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# INTRODUCTION

With the development of simple and easily handled equipment, suitable for use by other than electronic specialists, there has been a rapid advancement in studies involving acoustical activity under water. The portion of these studies concerned with fishes has developed chiefly along three lines: one concerned with the identification of the producers of specific sounds, e.g., Fish (1954, 1964); another concerned with the mechanisms that produce or receive sounds, on the basis of anatomy and operation, e.g., Tavolga (1960, 1962); and a third concerned with behavior in response to sounds or in sound production, e.g., Tavolga (1956, 1958a, 1958b, 1958c), Moulton (1956), Winn and Stout (1960), Delco (1960), Taylor and Mansueti (1960), Gray and Winn (1961), Tavolga and Wodinsky (1963), Stout (1963), Winn, Marshall, and Hazlett (1964), Nelson (1964), Marshall (1965), and Myrberg, Kramer, and Heinecke (1965). A general review and full bibliography were given by Tavolga (1965).

Very little work on sonic ecology and its relation to the life history and behavior of any species has been reported. Life-history studies undertaken before these developments have necessarily been without significant references to the role of sound production in connection with reproductive or other behavior. The subject has usually been treated as though fishes were both deaf and mute. The primary purpose of the studies reported herein is to provide preliminary background data in this area of study on certain shore fishes.

In order to obtain the necessary data a variety of instruments were obtained or constructed. These instruments consisted primarily of two basic kinds: those devoted to the listening to and the recording of under-water sounds, primarily electronic, and those devoted to the recording of environmental conditions, mostly not electronic. Because the former involved some novel use of components, these are described in detail in the Appendix on equipment.

The period during which these observations were made extended from March, 1961, to August, 1965, with occasional interruptions. Nearly all the observations were made from a single site, a permanent base on Lemon Bay, Florida, situated on the Gulf coast about 30 miles south of the city of Sarasota. This site seemed well suited to the purposes of this survey, as the fish fauna of the bay is well known and the number of species is somewhat restricted. These conditions obtain at least partly because this bay is very shallow, long and narrow, and blind at its north end. The site of the operation (pl. 18) is about 5 statute miles north of the nearest connection with the Gulf of Mexico, locally known as Stump Pass. The fact that the area has a rich representation of the family Sciaenidae, nearly all of which are vigorous sound-producers, was basic to this desire for a restricted representation.


## Acknowledgments

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Grateful acknowledgment is due to Dr. Eugenie Clark, formerly Director of the Cape Haze Marine Laboratory (now Mote Marine Laboratory), for permission to use the facilities of the Laboratory for some of these studies. Other parts of this work were carried out in Lemon Bay from private facilities, or elsewhere, as indicated in the text. Thanks are due to Drs. Phyllis H. Cahn, Marie P. Fish, and William N. Tavolga, and Mr. Howard A. Baldwin for assistance in various technical matters, and to Drs. James W. Atz, Donn E. Rosen, and Tavolga for carefully criticizing the manuscript and for editorial assistance.

# OBSERVATIONAL DATA

OBSERVATIONS ON THE PRESENCE of fish sounds, as noted in the Introduction, were made mostly at one place. Unless otherwise specified, sonic data were gathered at the end of the 100-foot dock shown in plate 18 and text figures 10 through 15. Primarily, two types of data were collected.

### SONIC CHECKS

Data so reported were obtained by simply listening to earphones or a speaker, connected to a hydrophone through a suitable amplifier, systems that provided the sonic information from which the written notes were made.

### TAPE RECORDINGS

Data so reported were obtained with the same hydrophone and amplifier, but with the output fed to a tape recorder. Two types of recordings were made, depending on the needs at the time. One was continuous recording to a maximum of two hours, which was the capacity of the recorder that was used. The other was intermittent recording for a maximum of 24 hours, with five-minute samples recorded every hour, by means of a time-clock arrangement that turned the recorder on and off appropriately. (See the Appendix on equipment for structural and functional details.)

### DAILY RECORDS

By the above two means, substantial information on the occurrences of fish sounds, on an around-the-clock basis, was obtained.

### SEASONAL RECORDS

The above daily records were continued through the annual cycle for the study of seasonal effects on the production of fish sounds. Because several years were involved in these studies, nearly every day in the year is represented at least once, and some days are represented several times (see table 1).

### ENVIRONMENTAL DATA

The occurrence of fish sounds, and estimates of their intensity on a daily basis, were plotted, along with lunar phases, tides, light intensity, water temperatures, barometric

TABLE 1

DISTRIBUTION OF DAYS PER MONTH ON WHICH OBSERVATIONS FOR FISH SOUNDS WERE MADE

| Month | 1961 | 1962 | 1963 | 1964 | 1965 | Totals |
|---|---|---|---|---|---|---|
| Jan. | — | — | 9 | 24 | 26 | 59 |
| Feb. | — | — | 2 | 29 | 25 | 56 |
| March | 6 | — | — | 16 | 30 | 52 |
| April | 7 | 4 | — | 12 | 24 | 47 |
| May | — | 15 | — | 16 | 27 | 58 |
| June | — | 3 | 15 | 30 | 23 | 71 |
| July | — | — | 29 | 31 | 30 | 90 |
| Aug. | — | — | 31 | — | 31 | 62 |
| Sept. | — | — | 20 | — | 6 | 26 |
| Oct. | 6 | — | 4 | 27 | — | 37 |
| Nov. | 4 | 6 | 2 | 25 | — | 37 |
| Dec. | — | 10 | 18 | 29 | — | 57 |
| Totals | *23* | *38* | *130* | *239* | *222* | *652* |

pressure, and the vagaries of the weather. The basic charts were constructed with information provided by a recording tide gauge, a recording light meter, a recording thermometer for air and water, and a recording barometer. A recording salinometer was abandoned, because the slight changes in salinity were too small to be of significance to these studies. The general aspects of the water temperatures are given in table 2 and shown as a graph in text figure 1. Text figure 2 shows a sample of the basic charts from which the others were derived. This sample, taken during a period of much cloudiness, gives lower light values than would have been recorded at other times. For instance, on July 22, 1963, with cloudless skies, peak values reached to more than 12,000 foot-candles.

The only items of environmental data that require comment follow.

NOTES ON RECORDING TIDE GAUGE: The Lemon Bay locality is one in which complex tides, generally known as mixed tides, have large components of both diurnal and semidiurnal frequencies. They are here recognized by the marked differences in the heights of one pair of successive high and low water. In the words of Marmer (1951): "The diurnal inequality in the tide depends primarily on the declination of the moon which varies from

TABLE 2

WATER TEMPERATURES (IN DEGREES FAHRENHEIT) BY MONTHS, INCLUDING MAXIMA, MEANS, MINIMA, MEANS OF DAILY HIGHS AND LOWS, LOWEST HIGH, AND HIGHEST LOW

| Year and Month | Max. | Mean | Min. | Mean Highs | Mean Lows | Lowest High | Highest Low | No. of Days |
|---|---|---|---|---|---|---|---|---|
| 1961 | | | | | | | | |
| March | 82.5 | 74.1 | 63.0 | 77.1 | 71.1 | 66.0 | 80.0 | 29 |
| April | 86.0 | 74.3 | 61.0 | 77.2 | 77.3 | 73.5 | 82.5 | 30 |
| Oct. | 88.0 | 76.1 | 63.0 | 79.2 | 73.0 | 71.0 | 81.5 | 21 |
| Nov. | 81.0 | 73.2 | 59.0 | 76.4 | 70.0 | 70.0 | 76.0 | 30 |
| 1962 | | | | | | | | |
| April | 84.5 | 72.1 | 54.0 | 76.0 | 68.2 | 70.0 | 79.0 | 30 |
| May | 90.0 | 80.5 | 69.0 | 83.4 | 77.8 | 74.0 | 85.0 | 31 |
| June | 85.5 | 81.7 | 77.5 | 84.2 | 79.2 | 83.0 | 81.0 | 3 |
| Nov. | 79.0 | 66.9 | 52.0 | 71.0 | 62.1 | 61.0 | 70.0 | 15 |
| Dec. | 80.0 | 61.4 | 43.0 | 67.2 | 55.7 | 45.0 | 69.0 | 31 |
| 1963 | | | | | | | | |
| Jan. | 77.0 | 61.3 | 41.0 | 67.3 | 55.2 | 58.0 | 67.0 | 31 |
| Feb. | 74.0 | 61.1 | 46.0 | 66.3 | 55.9 | 55.0 | 66.0 | 24 |
| June | 89.5 | 81.3 | 74.0 | 85.7 | 76.9 | 80.5 | 80.0 | 17 |
| July | 91.0 | 82.1 | 73.0 | 86.4 | 77.7 | 83.0 | 87.0 | 31 |
| Aug. | 92.5 | 83.1 | 75.0 | 87.4 | 78.7 | 84.0 | 83.0 | 31 |
| Sept. | 92.0 | 81.7 | 72.0 | 84.8 | 78.6 | 76.5 | 82.5 | 30 |
| Oct. | 82.0 | 73.6 | 54.0 | 77.4 | 69.9 | 71.0 | 76.0 | 28 |
| Nov. | 76.0 | 67.6 | 44.0 | 71.1 | 64.1 | 60.0 | 73.0 | 30 |
| Dec. | 71.0 | 60.0 | 50.0 | 62.3 | 57.7 | 57.0 | 67.0 | 31 |
| 1964 | | | | | | | | |
| Jan. | 71.5 | 61.8 | 43.5 | 64.0 | 59.6 | 52.0 | 67.0 | 31 |
| Feb. | 70.5 | 61.9 | 52.0 | 64.9 | 59.6 | 58.5 | 66.0 | 29 |
| March | 82.0 | 71.8 | 57.5 | 74.8 | 68.8 | 61.5 | 57.5 | 25 |
| July | 90.0 | 83.1 | 78.0 | 85.7 | 80.6 | 80.0 | 84.5 | 31 |
| Combined years | | | | | | | | |
| Jan. | 77.0 | 61.5 | 41.0 | 65.6 | 57.4 | 52.0 | 67.0 | 62 |
| Feb. | 74.0 | 61.5 | 46.0 | 65.5 | 57.4 | 55.0 | 66.0 | 53 |
| March | 82.5 | 73.2 | 57.5 | 76.0 | 70.0 | 61.5 | 80.0 | 54 |
| April | 86.0 | 73.2 | 54.0 | 76.6 | 69.7 | 70.0 | 82.5 | 60 |
| May | 90.0 | 80.5 | 69.0 | 83.4 | 77.8 | 74.0 | 85.0 | 31 |
| June | 81.7 | 81.4 | 74.0 | 85.5 | 77.2 | 80.5 | 81.0 | 20 |
| July | 98.5 | 82.6 | 84.2 | 86.0 | 79.1 | 80.0 | 87.0 | 62 |
| Aug. | 92.5 | 83.1 | 75.0 | 87.4 | 78.7 | 84.0 | 83.0 | 31 |
| Sept. | 92.0 | 81.7 | 72.0 | 84.8 | 78.6 | 76.5 | 82.5 | 30 |
| Oct. | 88.0 | 74.7 | 77.4 | 78.2 | 71.2 | 71.0 | 81.5 | 49 |
| Nov. | 81.0 | 69.7 | 44.0 | 73.2 | 66.1 | 60.0 | 76.0 | 75 |
| Dec. | 80.0 | 60.7 | 43.0 | 64.6 | 59.0 | 45.0 | 69.0 | 72 |
| All | *92.5* | *72.3* | *41.0* | *75.9* | *68.7* | *45.0* | *87.0* | *589* |

zero to its maximum north and south declination in half a fortnight. Hence, the diurnal inequality in the tide likewise varies within a fortnight, being generally least when the moon is close to the equator and greatest when the moon is near its fortnightly maximum north and south declination." One complete cycle, as seen at this place, is shown in text figure 2 (see also Defant, 1958).

How such a complex situation might bear on circadian rhythms has apparently not been studied, if indeed it is not too complicated for

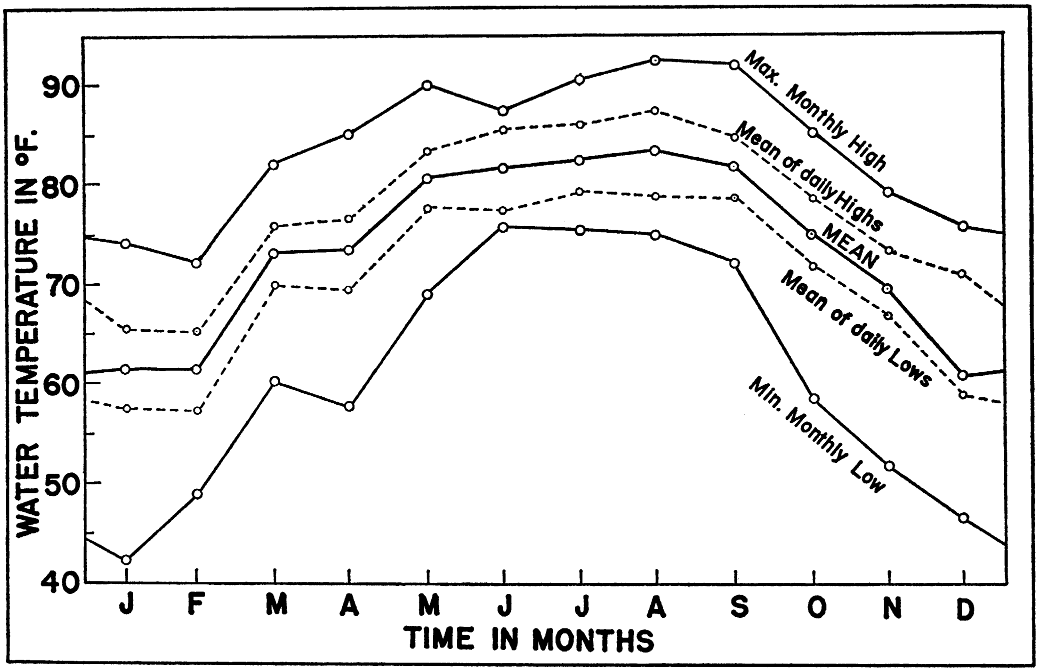



FIG. 1. Annual variation in the temperature of the water at the end of the dock at Lemon Bay, with means and extremes, by months for the years 1961 through 1964; based on data in table 2.

any organism to follow. It may be, however, that some of the irregularities in sound production heard at this locality are partially related to these conditions of tidal behavior, a matter that the present data cannot illuminate.

In addition, the location in a long, narrow, blind bay, running approximately 32 degrees west of north and situated about 5 miles north of the nearest connection with the Gulf, adds its own vagaries to the basic tidal pattern. Wind strength and direction account principally for these departures from lunar control. A sample of the tidal behavior is shown in text figure 2, in which the tides are shown to shift from what is nearly a semidiurnal tide to a nearly diurnal tide. During the approach of the diurnal type of tide, a nearly complete merging of the lower high tide and higher low tide appears, producing a condition that is known as the vanishing tide. In this location, at the extreme of the phenomenon, the rising tide shows what remains of the high and low pair merely as a slowing of the rate of rise in the water and, on tide charts, as a slight change in the angle of ascent, with no reversal of tidal direction.

NOTES ON RECORDING LIGHT-INTENSITY METER: Although in measurements of light intensity the unit lux is generally preferred by biologists, the more common term "foot-candles" is employed here. This unit can be converted to lux by multiplying by 10.75. For present purposes there appeared to be no point in converting to either lux or crep values. See Neilsen (1961) for the definition of the latter value, and Neilsen (1963) for a discussion of its usefulness and relationship to other usages in the estimation of light intensity.

Clearly the present data indicate that the beginning and ending of the choruses studied were not limited to civil twilight (the period between sunset and the time at which it becomes too dark to work outdoors without artificial illumination). Their average length completely bridges this period.

The photocell used for the measuring of foot-candles was provided with a Wratten filter No. 102, which approximates the human phototopic curve.

NOTES ON ESTIMATES OF SONIC INTENSITY:

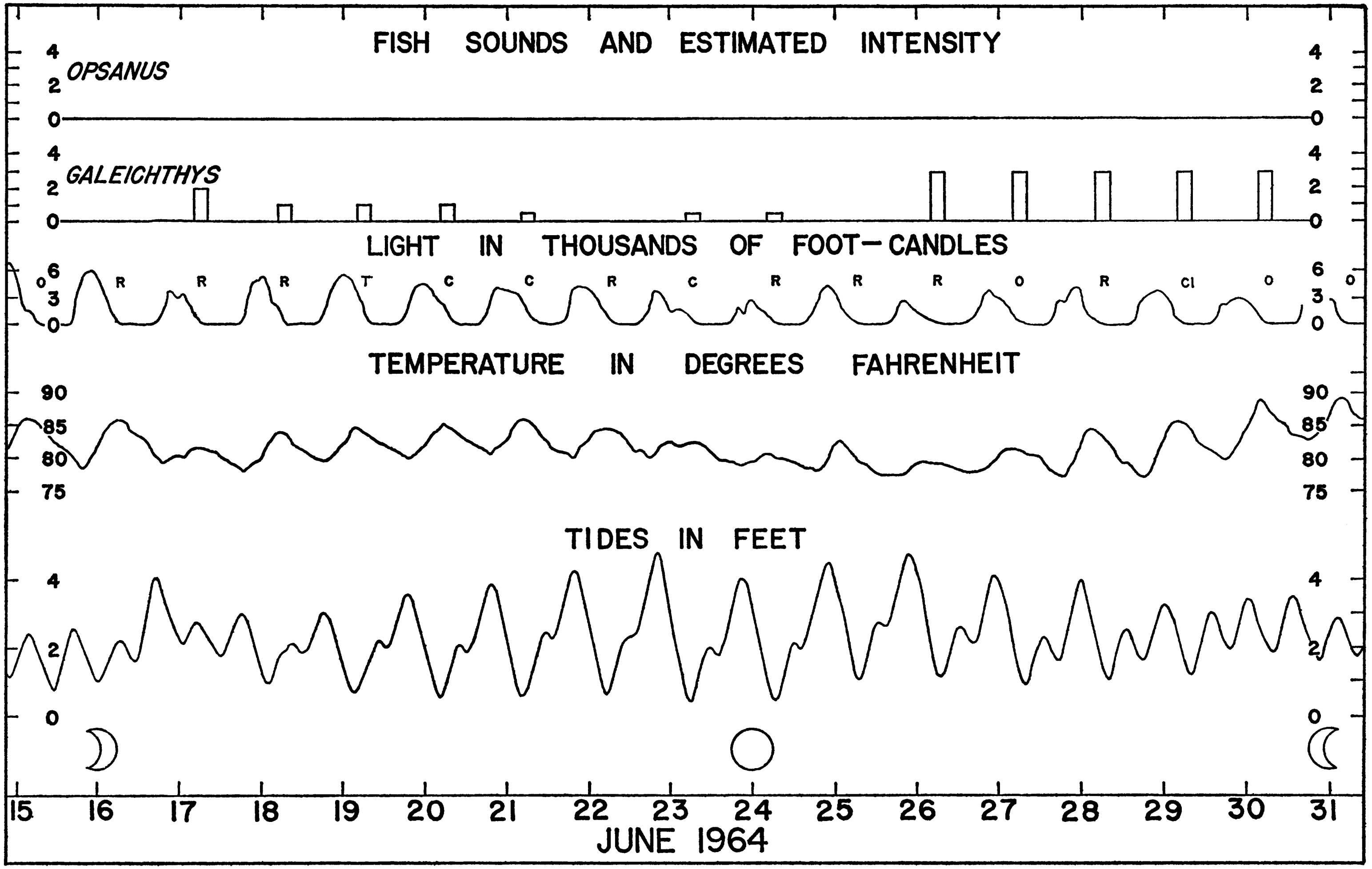



FIG. 2. Sample of basic data, indicating the complexity of the tides in Lemon Bay. By chance not a single sound from *Opsanus* was heard or recorded during this period, in the mid-summer slump; hence the blank line for that species.
*Symbols:* C, cloudy; Cl, clear; O, overcast; R, rain; T, thunderstorm.

The estimates of sonic intensity attempt to give a measure of the number of sound-producers present and the vigor of their sonic efforts. These would be very difficult to refer to instrumentation, which could easily measure volume output, but this would be meaningless because the groups of fishes did not station themselves at fixed distances from the hydrophone. It was easy enough, however, for the human ear to distinguish a few loud and vigorous sound-producers from a large number of feeble or distant choral elements.

Only four arbitrary categories were established, which were easily recognized by ear and are adequate for present purposes. These estimates attempted to relate the observed range of sounds to twice, three times, and four times the apparent number of sonic fishes necessary to make the smallest chorus usually noted. In a few cases, subsequent to the establishment of this scale of values, a value of one-half was assigned. These seemed to be the sound production of three or four fishes. Above that number, it was not possible to hazard even a guess as to the numbers present. If, however, that value has any real significance, then the largest group of sonic fishes heard was between 48 and 64, with intermediate values in proportion.

To insure that the volume of sound delivered each night was based on the same level of amplification, the following procedure was established. The volume control on the preamplifier was adjusted on a decibel meter in accordance with a known sound source, in this case an audiogenerator, at a known distance and volume setting with the use of 200 Hertz.

Because of the manner in which the four categories were used, the derived index values were obtained by dividing the intensity estimates by four times the number of days of choruses, in order to equate the maximum possible value with 100, for convenience.

## SPECIES INVOLVED

The fish sounds studied varied from those fully identifiable, through questionable ones, to some that could not be assigned to any particular species. The frequency with which any distinguishable sound could be heard also varied widely, from that of two species that were abundant and formed the basis of most of the sound production, through that of species that were heard at infrequent intervals, or rarely, to some sounds that were heard but once. The first two species, because of the large quantity of data obtained, made it possible to develop an extended analysis of the relationships of the sounds produced to the season and changing ecological conditions.

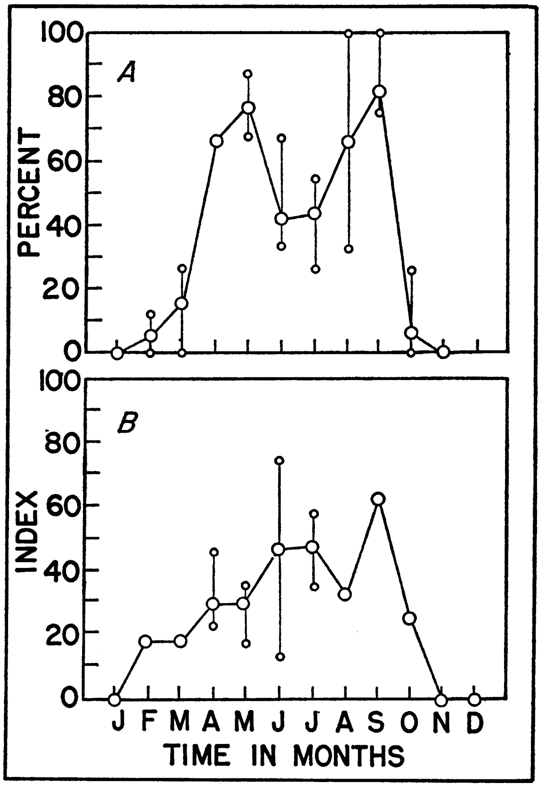



Fig. 3. Choruses of *Galeichthys* by months, in terms of occurrence (A) and of intensity (B), and in percentage and index values, respectively. Large circles represent means (in farthest right-hand column of table 3); small circles indicate maximum and minimum values (shown in table 3 under the year in which obtained).

### *Galeichthys felis* (Linnaeus)

The sound-producing mechanism of this species was described in considerable detail by Tavolga (1962). The "percolator" sound described by Kellogg (1955), in the view of Tavolga (*loc. cit.*), is merely a chorus of many fishes, all producing the grunts mentioned above. What are almost surely the individual grunts of this species were frequently heard in these experiments, but they formed no pattern and could not be related to any ecological conditions. The sounds given on the phonograph record accompanying the 1960 article by Tavolga were not distinguishable from those on the present tapes.

