INVESTIGATION OF THE ABUNDANCE AND BENTHIC DISTRIBUTION OF PINK SHRIMP, PANDALUS JORDANI, OFF THE NORTHERN OREGON COAST

FINAL REPORT
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INTRODUCTION

On July 1, 1969, the Fish Commission of Oregon, under contract by the Bureau of Commercial Fisheries, began a 1-year study of the pink shrimp (*Pandalus jordani* Rathbun) off Tillamook Head, Oregon. Our primary goal was to determine the seasonal movement of this species within a given area.

The range of *P. jordani* extends from southern California to Alaska, with the largest commercial concentrations off the Oregon coast. Dahlstrom (1970) presents a detailed synopsis of the biological data on pink shrimp. A summary of the life history of pink shrimp off Oregon is described by Magill and Erho (1963).

Little is known of the specific movement of this species of shrimp off Oregon. Dahlstrom (1970) mentions that populations of pink shrimp (presumably off California) appear to make only local movements apparently associated with the search for food with no migration of great distance involved. He states that males tend to occur in shallower water than females during the first 6 months of each year and in the latter half of the year the sexes are mixed. Dahlstrom also states that juveniles (assumed to be 0-age shrimp) are usually in shallower water than adults. He reports that females off California do make a winter spawning migration.

Informal observations by Oregon commercial shrimp fishermen suggest that pink shrimp are at times partly segregated by year class and that the heaviest concentrations of shrimp sometimes move several miles on a daily basis. Many fishermen have also commented on juveniles being inshore of adults.

Robinson (in processing) mentions differences of tows made in two different locations off Tillamook Head in 1968. In February, three tows made at depths of 69-73 fathoms had catches with 81-86% females and 64-69% of the shrimp were of the 1964-65 year classes (Age III and IV). One deep tow (90-91 fathoms) made a week later and approximately 13 miles to the northwest of the first three tows, had a catch comprised of 98% males of the 1966-67 year classes (Age I and II).

In our study we hoped to define patterns of sex or age segregation and seasonal movement of pink shrimp. To reach our goal of describing these movements, we had several objectives.

1. Determine benthic movements of pink shrimp in the area off Tillamook Head, Oregon by sampling at approximately monthly intervals for 1 year at stations arranged in a grid pattern.
    a. Analyze the abundance of shrimp based on sampling in pounds and numbers to determine if there is a pattern of movement.
    b. Analyze the age and sex composition of the samples to determine if there is a pattern of movement by any specific sex or age class.
2. Determine the location of 0-age shrimp to establish if:
    a. They move into the area from a specific direction indicating migration from a nursery area or:
    b. If they are interspersed among the adult population.

A second goal developed during the course of the study. This was to establish the effect of light intensity and the density of shrimp on their vertical distribution during the daytime.

STUDY AREA

The study area incorporated 18 stations off Tillamook Head (Figure 1). Twelve of the stations were arranged in a grid pattern with each station 4 nautical miles from an adjacent station. These stations were over areas ranging in depth from 56-84 fathoms. Three stations (1-3) were inshore of the block of 12 stations. They were about 2½ nautical miles apart, with depths ranging from 30-51 fathoms. Stations 7-9 were offshore from the block of 12 stations and were 4 nautical miles apart. Depths at these stations ranged from 80-159 fathoms.

All stations except 1-3 were over areas of green mud and sand, typical of shrimp grounds. Stations 1-3 were over an area with a sand bottom.

MATERIALS AND METHODS

A 59-foot commercial Pacific seiner-type trawler, the M/V Sunrise, was chartered for use in the study.

We used a 41-foot headrope Gulf semi-balloon trawl made of 1 1/8-inch stretched-mesh netting with a codend of 1½-inch mesh (Figure 2). An inner liner in the codend was made of ½-inch mesh. Plastic rollers were attached to the 52-foot footrope. A 50-foot 5/16-inch steel tickler chain was used. Each end of the tickler chain was attached to the ends of the footrope. Several 17-inch dropper chains along the length of the tickler connected it to the footrope. Fifteen feet of cable bridle connected the net to the V-trawl doors.

During the first cruise in July 1969, we towed only at stations 1-15. Tows at stations 1-3 and 7-9 were 30 minutes duration and at stations 4-6 and 10-15 we made two 15 minute replicate tows.

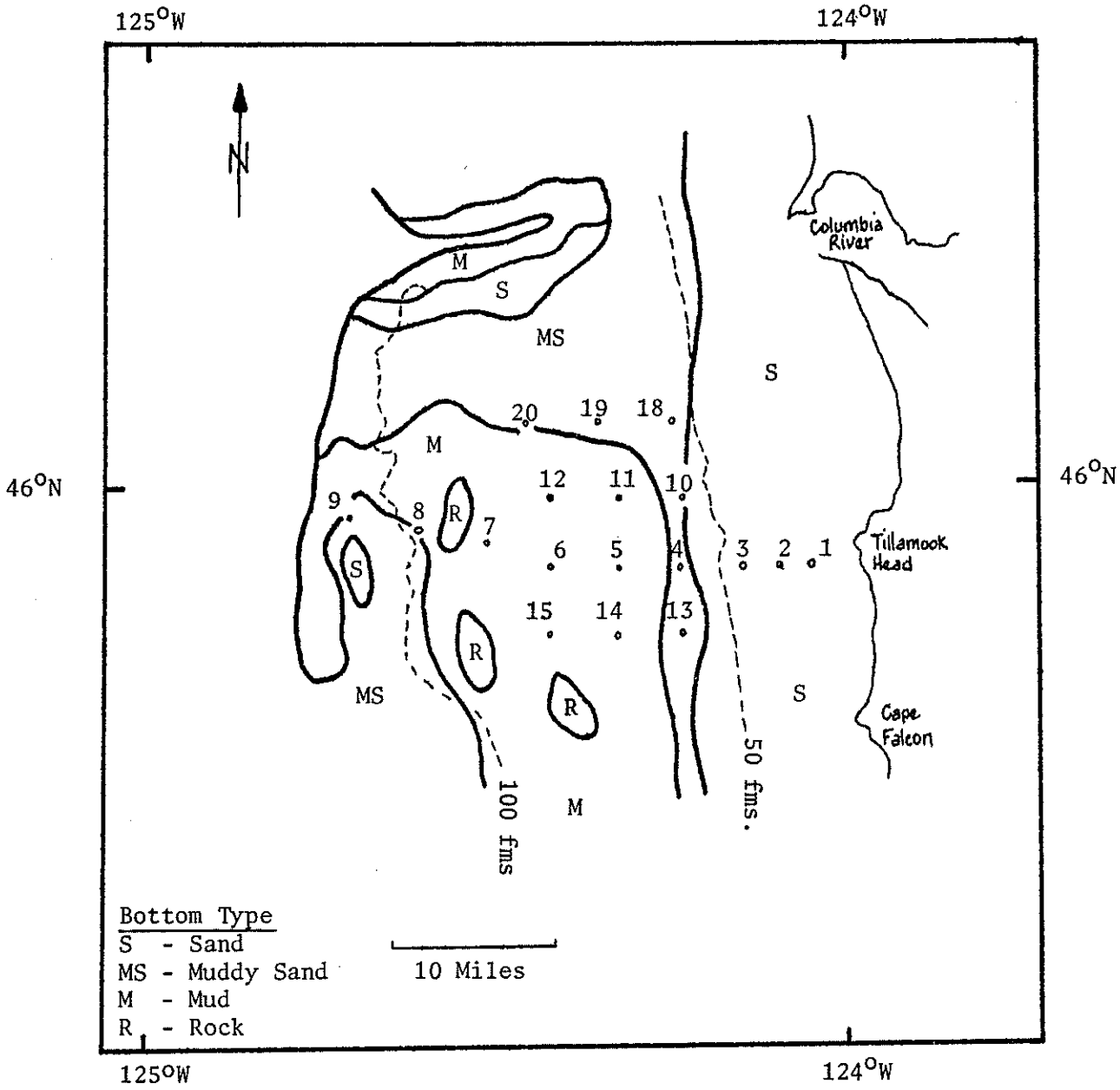


Figure 1. Location of Trawl Stations and Bottom Type, Pink Shrimp Benthic Distribution and Abundance Study (Bottom Type after Byrne and Panshin, 1968).

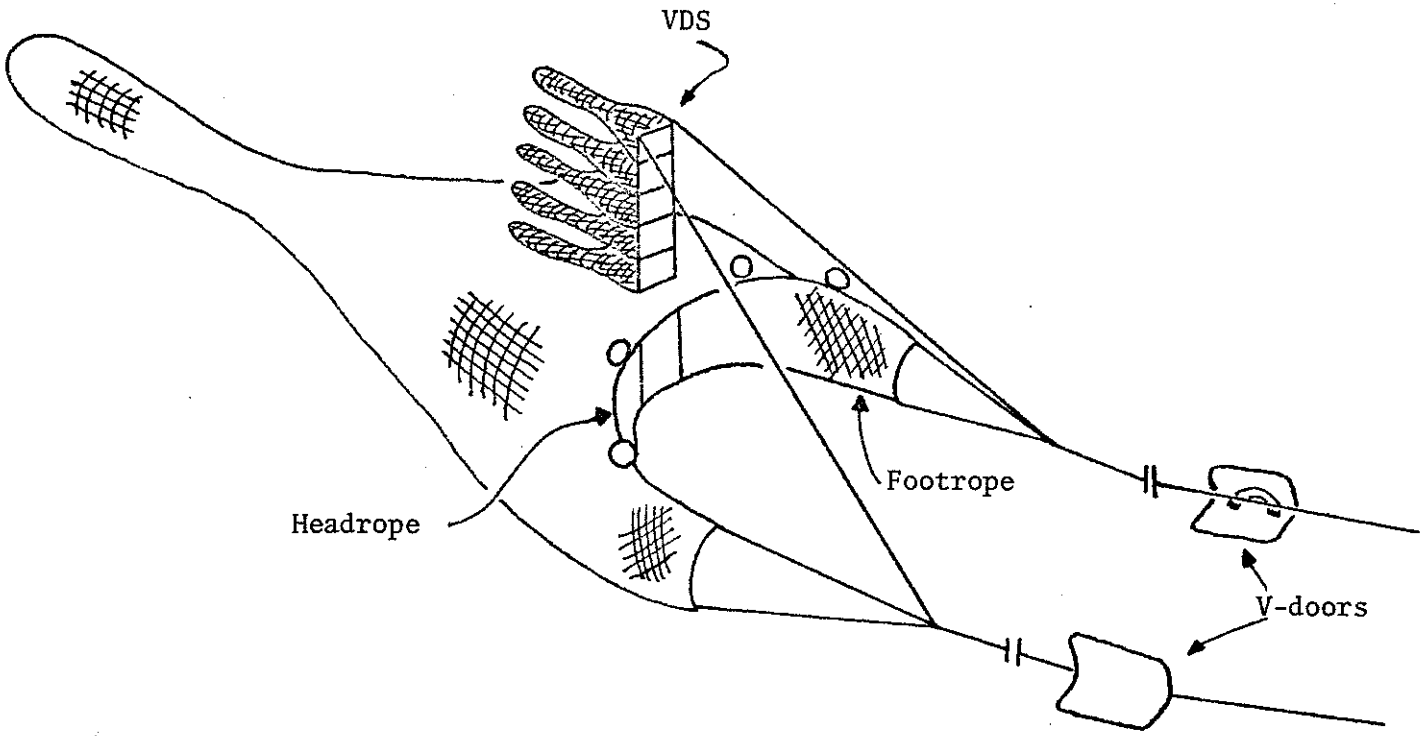


Figure 2. Gulf Semi-balloon Trawl with Vertical Distribution Sampler Attached.

After the first cruise, we expanded the study area by adding stations 18-20. The sampling procedure after the first cruise was also changed to single ½-nautical mile tows at each station instead of a timed tow. This method standardized tow length. We found that timed tows varied in length because of differences in ocean currents. During the last two cruises, April and June 1970, we eliminated stations 1-3 and 7-9 and made replicate ½-nautical mile tows at the remaining stations.

We took bottom water temperatures at selected stations on cruises from July 1969 - April 1970 using expendable bathythermographs. This was used as an aid in assessing shrimp distribution among stations during a cruise or shrimp movement between sample periods during the study.

The catch from each tow was weighed to determine gross weight. A 20-pound subsample was sorted to determine the percentage, by weight, of shrimp and incidental species. The calculated percent of shrimp was applied to the total weight of the remaining catch to determine pounds of shrimp caught. A random sample of approximately 400 shrimp was taken from the catch when a single tow was made at a station and approximately 200 shrimp were sampled from the catch of each of the replicate tows.

Sex of the shrimp in the samples was determined in the laboratory by examining the endopodite of the first pleopod. Pink shrimp are protandric hermaphrodites. They mature first as males and then change sex to function as females. The period of sex change to females is called the transition phase. It usually occurs during their 3rd year of life although shrimp will change sex at either an earlier or later age. The shape of the endopodite indicates phase of sex of the shrimp (Tegelberg and Smith, 1957).

The "length" of each shrimp was measured with a vernier caliper from the base of the eyestalk to the posterior mid-dorsal edge of the carapace. Length was recorded to the nearest lower 0.5 mm. Carapace length frequencies were used to determine age composition of catches.

During the course of the study, we learned of Alan Beardsley's work with a vertical distribution sampler (Beardsley and High, 1970; Beardsley, 1973). He found that during the day pink shrimp could be caught up to 12-feet off the bottom. This lead to some concern that our net, with a vertical opening of only 4-feet, may have been missing quantities of shrimp. With the cooperation of Beardsley and the National Marine Fisheries Service in Seattle, Washington, we were able to design and install a VDS suitable for our net (Figure 2). We tested the net with the VDS installed in 7-10 fathoms of water and divers observed that the configuration of the shrimp net was not greatly altered. We used the VDS during the last four cruises of the study in February, March, April, and June 1970.

