged from 11.0 to 24.7 million pounds (Rosen and Robinson, 1961, 1962; U. S. Fish and Wildlife Service, 1963, 1964, 1965, 1966, 1967, and 1968).

The life history of the pink shrimp is well known. Adults spawn in offshore oceanic waters, and metamorphosis takes place through numerous larval and postlarval stages. Young pink shrimp enter estuaries as postlarvae and remain for 6 to 9 months before they return to the sea as juveniles, gradually making their way back to the spawning grounds (Idyll, 1964).

Whitewater Bay (including Coot Bay), a large estuary in the Everglades National Park in southern Florida, is an important nursery area for young pink shrimp (Figure 1). Research on the juvenile phase of the life history of the pink shrimp began October 1, 1962, in the Everglades National Park nursery grounds, with the support of the Bureau of Commercial Fisheries. The present study was begun in June, 1964 and was directed toward a description of the vertical and horizontal distribution of juvenile pink shrimp in response to environmental variables as the shrimp emigrated from the nursery grounds through Buttonwood Canal.

SAMPLING GEAR AND METHODS

The sampling site was beneath the bridge crossing Buttonwood Canal about 1 km from Florida Bay (Figure 2). Buttonwood Canal is man-made, about 5.5 km long, and extends in an almost straight line between Coot Bay and Florida Bay. At the sampling site the canal is about 18 m wide and about 1.7 m deep in the center at mean low water. Tides are of the mixed semi-daily type described by Marmer (1954) and Tabb, Dubrow, and Manning (1962); the normal range is about 46 cm and the maximum is about 64 cm. Current velocities in Buttonwood Canal average about 0.5 m/sec with a maximum of about 0.9 m/sec.

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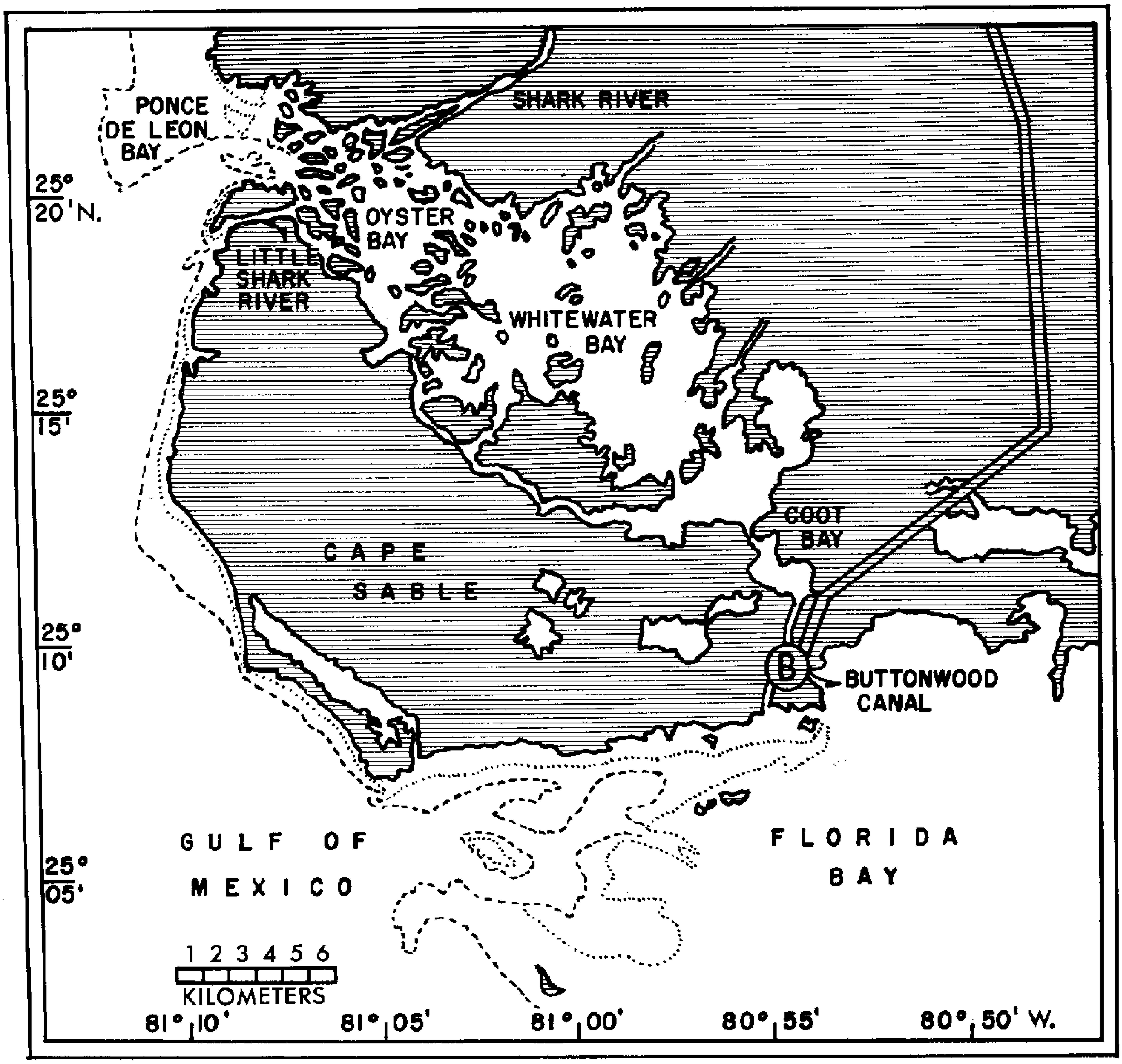