The interest here centers mostly on the choruses of "percolator" sounds that were produced seasonally in great abundance. The earliest they were heard was February 13, 1965; otherwise they were not heard earlier than April 9, in both 1961 and 1962. The latest they were heard was October 7, 1963. The month in which this sound was most frequently heard was May, but the month in which the sound intensity (defined above under Observational Data) was greatest was September. Both the presence of sound and intensity distinctly lessened during June, July, and August. (See table 3 and text fig. 3 for details.) Together with the water-temperature data (table 2 and text fig. 1), it is clearly indicated that temperature is a principal factor in the control of these choruses. The water temperatures from November through March are mostly below the lowest at which these sounds were heard. During this period, those instances when the temperature rose above 74° F. were all of very short duration, presumably too short to influence the fishes sufficiently to start choruses. The highest temperatures occurred from June through August and were often above 89° F., the highest temperatures at which this species was sonic. During these months the fish did not cease sound production, but its frequency, and to a less extent its intensity, decreased markedly with any increase in temperature, as is shown below in the discussion of thermal behavior antecedent to fish sounds.

TABLE 3

CHORUSES OF *Galeichthys* BY MONTHS, IN TERMS OF THE NUMBER OF DAYS PER MONTH HAVING CHORUSES (IN ROMAN) AND BY THE PERCENTAGE OF OBSERVATIONS PER MONTH (IN *ITALICS*), AS ESTIMATES OF INTENSITY (IN ROMAN) AND AS AN INDEX VALUE (IN *ITALICS*)

(The percentage figures in the upper part were derived by dividing the number of days with choruses by the number of observations given in table 1. The index values of the lower part were derived by dividing the intensity estimates by four times the number of days with choruses. See text for full explanation. This table corresponds to tables 10 and 14.)

| Month | 1961 | 1962 | 1963 | 1964 | 1965 | All |
|---|---|---|---|---|---|---|
| Feb. | — | — | 0 *0* | 0 *0* | 3 *12* | 3 *5* |
| March | 0 *0* | — | — | 0 *0* | 8 *27* | 8 *15* |
| April | 5 *71* | 2 *50* | — | 8 *67* | 16 *67* | 31 *66* |
| May | — | 10 *67* | — | 14 *87* | 20 *74* | 44 *76* |
| June | — | 1 *33* | 10 *67* | 11 *37* | 8 *35* | 30 *42* |
| July | — | — | 14 *48* | 17 *55* | 8 *27* | 39 *43* |
| Aug. | — | — | 10 *32* | — | 31 *100* | 41 *66* |
| Sept. | — | — | 15 *75* | — | 6 *100* | 21 *81* |
| Oct. | 1 *17* | — | 1 *25* | 0 *0* | — | 2 *6* |
| All | 6 *27* | 13 *59* | 50 *38* | 50 *33* | 100 *45* | 219 *34* |
| Intensity | | | | | | |
| Feb. | — | — | — | — | 2.0 *17* | 2.0 *17* |
| March | — | — | — | — | 5.5 *17* | 5.5 *17* |
| April | 9.0 *45* | 2.0 *25* | — | 7.0 *22* | — | 18.0 *28* |
| May | — | 6.5 *16* | — | 18.5 *34* | — | 25.0 *28* |
| June | — | 0.5 *12* | 23.0 *57* | 33.0 *75* | — | 56.5 *46* |
| July | — | — | 20.0 *36* | 38.5 *57* | — | 58.5 *47* |
| Aug. | — | — | 13.0 *32* | — | — | 13.0 *32* |
| Sept. | — | — | 37.5 *62* | — | — | 37.5 *62* |
| Oct. | 0.5 *12* | — | 0.5 *12* | — | — | 1.0 *12* |
| All | 9.5 *40* | 9.0 *17* | 94.0 *47* | 97.0 *43* | 7.5 *17* | 217.0 *45* |

Supporting the idea that some of the fish had left the bay in midsummer is the fact that fewer individuals of *Galeichthys* were caught by either anglers or commercial fishermen, or both combined, during June, July, and August than in the months preceding and following. Also, our own trapping showed the species to have continual, but reduced, representation in the bay, in good agreement with the sonic records for these months.

In addition to the effects of temperature on these choruses it appeared that the moon is, to some extent, influential, both directly through the light produced and indirectly through other effects that are discussed below. The necessary evidence bearing on the influence of the moon is given in table 4 and text figure 4. It is clear from these data that choruses are most frequent and intensity is at its maximum in the quarters preceding the last quarter and the new moon. This half of the lunar cycle is the one in which the moon rises in the morning during the early part of the period and sets in early evening, but in the last portions rises late in the day, brightening as the light of the sun fades. As the fish choruses at this location occur only between dusk and about three hours later, some lunar influence could be expected, and, as anticipated, the half cycle, bright in the early evening, has fewer choruses, 32 to 49, in terms of the percentage of observations made. Text figure 5, also based on table 4, indicates in another manner that the new moon shows the greatest number of sonic evenings and the full moon the least number, and that the two quarters are appropriately intermediate. It is noteworthy that the four

## TABLE 4

CHORUSES OF *Galiechthys* BY MOON PHASES, IN TERMS OF THE NUMBER OF OBSERVATIONS, THE NUMBER OF CHORUSES, AND PERCENTAGE, EACH IN THE PHASE INDICATED, WHICH IS THE LAST DAY OF THE RESPECTIVE QUARTER

(This table corresponds to tables 11 and 15.)

| Date of Full Moon | | To Last Quarter | | | To New Moon | | | To First Quarter | | | To Full Moon | | | All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | O[a] | C[b] | % | O | C | % | O | C | % | O | C | % | O | C | % |
| Feb. | | | | | | | | | | | | | | | | |
| 1963 | 8 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 |
| 1964 | 27 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 7 | 0 | 0 | 29 | 0 | 0 |
| 1965 | 15 | 8 | 0 | 0 | 6 | 0 | 0 | 8 | 0 | 0 | 3 | 2 | 66 | 25 | 2 | 8 |
| | | | | *0* | | | *0* | | | *0* | | | *20* | *56* | *2* | *4* |
| March | | | | | | | | | | | | | | | | |
| 1961 | 2 | 2 | 0 | 0 | — | — | — | 2 | 0 | 0 | 2 | 0 | 0 | 6 | 0 | 0 |
| 1964 | 27 | 6 | 0 | 0 | 6 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 16 | 0 | 0 |
| 1965 | 17 | 8 | 2 | 26 | 6 | 1 | 17 | 8 | 0 | 0 | 8 | 1 | 12 | 30 | 4 | 13 |
| | | | | *12* | | | *8* | | | *0* | | | *9* | *52* | *4* | *8* |
| April | | | | | | | | | | | | | | | | |
| 1961 | 1 | 2 | 0 | 0 | 2 | 2 | 100 | 1 | 1 | 100 | 2 | 2 | 100 | 7 | 5 | 71 |
| 1962 | 20 | 1 | 1 | 100 | 1 | 0 | 0 | 1 | 1 | 100 | 1 | 0 | 0 | 4 | 2 | 50 |
| 1964 | 26 | 5 | 5 | 100 | 1 | 0 | 0 | 3 | 3 | 100 | 3 | 0 | 0 | 12 | 8 | 67 |
| 1965 | 15 | 6 | 3 | 50 | 5 | 4 | 80 | 7 | 4 | 57 | 6 | 5 | 83 | 24 | 16 | 67 |
| | | | | *64* | | | *67* | | | *75* | | | *58* | *47* | *31* | *67* |
| May | | | | | | | | | | | | | | | | |
| 1962 | 19 | 7 | 4 | 59 | 5 | 5 | 100 | 1 | 0 | 0 | 2 | 1 | 50 | 15 | 10 | 67 |
| 1964 | 26 | 8 | 8 | 100 | — | — | — | — | — | — | 8 | 6 | 75 | 16 | 14 | 89 |
| 1965 | 15 | 7 | 5 | 71 | 7 | 7 | 100 | 7 | 7 | 100 | 6 | 1 | 18 | 27 | 20 | 74 |
| | | | | *77* | | | *100* | | | *87* | | | *50* | *58* | *44* | *76* |
| June | | | | | | | | | | | | | | | | |
| 1962 | 16 | — | — | — | 2 | 1 | 50 | 1 | 0 | 0 | — | — | — | 3 | 1 | 33 |
| 1963 | 7 | 2 | 2 | 100 | 5 | 5 | 100 | 6 | 3 | 50 | 2 | 0 | 0 | 15 | 10 | 67 |
| 1964 | 24 | 9 | 4 | 43 | 6 | 5 | 83 | 7 | 1 | 14 | 8 | 1 | 12 | 30 | 11 | 37 |
| 1965 | 13 | 8 | 4 | 50 | 2 | 0 | 0 | 6 | 1 | 17 | 7 | 3 | 43 | 23 | 8 | 35 |
| | | | | *53* | | | *73* | | | *25* | | | *24* | *71* | *30* | *42* |
| July | | | | | | | | | | | | | | | | |
| 1963 | 6 | 8 | 4 | 50 | 5 | 5 | 100 | 7 | 4 | 57 | 9 | 1 | 12 | 29 | 14 | 48 |
| 1964 | 24 | 9 | 8 | 89 | 7 | 2 | 29 | 7 | 0 | 0 | 8 | 7 | 87 | 31 | 17 | 55 |
| 1965 | 13 | 8 | 0 | 0 | 7 | 6 | 86 | 7 | 2 | 29 | 8 | 0 | 0 | 30 | 8 | 27 |
| | | | | *48* | | | *68* | | | *29* | | | *32* | *90* | *39* | *43* |
| Aug. | | | | | | | | | | | | | | | | |
| 1963 | 5 | 7 | 2 | 29 | 7 | 3 | 43 | 8 | 4 | 50 | 9 | 1 | 11 | 31 | 10 | 32 |
| 1965 | 12 | 7 | 7 | 100 | 7 | 7 | 100 | 8 | 8 | 100 | 9 | 9 | 100 | 31 | 31 | 100 |
| | | | | *64* | | | *71* | | | *75* | | | *56* | *62* | *41* | *66* |
| Sept. | | | | | | | | | | | | | | | | |
| 1963 | 3 | 7 | 4 | 57 | 7 | 7 | 100 | 1 | 1 | 100 | 5 | 3 | 60 | 20 | 15 | 75 |
| 1965 | 10 | — | — | — | — | — | — | — | — | — | 6 | 6 | 100 | 6 | 6 | 100 |
| | | | | *57* | | | *100* | | | *100* | | | *82* | *26* | *21* | *81* |
| Oct. | | | | | | | | | | | | | | | | |
| 1961 | 23 | 1 | 1 | 100 | 2 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 6 | 1 | 17 |
| 1963 | 2 | 2 | 1 | 50 | 1 | 0 | 0 | — | — | — | 1 | 0 | 0 | 4 | 1 | 25 |
| 1964[c] | 20 | 5 | 0 | 0 | 8 | 2 | 25 | 7 | 8 | 0 | 7 | 0 | 0 | 27 | 10 | 37 |
| | | | | *25* | | | *18* | | | *0* | | | *0* | *37* | *2* | *6* |
| All | | 142 | 65 | *45* | 112 | 62 | *55* | 115 | 40 | *35* | 130 | 49 | *38* | 499 | 214 | *43* |

[a] O, number of observations.

[b] C, number of choruses.

[c] According to the United States Weather Bureau, October of 1964 was the coldest October of any ever recorded for Florida.

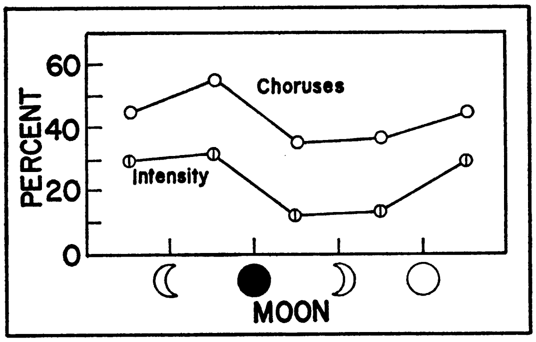



FIG. 4. Choruses of *Galeichthys* by moon phases, in terms of occurrence and of intensity, in percentage and index values, respectively. The moon symbols along the abscissa are to the right of the values shown on the graph, as these percentages represent the average of the quarter preceding the corresponding moon symbol. The last quarter, at the left, is repeated on the right, as an aid to visualizing relationships.

curves shown retain essentially the same form throughout the sonic period.

The data throughout the choral season, which occurred on nights for which there was a proper weather record, are shown in table 5 and text figure 6. Of these 218 records, it was found that 61 occurred during cloudy or rainy nights, and 157 occurred during nights that were clear or at most hazy.[1] Expressed in terms of percentage of observations, however, are 42 on cloudy nights and 45 on brights nights (table 5), which apparently indicates that the fishes operate in a similar manner on both bright and dark nights, differing slightly only quantitatively, with the bias to the bright nights. Because these nights are usually gentle, throughout the season of choruses, whereas the dark nights, which are caused by the presence of clouds or fog, are commonly rainy, stormy, or windy, these data suggest that the slight difference, 3 per cent, may indicate that rough water in the shallow places near the dock tends to silence the fishes or drive them to deeper water out of the range of our instruments.

Choral intensity in reference to moon phases and to bright and dark nights by moon phases are not given in either tables or figures, because they follow the chorus figures closely and would add nothing.

These data are not readily treated by statistical analysis in any meaningful manner, as the four moon phases have, of course, a moon rise about an hour later each day. The data, if treated against this feature, as they should be, break down into classes too small to provide significant values, that is, fewer than two for the cloudy and rainy nights. Moreover, a large variation in the presence and absence of choruses further dissipates exactness. All that can be said of these data is that they suggest that the moon has little or questionable significance on sound production.

Even with good series of observations at the heights of sonic production, an analysis of the numbers of choruses and their intensity shows no clear-cut relationships to the complex tidal stages found here (see notes above under Environmental Data). Tidal influence appeared only as a simple adjustment to water depth by the fishes. It was found that these choruses would not form in water shallower than about 3 feet and occurred mostly on beds of *Thallasia*. There is reason to believe that in the shallow depths of this bay the fish were sonic mostly from positions within the shelter of the long, straplike leaves of this plant. The reasons for this view are presented below in the account of the at-

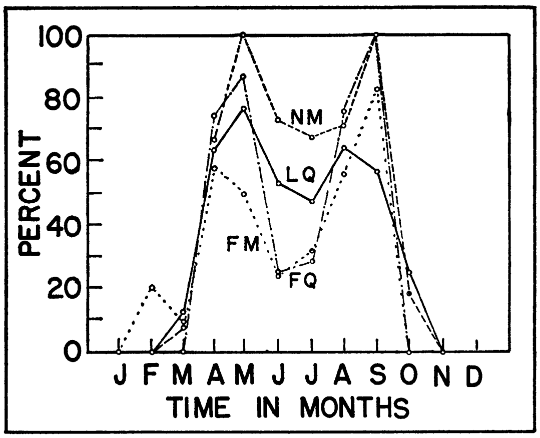



FIG. 5. Comparison of choruses of *Galeichthys* in percentage by moon phases throughout the season of sound production; based on table 4.

*Symbols:* FM, full moon; FQ, first quarter; LQ, last quarter; NM, new moon.

[1] There were actually few of these hazy nights. Even including them in the cloudy category would make no significant difference in the tabulation.

# TABLE 5

Choruses of *Galeichthys* by Moon Phases on Bright and Dark Nights, in Terms of the Number of Observations, the Number of Choruses, and Percentage, Each in the Phase Indicated, Which is the Last Day of the Respective Quarter
(This table corresponds to tables 12 and 16.)

| Month and Year | Bright Nights: To Last Quarter | | | Bright Nights: To New Moon | | | Bright Nights: To First Quarter | | | Bright Nights: To Full Moon | | | Bright Nights: All | | | Dark Nights: To Last Quarter | | | Dark Nights: To New Moon | | | Dark Nights: To First Quarter | | | Dark Nights: To Full Moon | | | Dark Nights: All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O[a] | C[b] | % | O | C | % | O | C | % | O | C | % | O | C | % | O | C | % | O | C | % | O | C | % | O | C | % | O | C | % |
| Feb. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 3 | 0 | 0 | 7 | 0 | 0 | 6 | 0 | 0 | 6 | 0 | 0 | 22 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 7 | 0 | 0 |
| 1965 | 5 | 1 | 20 | 4 | 0 | 0 | 6 | 0 | 0 | 3 | 1 | 33 | 18 | 2 | 11 | 3 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | — | — | — | 7 | 0 | 0 |
| | | | | | | | | | | | | | *42* | *2* | *5* | | | | | | | | | | | | | *14* | *0* | *0* |
| March | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1961 | 2 | 0 | 0 | — | — | — | 2 | 0 | 0 | 2 | 0 | 0 | 6 | 0 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 4 | 0 | 0 | 6 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 14 | 0 | 0 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 |
| 1965 | 4 | 2 | 50 | 4 | 0 | 0 | 4 | 0 | 0 | 4 | 1 | 25 | 16 | 3 | 19 | 4 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 4 | 1 | 25 | 14 | 1 | 7 |
| | | | | | | | | | | | | | *36* | *3* | *8* | | | | | | | | | | | | | *16* | *1* | *6* |
| April | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1961 | — | — | — | 1 | 1 | 100 | 1 | 1 | 100 | — | — | — | 2 | 2 | 100 | 2 | 0 | 0 | 1 | 1 | 100 | — | — | — | 2 | 2 | 100 | 5 | 3 | 60 |
| 1962 | 1 | 1 | 100 | — | — | — | 1 | 1 | 100 | 1 | 1 | 0 | 3 | 2 | 67 | — | — | — | 1 | 0 | 0 | — | — | — | — | — | — | 1 | 0 | 0 |
| 1964 | 5 | 5 | 100 | 1 | 1 | 100 | 2 | 2 | 100 | — | — | — | 8 | 8 | 100 | — | — | — | 1 | 0 | 0 | — | — | — | 3 | 0 | 0 | 4 | 0 | 0 |
| 1965 | 5 | 4 | 80 | 3 | 3 | 100 | 6 | 5 | 83 | 6 | 4 | 67 | 20 | 16 | 80 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | — | — | — | 4 | 0 | 0 |
| | | | | | | | | | | | | | *33* | *28* | *85* | | | | | | | | | | | | | *14* | *3* | *18* |
| May | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1962 | 4 | 2 | 50 | 1 | 1 | 100 | 1 | 0 | 0 | 2 | 1 | 50 | 8 | 4 | 50 | 3 | 2 | 67 | 4 | 4 | 100 | — | — | — | — | — | — | 7 | 6 | 86 |
| 1964 | 7 | 7 | 100 | — | — | — | — | — | — | 5 | 4 | 80 | 12 | 11 | 92 | 1 | 1 | 100 | — | — | — | — | — | — | 4 | 2 | 50 | 5 | 3 | 60 |
| 1965 | 6 | 5 | 83 | 4 | 4 | 100 | 8 | 7 | 87 | 6 | 2 | 33 | 24 | 18 | 75 | — | — | — | 3 | 2 | 67 | — | — | — | — | — | — | 3 | 2 | 67 |
| | | | | | | | | | | | | | *44* | *33* | *77* | | | | | | | | | | | | | *15* | *11* | *77* |
| June | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1962 | — | — | — | 2 | 1 | 50 | — | — | — | — | — | — | 2 | 1 | 50 | — | — | — | — | — | — | 1 | 0 | 0 | — | — | — | 1 | 0 | 0 |
| 1963 | 3 | 2 | 67 | 4 | 4 | 100 | 4 | 2 | 50 | 1 | 0 | 0 | 12 | 8 | 67 | — | — | — | 1 | 1 | 100 | 1 | 1 | 100 | 1 | 0 | 0 | 3 | 2 | 67 |
| 1964 | 7 | 4 | 57 | 5 | 4 | 80 | 6 | 1 | 17 | 5 | 1 | 20 | 23 | 10 | 43 | 1 | 0 | 0 | 2 | 1 | 50 | 1 | 0 | 0 | 3 | 0 | 0 | 7 | 1 | 14 |
| 1965 | 8 | 4 | 50 | 2 | 0 | 0 | 3 | 0 | 0 | 7 | 3 | 43 | 20 | 7 | 35 | — | — | — | — | — | — | 3 | 1 | | — | — | — | 3 | 1 | 33 |
| | | | | | | | | | | | | | *57* | *26* | *46* | | | | | | | | | | | | | *14* | *4* | *29* |
| July | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 8 | 4 | 50 | 4 | 4 | 100 | 4 | 3 | 75 | 9 | 1 | 11 | 25 | 12 | 48 | — | — | — | 1 | 1 | 100 | 3 | 1 | 33 | — | — | — | 4 | 2 | 50 |
| 1964 | 3 | 3 | 100 | 5 | 2 | 40 | 6 | 0 | 0 | 7 | 6 | 86 | 21 | 11 | 52 | 6 | 5 | 83 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 100 | 10 | 6 | 60 |
| 1965 | — | — | — | — | — | — | 5 | 2 | 40 | 6 | 0 | 0 | 11 | 2 | 18 | 8 | 0 | 0 | 7 | 6 | 87 | 2 | 0 | 0 | 2 | 0 | 0 | 19 | 6 | 32 |
| | | | | | | | | | | | | | *57* | *25* | *44* | | | | | | | | | | | | | *33* | *14* | *42* |
| Aug. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 6 | 1 | 17 | 4 | 1 | 25 | 5 | 1 | 20 | 6 | 1 | 17 | 21 | 4 | 19 | 1 | 1 | 100 | 3 | 2 | 67 | 3 | 3 | 100 | 3 | 0 | 0 | 10 | 6 | 60 |
| 1965 | 7 | 7 | 100 | 7 | 7 | 100 | 7 | 7 | 100 | — | — | — | 21 | 21 | 100 | — | — | — | — | — | — | 4 | 4 | 100 | 7 | 6 | 86 | 11 | 10 | 91 |
| | | | | | | | | | | | | | *42* | *25* | *60* | | | | | | | | | | | | | *21* | *16* | *76* |
| Sept. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 6 | 3 | 50 | 6 | 6 | 100 | — | — | — | 1 | 1 | 100 | 13 | 10 | 77 | 1 | 1 | 100 | 1 | 1 | 100 | 5 | 3 | 60 | — | — | — | 5 | 7 | 71 |
| 1965 | — | — | — | — | — | — | — | — | — | — | — | — | 0 | 0 | 0 | — | — | — | — | — | — | — | — | — | 6 | 6 | 100 | 6 | 6 | 100 |
| | | | | | | | | | | | | | *13* | *10* | *77* | | | | | | | | | | | | | *13* | *11* | *85* |
| Oct. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1961 | 1 | 1 | 100 | 2 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 6 | 1 | 17 | — | — | — | 1 | 0 | 0 | — | — | — | — | — | — | 1 | 0 | 0 |
| 1963 | 2 | 1 | 50 | 1 | 0 | 0 | — | — | — | 1 | 0 | 0 | 4 | 1 | 25 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 5 | 0 | 0 | 27 | 0 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | | | | | | | | | | | | | *37* | *2* | *5* | | | | | | | | | | | | | *1* | *0* | *0* |
| All | 106 | 57 | *54* | 80 | 39 | *49* | 89 | 32 | *36* | 85 | *26* | 32 | 359 | 154 | *40* | 37 | 10 | *27* | 35 | 19 | *54* | 32 | 13 | *41* | 44 | 18 | *41* | 140 | 60 | *43* |

[a] O, number of observations.
[b] C, number of choruses.