The VDS has a frame of 2½-inch aluminum tubing and is 2-feet wide by 10-feet high. There are five openings in the upper 6-feet, each measuring 1-foot vertically by 2-feet horizontally. Crosspieces of 2½-inch tubing separate the openings. Knotless ½-inch nylon mesh bags, 7-feet in length, were attached to each opening.

To give the VDS support while placed in the net, we attached the bottom of the frame to the footrope. To be positioned vertically, the legs of the frame had to be inserted through two holes in the canopy of the net. These holes were 4-feet behind the headrope. This positioning created a 4-foot long overhang in front of the VDS 4-feet above the bottom (footrope).

During the cruises, using the VDS, we measured light intensity with a submarine photometer to see if light influenced the daytime vertical distribution of pink shrimp. Several light readings were taken from the surface to 90-feet immediately after a tow.

To estimate the pounds and numbers of shrimp in the study area, we used the data obtained from the block of 12 stations (18-20, 10-12, 4-6, and 13-15). The catch at each station was considered to be a sample of the shrimp in a 16-square nautical mile area. The 12 stations represented an area of 192-square nautical miles. The data from the total catch of each tow at the 12 stations and total area trawled was expanded to an estimated catch for the 192-square nautical mile study area.

RESULTS AND DISCUSSION

Nine cruises were completed during the study. No cruises were made in August and December 1969 and May 1970 due either to adverse weather conditions or other commitments for the charter vessel. Table 1 summarizes the average catch per ½-nautical mile towed and the overall sex and age composition of the samples by month of capture.

Table 1. A Summary of Average Trawl Catch per ½-Nautical Mile and Sex and Age Composition of Samples Taken during Pink Shrimp Distribution Study, July 1969 - June 1970.

Cruise No.	Date	Avg. Catch Per ½-Mile (Lbs.)	Sex Composition %			Age Composition % 1/			
			Male	Transi-tional	Female	0	I	II	III+
69-2	7/16-19/69	120	59.1	15.9	25.0	0.4	61.9	9.2	28.5
69-4	9/ 8-10/69	92	53.5	12.6	33.9	1.1	61.3	9.0	28.6
69-6	10/11-12,17/69	52	63.7	6.4	29.9	2.9	64.9	6.1	26.1
69-7	11/11-13/69	39	64.5	1.1	34.4	3.6	66.4	5.3	24.7
70-1	1/4-5/70	11	74.4	- -	25.6	30.6	51.0	2.9	15.5
70-2	2/10-12/70	17	78.6	2.4	19.0	31.2	54.8	2.5	11.5
70-4	3/18-20/70	56	58.6	16.8	24.6	- -	45.4	38.5	16.1
70-7	4/27-30/70	93	55.1	19.2	25.7	- -	45.5	37.4	17.1
70-9	6/3,6-8/70	116	56.2	23.8	20.0	0.1	51.7	36.8	11.4

1/ For July 1969 through February 1970 age designations, refer to the following year classes: (see next page)

1/ Continued

Age	Year Class
0	1969
I	1968
II	1967
III+	1966 and earlier

For March 1970 through June 1970, the age designations were changed because March is considered the birth date.

Age	Year Class
0	1970
I	1969
II	1968
III+	1967 and earlier

Sex and Age Composition

The most notable change in the shrimp sex composition was that of the transitionals. In July 1969, nearly 16% of the shrimp in the study area were in the transitional phase. The percentage decreased until January 1970 when none were noted. In Feburary 1970, the males began their sex change starting with the transitional phase. The percentage of transitionals in the study area increased to nearly 24% by the time of the last cruise in June 1970.

The greatest change in the age composition percentages was the increase of the 1969 year class shrimp between the November 1969 and January 1970 cruises, possibly reflecting their increased vulnerability to the trawl net as they grew in size.

The 1968 year class (Age I), initially comprising the shrimp from 12 to 18 mm was a strong year class and can easily be distinguished in the length frequencies (Figures 3-5). The 1967 year class (Age II) was weak and difficult to separate from the 1966 year class (Age III+) shrimp. These latter two year classes were composed primarily of females. In January (Figure 4B), we began catching large numbers of the incoming 1969 year class shrimp (8.0 - 11.5 mm) which also appeared to be quite strong. They constituted 30.6 to 51.7% of the shrimp caught from January through

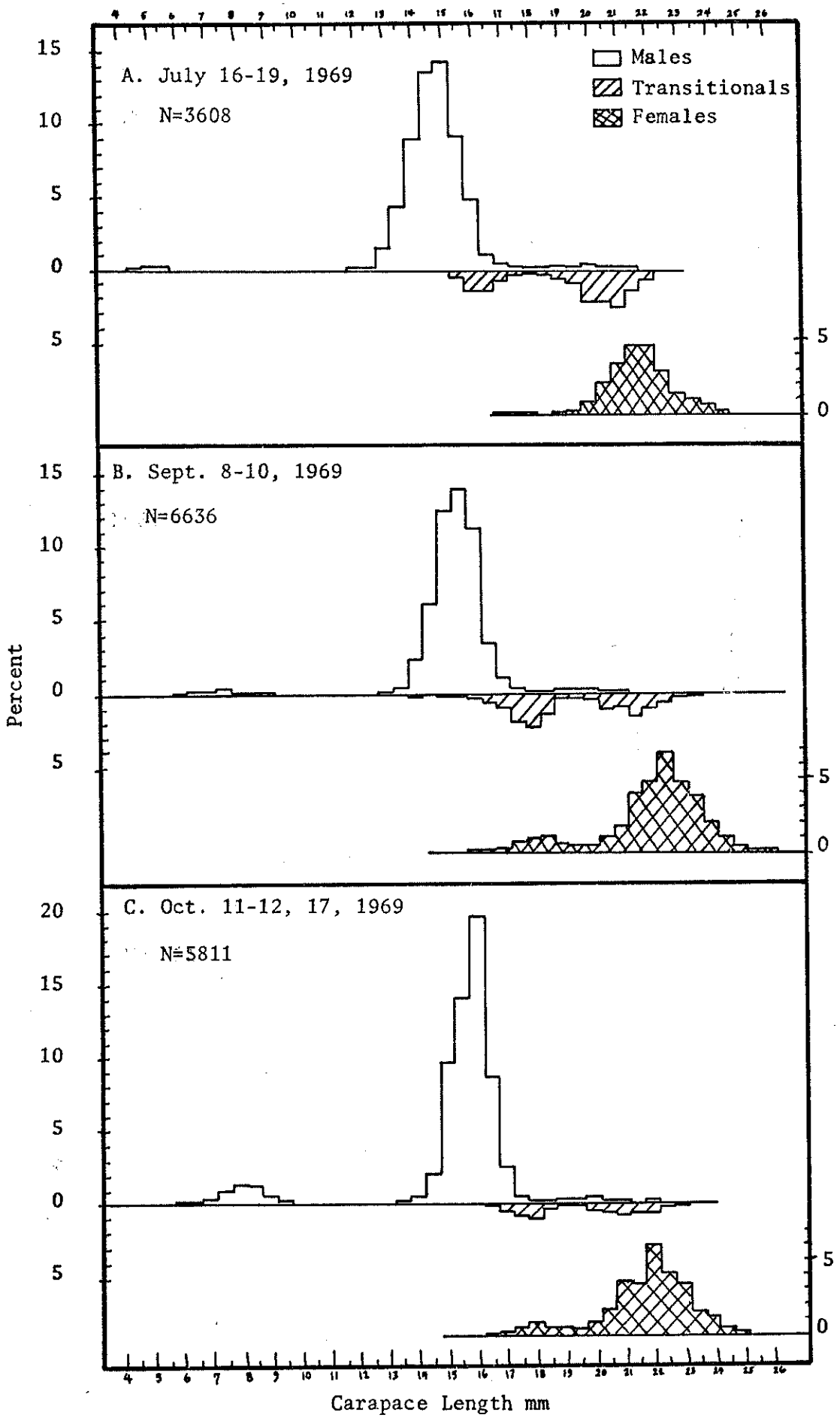


Figure 3. Pink Shrimp Carapace Length-Frequency Distribution by Sex, July-October 1969.

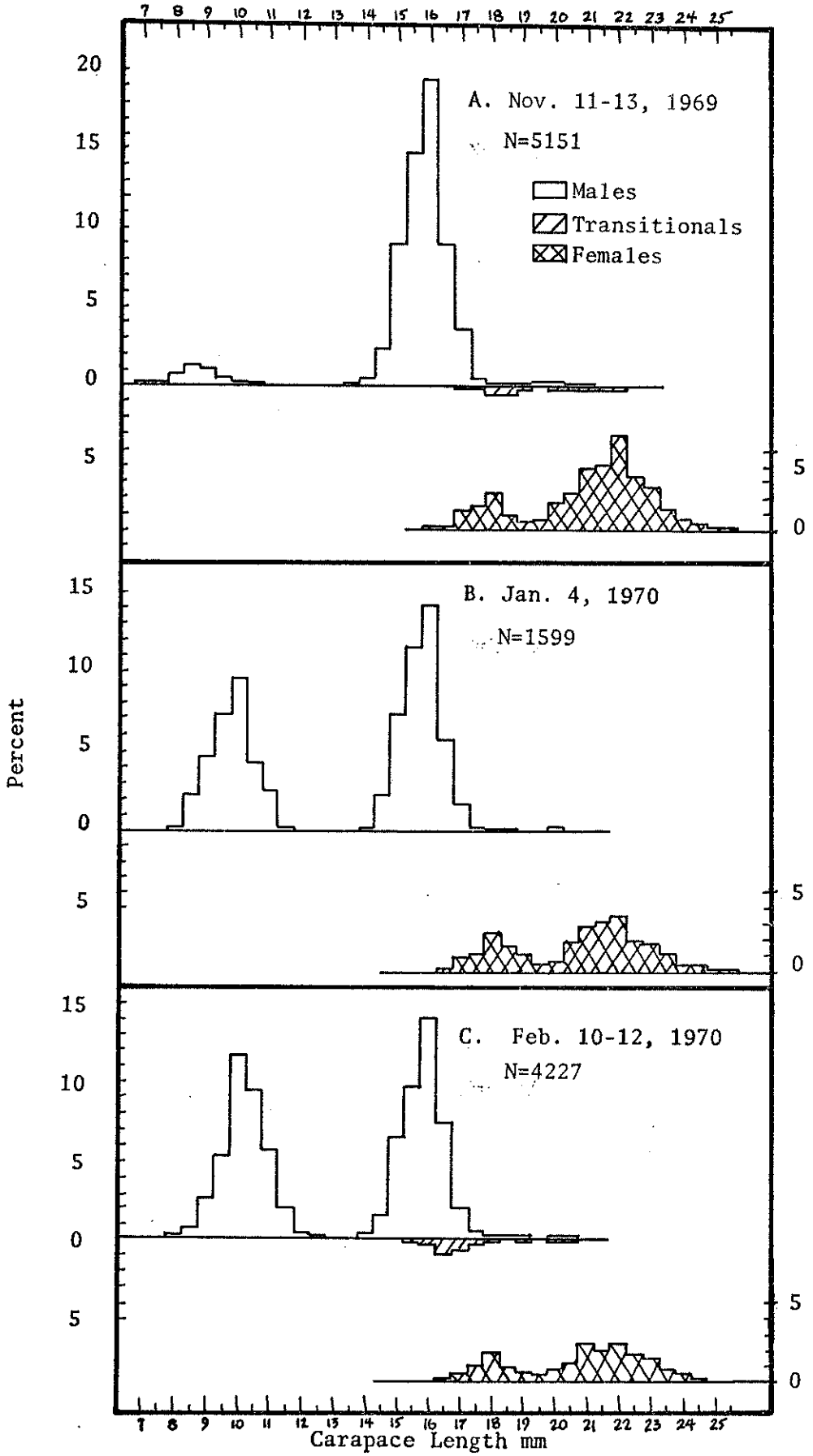


Figure 4. Pink Shrimp Carapace Length Frequency Distribution by Sex, November 1969 - February 1970 (continued).