FIGURE 1. The Whitewater Bay–Florida Bay area, showing the location (B) of the sampling site in Buttonwood Canal.

Samples were obtained with conical nylon nets, 2.7 m long and 51 cm in diameter, with 19-mm stretched mesh, mounted on circular iron hoops. The nets were fished from iron frames (Figure 3) suspended vertically at five stations spaced equally across the canal. The frames were supported by ropes attached to the bridge and were held in position by pointed spikes welded to the bottom of the frames. The nets slid up and down the frames on iron guides welded to the sides of the hoops which fitted into channels in the frames. The vertical distance between nets was adjusted so that each net fished at the desired depth. The shape of the hoop supporting the top net was modified so that it extended about 8 cm above the surface of the water, yet fished an area almost equal to that of the other nets.

Two sets of nets were fished alternately in each frame. When one set was withdrawn from the frame at the end of the sampling period, the other set (pre-adjusted for the change in water level) was lowered into position. The gear is shown suspended from the bridge in Figure 4.

The three frames in the middle of the canal fished three nets each—one on the surface, one in the middle of the water column, and

FIGURE 2. View of the sampling site at the bridge crossing Buttonwood Canal at Flamingo, Everglades National Park, Florida.

one on the bottom. The outermost frames fished only two nets—one at the surface and one on the bottom—because of shallower water (Figure 5).