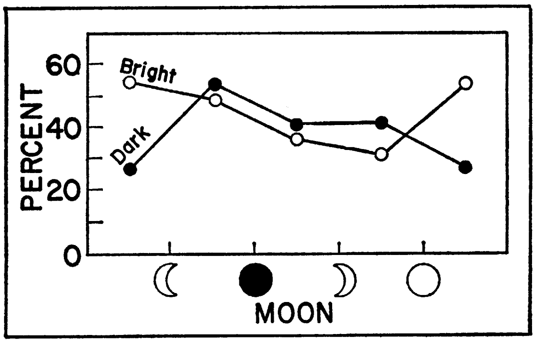



FIG. 6. Choruses of *Galeichthys* by moon phases and bright and dark nights, in terms of percentage; based on table 5.

tempts to establish more precisely the positions of the sound-producers.

The times of the beginning and of the ending of the choruses are shown in tables 7 and 8, and in text figures 7–9. At no other times of day or night were these sounds heard, for the duration of these extended studies at this one location in Lemon Bay. Occasionally listening at other places showed that individuals of *Galeichthys* in other, deeper, and less-confined localities did not adhere to this schedule, in which choruses never began before 5:00 P.M. and were never heard later than 10:20 P.M. The greatest duration of any chorus was four hours, beginning at 5:45 P.M. on July 3, 1964, during the height of the season for choruses. The shortest chorus lasted nine minutes, beginning at 6:42 P.M. on September 20, 1963, well past the peak of the season The periods of duration agree in a general way with the data on the frequency shown in text figure 3. That is, there was a general drift to longer sound-production periods as the height of the choral activity approached. There also appeared to be a slight tendency for the choruses to begin later as spring passed into summer, probably associated with the longer daylight periods. These two influences are not very strong and are certainly modified by many other environmental factors. Meaningful statistical treatment on this aspect would require many more data.

The light intensities at which sonic activity begins were measured on different kinds of evenings and were found to range from as high as 1900 foot-candles to as low as slightly less than 1 foot-candle. The mean for all data taken was 489 foot-candles. The details of these measurements are given in table 6 and text figure 7.

From May through June, with few exceptions (two at 7:30 P.M. in June) the times of beginning were all before 7:00 P.M., with one case just before 6:00 P.M. These account for the higher light values and higher means, 1090, 603, and 630, for the period covered. After June, from July through September, the beginning time was mostly after 7:00 P.M., with one value after 8:00 P.M. The lower light value means were 366, 75, and 36 foot-candles. Beginning with the first mean, the May data, there is a continual decrease in light intensity at which the choruses began, except for the July data which have a higher mean than that of June, probably indicating nothing more than an incidental variation because of the few observations made in July. The maximum values follow the same smoothly descending light values. The minimum values indicate only that the high minimum was in May, the others all being extremely low.

The above information seems to indicate that, in the early burst of spring activity, higher light values were tolerated, whereas later a lower light intensity was required before a chorus formed. Concomitantly with the later times of sunset, the evening cooling began later, up to the summer solstice, which

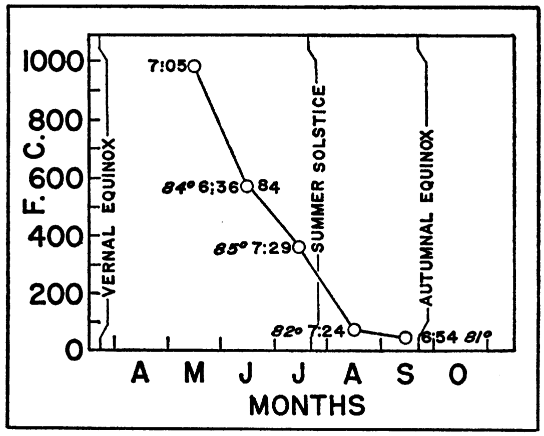



FIG. 7. Beginning times of *Galeichthys* choruses in reference to season, water temperature (shown in degrees Fahrenheit), and light intensity (in foot-candles), by months; based on table 6. Times are post meridiem.

TABLE 6

LIGHT INTENSITY (IN FOOT-CANDLES) AND TEMPERATURES (IN DEGREES FAHRENHEIT) AT WHICH *Galeichthys* CHORUSES BEGAN

| Year and Date | Intensity of Chorus Max. | | Min. | Choruses Began Early | | Late | Foot-Candles At Start Max. | | Min. | Water Temp. |
|---|---|---|---|---|---|---|---|---|---|---|
| May, 1964 | | | | | | | | | | |
| 26 | | 25 | | | 6:15 | | | 390 | | — |
| 27 | | 50 | | | 5:53 | | | 1680 | | — |
| 30 | | 50 | | | 6:03 | | | 1200 | | — |
| | *50* | *42* | *25* | *5:53* | *6:04* | *6:15* | *1680* | *1090* | *390* | — |
| June, 1963 | | | | | | | | | | |
| 14 | | 100 | | | 6:30 | | | 1200 | | 87 F[a] |
| 15 | | 50 | | | 6:50 | | | 430 | | 87 R |
| 19 | | 75 | | | 7:30 | | | 10 | | 81 L |
| 22 | | 50 | | | 7:30 | | | 175 | | 81 F |
| | *100* | *69* | *50* | *6:30* | *7:05* | *7:30* | *1200* | *454* | *10* | *84 RFL* |
| June, 1964 | | | | | | | | | | |
| 1 | | 50 | | | 6:37 | | | 1900 | | — |
| 2 | | 75 | | | 6:20 | | | 1550 | | — |
| 3 | | 100 | | | 6:35 | | | 600 | | — |
| 4 | | 100 | | | 6:40 | | | 1 | | — |
| 5 | | 100 | | | 6:40 | | | 59 | | — |
| 6 | | 100 | | | 6:25 | | | 480 | | — |
| 7 | | 100 | | | 6:58 | | | 273 | | — |
| 9 | | 75 | | | 6:30 | | | 180 | | — |
| | *100* | *87* | *50* | *6:20* | *6:36* | *6:58* | *1900* | *630* | *1* | — |
| July, 1964 | | | | | | | | | | |
| 14 | | 25 | | | 7:25 | | | 730 | | 88 F |
| 22 | | 12 | | | 7:34 | | | 3 | | 83 F |
| | *25* | *18* | *12* | *7:25* | *7:29* | *7:34* | *730* | *366* | *3* | *85 F* |
| Aug., 1963 | | | | | | | | | | |
| 10 | | 25 | | | 8:22 | | | 1 | | 85 F |
| 22 | | 50 | | | 6:55 | | | 145 | | 80 F |
| 23 | | 25 | | | 6:54 | | | 79 | | 82 F |
| | *50* | *33* | *25* | *6:54* | *7:24* | *8:22* | *145* | *75* | *1* | *82 F* |
| Sept., 1963 | | | | | | | | | | |
| 4 | | 25 | | | 7:18 | | | 1 | | 82 F |
| 5 | | 25 | | | 7:20 | | | 1 | | 83 F |
| 9 | | 100 | | | 7:00 | | | 1 | | 82 F |
| 10 | | 50 | | | 6:50 | | | 6 | | 81 F |
| 11 | | 100 | | | 6:33 | | | 138 | | 82 F |
| 12 | | 100 | | | 7:30 | | | 1 | | 80 F |
| 13 | | 50 | | | 7:05 | | | 1 | | 82 F |
| 14 | | 100 | | | 6:58 | | | 1 | | 77 F |
| 15 | | 100 | | | 6:15 | | | 120 | | 81 F |
| 16 | | 12 | | | 6:13 | | | 87 | | 80 F |
| | *100* | *66* | *12* | *6:13* | *6:54* | *7:30* | *138* | *36* | *1* | *81 F* |
| All | 100 | 67 | 12 | 5:53 | 6:51 | 8:22 | 1900 | 381 | 1 | 82 RFL |

[a] *Symbols:* F, falling tide; L, low water; R, rising tide.

may have had as great an influence as that of light intensity. These suppositions suggest that an activity such as reproduction may indeed be involved with this type of chorus. This matter is considered further below under Discussion.

TABLE 7

BEGINNING AND ENDING TIMES AND DURATION OF *Galeichthys* CHORUSES, BY MONTHS, ON DAYS ON WHICH BOTH WERE RECORDED

| Month and Year | No. of Chorus | Earliest Chorus | | Latest Chorus | | Chorus Duration in Hours | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Longest | | Shortest | | Mean |
| | | Date | P.M. | Date | P.M. | Date | Hours | Date | Hours | Duration |
| April, 1964 | 1 | 17 | 7.08 | 17 | 8.13 | 17 | 1:05 | — | — | *1:05* |
| May, 1962 | 8 | 16 | 6:05 | 26 | 9:50 | 29 | 2:45 | 24 | 1:30 | 2:06 |
| May, 1964 | 7 | 25 | 5:53 | 26 | 9:05 | 31 | 3:50 | 25 | 0:50 | 3:11 |
| | | | | | | | | | | *2:36* |
| June, 1962 | 1 | 1 | 7:30 | 1 | 8:35 | 1 | 1:05 | — | — | 1:05 |
| June, 1964 | 10 | 7 | 5:58 | 24 | 8:45 | 7 | 3:17 | 10 | 1:15 | 2:37 |
| | | | | | | | | | | *2:29* |
| July, 1963 | 7 | 20 | 7:06 | 20 | 9:05 | 20 | 1:59 | 22 | 0:35 | 1:33 |
| July, 1964 | 8 | 3 | 5:45 | 3 | 9:45 | 3 | 4:00 | 21 | 0:35 | 1:55 |
| | | | | | | | | | | 1:37 |
| Aug., 1963 | 1 | 23 | 6:47 | 23 | 7:20 | 23 | 0:33 | — | — | 0:33 |
| Sept., 1963 | 4 | 30 | 6:42 | 5 | 7:20 | 30 | 0:18 | 1 | 0:09 | *0:15* |
| All | *47* | | *5:53* | | *9:50* | | *4:00* | | *0:09* | *1:35* |

During the coming of spring in 1965, the particular manner in which sonic activity began was especially noted. It had already been established that at temperatures below 68° F. there was little, if any, sound production by the warm-season spawners. In the case of *Galeichthys* the start seemed to be merely erratic when water temperatures rose through the critical values, probably referable to the "random" wanderings of the wintering population of adult fishes and to local "warm spots" in the water. In other words these highly mobile fishes were not always within range of the dock-bound hydrophone, nor was the water temperature recorded there necessarily identical with that surrounding the fishes. The situation was quite different with *Opsanus* (see below).

It was evident from the recordings and sonic checks that the fishes comprising the *Galeichthys* choruses moved about considerably over the relatively short time that these choruses lasted. The motion could be noticed by the decrease or increase of the volume of sound, which occurred from time to time on some evenings and was completely absent on others. The very nearly omnidirectional hydrophones that were used and the very low main frequencies produced by the fishes prevented range finding by any simple means. It was often difficult, with these frequencies, to determine the direction from which the sounds came. Obviously, for these studies, it would be valuable to establish the sites and movements of the choruses. To this end an audiogoniometer was developed, which, although the low-frequency range on which it was necessary to operate was a handicap, yielded a good deal of information on the structure, movements, and shapes of the choral groups. The construction, functioning, and mode of operation of this device, a triangulating arrangement, are described in the Appendix. Only the results of its use are reported here.

In connection with it another device, for sonar direction and distance determination, employing its own and a much higher frequency than that produced by the choral fishes was employed.[1] In this situation, mostly because of the presence of many other fishes, it was impossible to correlate the presence

[1] This, a commercially available unit, was completely satisfactory for the purposes for which it was designed. It was supplied by the Enterprise Manufacturing Co. of Akron, Ohio, under the trade name of Fish-Finder and employs the Doppler principle. For this study it yielded data on the presence of several kinds of fishes other than *Galeichthys*, silent and sonic. Enough skill in the use of this device was developed for the operator to recognize the characteristic sound reflections from *Sciaenops ocellatus*, *Mugil cephalus*, *Cynoscion nebulosus*, and *Carcharinus* sp.

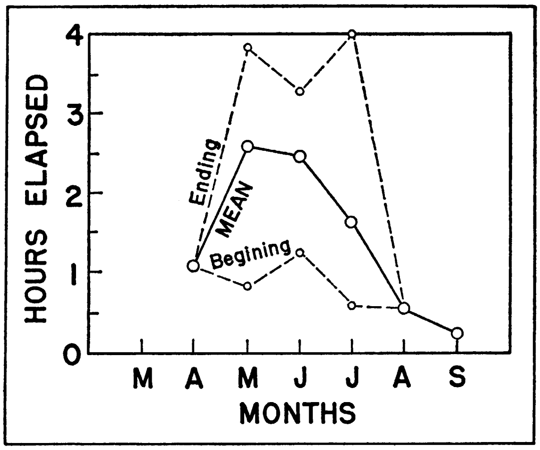



FIG. 8. Variation in the beginning times and ending times and duration of *Galeichthys* choruses by months, covering only the days from which complete data were available; based on table 7.

of silent individuals of *Galeichthys* with that of sonic ones. Consequently, the following data are based almost entirely on the results obtained by the audiogoniometer. At times it was possible to obtain a good fix, and at others it was clearly impossible. The peculiarities of this instrument were such that failures to make a fix were in themselves useful and often gave cues as to the true location of a group, by the manner in which it failed to give a "normal" reading (the technical reasons are given in the Appendix). This situation appeared to be related to the way the fishes were distributed, sometimes augmented by under-water sonic peculiarities. The specific data obtained were cross-checked by two operators and by special situations that occurred spontaneously or were specially treated by appropriate instruments.

Regarding the start and finish of a chorus, one of the natural questions concerning the individual participants was whether they moved up or down the bay and were heard only when they came within the range of the hydrophones. It was suspected, after some experience, that they were in the bay continuously and merely started or stopped sonic activity without undertaking any major movements that would remove them from the range of the hydrophones. The suspicion was fully confirmed by the audiogoniometer. Listening to it before the start of a chorus and into its early phases showed no substantial increase in volume other than that caused by an increase in the number of fishes with sonic output. This is clearly distinguishable from the gradual increase that would have occurred if sonic groups moved into the range of the hydrophones. Also, the audiogoniometer placed the fish in a position that revealed no substantial movement, as would have occurred if the sound-producers were either coming or going. The measurements showed that there was some milling about, but nothing more. The beginning of a chorus was not unlike the beginning of many frog choruses, in which a single individual emits a few "tentative" sounds, is soon joined by a few others, and then, almost simultaneously, is joined by the whole chorus, which causes a large crescendo which is maintained, usually at a

TABLE 8

BEGINNING AND ENDING TIMES AND DURATION OF *Galeichthys* CHORUSES, BY MONTHS, BASED ON ALL DATA, INCLUDING THOSE IN TABLE 7

| Month | No. of Choruses | Beginning Time | | | No. of Choruses | Ending Time | | | Diff. |
|---|---|---|---|---|---|---|---|---|---|
| | | Earliest | Mean | Latest | | Earliest | Mean | Latest | Means[a] |
| March | 1 | — | *5:30* | — | — | — | — | — | — |
| April | 2 | 5:22 | *6:15* | 7:08 | — | — | *8:13* | — | *1:58* |
| May | 18 | 5:53 | *6:52* | 8:04 | 17 | 7:58 | *8:58* | 10:20 | *2:06* |
| June | 29 | 5:00 | *6:10* | 7:30 | 11 | 8:27 | *9:13* | 10:00 | *3:03* |
| July | 18 | 5:45 | *7:15* | 8:00 | 16 | 7:33 | *8:25* | 9:30 | *1:10* |
| Aug. | 1 | — | *6:47* | — | 1 | — | *7:20* | — | *0:33* |
| Sept. | 6 | 6:42 | *7:13* | 7:20 | 4 | 7:00 | *7:31* | 7:37 | *0:18* |
| All | *75* | 5.00 | *6:34* | 8:04 | 50 | 7:00 | *8:16* | 10:20 | *1:31* |

[a] The difference between the beginning means and the ending means.

fairly constant level, for a long time. In terminating, a chorus simply died away somewhat less abruptly than when starting, but the audiogoniometer showed no substantial shift in the positions of the choristers. Interruptions occurred, of course, but they were few. One interruption happened when two operators were tending the two triangulation stations. At this time a porpoise entered the general area, a not very frequent occurrence at Lemon Bay, and dove sharply directly under the intersection of the sighting rods on the audiogoniometer. Instantly the chorus ceased, but, as the porpoise moved on, the chorus reappeared in less than 30 seconds. Not only did this interruption establish the fact that the proximity of a porpoise was one of the few causes for the cessation of sound by these rather persistent sound-producers, but also confirmed the fact that the bearing readings indicated the true location of the sound-producers.

The distribution of sonic individuals permitted the audiogoniometer in some cases to indicate clearly the position of the chorus. It was then possible to obtain three angular values from both stations: one a maximum value of volume from each station which, at their intersection, established the "center of sound," and one on each side of this from both stations where the sound dropped to inaudibility, which gave an approximation of the extent of the sonic mass. Table 9 and text figures 10 through 13 show various aspects on nights when the sound-producing individuals were in a rather tight group, presumably a simple aggregation.[1]

At other times it was impossible to obtain such information from the instrument, or to fix a bearing, because the maximum was indicated in nearly every direction. This difficulty implies, and in several cases proved, that the two hydrophones were surrounded by a sonic group instead of being outside it, as was clearly the case earlier. However, more frequently the differences were sufficient to show that the fishes were some distance off the end of the dock. Such a case is shown in text figure 14. It was established that an unusually large group of fishes was running

[1] "Aggregation" is used here in the sense of Breder (1959, 1965).

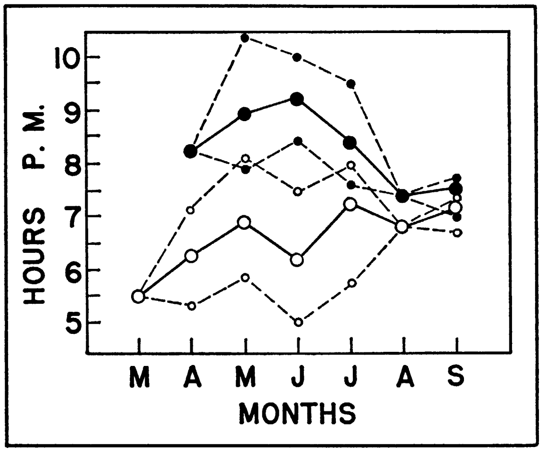
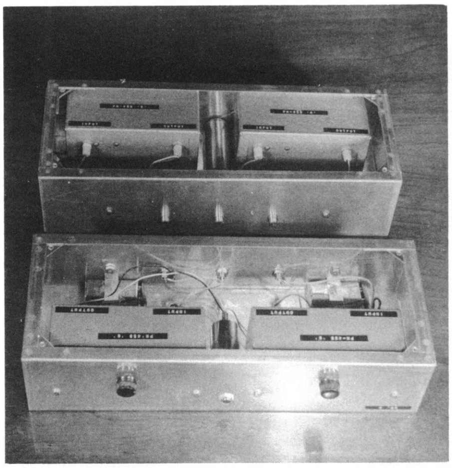



FIG. 9. Variation in the beginning times and the ending times and the full range of differences in *Galeichthys* choruses, by months, including all data, giving mean and earliest and latest beginning times and ending times; based on table 8. Light circles, starting times; solid circles, ending times; large circles of each, means; small circles of each, earliest and latest times.

like a broad ribbon up and down the bay, by a cutting of sections of the "ribbon" with a small boat, with an observer using a single portable hydrophone. When the boat was rowed gently back and forth, from intensity alone rough lines of equal sonic intensity, running lengthwise of the bay, were established. These were at approximately right angles to most of the passages of the boat. Increasing intensity of sound production was observed in the passages from the dock outward, which decreased when the other side of the "ribbon" had been passed (see text fig. 14, A–A represent the near edge of the "ribbon"). These conditions were encountered only in June and July, which cover the third and fourth month of sonic activity. Earlier the choruses were not so well organized or so well defined. Several of the readings taken in May (text fig. 15) indicate that in all but one case the fish were under or behind the end of the dock. At the time these readings were made, it was believed that something was wrong with the instrument. Subsequent results in June and July and a study of the working of the instrument indicate that these readings were substantially correct, subject to considerable displacement caused primarily by the

Air view of Lemon Bay, showing location and general environment of the dock from which these sonic studies were made. A circle with a 200-foot radius has been drawn with its center at the end of the dock. The town of Englewood shows in the lower part of the picture, and the Gulf of Mexico in the upper



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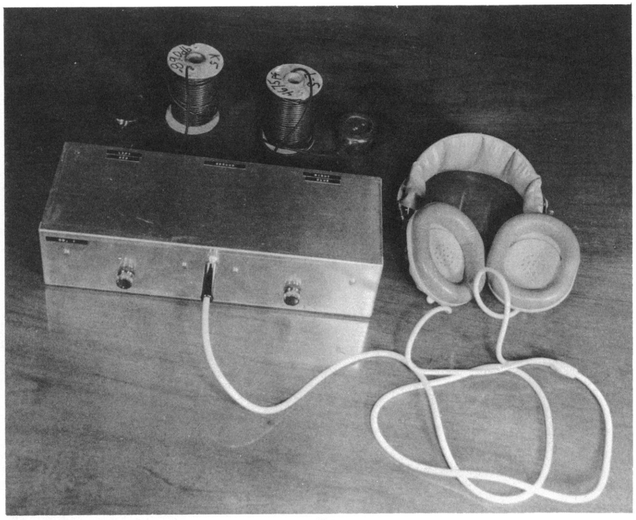

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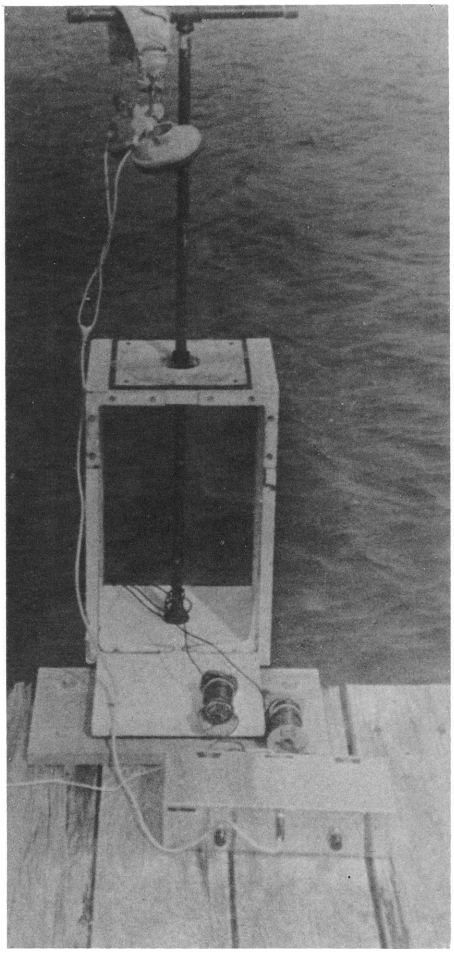