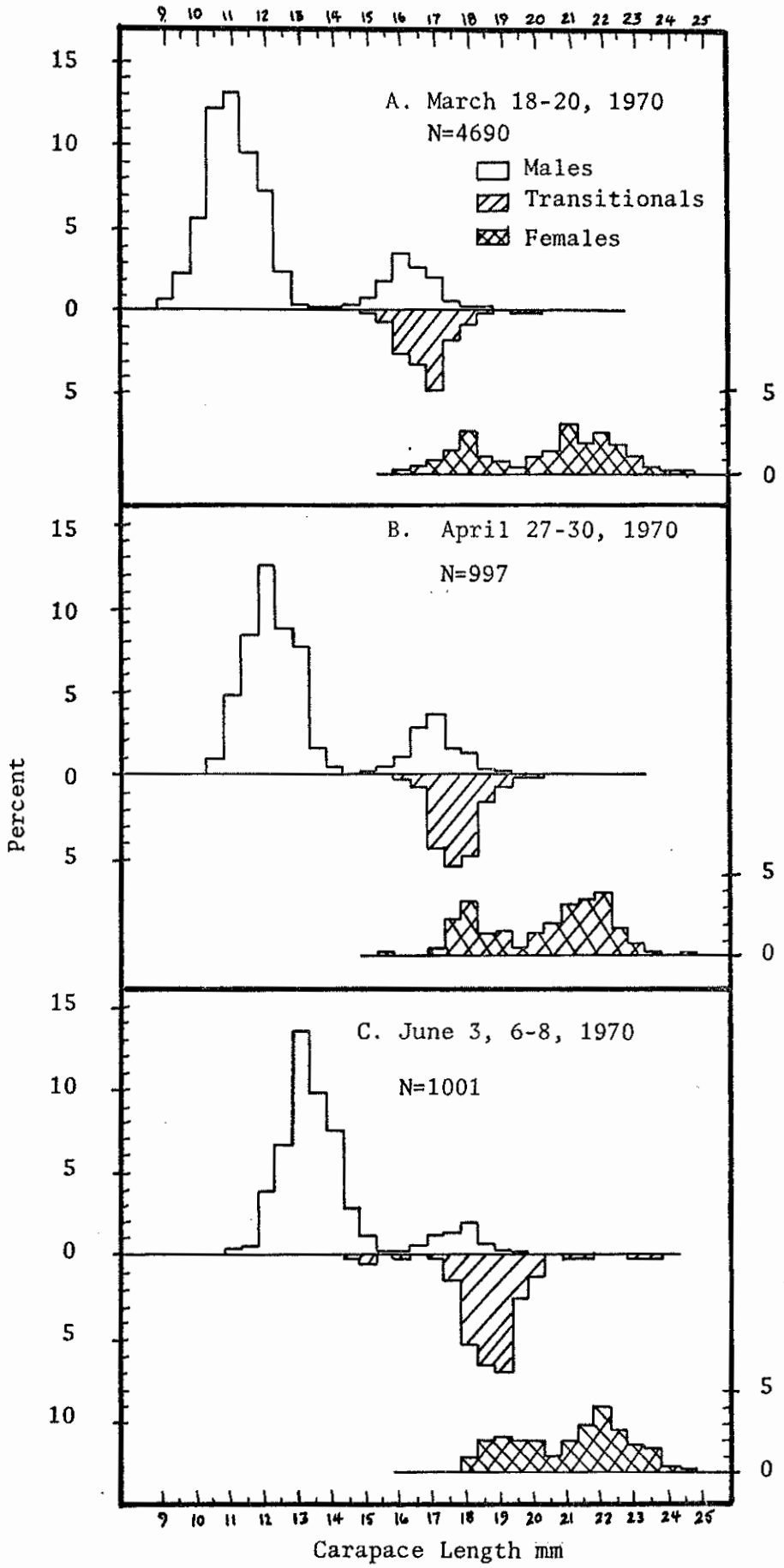


Figure 5. Pink Shrimp Carapace Length Frequency Distribution by Sex, March-June 1970 (continued).

July 1970 (Table 1). During the November cruise, the mean carapace length of the 1969 year class was 8.7 mm and they represented less than 4% of the catch. By January, the mean carapace length had increased to 9.7 mm and the percentage of 0-age shrimp in the catch increased to 30.6% (from Table 1).

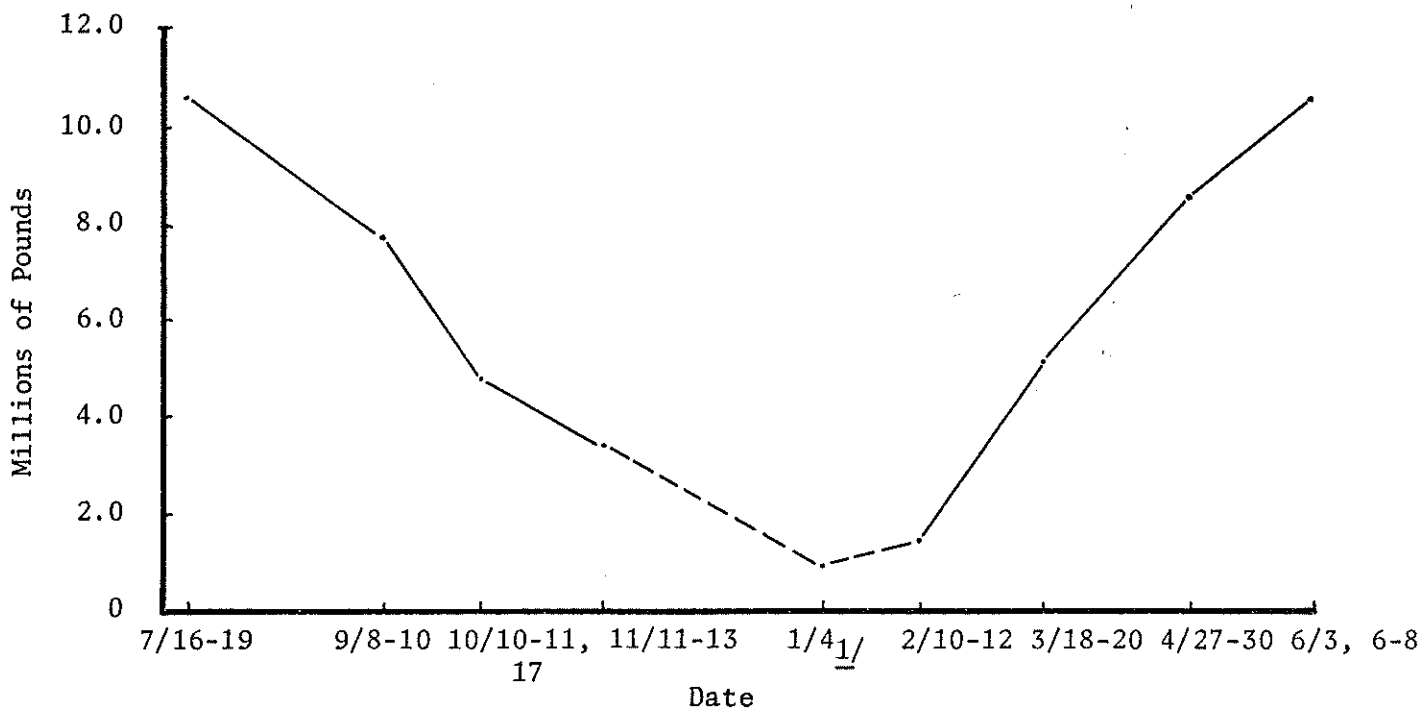
Fluctuations in Abundance of Shrimp

In analyzing the changes in abundance of pink shrimp, we considered only those stations in the central block of 12. Figure 6 depicts the changes in abundance in pounds from July 1969 to June 1970 at those 12 stations which represent a 192-square nautical mile area. The graph shows a decrease of 9.2 million pounds of shrimp in a 7-month period from July 1969 to February 1970. An estimated 860,000 pounds of shrimp were in the area in January but this was based on only four tows. By June 1970, the estimate had increased to nearly the level of July 1969.

The abundance of shrimp in numbers rather than pounds is shown in Figure 7. Although the total biomass in June 1970 was nearly the same as July 1969 (Figure 6), there were approximately 190 million more shrimp in the area in June 1970 compared with July 1969 (Figure 7). The lowest number of shrimp in the area was during January 1970, however, this estimate was based on only four tows.

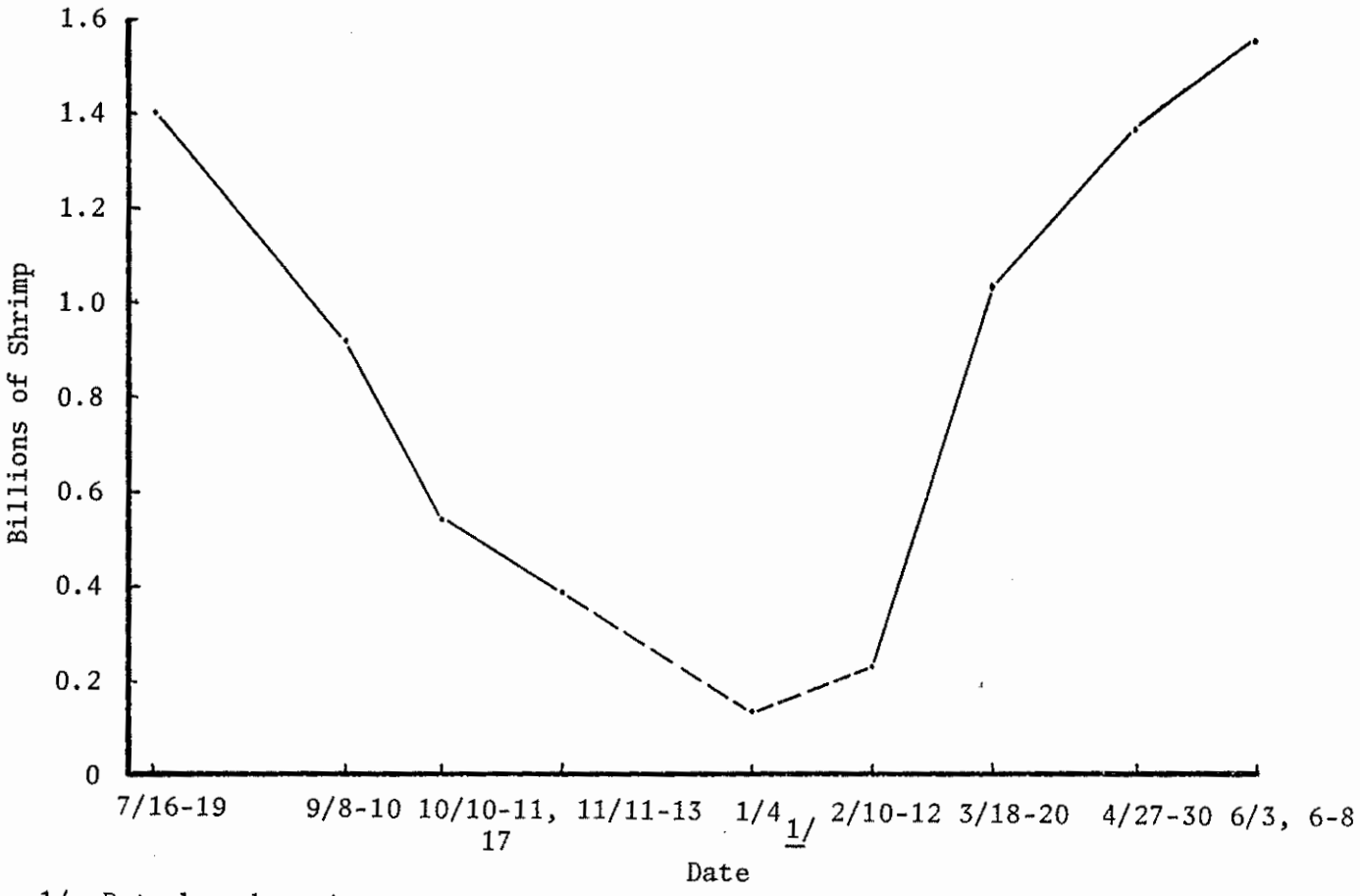
To better understand which year class was contributing to this increase, we calculated the total number of shrimp by year class (Figure 8) using the age composition percentages from Table 1. The 1966 and 1967 year classes were combined after February because they were difficult to separate. The January data was not included.

The three year classes of adult shrimp (1966-68) show a decrease through February and then an increase in numbers. However, by June 1970, the numbers of the 1966-68 year classes of shrimp were only 50% of the total number of the same three



1/ Data based on 4 tows.

Figure 6. Change in Abundance of Pink Shrimp, in Pounds, within Study Area, July 1969 - June 1970.



1/ Data based on 4 tows.

Figure 7. Change in Numbers of Shrimp, within Study Area, July 1969-June 1970.

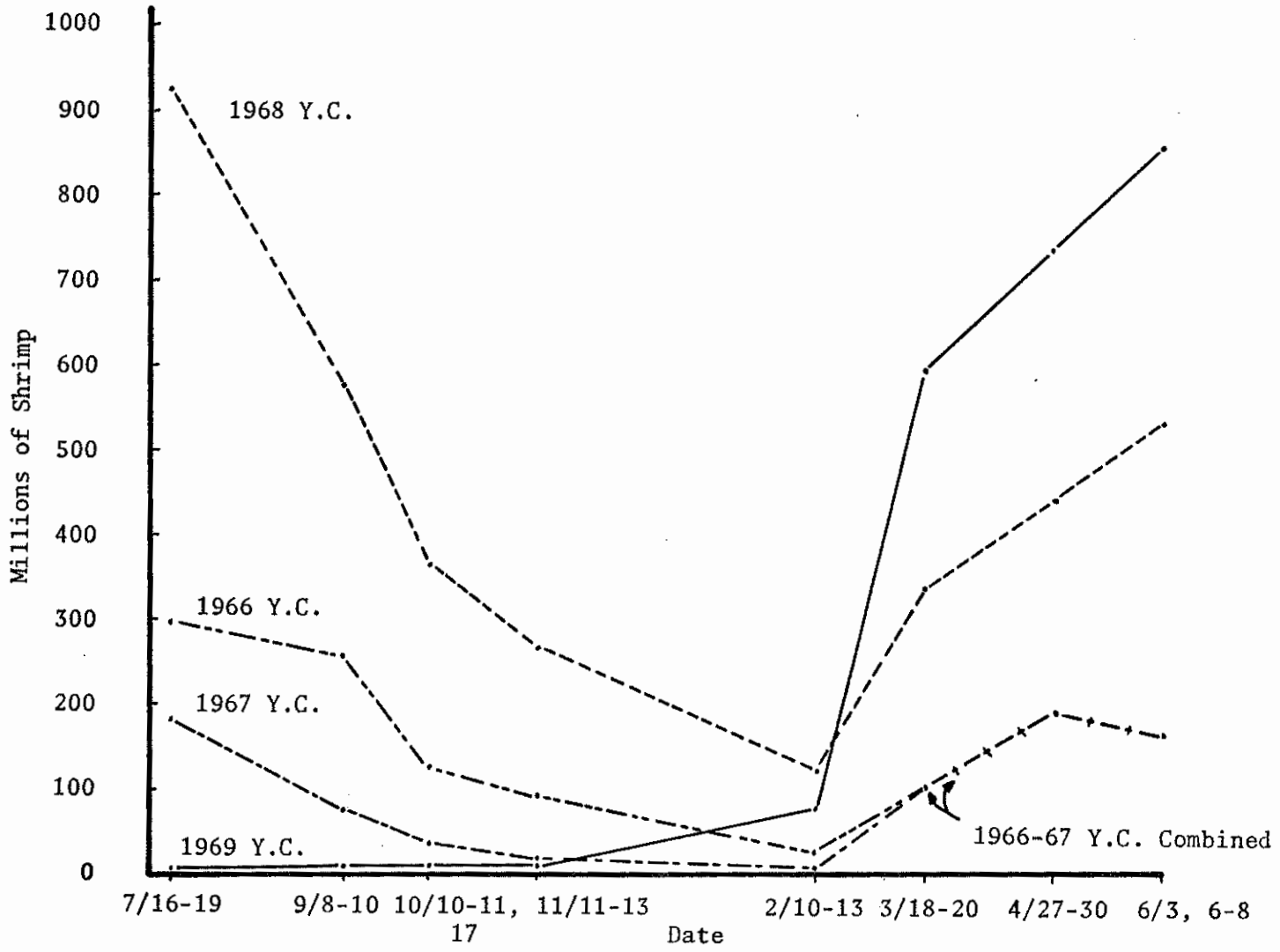


Figure 8. Change in Numbers of Shrimp, by Year Class, within Study Area, July 1969-June 1970.

year classes present in July 1969. It was the 1969 year class which contributed to increased numbers of shrimp and made it appear in Figures 4 and 5 that the shrimp had returned to their former levels of abundance.