Previous research demonstrated that few

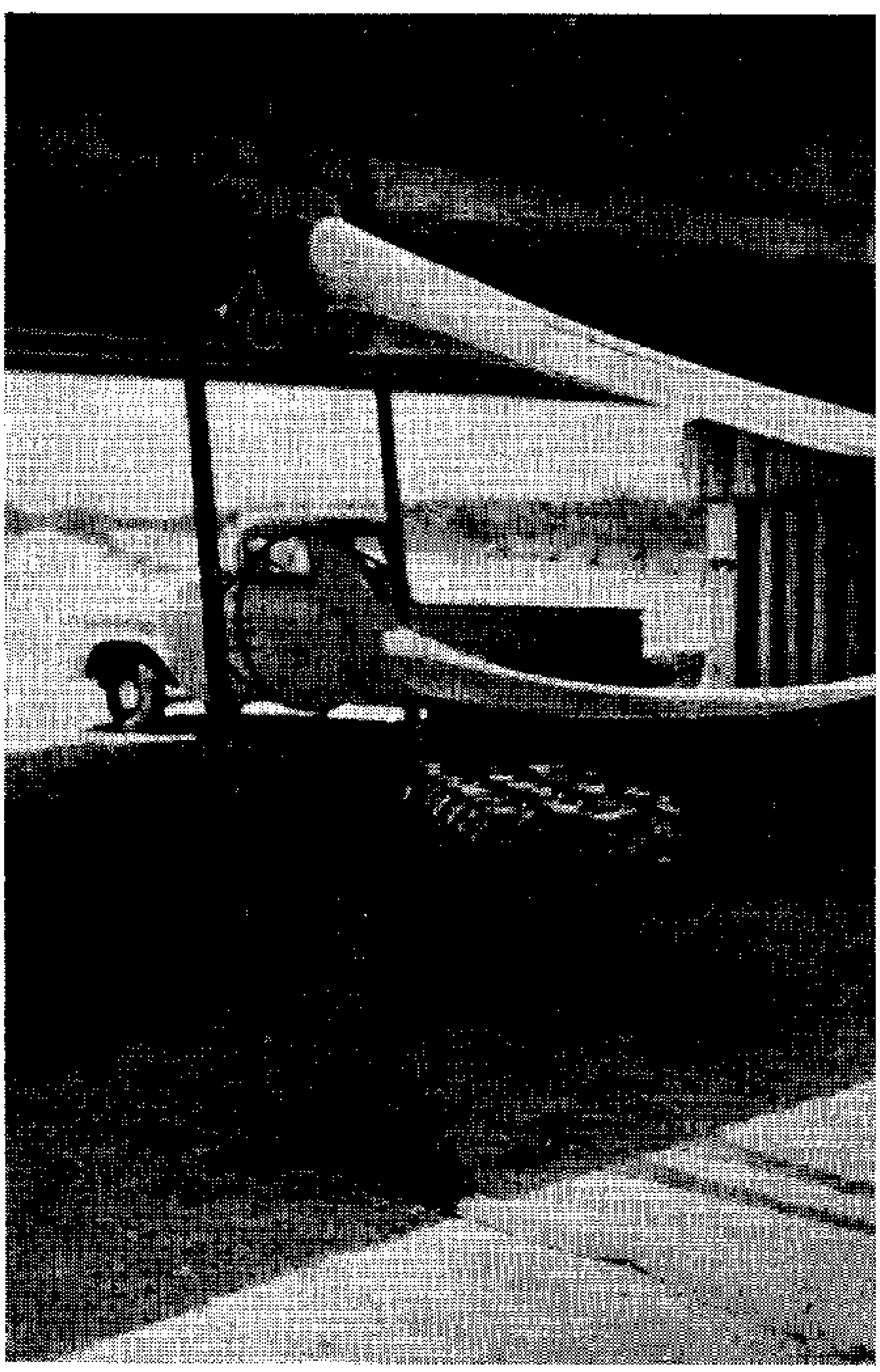

FIGURE 3. One set of conical nets and supporting frame used in shrimp sampling in Buttonwood Canal.