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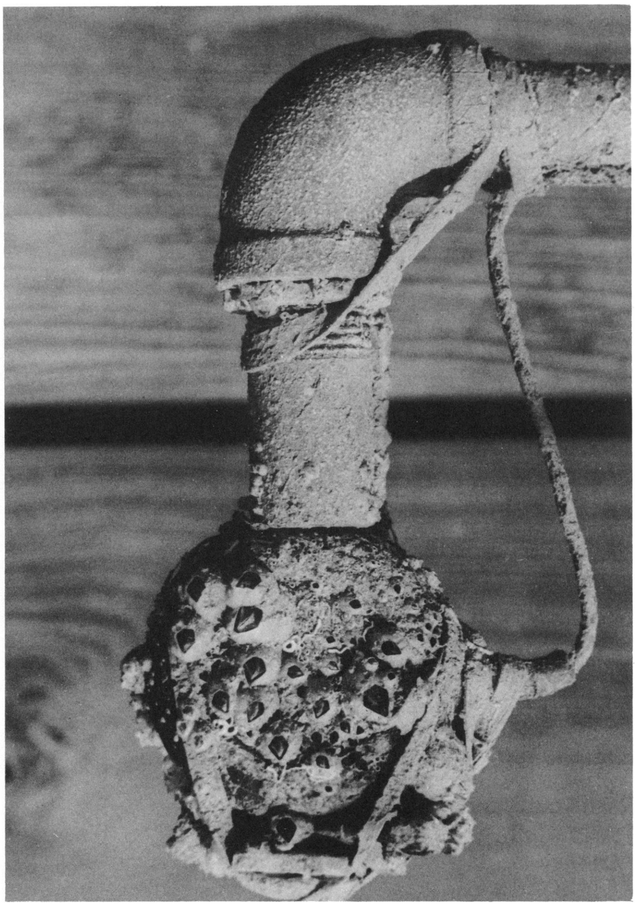

4

Details of the audiogoniometer. 1. Two inverted receivers, showing the front side, with the two volume controls and a binaural jack for the earphones, and the rear side showing jacks for the two hydrophones and, center, the jack for the overboard ground wire. The contained preamplifier boxes are seen in both views and may be removed for separate use with a portable unit with monaural stethoscope earphones, which plug in directly to their subminiature output jack; the hydrophone similarly plugs into the input jack. 2. Complete receiver for one triangulating station. The leads from the two hydrophones plug into this box. 3. One of the triangulating stations (see text). 4. Hydrophone with an overgrowth of barnacles

TABLE 9

AUDIOGONIOMETER READINGS, TAKEN IN 1964
(See text figures 10 through 15 and text for explanations.)

| Date and Hour (P.M.) | L[a] | r[b] | Date and Hour (P.M.) | L | r | Date and Hour (P.M.) | L | r | Date and Hour (P.M.) | L | r |
|---|---|---|---|---|---|---|---|---|---|---|---|
| March 9 | | | May 30 | | | June 2 | | | June 6 | | |
| 7.20 | 81 | 53.6 | 6:49 | | — | 8:15 | 102 | 18.8 | 6:25 | Chorus starts | |
| 7:35 | 89 | 51.5 | 6:55 | | — | 8:30 | 98 | 63.2 | 6:40 | | — |
| 7:45 | 78 | 26.3 | 6:59 | | — | 8:45 | 96 | 31.5 | 6:45 | | — |
| May 25 | | | 7:04 | | — | 9:00 | 100 | 30.4 | 6:50 | | — |
| 7:05 | 92 | 46.0 | 7:09 | | — | 9:15 | 113 | 40.3 | 6:55 | | — |
| 7:20 | 80 | 31.0 | 7:14 | | — | 9:30 | 105 | 23.3 | 7:00 | | — |
| 7:20 | 80 | 31.0 | 7:19 | | — | 9:45 | 87 | 28.3 | 7:15 | | — |
| 7:45 | 81 | 67.9 | 7:24 | | — | 10:00 | | — | 7:20 | | — |
| 8:45 | | — | 7:29 | 240 | 243.9 | June 3 | | | 7:35 | 86 | 12.7 |
| May 26 | | | 7:34 | 264 | 34.9 | 6:20 | No chorus | | 7:45 | | — |
| 7:35 | 295 | 15.3 | 7:39 | 275 | 11.0 | 6:30 | Some creaks | | 8:00 | | — |
| 8:10 | 311 | 18.6 | 7:44 | 285 | 4.2 | 6:35 | 124 | 7.7 | 8:15 | 93 | 31.5 |
| 8:38 | 298 | 20.0 | 7:49 | | — | 6:40 | 93 | 4.5 | 8:40 | 90 | 66.2 |
| 9:10 | 110 | 37.0 | 8:04 | | — | 6.45 | 107 | 6.1 | 8:55 | 120 | 108.1 |
| 9:30 | | — | 9:20 | | — | 6:55 | 108 | 22.1 | 9:10 | | — |
| May 27 | | | May 31 | | | 7:00 | 124 | 50.0 | 9:25 | 115 | 51.3 |
| 6:00 | | — | 6:30 | 299 | 3.6 | 7:05 | 122 | 51.9 | 9:35 | | — |
| 6:06 | | — | 6:58 | | — | 7:10 | 116 | 30.5 | 9:45 | | — |
| 6:14 | 334 | 26.6 | 7:06 | | — | 7:15 | 125 | 40.6 | June 7 | | |
| 6:18 | 350 | 20.3 | 7:13 | | — | 7:20 | 123 | 15.6 | 5.58 | Chorus starts | |
| 6:22 | 344 | 24.1 | 7:35 | 105 | 23.3 | 7:30 | 117 | 28.9 | 6:12 | Chorus ends | |
| 6:30 | 329 | 24.6 | 7:39 | 105 | 19.6 | 7:40 | 122 | 33.6 | 7:00 | | — |
| 6:40 | 306 | 29.1 | 7.48 | 100 | 19.2 | 7:50 | 114 | 64.2 | 7:05 | 67 | 157.7 |
| 6:45 | 291 | 50.4 | 7:56 | 99 | 26.8 | 8:00 | 116 | 41.3 | 7.15 | 90 | 48.5 |
| 6:46 | 291 | 44.3 | 8:07 | 92 | 25.8 | 8:10 | 98 | 24.1 | 7:30 | 90 | 104.2 |
| 6:53 | 308 | 32.6 | 8:18 | 92 | 18.2 | 8:20 | 108 | 40.5 | 7.45 | 102 | 458.4 |
| 7:00 | 315 | 30.3 | 8:43 | 92 | 18.2 | 8:30 | 99 | 16.8 | 8:00 | 121 | 71.7 |
| 7:05 | 329 | 57.8 | 9:00 | 89 | 16.2 | 8:40 | 103 | 11.8 | 8:15 | 116 | 275.9 |
| 7:12 | 323 | 35.5 | 10:20 | | — | 8:50 | 100 | 25.7 | 8:30 | | — |
| 7:55 | 334 | 16.6 | June 1 | | | 9:00 | 104 | 15.3 | 8.45 | | — |
| 8:34 | 327 | 28.8 | 6:37 | | — | 9:10 | 107 | 54.8 | 9:00 | 102 | 204.7 |
| 8:53 | 323 | 32.6 | 6.42 | 310 | 24.2 | 9:20 | 110 | 35.8 | 9:15 | | — |
| 9:20 | | — | 7:03 | 92 | 18.4 | 9.30 | 103 | 87.5 | 9.30 | | — |
| May 29 | | | 7:19 | 92 | 18.4 | 9:40 | 113 | 16.9 | 9:45 | | — |
| 7:30 | | — | 8:00 | 292 | 26.5 | 9:50 | 100 | 30.4 | June 9 | | |
| 7:50 | 326 | 33.8 | 8:27 | 99 | 24.8 | 10:00 | | — | 5.00 | No chorus | |
| 8:03 | 325 | 86.1 | June 2 | | | June 4 | | | 6:30 | | — |
| 8.15 | 290 | 20.6 | 6:20 | | — | 6:40 | No chorus | | 7:05 | 69 | 46.0 |
| 8:40 | 296 | 24.8 | 6:25 | | — | 7.00 | 122 | 13.6 | 7:15 | | — |
| 9:03 | 335 | 24.8 | 6:45 | 92 | 26.9 | 7:10 | 117 | 10.7 | 7:35 | | — |
| 9:20 | | — | 6:50 | 118 | 50.0 | June 5 | | | 8:05 | | — |
| May 30 | | | 6:55 | 118 | 50.0 | 6:40 | Chorus starts | | 8:15 | | — |
| 6:03 | | — | 7:00 | 123 | 31.0 | 7:20 | 108 | 38.0 | 9:35 | | — |
| 6:08 | | — | 7:15 | 129 | 80.8 | 7:30 | 123 | 89.5 | July 5 | | |
| 6:09 | 335 | 30.1 | 7:25 | 103 | 13.6 | 7:40 | | — | 6:00 | No chorus | |
| 6:19 | 7 | 29.1 | 7:35 | 103 | 13.6 | 7:45 | 125 | 100.6 | 7:20 | Chorus starts | |
| 6:24 | 31 | 38.5 | 7:40 | 99 | 7.6 | 7:55 | 96 | 16.3 | 7:43 | 66 | 134.5 |
| 6:29 | 303 | 68.9 | 7:45 | 98 | 6.7 | 8:05 | 82 | 108.9 | 7:50 | 55 | 248.4 |
| 6:34 | 308 | 695.6 | 7:50 | 94 | 10.3 | 8:15 | 91 | 75.9 | 8:00 | 104 | 224.8 |
| 6:39 | | — | 8:05 | 101 | 16.5 | 8:25 | 76 | 31.7 | 8:11 | 113 | 114.0 |
| 6:44 | | — | | | | | | | 8:17 | 136 | 316.3 |

[a] L, the angle of a line from the base line to the center of sound.
[b] $r$, the distance (in feet) to the center of sound.

extreme shallowness of the water near the shoreline. Checking with a mechanical sounding device confirmed the fact that the reliability was much less than in the deeper water off the dock.

A fuller discussion of the details of the audiogoniometric studies on typical nights (text figs. 10–15) is given below.

Text figure 10 shows the behavior of choruses on two successive nights (May 31 and June 1) when this activity was strong. On both nights three values from the two stations (as described above) were obtained. On both, the first readable sounds occurred at 6:30 P.M. and 6:42 P.M., respectively, in positions shoreward of the instrument. Those following were in a rather tight group off the end of the dock in a location that was found to be most favored by the local chorus. The "center of sound," that is, the intersection of the lines passing through the greatest intensity of sound, as heard in the earphones or as indicated by small circles connected by lines, which indicate the time sequence of the observations and the shifting of the centers of intensity. The dates given and starting times indicate the first point established.

The Fish-Finder was operated in this instance from a point on the dock near the left audiogoniometer station, from which a dense group of fishes was found, in general agreement with the triangulations obtained from the audiogoniometer. These data are given in numerical form in table 9. The lines radiating from each station indicate the limits of audibility. The larger and heavier circle (text fig. 10) intersected by two center lines (dot and dash) represents the sonic mean of all centers of intensity. This is frequently, but not necessarily, identical with the geometric center between the two angles, depending on the shape and varying depth of the sonic group. There is every reason to believe that these Fish-Finder readings represent the sonic fishes and that the slight discrepancy between the two instruments is caused by reinforcement behind the nearest fishes to the hydrophones of the audiogoniometer and the fact that the Fish-Finder input is confined to the reflection from the bodies of the nearest fishes. It is also possible that the sonic individuals were concentrated at the near end of a larger body of silent individuals. Tavolga (1962) was unable to find any sexual differences between the male and female sound-producing structures, so there is no evidence, on an anatomical basis, to suggest that the *Galeichthys* choruses were produced by one sex or the other, or by both. Sonic behavioral differences between the sexes are not, of course, thereby ruled out. Because, in most animals, the male is the sound-producer, in association with

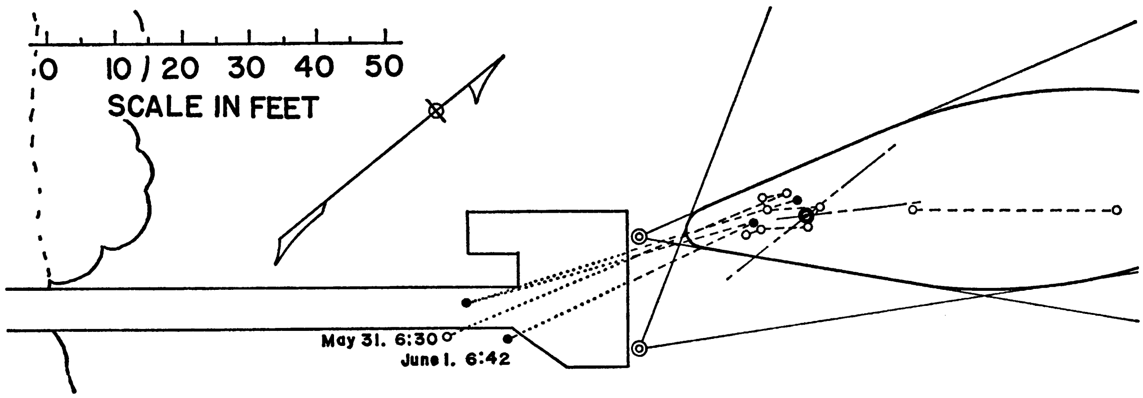


FIG. 10. Plot of the audiogoniometer data on *Galeichthys* choruses of May 31 and June 1, 1964. The two double circles at the end of the dock (which is shown in pl. 18) indicate the positions of the two triangulating stations. Small open circles, sonic centers of May 31; small solid circles, sonic centers of June 1. The two solid lines radiating from the two triangulation stations indicate range, and the dot-and-dash lines between them represent the means. The intersection of the two is marked by a larger and heavier circle, which is the mean of the sonic centers. Times are post meridiem. See table 9 and the text for further explanation.

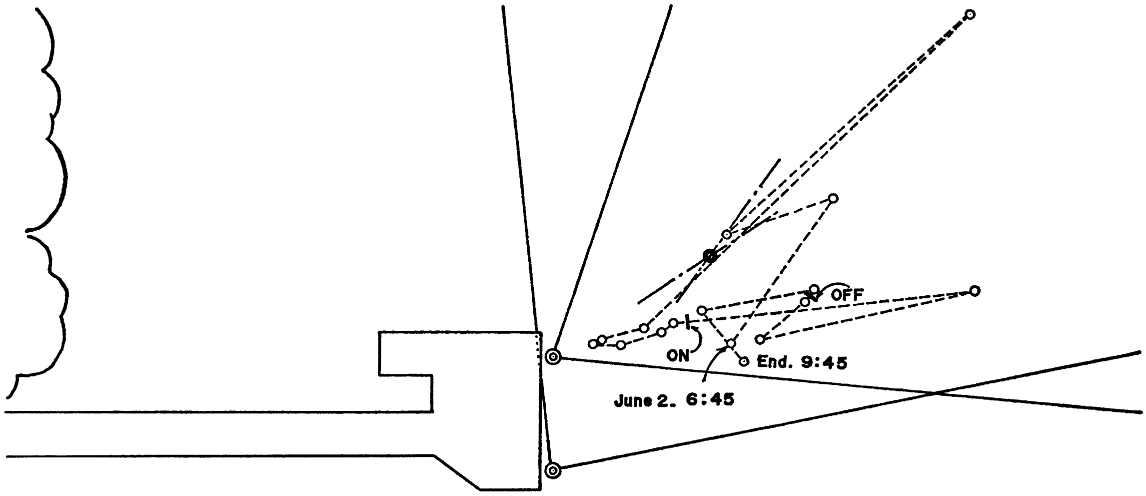


FIG. 11. Plot of *Galeichthys* choruses of June 2, 1964. Scale as in text figure 10; time is post meridiem. See text figure 10, table 9, and the text for further information.

reproduction, it would not be surprising if the females, at this season, were silent. A similar situation is found in *Opsanus*.

The first of the two evenings mentioned above was the occasion of the porpoise approach, as noted, which rather neatly established the validity of these triangulations.

The apparent outline of the near end of the group of fishes is indicated by the curved semi-enclosure. There is no way, of course, of delimiting the seaward extent of the group by a pair of triangulating stations, especially when they are rather close together. Table 9 indicates that the positions in text figure 10 were interspersed by a few indeterminate readings. The reasons for these indeterminate readings are discussed below.

Text figure 11 shows the conditions found on June 2. That evening all readings were unambiguous triangulations, except for the first two which were simply too faint and uncertain to yield a proper bearing. On these three consecutive evenings the fish displayed very similar and consistent behavior. From previous experience we learned that a small rowboat over a chorus did not disrupt it, nor did slapping the oars on the water. It was clear that an active porpoise could, and did, stop the chorus, but a submerged light suspended from a boat, turned on and off as it was towed through the chorus, had no evident effect either on sound production or on movements of the sonic center. Apparently, from this evidence, phenomena such as boats, un-

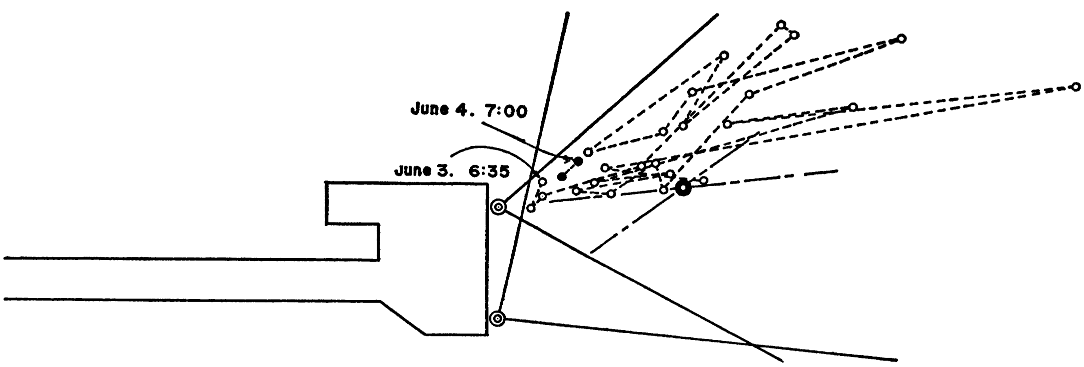


FIG. 12. Plot of *Galeichthys* choruses of June 3 and 4, 1964. Scale as in text figure 10; time is post meridiem. See text figure 10, table 9, and the text for further explanation.

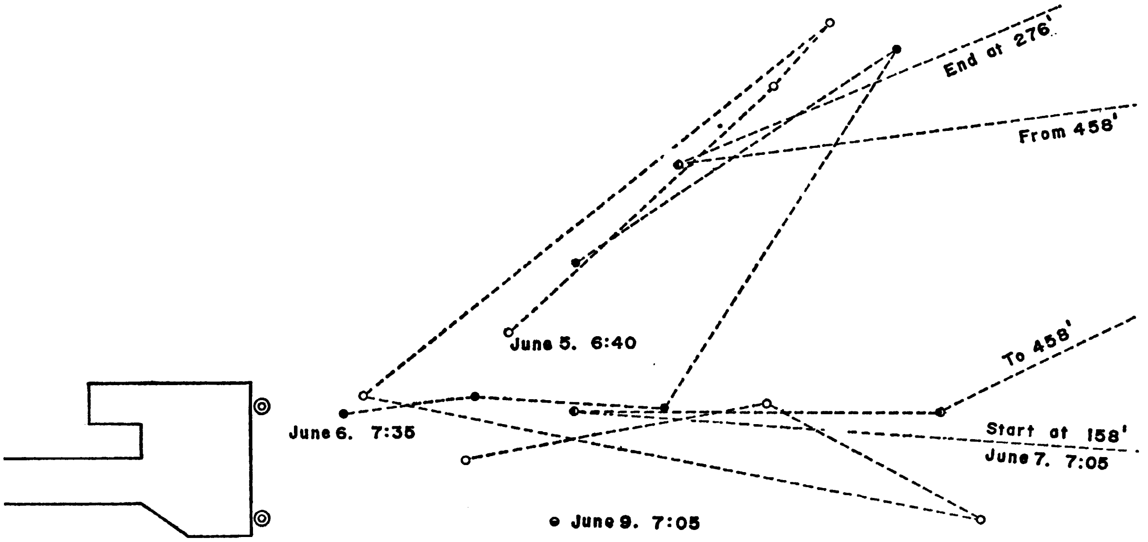


FIG. 13. Plot of *Galeichthys* choruses of June 5, 6, 7, and 9, 1964. Open circles, June 5; solid circles, June 6; circles with left half solid, June 7; circles with lower half solid, June 9. Scale as in text figure 10; time is post meridiem. See text figure 10, table 9, and the text for further explanation.

usual sounds, or lights, which had not been meaningful earlier to the sound-producers, were simply ignored.

The first date shown in text figure 12 had a long run, with all readings determinate except the first and last. On June 4 only two triangulations were possible because of a violent thunderstorm. That this storm did not interrupt the chorus was indicated by an undercover speaker. Both storm and chorus had ended by 9:50 P.M.

Text figure 13 shows that conditions had distinctly changed, so that satisfactory readings from June 5 through June 9 became exceedingly difficult to obtain, although the fishes were still centered in the same general area, but were more spread out. Also, many of the readings indicated positions impossibly far off; they were much too loud for the distances indicated. As tested by an under-water sound-producer, described in the Appendix, any reading substantially more than 100 feet from the hydrophones was too faint for the fixing of an unequivocal position. It is thought that this difficulty had to do with some change in the under-water acoustical conditions. Although the water in Lemon Bay was too shallow to be much influenced by many of the conditions that are found in deeper water, as discussed by Albers (1960), the very shallowness of the water presented others, especially those involving patches of *Thallasia* and mud. Repeated reflection between surface and bottom, the resultant much longer path traveled by most of the signal, and absorption by the soft bottom, as well as sharp temperature gradients in the very shallow water near the shoreline, are apparently the chief interfering environmental features. Tests made with the sound-producer and a frequency generator showed that the output could be completely quenched by placing them from 25 to 50 feet shoreward from the audiogoniometer, depending on the stage of the tide. At much higher frequencies than those produced by the fishes, the frequency generator penetrated much farther, as would be expected. Although the sound-producer was still audible at 250 feet seaward from the listening post and over much deeper water, the sound was too faint for its position to be easily established, mostly because of the small base (16 feet) and the poor directionality of the frequencies necessarily employed. It is for these reasons that chorus sounds of the usual volume, which the audiogoniometer showed emanated from distances considerably over 100 feet, were understood to be referable to the vagaries of under-water sound propagation.

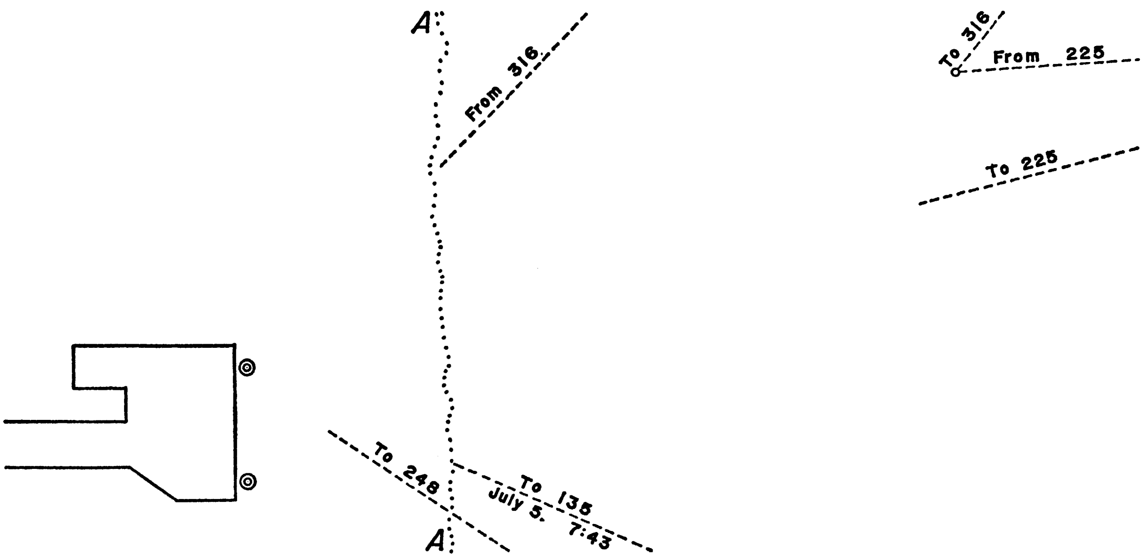


FIG. 14. Plot of *Galeichthys* choruses of July 5, 1964. The dotted line marked A–A represents the beginning of increased sound intensity, moving from left to right. Scale as in text figure 10; time is post meridiem. See text figure 10, table 9, and the text for further explanation.