Natural and fishing mortality probably accounted for most of the loss in numbers of the 1966-68 year classes. But it is also possible that many of the shrimp which were in the area in July 1969 and moved out, possibly did not return by June 1970.

The fluctuation in abundance by sex in numbers of shrimp is graphed in Figure 9 using sex composition percentages in Table 1. The data from the January cruise was not used. The 1969 year class was excluded because they were not truly represented until midway through the study. The transitionals were combined with the females from July - November 1969 since the transitionals were developing headroe and would function as females through the winter period. The same situation occurs with the males. The transitionals occurring from February - June 1970 were included with the male totals because they were functioning as males from July 1969 - January 1970.

Figure 9 shows that neither males nor females migrated out of or into the study area exclusive of the other sex. The decrease of females during June is the result of a decrease of females of the 1966-67 year classes. The number of 1968 year class females actually increased through June 1970 according to our data. The decline in numbers of these 1966-67 year class females may have been the result of their emigration from the area and/or fishing and natural mortality. We suspect that a great majority of the losses were from natural mortality since these are age III and IV year old shrimp near the end of their life span.

Movement of Shrimp

To determine if there was a definite pattern of shrimp movement out of and back into the study area, we looked at groups of stations along the same latitude and longitude lines and considered total numbers of shrimp, by sex and year class, caught along these lines. To detect any north-south movement, we considered four groups

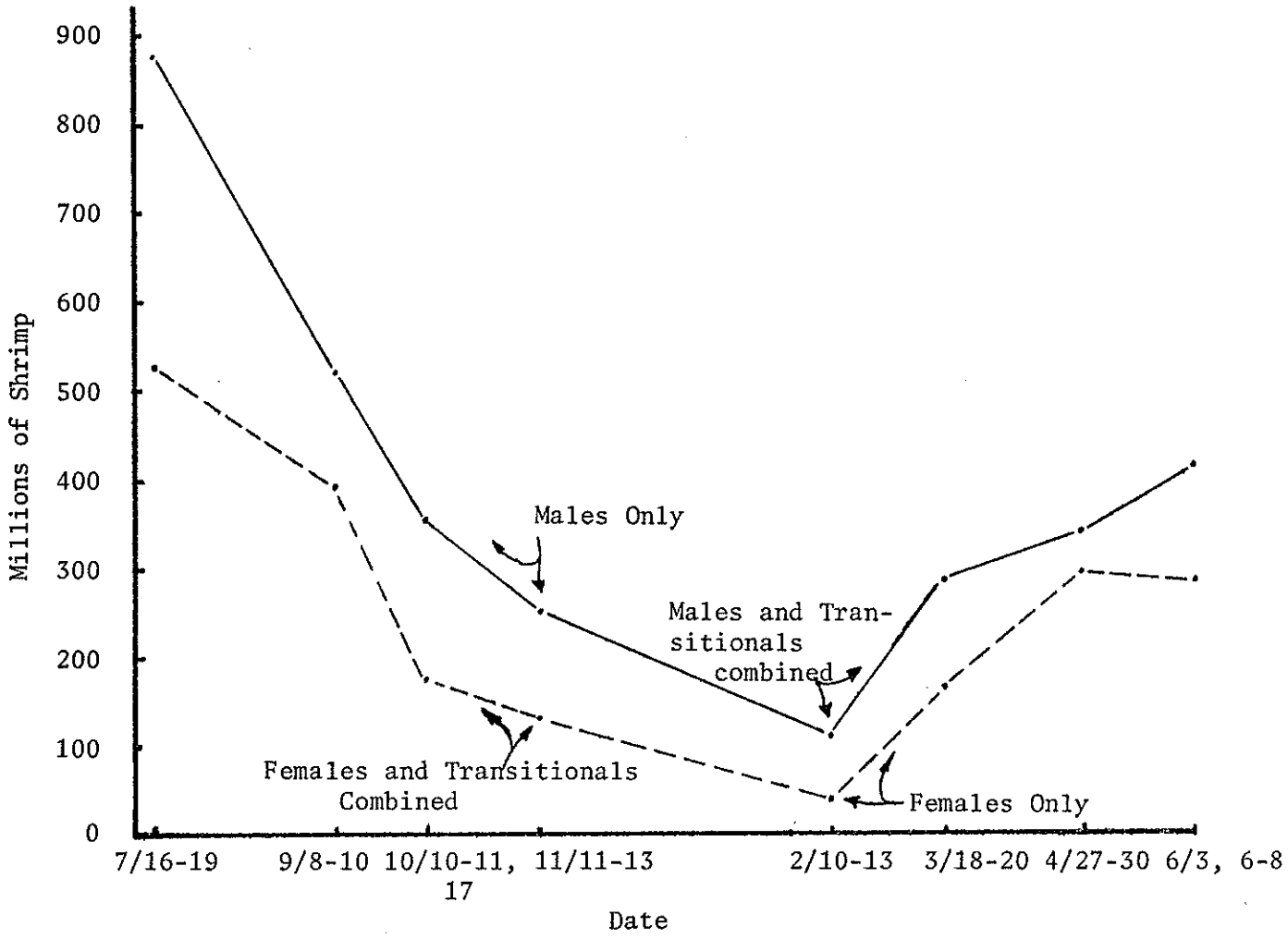


Figure 9. Change in Numbers of Shrimp, by Sex, within the Study Area, July 1969 - June 1970.

with three stations each (18-20, 10-12, 4-6, and 13-15). To describe inshore-offshore movement, we totaled the catch in numbers at four stations along the north-south lines (18, 10, 4, 13; 19, 11, 5, 14; and 20, 12, 6, 15). Data from the January cruise was not included because we had sampled only four stations.

After analysis of these groups, we could find no significant overall pattern of movement of shrimp in the study area, either inshore-offshore or north-south. One exception occurred during April 1970 when 1969 year class shrimp moved to the inshore line of stations. Although there was no significant pattern of migration, there were indications of a directional movement out of and back into the area. This movement could not be related to water temperature. The bottom water temperature data obtained on cruises from July 1969 - April 1970 showed that differences in temperatures between stations were not significant (Table 2). During the sample period, the maximum difference in temperatues was only 5 F(43.2 - 48.2 F), obtained in March 1970.

Table 2. Range of Bottom Temperatures (F), July 1969-April 1970[1/]

Month	Stations					
	18-20	10-12	1-3	4-6	7-9	13-15
July		44.3-44.5 (3)	45.2-46.0 (3)	44.2-44.9 (3)	44.2 (1)	44.5-45.0 (3)
September	44.0-44.5 (3)	44.8 (1)	44.9 (1)	44.0-44.1 (3)	43.9-44.6 (3)	44.0-44.2 (3)
October	45.6-45.8 (3)	45.6-45.9 (3)	46.3 (1)	45.6-46.1 (3)	44.9-45.6 (3)	45.3-45.7 (3)
November	46.3-47.0 (3)	46.4-47.2 (3)	47.5 (1)	46.3-47.1 (3)	44.3-46.4 (3)	46.6-47.0 (3)
February		46.4-48.2 (2)	49.7 (1)	46.4-47.9 (2)	46.3 (1)	47.0-48.0 (2)
March	46.8 (1)	46.7-48.2 (2)		47.6-48.1 (2)	43.2-45.4 (2)	47.5-47.7 (2)
April	43.8-44.0 (3)			43.5 (1)		

1/ Number of observations in parenthesis.

Figures 10-19 show the total number of adult shrimp by sex and 1969 year class shrimp caught at each station during each cruise. We will discuss these figures to point out the obvious shifts of abundance in the study area and refer to the suspected directional movement of the shrimp when the population decreased and again increased. They also show that at some stations or groups of stations there was a predominance of shrimp of one sex and/or year class. Since the study was only for 1 year, these observations cannot be considered typical of the shrimp population from year to year.

All stations, except 1-3, are depicted in figures 10-19 and are arranged in the same order as they are in the study area. Stations 1-3 are omitted because they never yielded more than trace amounts of shrimp. Observations at these three inshore stations, which were over areas of sand bottom, did indicate that shrimp do not prefer this substrate. Station 7, very near to a shale pile, had poor catches notably during the October and November cruises. Thus, we may have been towing over unsuitable bottom part of the time or bottom currents around this shale pile may have affected the catch. Station 9 was probably near the maximum depth limit of pink shrimp distribution. Our tows at this station varied in depth from 118-159 fathoms because of rapid increase in depth at the edge of the continental shelf and the difficulties in pinpointing the exact station location with the navigational aids (loran) we were utilizing.

Figures 10-12 show the number of female shrimp per ½-nautical mile towed by station for each cruise. The females included virtually all of the 1967 and earlier year classes and from 8 to 24% of the 1968 year class. The males (Figures 13-16) consisted primarily of 1968 year class shrimp plus a very small percentage of 1967 and earlier year classes which were still males. Figures 17-19 show the abundance of the 1969 year class shrimp. This year class did not begin to occur in large numbers in the catches until March 1970. In June 1970, about 0.7% were identified as transitionals.

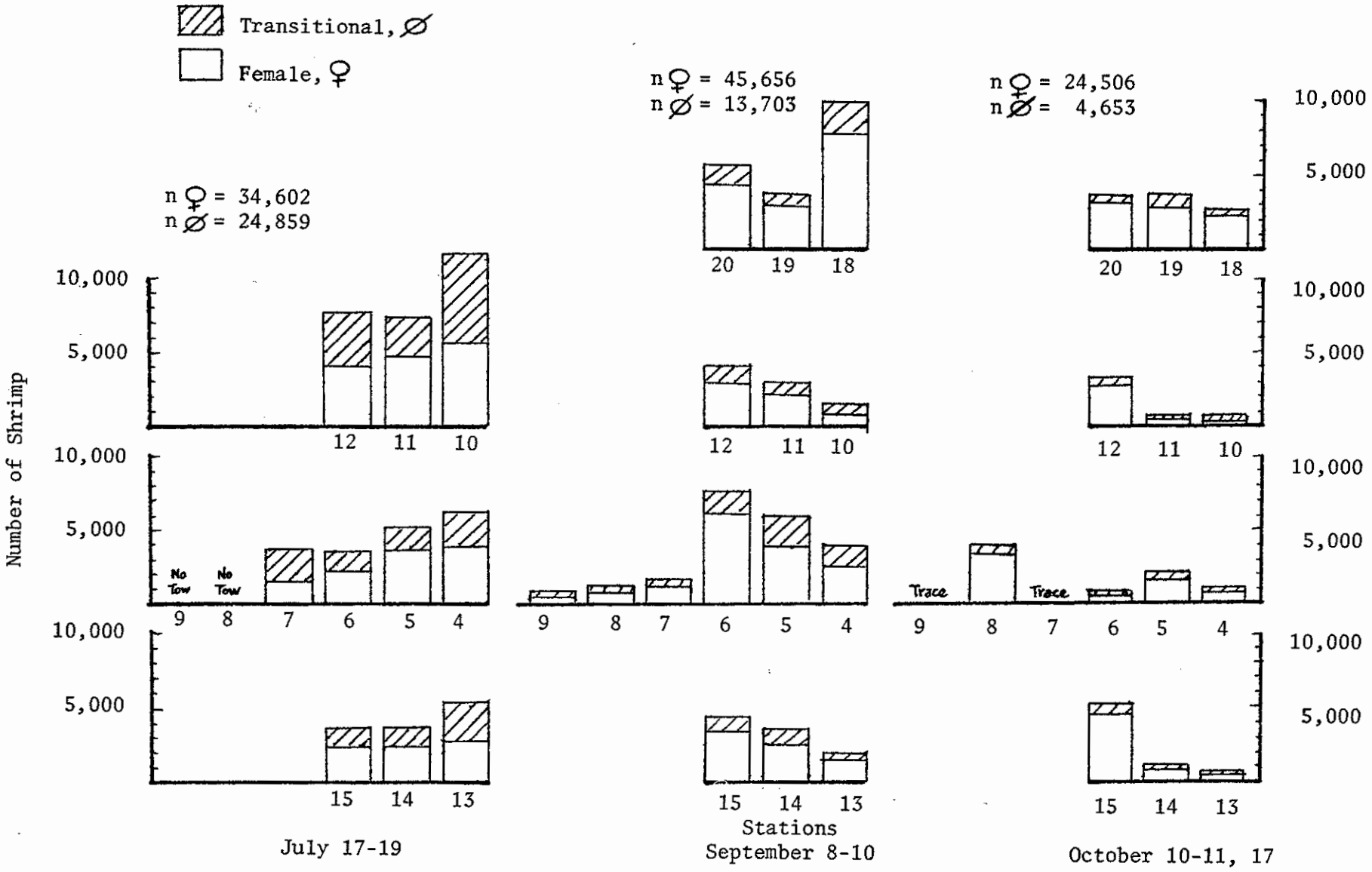


Figure 10. Number of Female and Transitional Shrimp per ½-Nautical Mile Tow, by Station, July-October 1969.