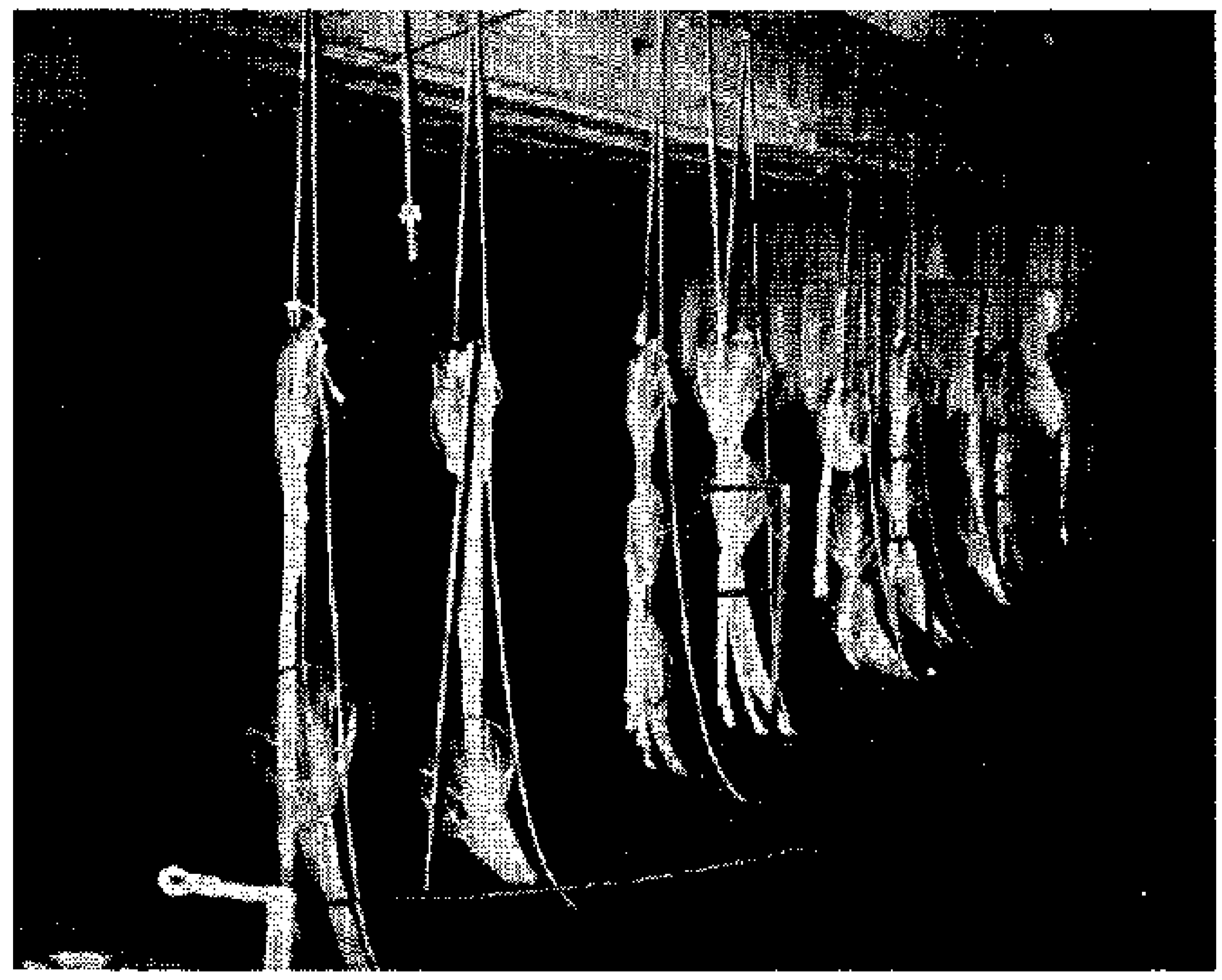

FIGURE 4. Conical nets and frames suspended from the bridge at Flamingo, Florida, before the start of sampling.

juvenile shrimp move with the flooding tide in Buttonwood Canal and that almost no shrimp moved by daylight on either the flood or ebb tide. Consequently, samples were taken only on the ebb tide during darkness. Collections were made thrice monthly from June, 1964 through June, 1965. Monthly sampling was scheduled on or within 3 days of the full moon, new moon, and either the last- or first-quarter moon. Each sampling period was 1 hour long; from two to four samples were taken each night, depending on the duration of the ebb tide. In 13 months, 145 samples were taken—45 on full-moon tides, 53 on new-moon tides, 28 on first-quarter-moon tides, and 19 on last-quarter-moon tides.

At the end of a sampling period the catch from each net was preserved in 10% formalin. Each frame was designated a station and numbered I through V, and the position fished by each net at a given station was designated A through C (A = surface net; C = bottom net). Environmental conditions were recorded for each sample. Wind direction was estimated

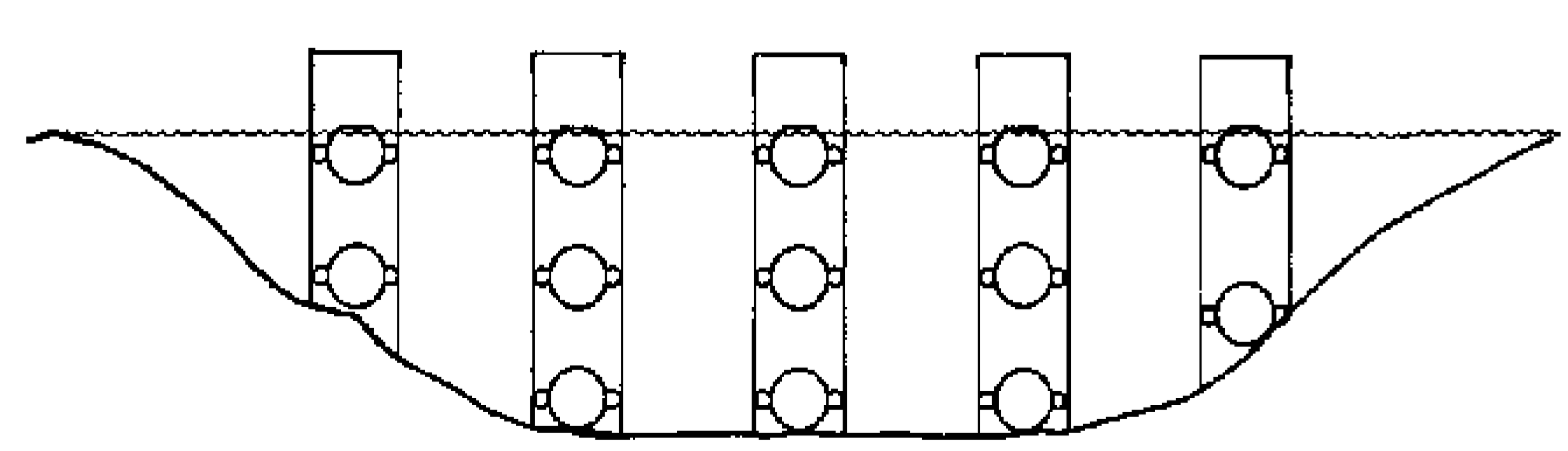

FIGURE 5. Cross section of Buttonwood Canal showing the spacing of the conical nets. The figure is not to scale.