The data obtained on June 5 and 6 (text fig. 13), although showing greater distances than any shown in the previous plots, were all within the bounds of credibility. The data from June 7 showed reasonable positions within the range of the previous evenings, but in addition indicated several as being produced at much greater distances, up to 458 feet.

On June 8 there was no chorus, and on June 9 only one reasonable reading could be obtained, because all other attempts resulted in impossible angular values. This situation was related to one discussed above, and probably also to an increase in the number and a spreading of the fishes over a wider area, sufficiently to defeat the audiogoniometer

A more extreme case of this kind of difficulty is shown in text figure 14, based on data of July 5, which evidently represents a condition in which fish were all about, possibly in small clusters or fairly evenly distributed. The instrument used, naturally, could not readily distinguish which. There was a high level of sound intensity, although not one reasonable reading could be made. Because it had been adequately established that the water-borne hydrophone checked well enough for all practical purposes with determinations of the audiogoniometer, on an intensity basis, the positions shown in text figure 14 were established by boat. Its position was determined by simple optical triangulation through the sighting tubes of the audiogoniometer. These spots of high volume suggest strongly that the fish were indeed in clusters. As tested by the water-borne hydrophone, there was a large general increase in the sonic level about 30 feet from the end of the dock, which indicated that the sonic individuals were staying in the slightly deeper water beyond that line. The deepest spot, within the area bounded by the 100-foot line, at the stage of the tide when these observations were made, was 5 feet 4 inches. This is identical with the position of the loudest choruses indicated in the earlier plots. The water depth at the left-hand listening station at this time was 3 feet 9 inches. When the boat was taken more than 300 feet from the dock the sound fell off, but when the boat was rowed up and down about halfway between these limits, 135 feet from the dock, there was no such diminution of sound, which indicated that these fishes were in a band parallel to the shoreline, about 270 feet wide and at least 1000 feet in length and probably much more. It was not on our agenda to plot the positions of sonic fish for great distance.

The above series of observations, beginning

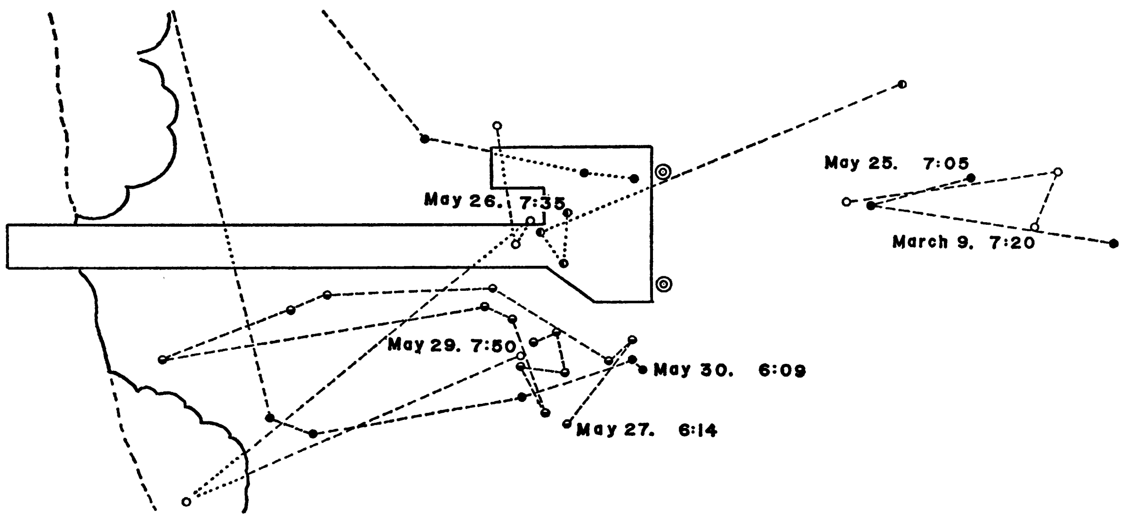


FIG. 15. Plot of *Galeichthys* choruses of March 9, May 25, 26, 27, 29, and 30, 1964. Open circles, March 9; solid circles, May 25; circles with left half solid, May 26; circles with lower half solid, May 27; open circles on the extreme right, May 29; solid circles on the extreme right, May 30. Scale as in text figure 10; time is post meridiem. See text figure 10, table 9, and the text for further explanation.

in late May and extending to early July, cover the greatest extent of choral activity. Early spring observations are discussed here, because these beginning choruses are rather confusing, and it was thought that it would be easier to follow those that are first described, which were typical full choruses. The conditions from March 9 through May 30 are indicated in text figure 15. The first two, on March 9 and May 25, are virtually identical and agree in position with the unambiguous dates discussed above. These choruses were short and of uncertain occurrence. Others between these two dates were too similar to be worth repeating here. After May 25 the activity changed, and different behavior had evidently started. By May 26 the fishes moved to positions partly under the dock, and the following night they were mostly south of the dock, with what appeared to be an excursion to the shoreline. These three values, separated from the main body of observations and culminating in very shallow water, are certainly an artifact caused by under-water peculiarities in sound transmission. The water at the extreme shoreward position was very shallow, about 8 inches or less, and no individuals of *Galeichthys* were there, in water that would scarcely float them. Also, it had been shown, as noted above, that the audiogoniometer could not detect sounds of such frequencies at that distance in these conditions. The same prevailed on the two following nights, May 29 and 30, in which two readings actually placed the fish on land. On May 31 and June 1 (text fig. 10), most of the positions were under the dock or east of it.

Although many data were obtained by these means at both the beginning of the choral season and at the summer decline, rather baffling auditory displacements appear, based partly on the changing deployment of the fishes and partly on characteristics of the under-water propagation of sound.

Differences in the stage of the tides seem to have little influence on these choruses other than to move them offshore a little when the tides are sufficiently low. Choruses have occurred at high tide and low tide and in both falling and rising water in about the proportion one would expect if there was no tidal influence, in terms of water depth and direction of horizontal flow.

From these varied data on chorus formation, a rather good case can be made out for considering the *Galeichthys* chorus as a sonic manifestation of some reproductive function, perhaps not unlike that of anuran choruses. The seasonal trends displayed and the vigor of the performances, taken together with various other non-sonic details, such as the state of the gonads, the fleshy folds on the female pelvics, and the sizes of young fish, make it difficult, in so lightly populated a spot, to doubt the sexual nature of the "percolator" chorus. Specific details, not of a sonic nature, are given in the section on trapping.

### *Opsanus beta* (Goode and Bean)

This species is responsible for at least two types of sound: a deep grunt and a more musical sound that has been likened to a "boat-whistle." (See Tavolga, 1958a and 1960, and Fish, 1964, for a full description of these sounds, with sonograms, and Gray and Winn, 1961, for a brief history of the use of the term "boat-whistle" for these sounds.) The "boat-whistle" is probably the best known fish sound, along our Atlantic and Gulf coasts at least, because, long before the advent of hydrophones, this sound, which is feebly audible without any electronic equipment, principally on docks, had been identified with the producer by some now unknown naturalist.

Gray and Winn (1961) tried to identify the functions of the two types of sound produced by these fishes, in the Atlantic coast form, *O. tau* (Linnaeus). They concluded that the "grunt" was a response to intrusion by other fishes or invertebrates and that the "boat-whistle," produced only by the males, was an attractant for females. Data obtained on the Gulf form does not dispute such a conclusion. As is the case in *Galeichthys*, both males and females have the necessary anatomical structures (see Tavolga, 1858b, and Gray and Winn, 1961).

Whereas each of the recognized species of *Opsanus* of the western North Atlantic has distinctive sounds (see Tavolga, 1958a; Fish and Mowbray, 1959; and Fish, 1964), each has two sounds that can be described in terms that are used herein for *O. beta*. The "grunt" sounds were heard in Lemon Bay only erratically, which in itself suggests agreement with the views of Gray and Winn. There is, furthermore, considerable uncertainty as to the true origin of all "grunt"-like sounds in Lemon Bay, for it is not implausible that several of the numerous sciaenids present may make sounds that are sufficiently similar to be difficult or impossible to distinguish with certainty.

The "boat-whistle," a fully distinguishable sound, waxes and wanes in an annual cycle. This fact alone suggests that this sound may indeed be associated with reproduction and could be used in support of the views of Gray and Winn. Except for the year 1965, the earliest it was heard was March 5, 1961, and the latest was in October, 1963. The year 1965 was exceptionally warm, and everything on land and in water was advanced well beyond the development in the other years of this survey. Individuals of *Opsanus* called as early as February 17, 1965. During May and September their sound was heard every day that observations were made. There was a much sharper decline in June and July than was shown by *Galeichthys* (see table 10 and text fig. 16).

The range in temperature in which the son-

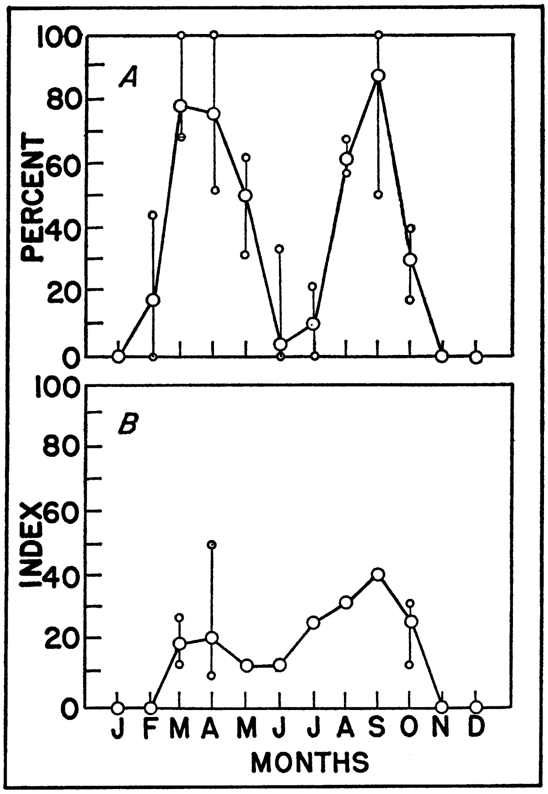


FIG. 16. Boat-whistles of *Opsanus* by months, in terms of (A) days of occurrence and (B) in intensity, percentage, and index values, respectively; based on table 10.

TABLE 10

BOAT-WHISTLES OF *Opsanus* IN TERMS OF THE NUMBER OF DAYS PER MONTH WITH SOUNDS (IN ROMAN) AND THE PERCENTAGE OF OBSERVATIONS PER MONTH (IN ITALICS), AS ESTIMATES OF INTENSITY (IN ROMAN) AND AS AN INDEX VALUE (IN ITALICS)

(The percentage figures in the upper part were derived by dividing the number of days with sounds by the number of observations given in table 1. The index values of the lower part were derived by dividing the intensity estimates by four times the number of days with sounds. See text. This table corresponds to tables 3 and 14.)

| Month | 1961 | | 1962 | | 1963 | | 1964 | | 1965 | | All | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. | — | | — | | 0 | *0* | 0 | *0* | 11 | *44* | 11 | *17* |
| March | 6 | *100* | — | | — | | 11 | *69* | 26 | *83* | 41 | *79* |
| April | 7 | *100* | 4 | *100* | — | | 8 | *100* | 13 | *51* | 32 | *76* |
| May | — | | 10 | *31* | — | | 10 | *62* | 12 | *44* | 28 | *50* |
| June | — | | 1 | *33* | 0 | *0* | 2 | *7* | 0 | *0* | 3 | *4* |
| July | — | | — | | 6 | *21* | 0 | *0* | 0 | *0* | 6 | *10* |
| Aug. | — | | — | | 18 | *58* | — | | 21 | *68* | 39 | *63* |
| Sept. | — | | — | | 20 | *100* | — | | 3 | *50* | 20 | *88* |
| Oct. | 1 | *17* | — | | 2 | *40* | 0 | *0* | — | | 3 | *30* |
| All | 14 | *74* | 15 | *39* | 46 | *36* | 30 | *22* | 86 | *50* | 159 | *32* |

| Intensity Month | 1961 | | | 1962 | | | 1963 | | | 1964 | | | All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S[a] | I[b] | % | S | I | % | S | I | % | S | I | % | S | I | % |
| March | 6 | 6.5 | *27* | — | — | — | — | — | — | 11 | 5.5 | *12* | 17 | 12.0 | *18* |
| April | 6 | 4.5 | *14* | 4 | 8.0 | *50* | — | — | — | 8 | 3.0 | *9* | 19 | 15.0 | *20* |
| May | — | — | — | 6 | 3.0 | *12* | — | — | — | 10 | 5.0 | *12* | 16 | 8.0 | *12* |
| June | — | — | — | 1 | 0.5 | *12* | — | — | — | 2 | 1.0 | *12* | 3 | 1.5 | *12* |
| July | — | — | — | — | — | — | 7 | 7.0 | *25* | — | — | — | 7 | 7.0 | *25* |
| Aug. | — | — | — | — | — | — | 18 | 22.5 | *31* | — | — | — | 18 | 22.5 | *31* |
| Sept. | — | — | — | — | — | — | 20 | 32.0 | *40* | — | — | — | 20 | 32.0 | *40* |
| Oct. | 1 | 0.5 | *12* | — | — | — | 2 | 2.5 | *31* | — | — | — | 3 | 3.0 | *25* |
| All | 13 | 11.5 | *20* | 11 | 11.5 | *26* | 43 | 64.0 | *37* | 31 | 14.5 | *12* | 98 | 100 | *26* |

[a] S, number of sounds.
[b] I, intensity.

ic activity took place extended from 63° F. to 90° F., the lower reading exceeding that of *Galeichthys* by 11° F., but the upper by only 1° F. Thus, obviously, *Opsanus* has a somewhat greater thermal range for sonic activity than does *Galeichthys*. Actually the upper limits of range may be identical, because of limitations in the instruments, but on the low side the extent of the activity of *Opsanus* is notably greater. The difference may be associated with the respective ancestry of the two species. *Opsanus* is of temperate and arctic affinities, whereas *Galeichthys* has distinctly tropical affinities.

In *Opsanus* the early spring sonic attempts seem uncertain, and often the second half of the "boat-whistle" is omitted. It is more difficult to define a similar difference between starting and mature *Galeichthys* choruses, because of the very considerable number of sonic individuals present. It seems, however, that there is a rather similar uncertainty among the starting *Galeichthys* choruses.

If these sounds are truly associated with reproduction, more or less similar to frog calls, this cessation would, as in the case of *Galeichthys*, indicate a spring and fall breeding period, but the spring period is much more sharply defined, which is in keeping with the idea that *Opsanus* is a fairly recent or secondary invader of warm waters, but one that normally breeds in summer, as does *O. tau* in the New York area. Fish (1964) reported that the peak of these sounds in Rhode Island begins in late May and ends in early July, which coincides with the height of spawning activity in our area as indicated by the sound production. She noted, moreover, that infrequent sounds have been heard as late as the end of September. When the differences in latitude and location are considered, such an agreement between the two localities is remarkable. Breder (1941) thought that the spawning season ended for *O. beta* by the end of March. Although the locality where those studies were made, Pine Island Sound, is only 18 miles from the Lemon Bay site, such an opinion may be correct because there the water is much more open, with a good circulation of Gulf water, which prevents both the low temperatures in winter and the extremely high summer temperatures found in Lemon Bay. Thus it is possible that the Pine Island individuals of *Opsanus* may have a single peak of both sonic and breeding activity, completing most of it, whereas the Lemon Bay fishes start later because of the colder winter waters and are then stopped by the summer heat, only to begin again after the highest temperatures have passed.

In Lemon Bay very small individuals of *O. beta* have been collected as late as December 5, 1965. Thus it may be impossible to maintain the idea that *Opsanus* produces "boat-whistles" well out of its breeding season. This is evidently protracted in a much-diminished form, because the small examples noted could not have been off the nest for more than a month (probably much less). That our latest date for hearing "boat-whistles" was October 9 does not disagree with the above statements, for the sounds evidently cease when a male has a full complement of eggs in his nest, as was indicated by Gray and Winn (1961). These young fishes were obviously moving about, for they were caught in an especially designed plastic trap which permits the entry of only very small fishes (Breder, 1960; and the section below on trapping).

One must be mindful, however, of the fact that the bimodal curve of sound production could be expected in Lemon Bay even if it had nothing whatever to do with reproduction. If it pertained to other features of the lives of these fishes, it could equally well be that sound production of this sort was simply undertaken, below and above two critical temperatures, irrespective of the nature of the ecological connections of the sounds.

The data of table 10 and text figure 16 show the same general characteristics as those displayed by *Galeichthys* (table 3 and text fig. 3), but with some notable differences. There is an abrupt rise of sound production in March, so that sound production was present every day in some years, followed by a more gradual decrease to June, after which there was an almost equivalent rise to 100 per cent in September. This was followed by a rapid drop as the winter season approached (see text fig. 16). The intensity data of table 10 and text figure 16 follow the same general course, but are much more moderate, as would be expected. Sonic intensity in reference to moon phases is not given in either tables or figures, because it follows the sonic frequency data closely and adds nothing. Text figures 4 and 17 show the extent of this similarity and illustrate why these data were omitted elsewhere.

*Opsanus* begins sound production, typically, about a month earlier than *Galeichthys;* an exception was the warm year of 1965 when both began in February. The peak is reached by *Opsanus* in March, whereas *Galeichthys* does not reach its peak until May. The intensity agrees well these times. In the fall the second peak for frequency and intensity in both species is reached in September, and in both species sound production ceases in October. Neither again produces such sounds until the following spring. Gill (1907) gave the spawning season of the Gulf form as April

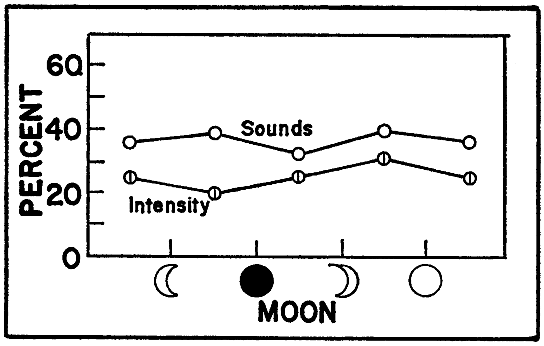


FIG. 17. Boat-whistles of *Opsanus* by moon phases in terms of percentage; based on table 11.

TABLE 11

BOAT-WHISTLES OF *Opsanus* BY MOON PHASES, IN TERMS OF THE NUMBER OF OBSERVATIONS, THE NUMBER OF SOUNDS, AND PERCENTAGE, EACH IN THE PHASE INDICATED, WHICH IS THE LAST DAY OF THE RESPECTIVE QUARTER

(This table corresponds to tables 4 and 15.)

| Month and Year | To Last Quarter | | | To New Moon | | | To First Quarter | | | To Full Moon | | | All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O[a] | S[b] | % | O | S | % | O | S | % | O | S | % | O | S | % |
| Feb. | | | | | | | | | | | | | | | |
| 1963 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 |
| 1964 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 7 | 0 | 0 | 29 | 0 | 0 |
| 1965 | 8 | 8 | 100 | 6 | 3 | 50 | 8 | 0 | 0 | 3 | 0 | 0 | 25 | 11 | 44 |
| | | | *47* | | | *23* | | | *0* | | | *0* | *56* | *11* | *20* |
| March | | | | | | | | | | | | | | | |
| 1961 | 2 | 2 | 100 | — | — | — | 2 | 2 | 100 | 2 | 2 | 100 | 6 | 6 | 100 |
| 1964 | 6 | 0 | 0 | 6 | 6 | 100 | 3 | 3 | 100 | 1 | 1 | 100 | 16 | 10 | 62 |
| 1965 | 8 | 7 | 87 | 6 | 6 | 100 | 8 | 6 | 75 | 8 | 6 | 75 | 30 | 25 | 83 |
| | | | *56* | | | *100* | | | *85* | | | *82* | *52* | *41* | *79* |
| April | | | | | | | | | | | | | | | |
| 1961 | 2 | 1 | 50 | 2 | 2 | 100 | 1 | 1 | 100 | 2 | 2 | 100 | 7 | 6 | 86 |
| 1962 | 1 | 0 | 0 | 1 | 1 | 100 | 1 | 1 | 100 | 1 | 1 | 100 | 4 | 3 | 75 |
| 1964 | 5 | 2 | 40 | 1 | 1 | 100 | 3 | 2 | 67 | 3 | 3 | 100 | 12 | 8 | 67 |
| 1965 | 6 | 6 | 100 | 5 | 5 | 100 | 7 | 6 | 86 | 6 | 2 | 33 | 24 | 19 | 79 |
| | | | *64* | | | *100* | | | *83* | | | *67* | *47* | *36* | *77* |
| May | | | | | | | | | | | | | | | |
| 1962 | 7 | 2 | 29 | 5 | 1 | 20 | 1 | 1 | 100 | 2 | 2 | 100 | 15 | 6 | 40 |
| 1964 | 8 | 2 | 25 | — | — | — | — | — | — | 8 | 8 | 100 | 16 | 10 | 62 |
| 1965 | 7 | 3 | 43 | 7 | 1 | 14 | 7 | 4 | 59 | 6 | 4 | 67 | 27 | 12 | 44 |
| | | | *32* | | | *15* | | | *62* | | | *87* | *58* | *28* | *48* |
| June | | | | | | | | | | | | | | | |
| 1962 | — | — | — | 2 | 1 | 50 | 1 | 0 | 0 | — | — | — | 3 | 1 | 33 |
| 1963 | 2 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 2 | 0 | 0 | 15 | 0 | 0 |
| 1964 | 9 | 0 | 0 | 6 | 2 | 33 | 7 | 0 | 0 | 8 | 0 | 0 | 30 | 2 | 7 |
| 1965 | 8 | 0 | 0 | 2 | 0 | 0 | 6 | 0 | 0 | 7 | 0 | 0 | 23 | 0 | 0 |
| | | | *0* | | | *20* | | | *0* | | | *0* | *71* | *3* | *4* |
| July | | | | | | | | | | | | | | | |
| 1963 | 8 | 0 | 0 | 5 | 0 | 0 | 7 | 3 | 43 | 9 | 1 | 11 | 29 | 4 | 14 |
| 1964 | 9 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 31 | 0 | 0 |
| 1965 | 8 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 30 | 0 | 0 |
| | | | *0* | | | *0* | | | *14* | | | *0* | *90* | *4* | *4* |
| Aug. | | | | | | | | | | | | | | | |
| 1963 | 7 | 3 | 43 | 7 | 0 | 0 | 8 | 7 | 87 | 9 | 8 | 89 | 31 | 18 | 58 |
| 1965 | 7 | 7 | 100 | 7 | 6 | 87 | 8 | 0 | 0 | 9 | 8 | 89 | 31 | 21 | 68 |
| | | | *71* | | | *43* | | | *44* | | | *89* | *62* | *39* | *63* |
| Sept. | | | | | | | | | | | | | | | |
| 1963 | 7 | 7 | 100 | 7 | 7 | 100 | 1 | 1 | 100 | 5 | 2 | 40 | 20 | 17 | 85 |
| 1965 | — | — | — | — | — | — | 1 | 1 | 100 | 5 | 2 | 40 | 6 | 3 | 50 |
| | | | *100* | | | *100* | | | *100* | | | *40* | *26* | *20* | *77* |
| Oct. | | | | | | | | | | | | | | | |
| 1961 | 1 | 0 | 0 | 2 | 1 | 50 | 1 | 0 | 0 | 2 | 0 | 0 | 6 | 1 | 17 |
| 1963 | 2 | 1 | 50 | 1 | 1 | 100 | — | — | — | 1 | 0 | 0 | 4 | 2 | 50 |
| 1964 | 5 | 0 | 0 | 8 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 0 | 24 | 0 | 0 |
| | | | *12* | | | *18* | | | *0* | | | *0* | *37* | *3* | *8* |
| All | 142 | 51 | *36* | 112 | 44 | *39* | 115 | 38 | *33* | 130 | 52 | *40* | 499 | 185 | *37* |

[a] O, number of observations.
[b] S, number of sounds.