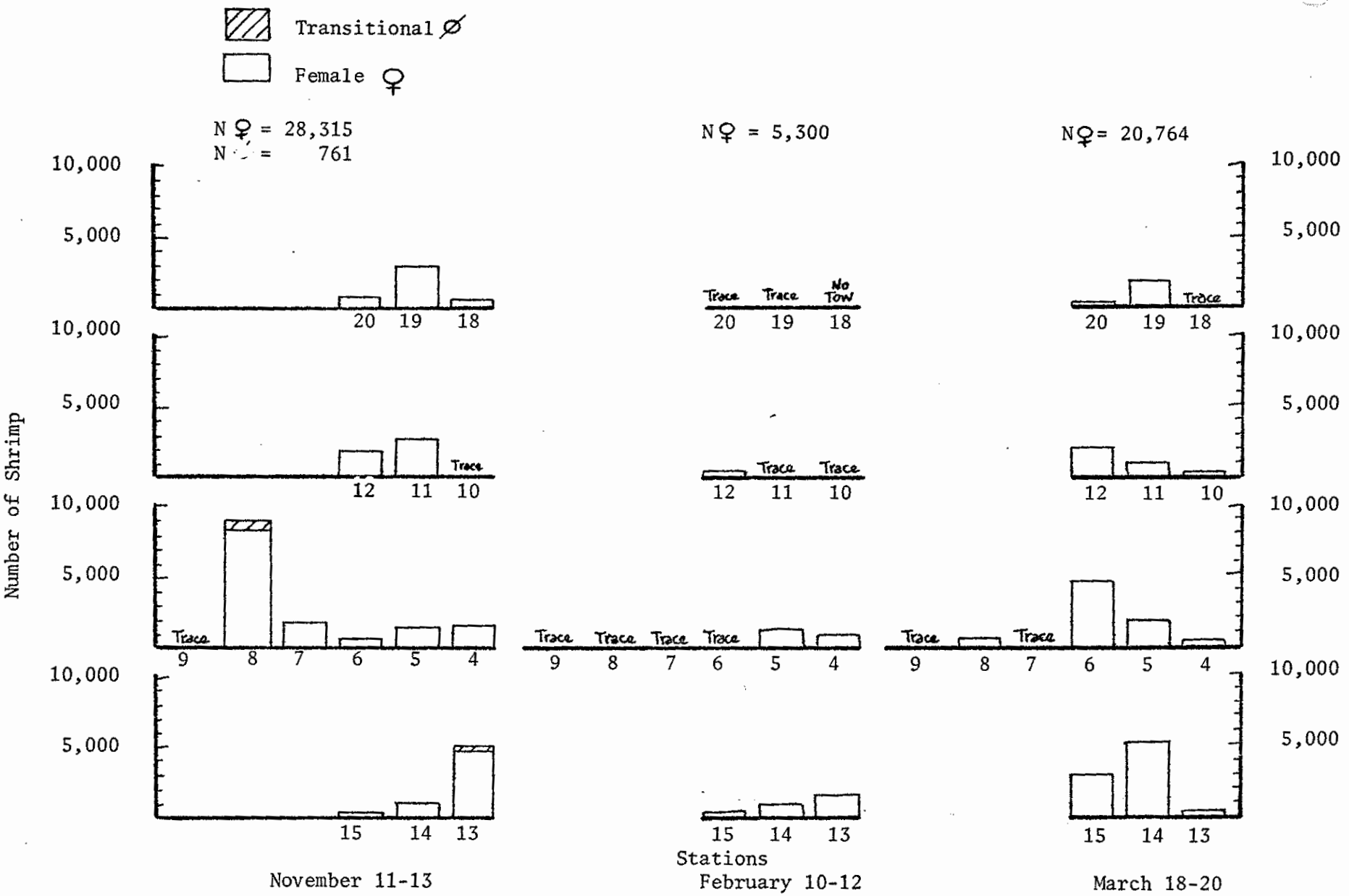


Figure 11. Number of Female and Transitional Shrimp per ½-Nautical Mile Tow, by Station, November 1969 - March 1970.

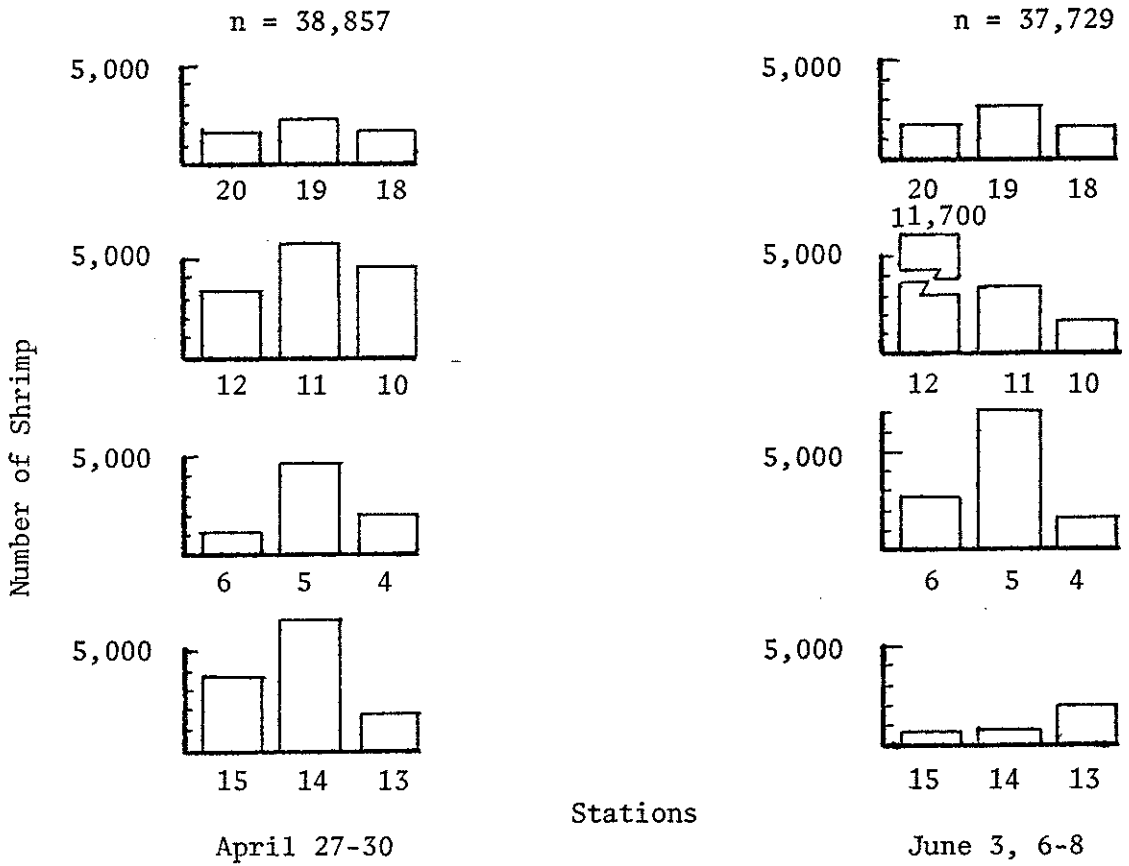


Figure 12. Number of Female Shrimp per ½-Nautical Mile Tow, by Station, April-June 1970.

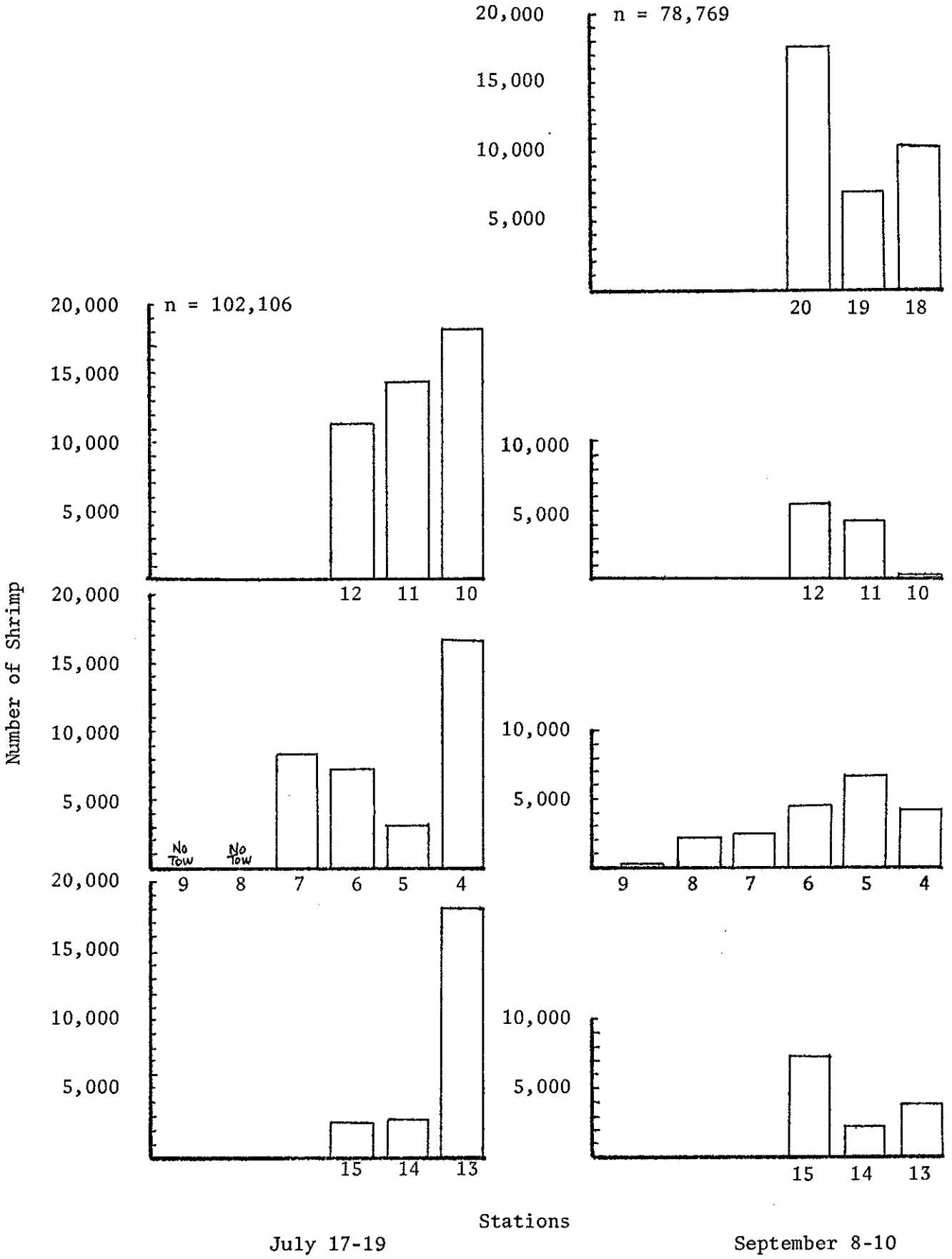


Figure 13. Number of Male Shrimp per ½-Nautical Mile by Station, July and September 1969.