TABLE 1.—*Current velocities at Stations IA, VA, and all bottom nets, as they relate to the reference meter. Correction factors shown were used to adjust the catches to a standard velocity*

Reference reading (revolutions per hour)	Average bottom reading (revolutions per hour)	Correction factor	Average reading at Stations IA, VA (revolutions per hour)	Correction factor
Increasing velocities				
1800–2400	1710	0.250	1980	0.132
2401–3000	2070	0.225	2460	0.079
3001–3600	2520	0.229	2910	0.112
3600>	2700	0.300	3150	0.186
Decreasing velocities				
1800–2400	1470	0.300	1650	0.214
2401–3000	1650	0.360	1860	0.279
3001–3600	1950	0.420	2220	0.339

and velocity was measured with a Dwyer Wind Gauge.[2] Water velocity was measured with a Gurley Current Meter positioned near the center of the canal about 60 cm below the surface. Estimates were made of the differences in current velocity at individual nets by taking 2-minute current readings at the reference station, then 2-minute readings at each net position. A new reference reading was taken every 10 minutes to compensate for changes in water velocity at the reference station. By combining a series of these readings, an estimate was made of the current pattern in the canal (Table 1).

Current velocities at the bottom nets (IC, IIC, IIIC, IVC, VC) were similar, as were velocities at the surface nets at either side of the canal (IA, VA). Both were lower than velocities at the reference meter. Correction factors were calculated for each group of nets, and shrimp catches from the nets were adjusted to a standard current velocity as read from the reference meter. The adjustments were made by increasing the shrimp catches at each of the bottom nets and at nets IA and VA by the amount of the correction factor corresponding to the position of the net and the current velocity during the sampling. Such adjustments were made for all samples and are included in all subsequent calculations. No corrections were needed for nets IIA, IIB, IIIA, IIIB, IVA, and IVB.

Because the current pattern in the canal changes during decreasing velocities compared to increasing velocities, a separate set of corrections was needed for each condition. For example, when the current velocity in the canal was increasing, the current velocity at the bottom nets was 75% of the velocity recorded on the reference meter; during decreasing velocities, the current velocity at the bottom nets was 65% of the reading at the reference meter.

[2] Trade names referred to in this publication do not imply endorsement of commercial products.