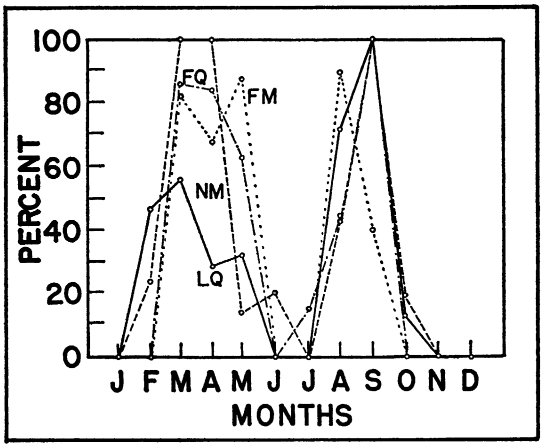


FIG. 18. Comparison of boat-whistles of *Opsanus* in percentage throughout the season of sound production; based on table 11.

*Symbols:* FM, full moon; FQ, first quarter; LQ, last quarter; NM, new moon.

or May, a period that is included in our observations for this area.

The volume of sound and its intensity are so evenly spread between moon phases that there would appear to be no clear correlation (table 11 and text fig. 17). This would seem reasonable, especially since the "boat-whistle" is to be heard at all hours of both day and night. The sounds are produced, however, in much greater quantity at the time that the *Galeichthys* choruses occur.

Text figure 18, based on table 11, indicates, in a manner analogous to the treatment of *Galeichthys* choruses in text figure 5 and table 4, that the basic differences in the sound production of these two forms are to some extent influenced by lunar phases. In *Opsanus* the extremes of low and high production by months exceed those of *Galeichthys*.

It was often not difficult to recognize individual sound-producers when few near the dockside were sonic. Recognition was possible when as few as three fish were sonic and situated at sufficiently different distances from the hydrophone to give them distinctive differences in volume, in addition to the quirks of individual behavior. It was not easy to break these down into an intelligible form suitable for analysis and comparison. Unlike the individuals of *Galeichthys* in Lemon Bay, the choruses of which are restricted to the early evening, *Opsanus* produces its "boat-whistle" irregularly, virtually around the clock, which gives it the semblance of being erratic. This seemingly unpredictable condition is believed to be associated with the basic differences in general behavior between the active and aggregating *Galeichthys* and the sedentary *Opsanus* (see Isaacson, 1964). Similarly, table 12 and text figure 19 show little if any correlation to weather conditions. These conditions are mentioned here simply to indicate reasons for the different manner in which the sound production in the two forms were handled, the details of which follow.

During periods when *Opsanus* was in "full cry," the intervals between sounds produced by a single individual were measured to determine if they showed any consistent relation to environmental features or such other possible influences as fatigue of the producer. The intervals of time between successive "boat-whistles" varied widely. When sounds occurred only after long stretches of silence, those cases that exceeded about seven minutes were no longer recognizable as a related series of sounds. Sounds that occurred at much shorter intervals, to a human observer, seemed to have a distinctly regular and rhythmic nature, in some cases more than a rate of 15 sounds per minute. The correlations between these spacing of sounds are not readily understood, as the fish are evidently responding to many different influences simultaneously. All rates of "call" above one per minute were found to occur at temperatures above 76° F. However, these basic data are difficult to follow in this form. Much clearer

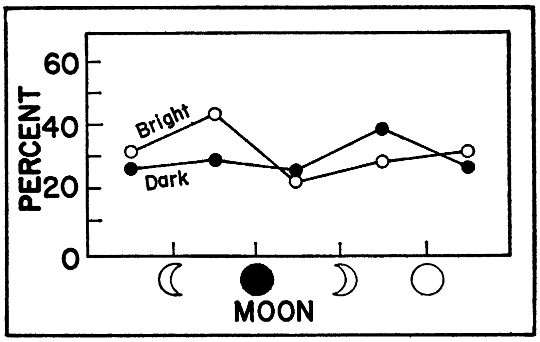


FIG. 19. Boat-whistles of *Opsanus* by moon phases on bright and dark nights; based on table 12.

## TABLE 12

BOAT-WHISTLES OF *Opsanus* BY MOON PHASES ON BRIGHT AND DARK NIGHTS IN TERMS OF THE NUMBER OF OBSERVATIONS, THE NUMBER OF SOUNDS, AND PERCENTAGES, EACH IN THE PHASE INDICATED, WHICH IS THE LAST DAY OF THE RESPECTIVE QUARTER

(This table corresponds to tables 5 and 16.)

| Month and Year | Bright Nights: To Last Quarter | | | To New Moon | | | To First Quarter | | | To Full Moon | | | All | | | Dark Nights: To Last Quarter | | | To New Moon | | | To First Quarter | | | To Full Moon | | | All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O[a] | S[b] | % | O | S | % | O | S | % | O | S | % | O | S | % | O | S | % | O | S | % | O | S | % | O | S | % | O | S | % |
| Feb. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 3 | 0 | 0 | 7 | 0 | 0 | 6 | 0 | 0 | 6 | 0 | 0 | 22 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 7 | 0 | 0 |
| 1965 | 5 | 0 | 0 | 4 | 0 | 0 | 6 | 0 | 0 | 3 | 2 | 67 | 18 | 2 | 11 | 3 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | — | — | — | 7 | 0 | 0 |
| | | | | | | | | | | | | | *42* | *2* | *5* | | | | | | | | | | | | | *14* | *0* | *0* |
| March | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1961 | 2 | 2 | 100 | — | — | — | 2 | 2 | 100 | 2 | 2 | 100 | 6 | 6 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 4 | 0 | 0 | 6 | 6 | 100 | 3 | 3 | 100 | 1 | 1 | 100 | 14 | 10 | 71 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 |
| 1965 | 4 | 4 | 100 | 6 | 6 | 100 | 2 | 2 | 100 | 4 | 4 | 100 | 16 | 16 | 100 | 5 | 5 | 100 | 4 | 4 | 100 | 4 | 1 | 25 | 1 | 0 | 0 | 14 | 10 | 71 |
| | | | | | | | | | | | | | *36* | *32* | *89* | | | | | | | | | | | | | *16* | *10* | *62* |
| April | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1961 | — | — | — | 1 | 1 | 100 | 1 | 1 | 100 | — | — | — | 2 | 2 | 100 | 2 | 1 | 50 | 1 | 1 | 100 | — | — | — | 2 | 2 | 100 | 5 | 4 | 80 |
| 1962 | 1 | 0 | 0 | — | — | — | 1 | 1 | 100 | 1 | 1 | 100 | 3 | 2 | 67 | — | — | — | 1 | 1 | 100 | — | — | — | — | — | — | 1 | 1 | 100 |
| 1964 | 5 | 2 | 40 | 1 | 1 | 100 | 2 | 1 | 100 | — | — | — | 8 | 4 | 50 | — | — | — | 1 | 1 | 100 | — | — | — | 3 | 3 | 100 | 4 | 4 | 100 |
| 1965 | 5 | 5 | 100 | 3 | 2 | 67 | 6 | 2 | 33 | 6 | 1 | 17 | 20 | 10 | 50 | 1 | 1 | 100 | 2 | 2 | 100 | 1 | 0 | 0 | — | — | — | 4 | 3 | 75 |
| | | | | | | | | | | | | | *33* | *18* | *53* | | | | | | | | | | | | | *14* | *12* | *86* |
| May | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1962 | 4 | 1 | 25 | 1 | 1 | 100 | 1 | 1 | 100 | 2 | 2 | 100 | 8 | 5 | 62 | 3 | 1 | 33 | 4 | 0 | 0 | — | — | — | — | — | — | 7 | 1 | 14 |
| 1964 | 7 | 0 | 0 | — | — | — | — | — | — | 4 | 4 | 100 | 11 | 4 | 36 | 1 | 0 | 0 | — | — | — | — | — | — | 4 | 4 | 100 | 5 | 4 | 80 |
| 1965 | 6 | 3 | 50 | 4 | 1 | 25 | 8 | 4 | 50 | 6 | 4 | 67 | 24 | 12 | 50 | — | — | — | 3 | 0 | 0 | — | — | — | — | — | — | 3 | 0 | 0 |
| | | | | | | | | | | | | | *43* | *21* | *49* | | | | | | | | | | | | | *15* | *5* | *40* |
| June | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1962 | — | — | — | 2 | 1 | 50 | — | — | — | — | — | — | 2 | 1 | 50 | — | — | — | — | — | — | 1 | 0 | 0 | — | — | — | 1 | 0 | 0 |
| 1963 | 3 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 12 | 0 | 0 | — | — | — | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 |
| 1964 | 7 | 0 | 0 | 5 | 2 | 0 | 6 | 0 | 0 | 5 | 0 | 0 | 23 | 2 | 9 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 |
| 1965 | 8 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 7 | 0 | 0 | 20 | 0 | 0 | — | — | — | — | — | — | 3 | 0 | 0 | — | — | — | 3 | 0 | 0 |
| | | | | | | | | | | | | | *57* | *3* | *4* | | | | | | | | | | | | | *14* | *0* | *0* |
| July | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 8 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 9 | 2 | 22 | 25 | 2 | 8 | — | — | — | 1 | 1 | 100 | 3 | 3 | 100 | — | — | — | 4 | 4 | 100 |
| 1964 | 3 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 7 | 0 | 0 | 21 | 0 | 0 | 6 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 10 | 0 | 0 |
| 1965 | — | — | — | — | — | — | 5 | 0 | 0 | 6 | 0 | 0 | 11 | 0 | 0 | 8 | 0 | 0 | 7 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 19 | 0 | 0 |
| | | | | | | | | | | | | | *57* | *2* | *4* | | | | | | | | | | | | | *33* | *4* | *12* |
| Aug. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 6 | 2 | 33 | 4 | 0 | 0 | 5 | 5 | 100 | 6 | 6 | 100 | 21 | 13 | 62 | 1 | 1 | 100 | 3 | 0 | 0 | 3 | 2 | 67 | 3 | 2 | 67 | 10 | 5 | 50 |
| 1965 | 7 | 7 | 100 | 7 | 6 | 86 | 7 | 0 | 0 | — | — | — | 21 | 13 | 62 | — | — | — | — | — | — | 1 | 0 | 0 | 9 | 8 | 89 | 10 | 8 | 80 |
| | | | | | | | | | | | | | *42* | *26* | *62* | | | | | | | | | | | | | *20* | *13* | *65* |
| Sept. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1963 | 6 | 6 | 100 | 6 | 6 | 100 | — | — | — | 1 | 1 | 100 | 13 | 13 | 100 | 1 | 1 | 100 | — | — | — | 3 | 3 | 100 | 3 | 3 | 100 | 7 | 7 | 100 |
| 1965 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 6 | 3 | 50 | 6 | 3 | 50 |
| | | | | | | | | | | | | | *13* | *13* | *100* | | | | | | | | | | | | | *13* | *10* | *77* |
| Oct. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1961 | 1 | 0 | 0 | 2 | 1 | 50 | 1 | 0 | 0 | 2 | 0 | 0 | 6 | 1 | 17 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1963 | 2 | 1 | 50 | 1 | 1 | 100 | — | — | — | 1 | 0 | 0 | 4 | 2 | 50 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 5 | 0 | 0 | 27 | 0 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | | | | | | | | | | | | | *37* | *3* | *8* | | | | | | | | | | | | | — | — | — |
| All | 106 | 33 | *31* | 82 | 35 | *43* | 87 | 22 | *25* | 85 | 30 | *28* | 360 | 120 | *33* | 38 | 10 | *26* | 35 | 10 | *29* | 29 | 9 | *33* | 39 | 25 | *64* | 139 | 54 | *39* |

[a] O, number of observations.
[b] S, number of observations.

pictures of what is in fact a primary influence on the sound production of these fishes may be had from a detailed examination of the behavior over an extended period of time, together with the corresponding temperature changes. The basic data are given in table 13. Text figure 20 shows various graphic treatments. The upper graph (A) clearly shows that the fastest rate of production, nearly five "boat-whistles" per minute, occurred during May, with much reduction during July, when all records were less than one and one-half per minute, fewer in fact than those during the starting month (March) which ran up to nearly four per minute and about equal to the rate during the ending month (October). The differences in rate are indicated more clearly in the middle graph (B) of text figure 20, in which there has been a great reduction in the number of plotted points. January, February, October, November, and December have been plotted as single months, as in the upper graph, whereas March and April, and May through September, have been combined. The change applies only to the data on sound-production rate; the temperature data are given for every month. The weather peculiarities of the area justify such a treatment. Dr. Maurice W. Provost, Director of the Entomological Research Center of the Florida State Board of Health, Vero Beach (personal communication), referring to air temperatures, wrote: "... in peninsular Florida the summer maxima and minima assume the proportions of a plateau, with remarkable constancy for four or five months." This condition is clearly reflected in the water temperatures of the very shallow Lemon Bay, modified somewhat by the tidal inflow of the more stable Gulf water, an influence that is here minimized by the use of mean temperatures (see table 2 and text fig. 1). Note that the values for the mean rates of sound production run virtually parallel from the March to April period and then drop below a rate of one per minute in the final month (October). The combining of months over this period brings out the basic identity of mean values and suppresses the incidental vagaries of means based on small series for some of these months, indicating the essentially parallel nature of both water temperature and rate of call. They also indicate how the rate of production of "boat-whistles" virtually reaches its peak in the month it starts and runs essentially horizontal to July. The extreme high and low sound-production rates in these three periods are indicated by the lengths of the three vertical lines in text figure 20 (middle graph, B). The maxima for the first two periods rise on occasion to nearly four sounds or more per minute, whereas the

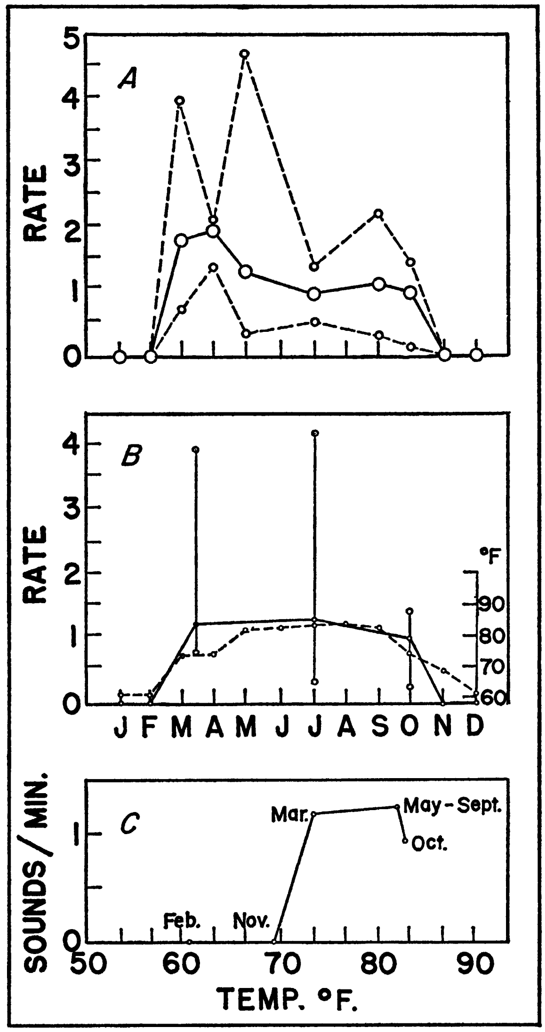


FIG. 20. Rate of boat-whistle production of *Opsanus* in terms of months, temperature, and season; based on table 13. A. Maximum, mean, and minimum number of sounds per minute by months. B. Mean, as in A but with great reduction in the plotted points and with monthly thermal averages shown by dotted line; see text for full explanation. C. Sounds per month plotted against monthly temperature.

last does not reach one and one-half. The minimum during the first period is more than one-half sound per minute, whereas the other two are below that value, the last showing the slowest rate, 0.14 per minute. Below that point the serial production evidently breaks down and cannot be maintained.

The lower graph (C) of text figure 20 shows these relationships in still another way. In this graph sounds per minute are plotted against mean temperatures by months, which produces a curve that rises from zero to a value of less than 0.25 sound per minute in the low seventies, but hooks over in the low eighties and stops before 85° F. is reached. Because of the conditions under which these data were obtained, it is impossible to determine fully whether this apparent reduction in rate, just before the limiting temperature is reached, is an artifact of statistics or a true slowing of the rate. If it is an artifact, the situation would then be that the rate was highest up to the point that completely inhibits sound production, which would seem to be less likely. In either case the indicated situation is that the rate of production increases from its start in the low seventies and rises as a decreasing increment to about 82° F., after which it either falls or simply stops before another degree of temperature is reached.

It should be noted that the volume of sound falls at this same time, suggesting that the *rate* of production acts much as though it were completely determined by the temperature, whereas the volume would seem to be influenced by several other parameters, including at least the sexual exhaustion of some of the participants as well as various as yet unstudied behavioral details, both sexual and other. These items could then account for the peak in volume of sound in May and again in September. Schneider (1967) found that the "threatening" sounds of *Therapon jarbua* Forskål had a repetition rate which approximately doubled with every rise in temperature of 10° C., in accordance with van't Hoff's law. Although the present data were not taken for the purpose of studying this point, and no precise comparable calculations can be made, nothing in it suggests any other re-

TABLE 13

RATE[a] OF THE BOAT-WHISTLE PRODUCTION BY INDIVIDUALS OF *Opsanus* BY MONTHS, IN TERMS OF THE NUMBER PER MINUTE IN RELATION TO THE WATER TEMPERATURE (IN DEGREES FAHRENHEIT)

| Month and Year | Sounds/Minute | | | No. of | Elapsed | Water Temperature | | |
|---|---|---|---|---|---|---|---|---|
| | Max. | Mean | Min. | Sounds[b] | Time[c] | Max. | Mean | Min. |
| March, 1964 | 3.98 | 1.73 | 0.67 | 1035 | 10:07 | 77.0 | 76.5 | 76.0 |
| April, 1964 | 2.11 | 1.92 | 1.31 | 491 | — | — | — | — |
| May, 1964 | 4.61 | 1.25 | 0.30 | 665 | 8:53 | — | — | — |
| July, 1963 | 1.36 | 0.93 | 0.50 | 119 | 2:24 | 86.0 | 81.5 | 77.0 |
| Aug., 1963 | 3.04 | 1.48 | 0.78 | 1281 | 14:26 | 85.5 | 83.2 | 81.0 |
| Sept., 1963 | 2.20 | 1.05 | 0.32 | 1301 | 20:35 | 91.0 | 82.6 | 76.0 |
| Oct., 1963 | 1.43 | 0.93 | 0.14 | 91 | 1:36 | 77.0 | 74.2 | 73.0 |
| Lowest | *1.36* | *0.93* | *0.14* | — | — | *77.0* | *74.2* | *73.0* |
| Highest | *4.61* | *1.92* | *1.31* | — | — | *91.0* | *83.2* | *81.0* |
| Mean of all | | *1.50* | | | | | *81.1* | |
| Totals | | | | 4983 | 62:22 | | | |

Combined rates versus water temperature

| | Feb. | March–April | May–Sept. | Oct. | Nov. |
|---|---|---|---|---|---|
| Mean temperature | 61.5 | 73.2 | 82.0 | 82.7 | 69.7 |
| Mean rate | 0 | 1.2 | 1.3 | 0.9 | 0 |

[a] The rate was established on a basis of the elapsed time for the production of 10 boat-whistles and recalculated to terms of boat-whistles per minute. See text for this handling of the data.

[b] Boat-whistles per month.

[c] Duration of observation per month.

lationship, considering the short range of temperatures involved.

To refine these matters further would require techniques other than those applied in these studies. They would demand a precise knowledge of the temperature to which each individual fish was exposed. Although the degree of divergence of these temperatures from the temperature given by the stationary recording thermometer is not believed to be more than plus or minus a few degrees at most, and probably very much less most of the time, it nonetheless limits the precision that could be attained possibly by monitoring the temperature inside the shelter in which the fish under study resided or by telemetry from a small device attached to fish, which preferably in both cases would transmit both temperature and sound production. As very little interference with fishes easily inhibits sound production and reproduction, such an approach would probably have very little application for these purposes.

Although it was impractical to keep full records of the "boat-whistle" sound, it was clear that more sonic activity of this kind occurred at about sunset than at any other time, which closely coincided with the period of the *Galeichthys* choruses, although Knudsen, Alford, and Emling (1948) thought that no variation was associated with the daily, monthly, and seasonal cycles of the environment. The fact that we were able to estimate the rate of sound production in terms of sounds per minute and days per month of sound production and to estimate intensity is evidently responsible for this difference of view.

The sedentary and bottom-dwelling species of *Opsanus* was apparently present at all times during the winter and early spring, unlike the free-swimming *Galeichthys*. The data on the sonic beginnings are more consistent, therefore, in the case of *Opsanus*. The first intimations of increased sound production came always in the evening during a period earlier than the commencing sound of *Galeichthys*. No precise data were obtained on the details of the sonic activity of *Opsanus* at other times, as noted above.

The audiogoniometer, used in the efforts to establish the positions occupied by the sonic *Galeichthys*, was not suitable for similar studies on *Opsanus*, chiefly because the time between sounds is usually long enough to make such triangulation inconvenient or even impossible. Furthermore, simpler methods are available for finding these sedentary sonic fishes. A simple inspection of the bottom, if the water is sufficiently clear and shallow, will usually show every available shell, tin can, or similar cavity that a male of *Opsanus* in the breeding season might occupy. The great increase of volume in an earphone or speaker when the hydrophone is almost in contact with such a nest site confirms the presence of a sonic individual of *Opsanus*. In turbid water the earphones or speaker may be used blind, on an intensity basis, which requires not much increase in the time spent finding the fishes over that spent bv the first method.

## "Repeater"

The only other fish sound that occurred with sufficient regularity to be tabulated was present all winter but was absent during the summer. The details are given in table 14 and text figure 21. Because of the repetition of the soft tapping sounds that were produced, which ranged from as few as three to a dozen or more, this one was designated merely as the "Repeater." It was not successfully identified but was believed to be a sciaenid, because the sciaenids are abundant in the area, and there are no other known notably sonic species in the bay that had not already been identified. The only two sciaenids that reproduce in the cooler periods of the year and that regularly inhabit the bay are *Sciaenops ocellata* (Linnaeus) and *Leiostomus xanthurus* Lacépède. Both the literature (Welsh and Breder, 1923; Hildebrand and Schroeder, 1928; Pearson, 1929; Hildebrand and Cable, 1930 and 1934; and Springer and Woodburn, 1960), and further personal observations, including the finding of small young of both species in winter and spring, attest to the reproduction of these two species in the bay, or near enough to it for easy access to it of barely post-larval young. "Protest" sounds of both species were kindly supplied on tape by Dr. M. P. Fish for study. There is a certain similarity between the soft "protest" sounds of *Sciaenops* and the sounds heard in Lemon Bay. There is no such resemblance between these sounds and the "protest" sounds of *Leiostomus*. Although, of course, fishes need not confine themselves to a single type of sound, the above is mentioned merely to suggest that it would not be surprising if *Sciaenops* was eventually identified as the "Repeater." The soft sound mentioned sometimes apparently changes into a similarly paced hard tapping sound, unless a confusion of species has occurred here.