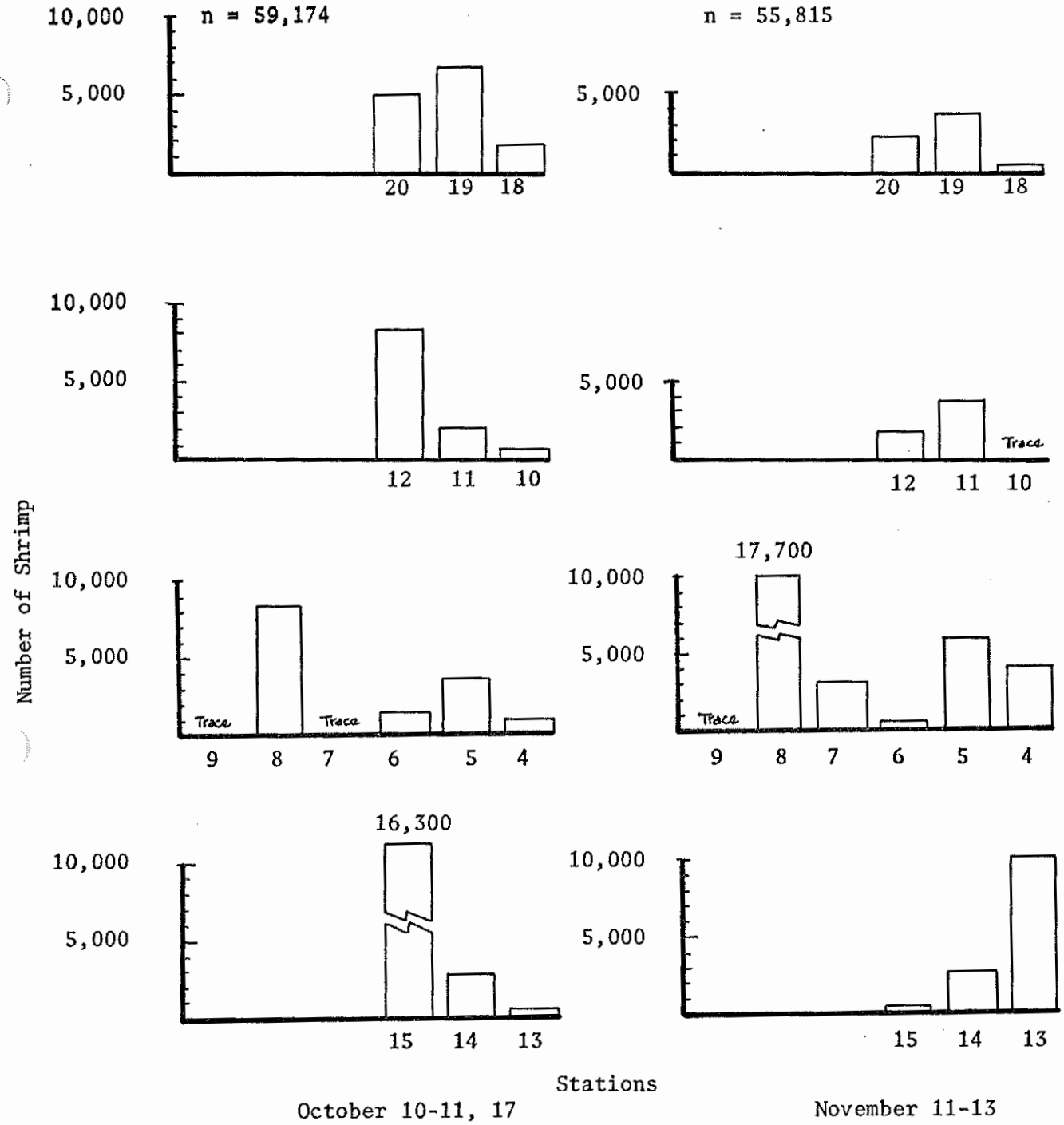


Figure 14. Number of Male Shrimp per ½-Nautical Mile Tow by Station, October-November 1969.

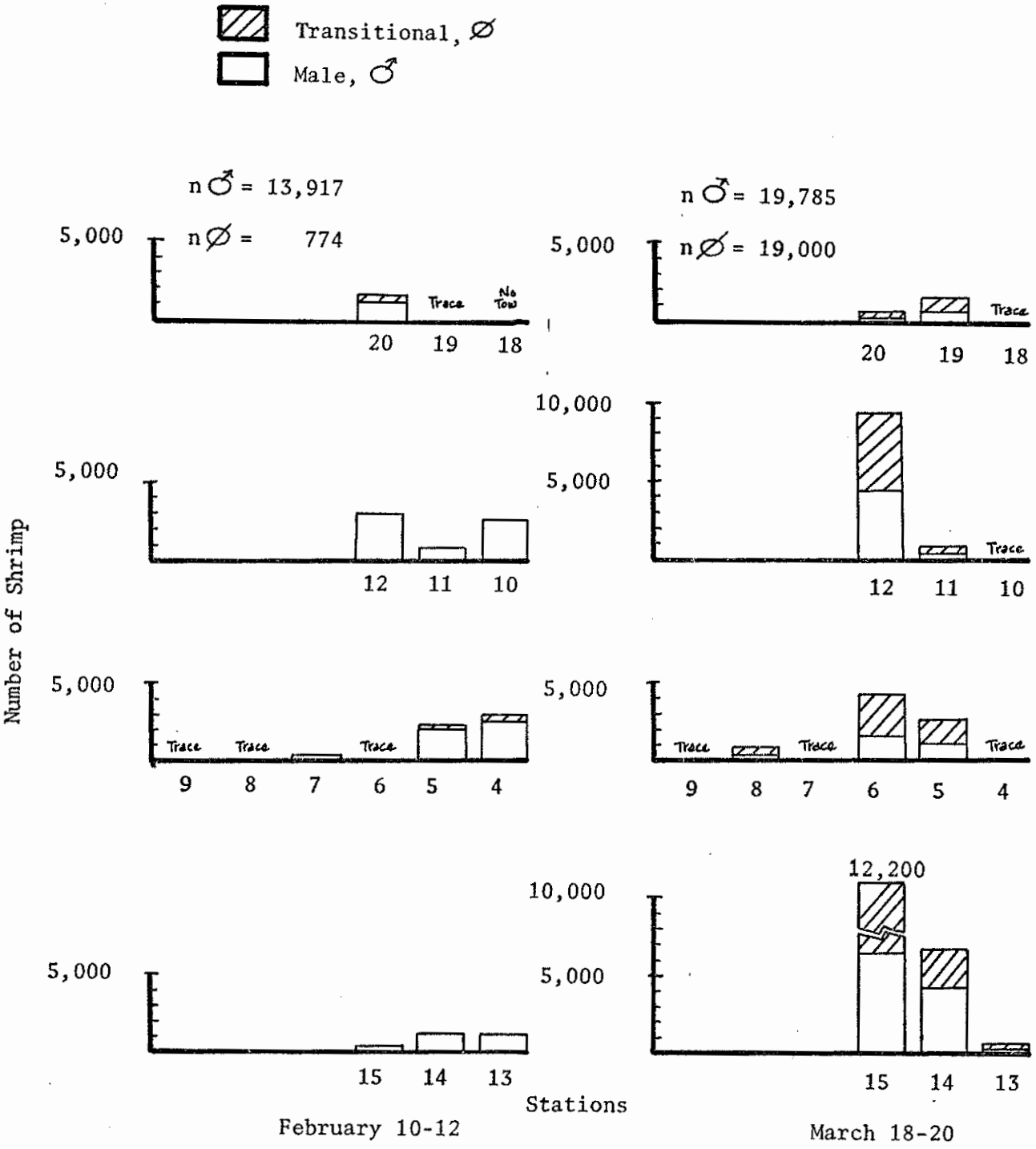


Figure 15. Number of Male and Transitional Shrimp per ½-Nautical Mile Tow by Station, February-March 1970.

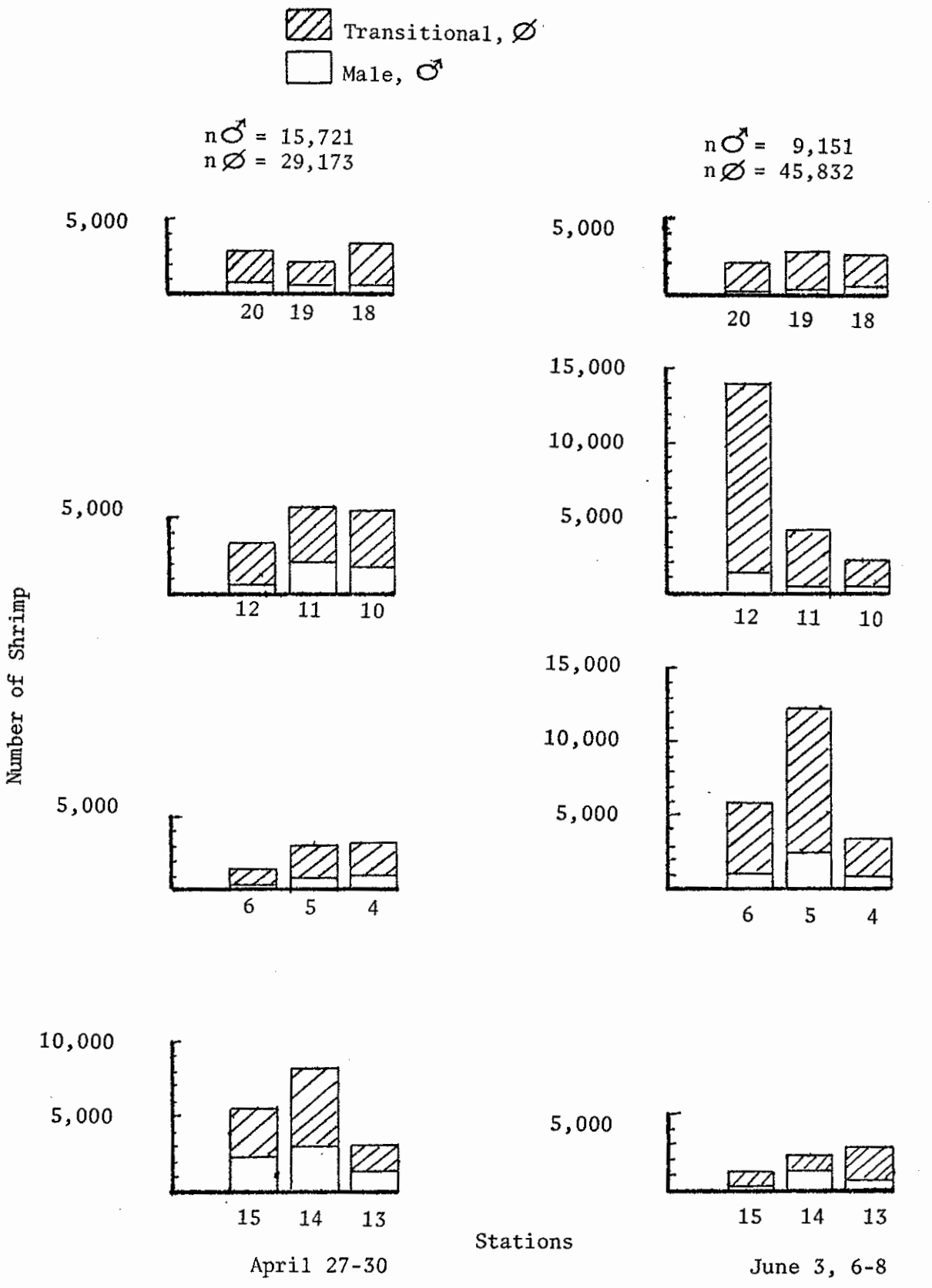


Figure 16. Number of Male and Transitional Shrimp per ½-Nautical Mile by Station, April-June 1970.

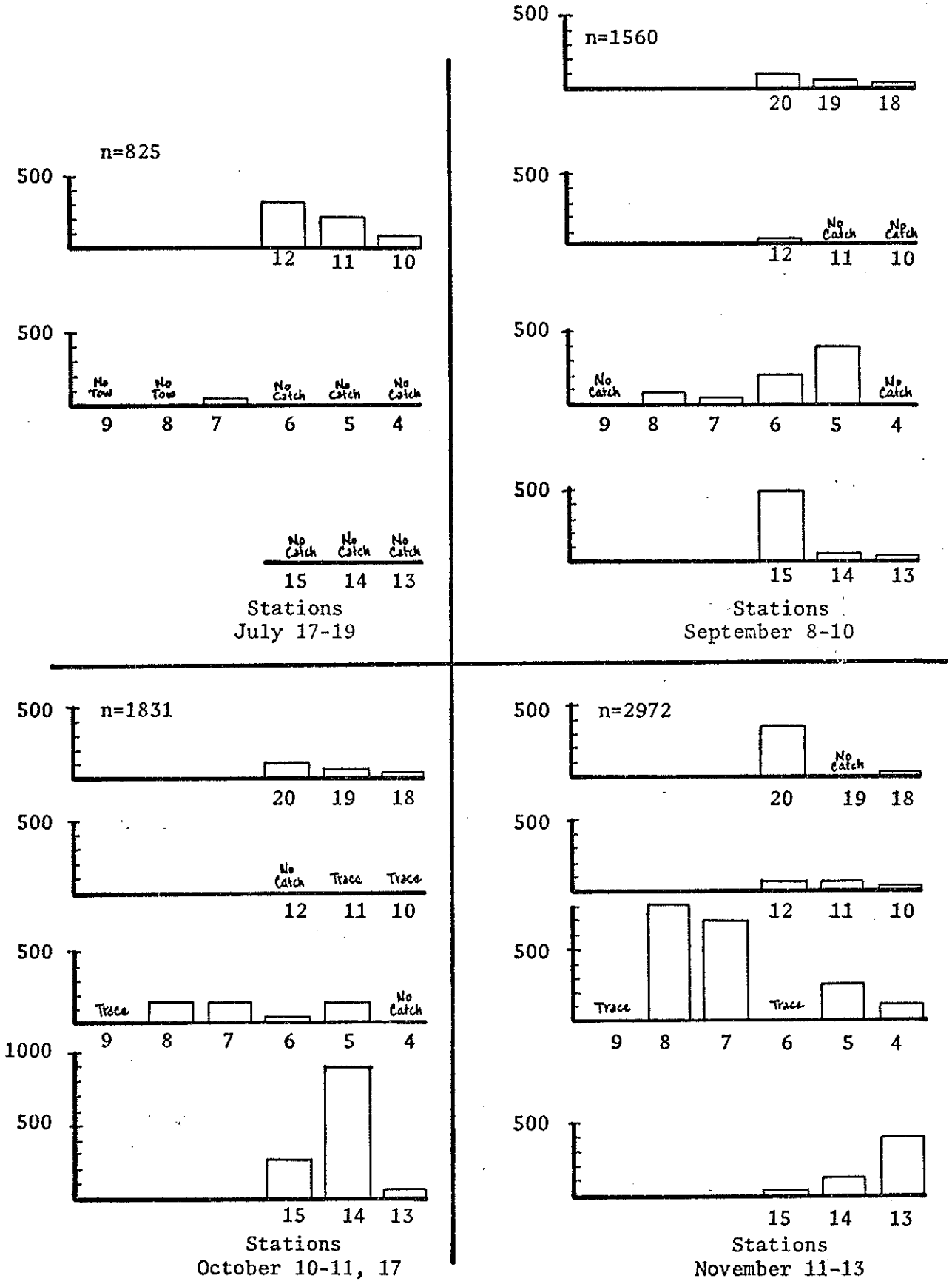


Figure 17. Number of 1969 Year Class Shrimp per ½-Nautical Mile by Station, July-November 1969.