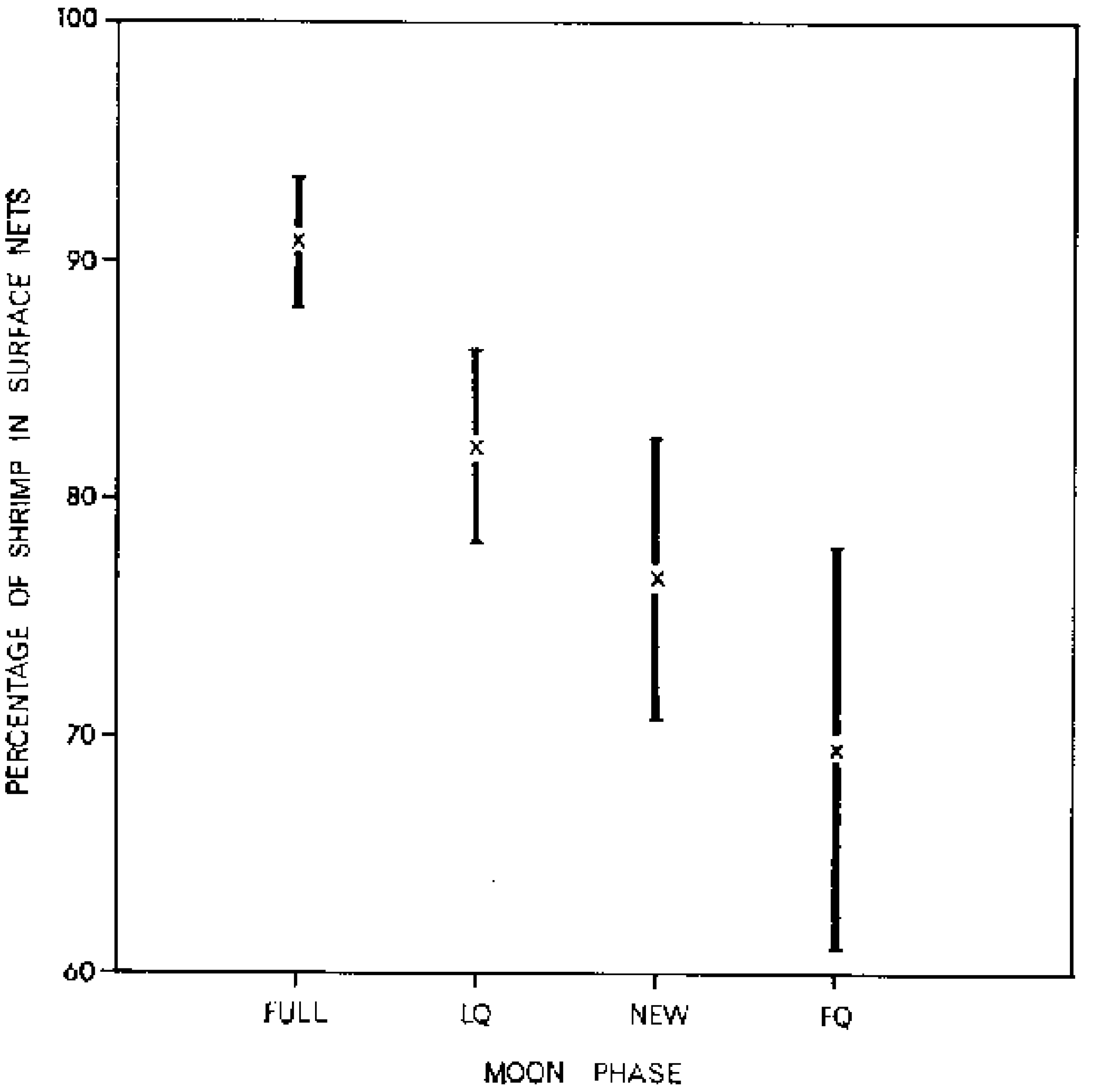

FIGURE 6. Percentage of juvenile shrimp caught in the surface nets during different moon phases. Crosses are average values, and solid lines indicate two standard errors on either side of the mean.

VERTICAL DISTRIBUTION

The distribution of catches of juvenile pink shrimp among the surface, middle, and bottom nets showed that juvenile shrimp were concentrated in the surface layers of the canal under all conditions during the ebb tide. A total of 53,086 shrimp were captured during the study; 44,036 (83%) were caught in the surface nets. Preliminary analysis of the data indicated that of all environmental conditions recorded or measured during the study, moon phase and possibly current velocity were the two variables most likely to be responsible for variations in vertical distribution. Vertical distribution separated by phases of the moon showed differences in the percentage of shrimp taken by the surface nets (Figure 6). More detailed analyses were then performed to test the significance of these differences.

To simplify analysis, only the catches of shrimp from stations II, III, and IV were used

TABLE 2.—*Average vertical centers of density (CD) of juvenile pink shrimp in Buttonwood Canal by moon phase and current velocity. [See text for explanation of center of density.]*

Current velocity (revolutions/hour)	Moon phase			
	Full	New	Last quarter	First quarter
<2000	1.48	1.63	1.63	1.69
2000–3000	1.41	1.57	1.48	1.57
3000>	1.32	1.64	1.56	1.68

TABLE 3.—*Analysis of variance of the vertical distribution of juvenile pink shrimp in Buttonwood Canal*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Moon phase	3	0.1044	0.0348	13.38**
Current velocity	2	0.0202	0.0101	3.88
Experimental error	6	0.0157	0.0026	—
Total	11	0.1403	—	—

** Significant at 99% level

because each of these stations fished three nets whereas stations I and V fished only two. The percentage of shrimp caught by the three nets at the surface, middle, and bottom levels of the canal were transformed by means of the arcsin transformation described by Snedecor (1956) to satisfy the requirement of a normal distribution in the analysis of variance model. The transformed values were then used to compute what I choose to call a "center of density" (CD) number for each sample. The CD number was obtained as follows: the surface, middle, and bottom levels (or groups of nets) were designated 1, 2, and 3, respectively; the transformed percentage catch at each level was multiplied by the number corresponding to its level, and the three levels were added. The sum thus obtained was then divided by the sum of the three transformed percentage values obtained before multiplying by the respective level coefficients. The resulting number was between 1 and 3—the smaller values indicated a higher position in the water column than larger values. A CD of 1.00 shows that all shrimp were caught in the surface nets; 2.00 indicated an equal distribution around the middle nets.

The sample CD's were grouped by moon phase and current velocity, and means were obtained for each group (Table 2). An analysis of variance (Table 3) yielded a highly significant F for moon phase ($p < 0.01$) and non-significant F for current velocity. The small mean square for the error or interaction term indicates that most of the variation in vertical distribution of migrating juvenile pink shrimp is attributable to changes in moon phase.