Text figure 21 is a fairly "empty" graph, but it is rendered on the same scale as the corresponding graphs of the preceding species, because it shows at once the comparative volumes of total sound of the three, without possibility of confusion. Unlike the graphs in text figures 19 and 20, this graph runs from summer to summer, because of the break in the sonic activity from June to October.

The earliest date for sound production by the "Repeater" was October 20, 1961, and the latest was June 1, 1962, with peaks in December and April. Consequently, if sound production of these three species has significance in mating, not only do the species that reproduce in the summer have an interruption because of excessively hot water, but so, too, do the winter spawners, because of excessively cold water. A comparison of text figure 2, showing the thermal conditions in the bay, with text figure 21, of sound production of this species, will emphasize this clearly. The section on trapping gives further bases for some of these views, in regard to the presence of young fish.

The relation to moon phases (see text fig. 22; data in table 15) is expressed by a nearly straight line, with a slight rise, probably not significant, in the new-moon quarter. The relation to bright and dark nights by moon phases suggests more sound production on dark nights in the first and full-moon quarters (table 16 and text fig. 23). The data here are just too scant to warrant further attempts at analysis.

Sound production occurred in the early evening, the earliest being 5:31 P.M., on January 13, 1963, and the latest occurring at 8:17 P.M., with a mean at 6:06 P.M. The lowest water temperature at which these sounds were heard was 64° F. on January 17, 1963,

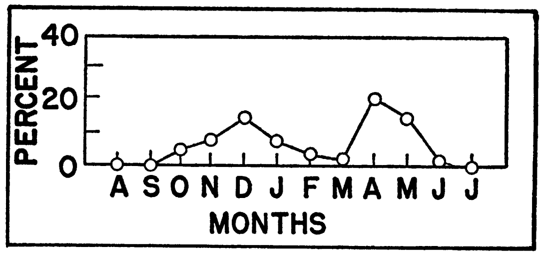


FIG. 21. Mean sound production of "Repeater" by months; based on table 14.

TABLE 14

SOUND PRODUCTION OF "REPEATER"[a] BY MONTHS, SHOWING THE NUMBER OF DAYS PER MONTH WITH CHORUSES (IN ROMAN) AND THE PERCENTAGE OF OBSERVATIONS PER MONTH (IN ITALICS)

(The percentage figures were derived by dividing the number of days with choruses by the number of observations given in table 1. See text for full explanation. This table corresponds to tables 3 and 10.)

| Month | 1961 | | 1962 | | 1963 | | 1964 | | 1965 | | All | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. | 2 | *33* | — | | 0 | *0* | 0 | *0* | — | | 2 | *5* |
| Nov. | 1 | *25* | 1 | *17* | 0 | *0* | 1 | *4* | — | | 3 | *8* |
| Dec. | — | | 7 | *70* | 0 | *0* | 0 | *0* | — | | 7 | *12* |
| Jan. | — | | — | | 4 | *44* | 0 | *0* | 0 | *0* | 4 | *7* |
| Feb. | — | | — | | 1 | *50* | 0 | *0* | 1 | *4* | 2 | *4* |
| March | 1 | *17* | — | | — | | 0 | *0* | 0 | *0* | 1 | *2* |
| April | 4 | *57* | 0 | *0* | — | | 3 | *25* | 3 | *12* | 10 | *21* |
| May | — | | 0 | *0* | — | | 7 | *44* | 0 | *0* | 7 | *12* |
| June | — | | 1 | *33* | 0 | *0* | 0 | *0* | 0 | *0* | 1 | *1* |
| All | 8 | *35* | 9 | *23* | 5 | *10* | 11 | *5* | 4 | *3* | 37 | *8* |

[a] No estimates of intensity were made of this relatively seldom-heard form.

TABLE 15

SOUND PRODUCTION OF "REPEATER" BY MOON PHASES, IN TERMS OF THE NUMBER OF OBSERVATIONS, THE NUMBER OF SOUNDS, AND IN PERCENTAGE, EACH IN THE PHASE INDICATED, WHICH IS THE LAST DAY OF THE RESPECTIVE QUARTER

(This table corresponds to tables 4 and 11.)

| Date of Full Moon | | To Last Quarter | | | To New Moon | | | To First Quarter | | | To Full Moon | | | All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | O[a] | S[b] | % | O | S | % | O | S | % | O | S | % | O | S | % |
| Oct. | | | | | | | | | | | | | | | | |
| 1961 | 23 | 6 | 2 | 33 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 100 | 10 | 3 | 30 |
| 1963 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | — | — | — | 5 | 0 | 0 |
| 1964 | 20 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 5 | 0 | 0 | 27 | 0 | 0 |
| | | | | *25* | | | *0* | | | *0* | | | *17* | *42* | *3* | *7* |
| Nov. | | | | | | | | | | | | | | | | |
| 1961 | 22 | 1 | 1 | 100 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 4 | 1 | 25 |
| 1962 | 17 | 2 | 1 | 50 | — | — | — | 1 | 0 | 0 | 2 | 0 | 0 | 5 | 1 | 20 |
| 1963 | 30 | — | — | — | 1 | 0 | 0 | — | — | — | 1 | 0 | 0 | 2 | 0 | 0 |
| | | | | *67* | | | *0* | | | *0* | | | *0* | *11* | *2* | *18* |
| Dec. | | | | | | | | | | | | | | | | |
| 1962 | | 2 | 0 | 0 | 5 | 5 | 100 | 2 | 2 | 100 | 1 | 0 | 0 | 10 | 7 | 70 |
| 1963 | | 8 | 0 | 0 | 7 | 0 | 0 | 3 | 0 | 0 | — | — | — | 18 | 0 | 0 |
| 1964 | | 6 | 0 | 0 | 8 | 0 | 0 | 9 | 0 | 0 | 6 | 0 | 0 | 29 | 0 | 0 |
| | | | | *0* | | | *0* | | | *0* | | | *0* | *57* | *7* | *12* |
| Jan. | | | | | | | | | | | | | | | | |
| 1963 | 9 | 5 | 3 | 60 | 2 | 1 | 50 | 1 | 0 | 0 | 1 | 0 | 0 | 9 | 4 | 44 |
| 1964 | 28 | 3 | 0 | 0 | 6 | 0 | 0 | 6 | 0 | 0 | — | — | — | 15 | 0 | 0 |
| 1965 | 17 | 4 | 0 | 0 | 2 | 0 | 0 | 8 | 0 | 0 | 5 | 0 | 0 | 19 | 0 | 0 |
| | | | | *25* | | | *10* | | | *0* | | | *0* | *43* | *4* | *8* |
| Feb. | | | | | | | | | | | | | | | | |
| 1963 | 8 | 2 | 1 | 50 | — | — | — | — | — | — | — | — | — | 2 | 1 | 50 |
| 1964 | 27 | 5 | 0 | 0 | 8 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 0 | 27 | 0 | 0 |
| 1965 | 15 | 5 | 0 | 0 | 8 | 0 | 0 | 8 | 0 | 0 | 6 | 0 | 0 | 27 | 0 | 0 |
| | | | | *8* | | | *0* | | | *0* | | | *0* | *56* | *1* | *2* |
| March | | | | | | | | | | | | | | | | |
| 1961 | 2 | 2 | 1 | 50 | — | — | — | 2 | 0 | 0 | 2 | 0 | 0 | 6 | 1 | 17 |
| 1964 | 27 | 6 | 0 | 0 | 6 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 | 22 | 0 | 0 |
| 1965 | 17 | 8 | 0 | 0 | 6 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 0 | 28 | 0 | 0 |
| | | | | *4* | | | *0* | | | *0* | | | *0* | *56* | *1* | *2* |
| April | | | | | | | | | | | | | | | | |
| 1961 | 1 | 2 | 1 | 50 | 2 | 2 | 100 | 1 | 1 | 100 | 2 | 0 | 0 | 7 | 4 | 57 |
| 1962 | 20 | 1 | 0 | 0 | 1 | 1 | 100 | 1 | 0 | 0 | 2 | 1 | 50 | 5 | 2 | 40 |
| 1964 | 26 | 5 | 0 | 0 | 7 | 0 | 0 | 6 | 2 | 33 | 8 | 1 | 12 | 26 | 3 | 12 |
| 1965 | 15 | 7 | 0 | 0 | 7 | 0 | 0 | 7 | 1 | 14 | 6 | 0 | 0 | 27 | 1 | 4 |
| | | | | *7* | | | *18* | | | *27* | | | *11* | *65* | *10* | *15* |
| May | | | | | | | | | | | | | | | | |
| 1962 | 19 | 7 | 1 | 14 | 8 | 0 | 0 | 1 | 1 | 100 | 2 | 0 | 0 | 18 | 2 | 11 |
| 1964 | 26 | 4 | 0 | 0 | — | — | — | — | — | — | 8 | 8 | 100 | 12 | 8 | 67 |
| 1965 | 15 | 6 | 0 | 0 | 5 | 2 | 40 | 7 | 0 | 0 | 6 | 0 | 0 | 24 | 2 | 8 |
| | | | | *6* | | | *15* | | | *12* | | | *50* | *54* | *12* | *22* |
| June | | | | | | | | | | | | | | | | |
| 1962 | 18 | — | — | — | 2 | 1 | 50 | — | — | — | — | — | — | 2 | 1 | 50 |
| 1963 | 7 | 2 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 9 | 0 | 0 | 22 | 0 | 0 |
| 1964 | 24 | 3 | 0 | 0 | 6 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 24 | 0 | 0 |
| 1965 | 13 | 8 | 0 | 0 | 2 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 0 | 24 | 0 | 0 |
| | | | | *0* | | | *7* | | | *0* | | | *0* | *72* | *1* | *1* |
| All | | 112 | 11 | *10* | 109 | 12 | *11* | 103 | 7 | *7* | 105 | 11 | *10* | 429 | 41 | *9* |

[a] O, number of observations.
[b] S, number of sounds.

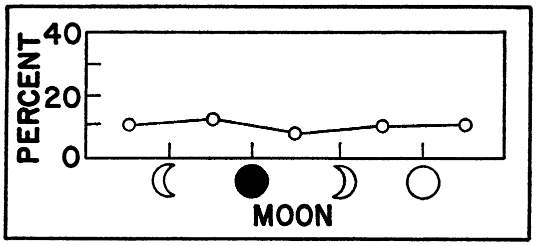


FIG. 22. Sound production of "Repeater" by moon phases; based on table 15.

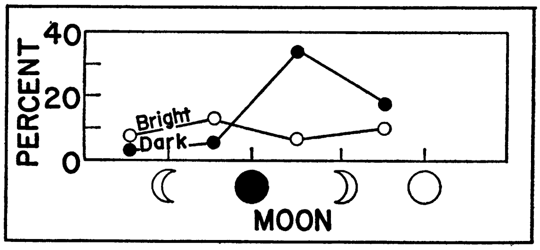


FIG. 23. Sound production of "Repeater" by moon phases on bright and dark nights; based on table 16.

and the highest was 83° F. on May 20, 1962, with a mean of 72° F. Foot-candles at the initiation of sound production varied from zero on December 19, 1962, to 150 on December 24, 1962, with a mean at 68 foot-candles.

### "GALLOPER"

This designation results from the surprising resemblance to a fast-moving riding horse being suddenly reined to a quick stop. The sounds are very like sharp hoofbeats rapidly brought to a halt. Heard only in the summers of 1964 and 1965, the sounds of this fish are too few to be accorded further treatment. These sounds were heard in the evening of June 13, 1964, on June 20, 23, and 25 through June 30, and on July 1 through July 3, and on June 17, 1965, only. This type of sound production began as early as 6:10 P.M., July 3, 1964, and as late as 8:10 P.M., July 2, and at a light intensity ranging from zero to 20 foot-candles, with water temperatures ranging between 83° F. and 85° F.

### OTHER FISH SOUNDS

Presumably fish sounds, which were seldom heard, were produced by species rare or casual in Lemon Bay, or at least mostly silent when they were within its confines. Some of the sounds were rather striking, and they are roughly described in order to indicate the range of fish sounds that may be heard in that bay. These sounds are "hoots," "honks," "bleats," "chuckles," "grunts," "clicks," "chirps," "knocks," "thumps," "creaks," and "chattering." All were single, short sounds, not repeated, except for those that imply a time span, i.e., "bleats," "chuckles," "creaks," and "chattering." All were seldom heard and most probably represented species other than those discussed above, although several possibly could be assigned to *Galeichthys*, *Opsanus*, or even the other, unidentified, groups. The suspected sounds are those that are mentioned above as "hoots," "honks," "clicks," "knocks," "thumps," and "creaks."

### SOUNDS OF INVERTEBRATES

Although a survey of sound production by invertebrates was not intended for this study, notes on certain features of sounds that were encountered are given below as part of the ecological background against which the fishes operate.

Alpheids are abundant in Lemon Bay, many inhabiting the piles supporting the dock on which this work was carried out. Their snapping formed a considerable background to most of the sonic observations. In general terms, it was noticed that they were more noisy at night than during the day. On calm days the sounds, generally speaking, greatly diminished, and they increased, chiefly in proportion to the wave action, to the point where they were obliterated by the increasing noises of the water in stormy weather. Reduction of the sound on calm days was especially notable in summer, when the water was unusually warm, possibly owing merely to the influence of near lethal conditions. The relation to water movement may be that "snapping" increased as the alpheids were pushed about in their crevices by the water simply as a general response to disturbance. (SeeTavolga, 1965, for a review of the literature on alpheid behavior.)

Occasional rasping and grating sounds were thought to be referable to the general activity of brachyurans among oyster and other shells. The largest species locally common was *Callinectes sapidus*, which would be

# TABLE 16

Sound Production of "Repeater" by Moon Phases on Bright and Dark Nights, in Terms of the Number of Observations, the Number of Sounds, and Percentage, Each in the Phases Indicated Which is the Last Day of the Respective Quarter
(This table corresponds to tables 5 and 12.)

**Bright Nights**

| Month and Year | To Last Quarter O[a] | S[b] | % | To New Moon O | S | % | To First Quarter O | S | % | To Full Moon O | S | % | All O | S | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. | | | | | | | | | | | | | | | |
| 1961 | 1 | 0 | 0 | 2 | 1 | 50 | 1 | 0 | 0 | 2 | 1 | 50 | 6 | 2 | 33 |
| 1963 | 2 | 0 | 0 | 1 | 0 | 0 | — | — | — | 2 | 0 | 0 | 5 | 0 | 0 |
| 1964 | 7 | 0 | 0 | 7 | 0 | 0 | 8 | 0 | 0 | 5 | 0 | 0 | 27 | 0 | 0 |
| | | | | | | | | | | | | | *38* | *2* | *5* |
| Nov. | | | | | | | | | | | | | | | |
| 1961 | 1 | 1 | 100 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 4 | 1 | 25 |
| 1962 | 2 | 1 | 50 | — | — | — | 1 | 0 | 0 | 2 | 0 | 0 | 5 | 1 | 20 |
| 1963 | — | — | — | 1 | 0 | 0 | — | — | — | 1 | — | — | 2 | 0 | 0 |
| | | | | | | | | | | | | | *11* | *2* | *18* |
| Dec. | | | | | | | | | | | | | | | |
| 1962 | 2 | 0 | 0 | 5 | 5 | 100 | 2 | 2 | 100 | 1 | 0 | 0 | 10 | 7 | 70 |
| 1963 | 4 | 0 | 0 | 7 | 0 | 0 | 3 | 0 | 0 | — | — | — | 14 | 0 | 0 |
| 1964 | 5 | 0 | 0 | 3 | 0 | 0 | 5 | 0 | 0 | 2 | 0 | 0 | 15 | 0 | 0 |
| | | | | | | | | | | | | | *39* | *7* | *18* |
| Jan. | | | | | | | | | | | | | | | |
| 1963 | 5 | 3 | 60 | 2 | 1 | 50 | 1 | 0 | 0 | 1 | 0 | 0 | 9 | 4 | 44 |
| 1964 | 3 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | — | — | — | 5 | 0 | 0 |
| 1965 | 3 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 12 | 0 | 0 |
| | | | | | | | | | | | | | *26* | *4* | *15* |
| Feb. | | | | | | | | | | | | | | | |
| 1963 | 2 | 1 | 50 | — | — | — | — | — | — | — | — | — | 2 | 1 | 50 |
| 1964 | 3 | 0 | 0 | 7 | 0 | 0 | 6 | 0 | 0 | 6 | 0 | 0 | 22 | 0 | 0 |
| 1965 | 5 | 0 | 0 | 4 | 0 | 0 | 6 | 0 | 0 | 3 | 0 | 0 | 18 | 0 | 0 |
| | | | | | | | | | | | | | *42* | *1* | *2* |
| March | | | | | | | | | | | | | | | |
| 1961 | 2 | 1 | 50 | — | — | — | 2 | 0 | 0 | 2 | 0 | 0 | 6 | 1 | 17 |
| 1964 | 4 | 0 | 0 | 6 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 14 | 0 | 0 |
| 1965 | 4 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 16 | 0 | 0 |
| | | | | | | | | | | | | | *36* | *1* | *3* |
| April | | | | | | | | | | | | | | | |
| 1961 | — | — | — | 1 | 1 | 100 | 1 | 1 | 100 | — | — | — | 2 | 2 | 100 |
| 1962 | 1 | 0 | 0 | — | — | — | 1 | 0 | 50 | 2 | 1 | 50 | 4 | 1 | 25 |
| 1964 | 5 | 0 | 0 | 6 | 0 | 0 | 6 | 1 | 17 | 5 | 1 | 20 | 22 | 2 | 9 |
| 1965 | 5 | 0 | 0 | 3 | 0 | 0 | 6 | 1 | 17 | 6 | 0 | 0 | 20 | 1 | 5 |
| | | | | | | | | | | | | | *48* | *6* | *12* |
| May | | | | | | | | | | | | | | | |
| 1962 | 4 | 1 | 25 | 1 | 1 | 100 | 1 | 0 | 0 | 2 | 0 | 0 | 8 | 2 | 25 |
| 1964 | 4 | 0 | 0 | — | — | — | — | — | — | 4 | 4 | 100 | 12 | 4 | 33 |
| 1965 | 6 | 0 | 0 | 4 | 1 | 25 | 8 | 1 | 12 | 6 | 0 | 0 | 24 | 2 | 8 |
| | | | | | | | | | | | | | *44* | *8* | 18 |
| June | | | | | | | | | | | | | | | |
| 1962 | — | — | — | 2 | 1 | 50 | — | — | — | — | — | — | 2 | 1 | 50 |
| 1963 | 3 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 12 | 0 | 0 |
| 1964 | 7 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 5 | 0 | 0 | 23 | 0 | 0 |
| 1965 | 8 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 | 20 | 0 | 0 |
| | | | | | | | | | | | | | *57* | *1* | *2* |
| All | 98 | 8 | *8* | 83 | 11 | *13* | 86 | 6 | *7* | 72 | 7 | *10* | 341 | 31 | *9* |

**Dark Nights**

| Month and Year | To Last Quarter O | S | % | To New Moon O | S | % | To First Quarter O | S | % | To Full Moon O | S | % | All O | S | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. | | | | | | | | | | | | | | | |
| 1961 | — | — | — | 1 | 1 | 100 | — | — | — | — | — | — | 1 | 1 | 100 |
| 1963 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | | | | | | | | | | | | | *1* | *1* | *100* |
| Nov. | | | | | | | | | | | | | | | |
| 1961 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1962 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1963 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | | | | | | | | | | | | | — | — | — |
| Dec. | | | | | | | | | | | | | | | |
| 1962 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1963 | 4 | 0 | 0 | — | — | — | — | — | — | — | — | — | 4 | 0 | 0 |
| 1964 | 1 | 0 | 0 | 5 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 14 | 0 | 0 |
| | | | | | | | | | | | | | *18* | *0* | *0* |
| Jan. | | | | | | | | | | | | | | | |
| 1963 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 3 | 0 | 0 | 5 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 19 | 0 | 0 |
| 1965 | 1 | 0 | 0 | 5 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 14 | 0 | 0 |
| | | | | | | | | | | | | | *33* | *0* | *0* |
| Feb. | | | | | | | | | | | | | | | |
| 1963 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 7 | 0 | 0 |
| 1965 | 3 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 9 | 0 | 0 |
| | | | | | | | | | | | | | *16* | *0* | *0* |
| March | | | | | | | | | | | | | | | |
| 1961 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1964 | 2 | 0 | 0 | — | — | — | — | — | — | — | — | — | 14 | 0 | 0 |
| 1965 | 4 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 16 | 0 | 0 |
| April | | | | | | | | | | | | | | | |
| 1961 | 2 | 1 | 50 | 1 | 0 | 0 | — | — | — | 2 | 1 | 50 | 5 | 2 | 40 |
| 1962 | — | — | — | 1 | 1 | 100 | — | — | — | — | — | — | 1 | 1 | 100 |
| 1964 | — | — | — | 1 | 0 | 0 | — | — | — | 3 | 1 | 33 | 4 | 1 | 25 |
| 1965 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | — | — | — | 4 | 0 | 0 |
| | | | | | | | | | | | | | *14* | *4* | *29* |
| May | | | | | | | | | | | | | | | |
| 1962 | 3 | 0 | 0 | 4 | 0 | 0 | — | — | — | | — | — | 7 | 0 | 0 |
| 1964 | 1 | 0 | 0 | — | — | — | — | — | — | 4 | 4 | 100 | 5 | 4 | 80 |
| 1965 | — | — | — | 3 | 0 | 0 | — | — | — | — | — | — | 3 | 0 | 0 |
| | | | | | | | | | | | | | *15* | *4* | *27* |
| June | | | | | | | | | | | | | | | |
| 1962 | — | — | — | — | — | — | 1 | 0 | 0 | — | — | — | 1 | 0 | 0 |
| 1963 | — | — | — | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 |
| 1964 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 |
| 1965 | — | — | — | — | — | — | 3 | 0 | 0 | — | — | — | 3 | 0 | 0 |
| | | | | | | | | | | | | | *14* | *0* | *0* |
| All | 30 | 1 | *3* | 36 | 2 | *6* | 27 | 0 | *0* | 34 | 6 | *18* | 127 | 9 | 7 |

[a] O, number of observations.
[b] S, number of sounds.

expected to be the most noisy in this respect.

A peculiar sound, very like that referred to squid by Iversen, Perkins, and Dionne (1963) and aptly described by Tavolga (1965) as a "Bronx-cheer-like sound," was heard on several occasions. It seems unlikely that any fish would have the means of producing such a sound, or any other animal appearing about the dock other than cephalopods. Because both squids and octopuses are sparingly present in the bay but abundant in the Gulf, and because these sounds were never heard more than once on any occasion, indicates the behavior of an octopus which often employs just one "puff" to move it from one holdfast object to another. Also, the local squids usually travel in groups from which a series of such "puffs" would be expected, and also, because of their habitual open-water travel, a series would be expected from each individual.

No oyster beds are near enough to the dock for one to expect to pick up their shell-snapping sounds. Barnacles were present on the dock piles in abundance, but no sounds whatever could be referred to them. As an extreme case, one of the hydrophones inadvertently was allowed to become covered with them (see pl. 19, fig. 1). These in no way seemed to interfere with the use of the transducer, the barnacles seemingly being entirely permeable to the frequencies with which we were concerned. In a personal communication, Dr. William N. Tavolga reported a similar experience elsewhere.