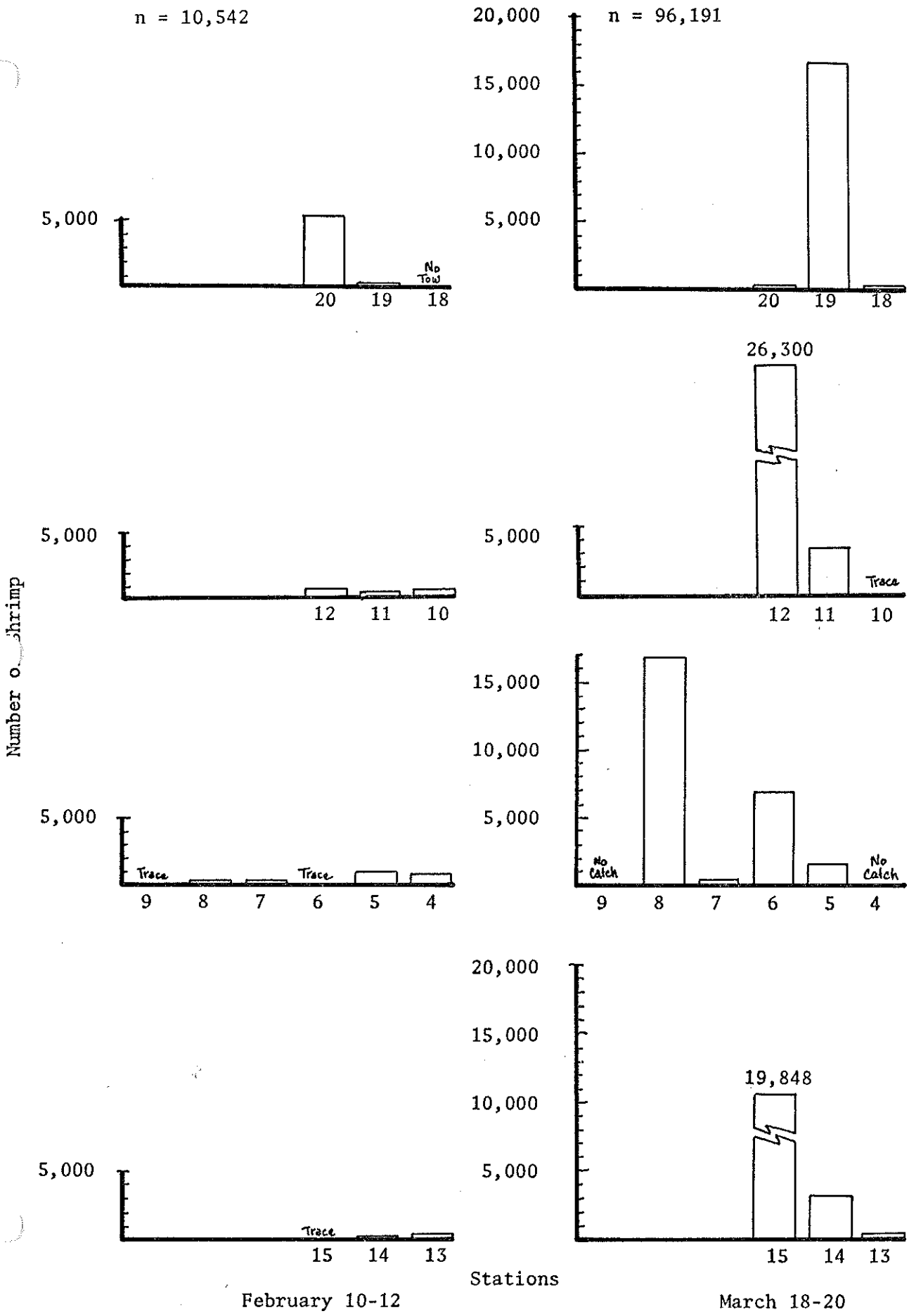


Figure 18. Number of 1969 Year Class Shrimp per ½-Nautical Mile by Station, February-March 1970.

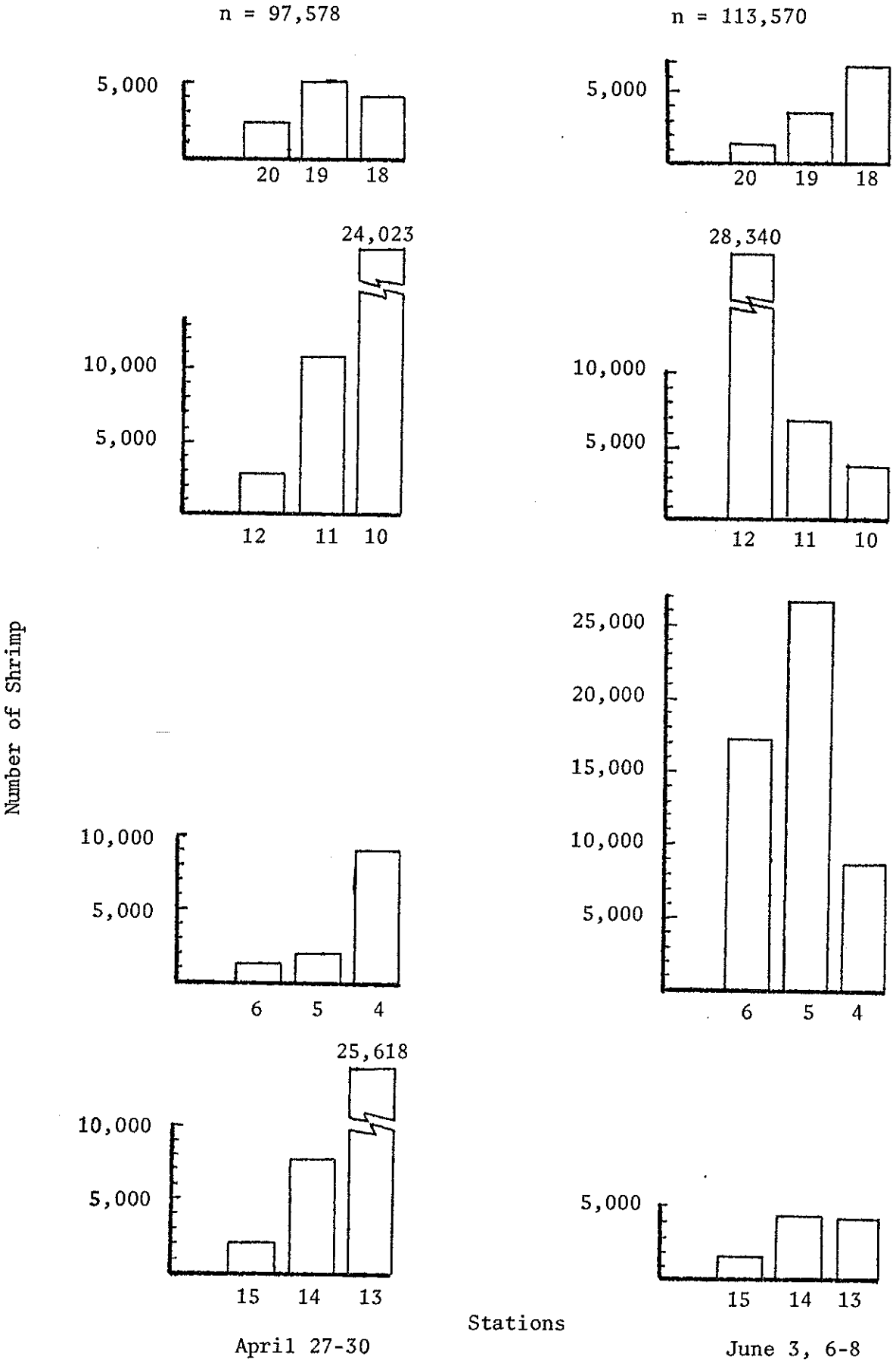


Figure 19. Number of 1969 Year Class per ½-Nautical Mile Tow by Station, April-June 1970.

Distribution of Female Shrimp

The changes in abundance of the female pink shrimp suggested a movement offshore out of the area and an influx from the south in the early spring back to the study area (Figures 10-12).

In July 1969, it appeared that females were more abundant inshore than offshore and more abundant at the northern stations (10-12) than at the southern stations. Two months later, in September, it seemed that the females were moving offshore, as seen by the shift in abundance. No north-south shifts were noted in September 1969. In October, catches of females were further reduced and they may have moved out of the area by migrating further offshore. Station 8 catches gives some indication of the abundance of shrimp in that area. The apparent offshore movement out of the area agress with the findings of Dahlstrom (1970). He reported that in California waters female pink shrimp make an offshore spawning migration during the winter. Shrimp from the Tillamook Head area made this migration in the fall. In November, the catch of females increased slightly probably because of the transitionals reaching the female stage. Some stations in the main study area had relatively large numbers of females but there was no pattern to their distribution. The catch in November at station 8 had doubled since October. Catches of females were at their lowest point in February and station 8 had only a trace catch. By March, the abundance of females began to increase and their distribution suggests that they moved in from the south. During April and June, there was no specific pattern to their distribution of abundance.

Distribution of Male Shrimp

The distribution of male shrimp somewhat followed the pattern of the female shrimp (Figures 13-16). In July 1969, the males were most abundant at the inshore and northern stations. Two months later in September, no pattern of abundance was evident. During October and November, the catch as station 8 increased but the catches at the other stations in the main study area did not show evidence of a shift of males to the offshore areas.

During February 1970, the numbers of male shrimp were also at their lowest point. By March the number of males had increased and, as with the females, it appeared the influx was from the south. It was during March that a large number of males entering the transitional phase were noted. During April and June, the males and transitionals showed no specific pattern of distribution.

Distribution of 1969 Year Class Shrimp

In July 1969, the incoming 1969 year class occurred only at the northern stations (10-12) and at station 7. After July, these shrimp were fairly well distributed throughout the study area mingling with the adult population. The catch of 0-age shrimp increased at station 8 during the same months that the male and female catches increased at that station indicating that they were moving with shifts in distribution of the adults.

By March 1970 the abundance of the 1969 year class was greatly increased (Figure 18). This was probably related to their increase in length and hence increased vulnerability to the gear. However, the increase in 1969 year class shrimp also coincided with the increase of adults in the catch. It is difficult to determine if the increased abundance of this year class was related to an actual influx of shrimp into the area or the increase in length or a combination of both.

The abundance of the 1969 year class was nearly equal from the north to south latitudes during March 1970. The catch was largest at the offshore and midline stations and station 8. There is no indication, as there was with the adults, to suggest that this year class moved into the study area from the south. In fact, they may have moved in from the offshore areas. During April 1970, this year class showed a definite shoreward shift in abundance (Figure 19). This was the only instance where a group of shrimp showed a definite pattern of distribution. By June 1970, they apparently had moved offshore and were concentrated in the middle of the study area.

Distribution of Gravid Female Shrimp

During the study, we attempted to determine if gravid females migrated to a specific area prior to the hatching of their eggs which, if true, would effect distribution of their progeny. We hypothesized that female shrimp migrate to an area where the newly hatched larvae would be transported by the currents back to the shrimp grounds where their parents reside.

As discussed previously, the majority of the female shrimp in the study area appeared to migrate offshore in September and October. The total number of female shrimp in the study area remained low until March when it appeared that an influx of shrimp occurred from the south. Even though the majority of the female shrimp had migrated out of the study area, we observed the development of the remaining sexually maturing females to determine when the hatching of larvae occurred and if the females were distributed in a definite portion of the study area. In October, female shrimp in the gravid stage began occurring in the catches (Table 3).

Table 3. Percentage of Female Shrimp with and without Headroe, Gravid & Spent by Month

Cruise Date	Stage of Development			
	Without Headroe %	With Headroe %	Gravid %	Spent %
Sept. 8 - 10	10.7	89.3	-	-
Oct. 11-12, 17	-	83.6	16.4	-
Nov. 11-13	-	15.1	84.9	-
Jan. 4	-	-	100.0	-
Feb. 10-12	-	-	97.2	2.8
Mar. 18-20	-	-	2.8	97.2
Apr. 27-30	-	-	-	100.0

By February, 97.2% of the shrimp were gravid and were distributed at the southern mid- and inshore portion of the study area. Because of this observation, we feel that the females which had moved out of the area in September and October were to the south. Five weeks later, during the March cruise, 97.2% of the females were spent. The number of females in the study area had increased to 165 million compared with 40 million in February (Figure 9). We felt that the influx of shrimp was from the south since the majority of the female shrimp were at the southern stations (Figure 11). Catches of shrimp at the offshore stations, 7-9, were low, leading us to believe that they did not move in from offshore areas.

Based on the behavior of the gravid and spent females in February and March, we feel that their offshore migration in the fall was followed by a southern and then inshore migration during the winter. Accordingly, the bulk of the females were porbably south of the study area when the larvae were hatching.

If the movements described above did occur, then direction and speed of water currents in the hatching area should be considered because they could effect distribution of the larvae. Barr (1970) in discussing the general life history of *Pandalus borealis* in Alaska waters stated that the larvae inhabit the midwater depths where they drift passively or swim weakly. Berkeley (1930) found that the early zoel stages of *Pandalus danae* were found throughout the water column below 4 fathoms. *P. danae* in the later stages were found in deeper water. Nothing is known of the vertical distribution of larval *P. jordani* but they may function in a similar manner. Surface water currents off northern Oregon in March are from the south with the months of April and May being a transition period during which the direction of flow is variable (Burt and Wyatt, 1964). After this transition period, the surface currents flow southward. David Wright (Oregon State University, School of Oceanography, personal communication) has stated, based on partially confirmed theory, that over the central Oregon continental shelf the midwater and bottom currents during winter

and early spring are moving to the south. These currents change direction in the late spring and early summer, when upwelling occurs and move to the north. Pink shrimp larvae hatching during the spring and occupying the midwater and/or bottom depths may be carried southward initially but could experience a net movement to the north.