Several factors associated with different moon phases might be responsible for the significant variation in vertical distribution of juvenile pink shrimp. The most obvious is the change in the amount of illumination during the various moon phases. At the sampling site in Buttonwood Canal, the following relations exist between moon phase, ebb tide, and illumination: 1) Full moon—moon rises near sunset; tide begins to ebb near sunset; moonlight present throughout sampling, 2) new moon—moon sets near sunset; tide begins to ebb near sunset; no moonlight during sampling, 3) last-quarter moon—moon rises near midnight; tide begins to ebb near midnight; moonlight present throughout sampling though not as bright as full moon, and 4) first-quarter moon—moon sets near midnight; tide begins to ebb near midnight; no moonlight during sampling.

Another possible factor associated with moon phase that might affect the vertical distribution of juvenile shrimp is the amplitude of the tides; amplitudes are higher with spring tides on full and new moons. The time of the ebb may also have some effect on vertical distribution. On full and new moons, the tide starts to ebb around sunset; on last- and first-quarter moons, it begins to ebb around midnight.

Data from Table 2 were analyzed further by three orthogonal comparisons (Table 4). The comparison between the CD means for full and last-quarter moons and the CD means for new and first-quarter moons tested the significance of the difference in vertical distribution on moonlit nights and on dark nights. A highly significant F ($p < 0.01$) indicated that moonlight probably was a major influence on the vertical distribution of migrating juvenile pink shrimp in Buttonwood Canal. The other comparisons—new moon with first-quarter moon, and full moon with last-quarter moon—provide information about the influence on juvenile shrimp dis-

TABLE 4.—*Analysis of variance showing selected treatment comparisons of the vertical distribution of juvenile pink shrimp in Buttonwood Canal between moon phases*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Full and last-quarter moons versus new and first-quarter moons	1	0.0675	0.0675	25.96**
Full moon versus last-quarter moon	1	0.0352	0.0352	13.54**
New moon versus first-quarter moon	1	0.0017	0.0017	0.65
Total		0.1044	—	—

** Significant at 99% level

tribution of tidal amplitude, time of the ebb, and differences in intensity of illumination. Both tests compared high amplitudes with low amplitudes and early ebb tides with late ebb tides. The only difference between the two comparisons was that one (full versus last-quarter moon) compared samples taken during two periods of different intensity of moonlight, and the other (new versus first-quarter moon) compared nights when there was no moonlight during sampling. If either tidal amplitude or time of the ebb tide influenced vertical distribution, significant F values would be expected for both comparisons. Only the comparison between full moon and last-quarter moon produced a significant F, however, indicating that juvenile shrimp responded to different levels of intensity of moonlight but did not react to tidal amplitude or time of the ebb tide.

The effects of salinity, temperature, size, sex, and water depth on vertical distribution were also analyzed but no differences were detected. Salinities and temperatures in Buttonwood Canal varied little throughout the water column because of turbulence and mixing.

The above analyses indicate that migrating juvenile pink shrimp in Buttonwood Canal respond positively to moonlight by moving toward the surface of the canal during the ebb tide. Workers in other areas have noticed significant differences in the behavior of penaeid shrimp in relation to moonlight. Ghidalia and Bourgois (1961) reported a positive response to moonlight by *Parapenaeus longirostris* in the Mediterranean; the shrimp moved from deep offshore waters to shallower inshore waters when the moon was full, and the response of young shrimp was stronger than that of adults. Gunter (1950) stated that the largest catches of brown shrimp, *Penaeus aztecus*, were made near the Texas coast when the moon was full.

Idyll (1964) suggested that larval and postlarval shrimp maintain their position during adverse currents by moving to the bottom and clinging to algae, rocks, or other material during their migration from the spawning grounds to the estuarine nursery areas, and that during favorable or onshore currents they release their hold and let the currents assist them in moving into the estuaries.

I believe that at the end of the ebb tide in Buttonwood Canal, juvenile pink shrimp behave similarly by descending to the bottom of the canal and hiding in crevices, or burying in the mud to maintain their position during the flood tide. A large net that completely blocked the canal was used in earlier sampling; low catches showed that very few shrimp moved with the flood tide. As soon as the tide began to ebb, however, catches increased greatly. For example, on April 15, 1963, the large net caught no shrimp on the flood tide, but caught 7,048 on the following ebb tide. On September 9, 1963, 241 shrimp were caught on the flood tide and 2,331 were caught on the following ebb tide. Most of the shrimp caught during the flood tide were caught at the end of the tide, when the current velocity had slowed considerably. Probably the shrimp began to move off the bottom in response to decreasing current velocity preparatory to moving out with the coming ebb.