Nursery Area Concept

We wished to determine if juvenile pink shrimp settling to the bottom, occupy a nursery area separate from the adults or if they mingle with the adult population. Berkeley (1930) found that juveniles (0-age) of three species of British Columbia pandalids spent their first summer in shallow water (35 fathoms or less) and during their first winter they move into deeper water to join the adults. However, juveniles of one other species (*P. danae*) were found with the adults during their first summer.

In July 1969, during the first cruise of our study, we caught 1969 year class shrimp which at that time were 3-4 months old. They occurred only at the northern stations (10-12) and at station 7. We did not find any juveniles at the shallow (30-51 fathoms) near-shore stations (1-3).

In the succeeding months, they were dispersed throughout the study area. Based on the July 1969 data, we felt that the northern part of the study area could be a nursery area, at least up to the time the 0-age shrimp were 3-4 months old.

In June 1970, we had one more opportunity to examine the distribution of an incoming year class of shrimp. In this case it was the 1970 year class which at this time of year were 2-3 months old. We increased our sampling to 1,000 shrimp per station to get a better indication of distribution of this year class. However, the total catch was small and did not permit any conclusions to be drawn from the results (Table 4).

Table 4. Number of 1970 Year Class Shrimp by Station, June 1970

Station Number	Number of 1970 Year Class Shrimp
18	2
10	1
12	1
6	21
15	2

The catch of 1970 year class shrimp in the VDS in June 1970 was of a greater magnitude and suggested a pattern of distribution as depicted in Table 5. Stations 20, 12, 6, and 15 in the left column are the offshore stations and stations 18-20 at the top of the table are the northern stations. The numbers of 0-age shrimp caught in the VDS were probably minimal as it was noted that when the bags were handled prior to emptying, many of the shrimp passed through the mesh.

Table 5. Number of 1970 Year Class Shrimp Caught in the Vertical Distribution Sampler, by Tow, June 1970

Station No. and Tow	No. 1970 Year Class	Station No. and Tow	No. 1970 Year Class	Station No. and Tow	No. 1970 Year Class
20a	4	19a	4	18a	6
b	0	b	8	b	0
12a	178[1/]	11a	22	10a	0
b	269	b	7[1/]	b	0
6a	156	5a	84	4a	2
b	392	b	9	b	0
15a	66[1/]	14a	35	13a	11
b	10	b	30	b	4

1/ One bag not fishing properly.

The VDS catches indicated a concentration of 0-age shrimp in the west central portion of the study area in June 1970. Very few 1970 year class shrimp were caught at the northern and inshore stations during this month. Station 6 had the greatest number of 0's in both the VDS and trawl catch.

The catch distribution of 1970 year class shrimp was not comparable with the 1969 year class distribution in July 1969. However, during July, station 12, an offshore station, did have the greatest abundance of 0's. This is somewhat similar to June 1970 when both stations 12 and 6 had the greatest number of 0-age shrimp.

Comparison of the distribution of the adult shrimp in June with the distribution of the 1970 year class showed that they were nearly similar. Therefore, we felt that the nursery area concept was not valid. Juvenile pink shrimp probably do mingle with the adult population soon after they metamorphosed and settle to the bottom. We do not understand why the 1969 year class shrimp in July 1969 were found only in the northern portion of the study area. It may be that these shrimp, being young and probably still not strong swimmers, were carried northward beyond the study area, but as they grew, they were able to disperse southward throughout the area.

Vertical Distribution Sampler Catches

The results of the VDS catches during the last four cruises in February, March, April, and June 1970 alleviated our concern that large numbers of shrimp might have been too high in the water column and missed by our net. A summary of the total number of adult pink shrimp caught in the VDS by month and the average number caught per tow is presented in Table 6.

Table 6. Summary of Vertical Distribution Sample Catches in Numbers of Shrimp per Month and Average Catch per Tow, February - June 1970

Month	Number of Tows	Total Number Caught	Average Catch per Tow
February	15	1	0.07
March	16	9	0.7
April	24	642	26.8
June	24	3,423	142.6

Catches in the VDS initially were poor but increased substantially during April and June 1970. To evaluate the extent of these increased catches above the net, we extrapolated the VDS catches to an estimate of pounds in an area equal in width to the net and the same height of the VDS. This estimate cannot be considered entirely reliable but does have some value in providing a "ball park" estimate of pounds of shrimp which might have been above our net.

Because of the poor VDS catches in February and March 1970, the expanded catches for these months were negligible. During April 1970, catches in the VDS increased. The expanded catches of 8 of 24 tows ranged from 1 to 18.7 pounds per ½-nautical mile. The remaining 16 tows had estimated catches of 1 pound or less. An estimate of the total poundage of shrimp extrapolated from these expanded VDS catches amounts to 107,000 pounds in the 4 to 10-foot area above the net. This total is insignificant compared with the 8.4 million pounds estimate based on trawl catches.

In June 1970, VDS catches greatly increased. An average of 13 pounds per ½-nautical mile tow was estimated to be above the net. The largest estimate of a single tow was 65 pounds compared with 340 pounds caught in the corresponding trawl catch.

The total calculated poundage of shrimp above the net in the 192-square nautical mile study area during the cruise was 587,000 pounds, still insignificant in comparison with the 1055 million pound estimate of shrimp 1-4-feet off bottom.

Response of Shrimp to Daylight

While using the VDS, we hoped to get an indication of why shrimp were off the bottom during the day. Beardsley and High's (1970) and Beardsley's (1973) work indicated that vertical distribution of shrimp changes from day to day and tow to tow. They suggest that the vertical distribution is related to the amount of available light. Murky water and overcast weather decrease the amount of available light. These conditions generally cause an increase in the height of shrimp off the bottom.

We measured the intensity of light from the surface to 90-feet with a submarine photometer. These readings accounted for the effect both cloud cover and transparency of the water had on the amount of light available below the surface. The rate of decrease of light intensity from the surface to 90-feet was calculated and used to extrapolate an estimated value of the amount of light reaching the bottom.

By having the VDS attached to the trawl net, we were able to get an estimate of both the amount of shrimp caught in a typical shrimp trawl and the amount of shrimp above the net. We feel that the VDS catches accurately reflected the amount of shrimp 4-10-feet off bottom at the time the net was being towed. Because of the configuration of the net at the opening and the placement of the VDS frame, there was an overhang of mesh which acted as a barrier to shrimp if they were moving off bottom more than 4-feet in response to the approaching net.

Since our study was set up primarily to detect movement and abundance of shrimp from station to station, we were not able to devote the time and appropriate methodology to studying vertical distribution during the daytime. However, the results

that we obtained did provide an insight on the effects of light and density of shrimp on the magnitude of the VDS catches during the daytime.

Weather conditions and the Columbia River plume both had an effect on the amount of light penetration. Table 7 gives the mean b values and general weather observations made during each cruise. The b value is the estimated change in the natural logarithms of photometer measurements per foot increase in water depth. This factor was used for estimateing light intensity at the bottom. The smaller the value the larger the percentage of light reaching 90-feet.

Table 7. Mean b Values and Weather Observations, February-June 1970

Month	Mean b Value	Weather Observation
February	-0.340	Partly cloudy, cloud cover 50 - 95%
March	-0.231	Clear to partly cloudy, cloud cover 0 - 10%
April	-0.426	Overcast, 100% cloud cover during most of cruise
June	-0.605	Partly cloudy to overcast, cloud cover 60 - 100%

During the first two cruises we used the VDS, the water was relatively clear. The Columbia River plume was not over the study area. The March cruise had the best light penetration to 90-feet, based on the b value, as well as the least amount of cloud cover. During the last two cruises, the Columbia River plume had shifted southward over the study area resulting in murky water at the surface. Cloud cover at 60 - 100% also cut down the amount of available light. These two conditions resulted in a higher b value.

We did not use all the catch data in making the analysis to determine the b value. Tows were deleted either because we did not take photometer reading or because one or more of the bags of the VDS were not fishing properly.

During February and March, the VDS catches were very poor, even though the March cruise had the highest mean trawl catch (Table 8). However, the light penetration was high (Table 7). During April and June, the VDS catches increased while the trawl catches decreased but still remained at a high level. But with the shift of the Columbia River plume over the area, the amount of light penetration decreased. The highest mean VDS catch and the least observed amount of light penetration occurred during June.

Table 8. Summary of Mean Trawl and Vertical Distribution Sampler Shrimp Catch, in Numbers

Month	Number of Tows	Trawl	VDS
February	9	2,316	0
March	8	23,090	1
April	10	16,536	37
June	19	16,962	152

In analyzing the results, we calculated correlation coefficients for several pairs of variables. The variables were month, VDS catch, trawl catch, photometer reading at 90-feet, b value, and estimated light intensity at the bottom. Multiple regression analysis showed that 70% of the variance of the VDS data was associated with measurements of light and trawl catch. Table 9 shows the correlation coefficients for all pairs of variables analyzed.

Table 9. Correlation Coefficients (r) of Variables Related to Vertical Distribution Sampler Catches[1/]

Variable	Month	VDS Catch
VDS Catch	0.40	1.00
Trawl Catch	0.18	0.56
Photometer reading at 90-feet	-0.58	-0.46
b Value	-0.70	-0.47
Estimated light intensity at tow depth	-0.65	-0.55

1/ Values of r greater than 0.30 or less than -0.30 are significant at the 5% level.

Implications of VDS Data

The fact that shrimp were above the net during periods of murky water conditions and overcast weather off Tillamook Head may be of some importance to commercial shrimp fishermen. Although we did not have large catches in the VDS, they might have increased during the summer months when upwelling causes murky water. On the shrimp grounds off Coos Bay, "brown water" is a seasonal occurrence and the shrimp catches decrease during this period. These conditions coupled with overcast weather may cause a large number of shrimp to move off the bottom. Oregon shrimp fishermen currently use a Gulf semi-balloon trawl which has a vertical opening of about 4-feet. Therefore, they may be missing significant amounts of shrimp during certain periods of the year. It is apparent from our data that a trawl net needs to be designed which has a larger vertical opening. The catch rate of a new trawl net should then be compared with the Gulf semi-balloon trawl during summer periods when murky water exists off the coast.

CONCLUSIONS

The results of the study provided some insight of the movement and behavior of shrimp. However, since the study was only for 1 year, the results can only be considered typical of the shrimp population during this period. Additional work over an expanded study area would be needed to verify the suggested patterns of movement.

The fluctuation in abundance of shrimp in the study area is not the result of one particular year class or sex group migrating. The data from the monthly observations suggests that the majority of the population moved offshore during the fall and early winter. In the spring, they reappeared in the study area apparently moving in from the south.

Within the study area, shrimp were not dispersed in a random pattern. There were occasions at certain stations when the shrimp were predominantly of one sex or year class. Because of these nonrandom distributions, it is important that future pink shrimp population assessment surveys include stations distributed over the entire known shrimp grounds. Also, because of fluctuations in abundance, surveys should be completed in the shortest possible time period and at the same time of year if they are on a continuing basis. The population off Tillamook Head increased 3.5 million pounds in one 5-week period in February and March 1970.

The VDS data indicates that shrimp are sometimes 4 to 12-feet off the bottom during the day and this behavior in inversely correlated to the amount of light reaching the bottom. The number of shrimp caught in the VDS indicated we were not missing significant amounts of shrimp at 4-10-feet off the bottom during February, March, April, and June 1970. However, the project terminated and we were unable to make tows during the summer and assess the significance of the conditions when the water is more murky and allows less light to reach the bottom.

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LITERATURE CITED

Beardsley, Alan J. 1973. Design and evaluation of a sampler for measuring the near-bottom vertical distribution of pink shrimp, *Pandalus jordani*. Fishery Bull. 71(1): 243-253.

Beardsley, Alan J. and William L. High. 1970. Shrimp sorting trawls in the Pacific Northwest. National Fishermen Yearbook 50(13): 49, 51-52.

Berkeley, Alfreda A. 1930. The post-embryonic development of the common pandalids of British Columbia. Contrib. Can. Biol., N.S. 6(6): 79-163.

Burt, Wayne V. and Bruce Wyatt. 1964. Drift bottle observations of the Davidson Current off Oregon. Collected Reprints, Dept. of Ocean., Ore. St. Univ. 3: 286-295.

Byrne, John V. and Daniel A. Panshin. 1968. Continental shelf sediments off Oregon. Sea Grant Publication, Cooperative Extension Service, Ore. St. Univ.

Dahlstrom, W.A. 1970. Synopsis of biological data on the ocean shrimp *Pandalus borealis* Rathbun, 1902. In: Proceedings world scientific conference on the biology and culture of shrimps and prawns, FAO Fish. Rpt. 57(Vol. 4): 1377-1416.

Magill, Austin R. and Michael Erho. 1963. The development and status of the pink shrimp fishery of Washington and Oregon. Pac. Mar. Fish. Comm. Bull. 6: 61-80.

Robinson, Jack G. (In processing). The vertical distribution and diel migration of pink shrimp, *Pandalus jordani*, off Oregon. Ore. Fish Comm.

Tegelberg, H.C. and J.M. Smith. 1957. Observations on the distribution and biology of the pink shrimp (*Pandalus jordani*) off the Washington coast. Wash. Dept. of Fish., Res. Pap. 2(1): 25-34.