LATERAL DISTRIBUTION

The percentages of shrimp caught by the three nets at each of the three middle stations (II, III, and IV) were transformed by means of arcsin, and lateral CD's were computed for each sample. Station II (east side of the canal) was designated as 1, Station III (center) as 2, and Station IV (west side) as 3. The transformed percentage at Station II was multiplied by 1, at Station III by 2, and at Station IV by 3; the three values were added, and the sum was divided by the sum of the

TABLE 5.—*Average lateral centers of density (CD) of juvenile pink shrimp in Buttonwood Canal by moon phase and current velocity*

Current velocity (revolutions/hour)	Moon phase			
	Full	New	Last quarter	First quarter
<2000	2.24	2.05	2.17	1.96
2000–3000	2.11	2.03	2.10	2.04
3000>	2.06	1.99	2.11	1.91

three percentages obtained before multiplying by the coefficients. A CD of 2.00 indicated that the sample of shrimp was evenly distributed laterally around Station III in the center of the canal.

The three nets at Station III usually caught the most shrimp. Station IV generally caught more shrimp than Station II during full and last-quarter moons. Average CD's computed for full- and last-quarter-moon samples were 2.09 and 2.10, respectively, and for new- and first-quarter-moon samples were 2.01 and 1.98. The CD's were separated by moon phase and current velocity, averaged (Table 5), and an analysis of variance prepared (Table 6). The significant F ($p < 0.05$) for moon phase indicated that most of the variation in lateral distribution was between moon phases. The data were separated into orthogonal comparisons to examine the variation among the four moon phases. The results (Table 7) indicated that the differences in lateral distribution between moonlit nights and dark nights could occur by chance less than once in 100 times. No differences in lateral distribution were detected between full and last-quarter moons or between new and first-quarter moons.

Although the results might suggest that juvenile shrimp move away from the source of moonlight when they group on the western side of the canal on full and last-quarter phases of the moon, in reality the shrimp are moving toward the moonlit side—the eastern side of the canal is shadowed during the early portion of the ebb tide on full and last-quarter moons.

TABLE 6.—*Analysis of variance of the lateral distribution of juvenile pink shrimp in Buttonwood Canal*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Moon phase	3	0.0591	0.0197	7.88*
Current velocity	2	0.0155	0.0078	3.12
Experimental error	6	0.0151	0.0025	—
Total	11	0.0897	—	—

* Significant at 95% level

TABLE 7.—*Analysis of variance showing selected treatment comparisons of the lateral distribution of juvenile pink shrimp in Buttonwood Canal between moon phases*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Full and last-quarter moons versus new and first-quarter moons	1	0.0546	0.0546	21.84**
Full moon versus last-quarter moon	1	0.0002	0.0002	0.08
New moon versus first-quarter moon	1	0.0043	0.0043	1.72
Total		0.0591	—	—

** Significant at 99% level

Wind direction was recorded for all samples but was not a factor in affecting shrimp distribution. The banks of Buttonwood Canal are well protected by shrubbery and trees, and the effect of wind is probably slight except directly at the surface.

A factor that might affect the lateral distribution of juvenile shrimp caught by the conical nets is the current pattern upstream from the sampling site. Current flow down the canal is probably not laminar, and eddies or other unusual current patterns upstream may have affected distributions of shrimp before they reached the sampling site. Although this factor was not measured, current velocities as measured by the meter stationed near the center of the canal at the sampling site apparently did not affect distributions of shrimp (Table 6).

SUMMARY

Significant changes in vertical and lateral distribution of migrating juvenile pink shrimp were apparent in Buttonwood Canal. An analysis of the relation between environmental factors and distributional changes indicated that shrimp responded primarily to moonlight. In the period of study, most shrimp were on or near the surface of the canal, but during the full moon the percentage taken at the surface was greater than in any other moon phase. No differences in vertical distribution were detected in relation to salinity, sex, size,

tidal amplitude, time of tide, water depth, or water temperature.

Moonlight also appeared to have an effect on lateral distribution of migrating juvenile pink shrimp. During full and last-quarter moons, catches of shrimp were larger on the western side of the canal than on the eastern side. During new and first-quarter moons catches were usually evenly distributed around the center of the canal. The eastern side of the canal was in shadows for the early part of the ebb tide during full and last-quarter moons, and shrimp seemed to move to the western or moonlit side of the canal during those periods.

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