Mr. Arnold Ross, then of the University of Florida, kindly identified specimens as *Balanus eburneus* Gould. It would seem, at the very least, that this species, at the sizes that we encountered, does not produce sounds capable of being picked up by the hydrophones of our equipment, even when attached to the face of the instrument. These animals could be seen feeding in their characteristic manner, and they grew rapidly until the experiment was terminated.

No sea urchins occur near the dock. The sounds mentioned above were the only ones made by invertebrates that were heard at this site.

# DATA BASED ON TRAPPING

FYKE AND GILL NETS were used sparingly to obtain positive checks on the presence, condition, and extent of activity of the various kinds of fishes known or supposed to be present. Plastic traps were employed to obtain samples of young and larval fishes in order to check on which fishes had recently been reproducing. The larger nets were used sparingly to avoid, as far as possible, any significant disruption of the local fish population or its ordinary activities. The species so obtained are listed below, together with the information that was obtained pertinent to these studies. The various types of nets used and the periods when they were operated are also given.

The names of those species that had no known, significant relation to the sonic activity are marked with an asterisk.

### GILL-NET OPERATIONS

NET: Of nylon, 2-inch-square mesh, 6 feet deep by 100 feet, with floats and leads.

PERIODS OF OPERATION: January 23, 1964, to March, 1964, and May 26 to July 31, 1964.

**Elops saurus* Linnaeus
**Harengula pensacola* Goode and Bean
**Synodus foetens* (Linnaeus)
*Galeichthys felis* (Linnaeus)

Examples were taken from May 30 to July 13, although none entered the fyke nets. A female of 260 mm. in standard length, June 9, had developed gonads, with the largest egg 10 mm. in diameter. There were 21 eggs of similar size, 12 in the right, and nine in the left, ovary. The fleshy pelvic fin folds were not fully developed. On June 21 and 24 two individuals, of 215 and 222 mm. in standard length, respectively, had undeveloped gonads. On July 6 a female 275 mm. in standard length had 26 advanced ovarian eggs, the largest of which was 12 mm. in diameter; of these 14 were in the right ovary and 10 in the left. The pelvic folds were well developed. The stomach contents of these and the other specimens included small individuals of *Lagodon* and other, but unidentifiable, small fish remains, a tunicate (?), and the remains of some shrimp.

It is notable that no young of the year were taken in any of the traps, nor were any taken in the small-fish trapping reported earlier by Breder (1962). The absence of young coincides with the findings of Gunter (1945), Springer and Woodburn (1960), and Gunter and Hall (1963), all of whom reported the presence of young in estuarine water of lower salinity. What little fresh water enters Lemon Bay necessarily comes from small streams on its eastern shore. However, such a situation is not invariable, as is indicated by Joseph and Yerger (1956), who found young in tidal streams.

Although *Bagre marinus* (Mitchill) is common in the general area, mostly in the Gulf but sometimes in Lemon Bay, no sounds were heard during this study that could be attributed to it. This absence was also true of the few sounds studied from more open areas, which are discussed in the following section.

**Strongylura notata* (Poey)
**Centropomis undecimalis* (Bloch)
**Lutianus griseus* (Linnaeus)
**Oligoplites saurus* (Bloch and Schneider)
*Cynoscion nebulosus* (Cuvier)

Examples were taken from May 26 to July 30. Eight mature females measured from 225 to 429 mm. in standard length, with a mean of 324 mm. Undoubtedly these fish spawned in 1964. Many had empty stomachs, or the stomach contents was too well digested for any possible identification, which suggests that the pre-spawning cessation from feeding had begun. One fish contained a small individual of the genus *Leiostomus* and others the remains of other small fish, but the bulk of the stomach contents consisted of shrimp remains. This species is clearly a spring and summer spawner (see Welsh and Breder, 1923; Pearson, 1929; Moody, 1950; Guest and Gunter, 1958; and Springer and Woodburn, 1960).

*Bairdiella chrysura* (Lacépède)

Examples were taken from May 26 to June 12. Seven mature females measured from 155 to 180 mm. in standard length, with a mean of 166 mm. No males were taken. These females were about ready to spawn. Of the stomach contents, which was well digested, it was possible to recognize the remains of shrimp, isopods, and the dark form of the small gastropod *Batillaria minima* Gmelin. (See Kuntz, 1916; Welsh and Breder, 1923; Hildebrand and Schroeder, 1928; Hildebrand and Cable, 1930; Gunter, 1938 and 1945; and Springer and Woodburn, 1960; for further data on spawning seasons.)

*Leiostomus xanthurus* Lacépède

See notes about this species below, under Plastic-Trap Operations.

*Sciaenops ocellata* (Linnaeus)

See notes about this species below, under Plastic-Trap Operations.

*Lagodon rhomboides* (Linnaeus)

See notes about this species below, under Plastic-Trap Operations.

**Mugil cephalus* Linnaeus
**Paralichthys albigutta* Jordan and Gilbert
*Opsanus beta* (Goode and Bean)

See notes about this species below, under Plastic-Trap Operations.

### Fyke-Net Operations

Nets: Two hoop nets, 2 feet and 4 feet, respectively, in diameter, both of 1½-inch-square mesh.

Periods of Operation: December 24, 1963, to July 31, 1964, and May 26, 1965, to June 20, 1965.

**Lutianus griseus* (Linnaeus)
*Diapterus plumieri* (Cuvier)

An immature individual of 153 mm. in standard length was taken on June 12, and another, a mature male of 200 mm., on June 18, 1964. This species is not very common in the bay, and no young have been found, so that it would seem unlikely that it is involved significantly in the local sound production.

*Archosargus probatocephalus* (Walbaum)

Examples were taken from April 10 to June 1, 1964. All were evidently immature, although some measured as much as 300 mm. in standard length. They did not seem to be in any way involved in the local sound production. Springer and Woodburn (1960) indicated that the fish of this species spawn in the spring, off shore.

*Lagodon rhomboides* (Linnaeus)

See notes about this species below, under Plastic-Trap Operations.

**Mugil cephalus* Linnaeus
*Opsanus beta* (Goode and Bean)

See notes about this species below, under Plastic-Trap Operations.

### Plastic-Trap Operations[1]

For the details of construction of this trap, see Breder (1960).

Periods of Operation: October 1, 1961, to December 1, 1961; April 16, 1962, to May 13, 1962; December 20, 1962, to September 16, 1963; December 21, 1963, to July 31, 1964 and November 6, 1964, to May 30, 1965.

**Brevoortia patronus* Goode
**Myrophis punctatus* Lütken
**Strongylura notata* (Poey)
*†*Cyprinodon variegatus* Lacépède
**Fundulus confluentus* Goode and Bean
**Lucania parva* (Baird and Girard)
**Syngnathus floridae* (Jordan and Gilbert)
*†*Syngnathus louisanae* Günther
*†*Syngnathus scovelli* (Evermann and Kendall)
*†*Hippocampus erectus* Perry
*†*Lutianus griseus* (Linnaeus)
**Eucinostomus gula* (Quoy and Gaimard)
*Leiostomus xanthurus* Lacépède

Small examples were taken in the plastic trap only from December 24; at that time most of them were barely identifiable by taxonomic procedures. They were reared in an aquarium to March 10; by that date they had grown to a size that rendered them easily

[1] The list of species under this heading is a continuation of the list in Breder (1962) but without annotations except for those pertaining to the present work. The names of species not in the previous list are marked herein with a dagger sign. Species listed in the 1962 article but not taken in the period covered by the present report are *Anchoa hepsetus* (Linnaeus), *Synodus foetens* (Linnaeus), *Strongylura acus* (Lacépède), *Mollienesia latipinna* LeSueur, *Hippocampus zosterae* Jordan and Gilbert, *Trachinotus falcatus* (Linnaeus), *Menticirrhus focaliger* Ginsburg, *Prionotus tribulus* Cuvier, and *Chasmodes saburrae* Jordan and Gilbert.

identifiable, but at this size on that date they were too large to pass through the quarter-inch slit of the plastic trap. This fact further establishes the species as a winter spawner. An example of *Leiostomus* of 138 mm. in standard length, taken in the gill net July 18, 1964, was immature, as would be expected. The absence of adults, either from the traps or from sight records, suggests that spawning takes place outside Lemon Bay and that the eggs or fry drift in with the tide. This view is well supported by Pearson (1929), Dawson (1958), and, especially, Springer and Woodburn (1960), who worked somewhat north of this area.

*Sciaenops ocellata* (Linnaeus)

Examples were taken from November 10 to January 12; after the latter date fishes of this species were evidently too large to enter the plastic trap. An immature specimen of 193 mm. in standard length was taken by gill net on June 18, surely the young of the previous winter's spawning. This size is seldom seen locally. Evidently, in Lemon Bay at least, these fish do not usually frequent readily accessible places at this age. (See Mansueti, 1960, for a discussion of the behavior of the young of *Sciaenops* in shallow estuaries.)

*Lagodon rhomboides* (Linnaeus)

Although this species is one of the common fishes of Lemon Bay, present throughout the year, no mature individuals have been taken in any of the traps. Gill-netted individuals measured from 84 to 153 mm. in standard length, with a mean of 128 mm. As noted by Breder (1962), no large individuals of *Lagodon* have been seen at this site since the hurricane of 1960, which brushed Lemon Bay on September 10. Consequently there seems to be no reason to implicate this species in the local sound production. It spawns in the fall and winter, according to Hildebrand and Cable (1930), Gunter (1945), Reid (1954), Kilby (1955), and Caldwell (1957), and the spawning extends into spring, according to Springer and Woodburn (1960), and Gunter and Hall (1963).

**Gobiosoma bosci* (Lacépède)
*†*Microgobius gulosus* (Girard)
*†*Ophidion holbrooki* (Putnam)
**Mugil cephalus* Linnaeus
**Mugil curema* Valenciennes
**Menidia beryllina* (Cope)
**Paralichthys albigutta* Jordan and Gilbert
**Symphurus plagiusa* (Linnaeus
*†*Achirus lineatus* (Linnaeus)
**Spheriodes maculatus* (Bloch and Schneider)
†*Opsanus beta* (Goode and Bean)

On June 24, 1964, one individual just small enough to enter the quarter-inch slit was taken. Two individuals, too large to squeeze through the slit, were taken in the mouth of the trap on June 30 and July 13. These were clearly the young of the early spring spawning season. On December 5, 1964, two individuals, evidently not a month off the nest, were taken in the same trap. These captures testify to how late these fish may breed, and they fit well with the last "boat-whistle" of October, if allowance is made for a fairly slow development owing to the rather cool water of the three terminal months of the year (see table 2 and text fig. 1). Three young of from 40 to 50 mm. were taken in the gill net on July 3, clearly the young of the early spring spawnings. (See also the data of Reid, 1954; Joseph and Yeager, 1956; and Springer and Woodburn, 1960.)

These lists are not intended as a list of Lemon Bay fishes. These traps were placed near the hydrophones so that one could detect what species approached closely to that particular area. Not more than 200 feet from the site a small boat basin swarmed with *Gambusia affinis* (Baird and Girard) and *Fundulus grandis* (Baird and Girard), neither of which seems to enter the comparatively open waters of Lemon Bay itself. Also, sizable fishes of the genera *Sciaenops*, *Cynoscion*, *Centropomis*, and *Megalops* are frequently hooked nearby and may be seen at times, but all seem to be transients. Also, large schools of large individuals of *Mugil cephalus* (Linnaeus), and solitary ones of *Dasyatis sayi* (LeSueur) and *D. sabina* (LeSueur), large and small, may frequently be seen near the dock, as well as various juvenile sharks.

# FISH SOUNDS FROM OTHER LOCALITIES

ALTHOUGH IT WAS IMPOSSIBLE to carry out extensive explorations in the regions adjacent to the site of these studies, nor were any planned for this project, those that were made indicated that the first listed sound-producers were the same ones contributing to underwater sound production in nearby areas. The details of these observations, which were made in 1964, are given below by localities.

SOUTH BRIDGE TO MANASOTA KEY, ABOUT 1¾ MILES SOUTH OF MAIN WORK AREA; DEEPER WATER, AVERAGING ABOUT 20 FEET

April 17, 6:30–7:00, no fish sounds
April 17, 7:45–8:00, "Repeater"
April 21, 9:00, same as April 17, but less intense
April 23, 8:00, *Galeichthys* chorus and "Repeater"
May 25, 7:30, *Galeichthys* chorus and "Repeater"
May 25, 8:00, "Repeater" only
May 25, 10:00, "Repeater" only, but louder
May 26, 8:00, "Repeater" only
May 30, 6:00, no fish sounds
May 30, 7:00, strong *Galeichthys* chorus
June 5, 9:15, strong "Repeater"
June 6, 11:00, "Repeater" and occasionally *Opsanus*
June 11, 8:45–9:00, "Repeater" only

NORTH BRIDGE TO MANASOTA KEY, ABOUT 4¼ MILES NORTH OF MAIN WORK AREA; SHALLOWER WATER, AVERAGING ABOUT 1 FOOT

May 19, 8:00–8:30, "Repeater," with both soft and hard sounds; occasionally *Opsanus*
May 25, 9:00, a few distant individuals of *Opsanus*

GULF SIDE OF MANASOTA KEY; HEARD WHILE SWIMMING, WITHOUT HYDROPHONE

June 23, 9:00–10:00, "Repeater"
July 13, 7:00–8:00, "Repeater" and a fair *Galeichthys* chorus

MOTE (FORMERLY CAPE HAZE) MARINE LABORATORY, SOUTH END OF SIESTA KEY, JUST NORTH OF MIDNIGHT PASS; 1960 ON

*Opsanus* only; Tavolga (personal communication) noted complete absence of *Thallasia* beds here, which he thought responsible for absence of *Galeichthys;* also seldom, if ever taken by anglers

NORTH END OF SIESTA KEY

April 29, 8:25–9:20, no fish sounds
May 3, 7:30–7:50, two of *Opsanus*
May 3, 8:10, no fish sounds
May 3, 9:00, *Opsanus*

HUMPBACK BRIDGE OVER BAYOU HANSON, SIESTA KEY

May 29, 8:00, no fish sounds

SARASOTA PASS (BIG PASS), NORTH OF SIESTA KEY

John Strong, then collector for Mote Marine Laboratory, heard *Galeichthys* choruses while swimming at night on several occasions

The above observations are similar to those recorded in Lemon Bay. Such differences as there are appear to be associated only with environmental variation. For instance, at the South Bridge there are many more fishes and the water is much deeper, which in itself improves transmission, so that the volume of sound is much greater. It is intense enough, when all three species are sounding strongly, to produce considerable confusion, as each sound takes the characteristics of a chorus and masks the others in a way difficult to interpret. Also, presumably, the odd and occasional sounds heard at the primary station are completely obliterated in the general cacophony. No new sounds were heard at any of these ancillary listening posts.

# DISCUSSION

The treatment of the three principal species here considered is virtually complete and includes the relationships of their sonic activity to their general manner of life and their life histories. Other aspects of this study of a general ecological nature have been relegated, as more suitable, to this section.

In Lemon Bay there is evidently a con-

TABLE 17

Comparison of Sonic Activity by *Galeichthys* and *Opsanus* by Months

| Month and Year | *Galeichthys* Only | *Opsanus* Only | Both Species | No. of Observations | Per Cent[a] *Galeichthys* | Per Cent[a] *Opsanus* |
|---|---|---|---|---|---|---|
| Feb. | | | | | | |
| 1965 | *2* | *9* | *1* | *26* | *8* | *35* |
| March | | | | | | |
| 1961 | 0 | 6 | 0 | 6 | 0 | 100 |
| 1964 | 0 | 11 | 0 | 16 | 0 | 69 |
| 1965 | 9 | 18 | 9 | 30 | 30 | 60 |
| | *9* | *35* | *9* | *52* | *17* | *67* |
| April | | | | | | |
| 1961 | 4 | 1 | 1 | 7 | 57 | 14 |
| 1962 | 0 | 2 | 0 | 4 | 0 | 50 |
| 1965 | 5 | 4 | 9 | 25 | 20 | 16 |
| | *9* | *7* | *10* | *36* | *25* | *19* |
| May | | | | | | |
| 1962 | 7 | 2 | 3 | 15 | 47 | 13 |
| 1964 | 12 | 2 | 2 | 15 | 80 | 13 |
| 1965 | 13 | 3 | 6 | 27 | 48 | 11 |
| | *32* | *7* | *11* | *57* | *56* | *12* |
| June | | | | | | |
| 1962 | 1 | 0 | 0 | 3 | 33 | 0 |
| 1963 | 10 | 0 | 0 | 14 | 71 | 0 |
| 1964 | 11 | 0 | 0 | 30 | 37 | 0 |
| 1965 | 8 | 0 | 0 | 24 | 33 | 0 |
| | *30* | *0* | *0* | *71* | *42* | *0* |
| July | | | | | | |
| 1963 | 11 | 3 | 3 | 29 | 38 | 10 |
| 1964 | 17 | 0 | 0 | 31 | 55 | 0 |
| 1965 | 8 | 0 | 0 | 30 | 27 | 0 |
| | *36* | *3* | *3* | *90* | *48* | *3* |
| Aug. | | | | | | |
| 1963 | 15 | 13 | 3 | 31 | 49 | 42 |
| 1965 | 11 | 0 | 20 | 31 | 35 | 0 |
| | *26* | *13* | *23* | *62* | *42* | *21* |
| Sept. | | | | | | |
| 1963 | 15 | 5 | 15 | 30 | 50 | 17 |
| 1965 | 3 | 0 | 3 | 6 | 50 | 0 |
| | *18* | *5* | *18* | *36* | *32* | *9* |
| Oct. | | | | | | |
| 1061 | 1 | 1 | 0 | 6 | 17 | 17 |
| 1963 | 0 | 1 | 1 | 5 | 0 | 20 |
| 1964 | 0 | 0 | 0 | 9 | 0 | 0 |
| | *1* | *2* | *1* | *20* | *5* | *10* |
| All | 163 | 81 | 76 | 460 | 35 | 18 |

[a] In terms of each species alone, i.e., with the other not being sonic that day.

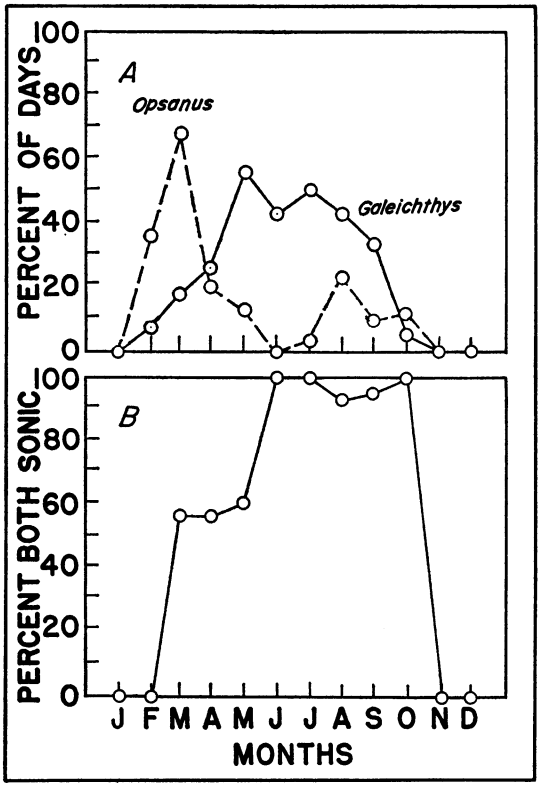


FIG. 24. Comparison of the sonic activity of *Opsanus* and *Galeichthys* by months; based on tables 17 and 18. A. When calling separately. B. When calling, to some extent, simultaneously.

siderable instability of populations and, as a consequence, each year may bring unexpected changes in the population structure at any given place. Some of these features have been indicated in an earlier article (Breder, 1962) in which extraordinary changes due to the passage of a hurricane were discussed. Changes are reflected in the present data on sound production. Tables 3, 10, and 14, together with text figures 3, 16, and 21, indicate some of the features of this situation by a comparison of the different years over the five-year span included. Some of the changes are evidently referable to thermal or other environmental variables, but some, at this writing, are not readily analyzed. The complex tidal situation is probably importantly involved, as any change in the tidal pattern is modified by such day-to-day vagaries as wind direction and velocity, as well as air temperature, intensity of sunlight, cloud cover, and rainfall at the times of tidal reversal and at times of change from a diurnal to a semidiurnal condition, or vice versa. Also involved is the temperature of the incoming Gulf water

TABLE 18

EXTENT OF SIMULTANEOUS SONIC ACTIVITY BY *Galiechthys* AND *Opsanus* ON DAYS WHEN BOTH WERE SONIC

| Month and Year | Sonic Separately | Sonic Together | Per Cent Sonic Together |
|---|---|---|---|
| Feb. | | | |
| 1965 | *1* | *0* | *0* |
| March | | | |
| 1961 | 0 | 0 | 0 |
| 1962 | 0 | 0 | 0 |
| 1964 | 4 | 5 | 56 |
| | *4* | *5* | *56* |
| April | | | |
| 1961 | 1 | 4 | 60 |
| 1962 | 0 | 2 | 100 |
| 1965 | 6 | 3 | 33 |
| | *7* | *9* | *56* |
| May | | | |
| 1962 | 0 | 1 | 100 |
| 1964 | 0 | 8 | 100 |
| 1965 | 6 | 0 | 0 |
| | *6* | *9* | *60* |
| June | | | |
| 1963 | 0 | 0 | 0 |
| 1964 | 0 | 2 | 100 |
| 1965 | 0 | 0 | 0 |
| | *0* | *2* | *100* |
| July | | | |
| 1963 | 0 | 4 | 100 |
| 1964 | 0 | 0 | 0 |
| 1965 | 0 | 0 | 0 |
| | *0* | *4* | *100* |
| Aug. | | | |
| 1963 | 0 | 5 | 100 |
| 1965 | 2 | 18 | 90 |
| | *2* | *23* | *92* |
| Sept. | | | |
| 1963 | 0 | 14 | 100 |
| 1965 | 1 | 2 | 67 |
| | *1* | *16* | *94* |
| Oct. | | | |
| 1961 | 0 | 0 | 0 |
| 1963 | 0 | 1 | 100 |
| 1964 | 0 | 0 | 0 |
| | *0* | *1* | *100* |
| All | 21 | 69 | *77* |

and its relation to the temperature of the Bay water.

A comparison of the sonic activity of *Galeichthys* and *Opsanus* is shown in table 17 and text figure 24. The number of days in each month that the two species were sonic on separate days and the number on which the two were sonic on the same day, although not necessarily at the same time, is followed by the percentage of days on which each alone was sonic. This last column indicates that the early days of sound production were in less agreement than the latter days.

The percentage of times that sound production was simultaneous, as shown in table 18 and text figure 24, although measured in a different manner than the preceding, indicates the same general behavior.

Evidently the only other study of fish sounds that took a similar point of view is the elaborate and highly instrumented operation undertaken at the Lerner Marine Laboratory in the Bahamas. (See Cummings, Brahy, and Herrenkind, 1964; Kronengold, Green, and Lowenstein, 1964; and Sternberg, Cummings, Brahy, and MacBain, 1965.) In an operation about a mile off the west coast of North Bimini, an entirely different faunal area is encountered. Nevertheless, the data accumulated as to the season of activity and the lunar influence apparently do not differ widely from the data here presented, which are based on fishes in a very small and shallow arm of the Gulf of Mexico. Of the various Bahamian fishes discussed in the papers on offshore sounds, some produced sounds only during the daytime, some specialized in night sounds, some seemed to be largely aperiodic, some were active only at sunset and sunrise, and some were active only at sunset.

## SUMMARY

1. Studies on fish-produced sounds were made around the clock and through the seasons in a small Florida bay.

2. The dominant sounds were produced by *Galeichthys felis* and *Opsanus beta*, and an as yet unidentified species. Less frequently occurring unidentified sounds of considerable variety seemed to be made by transients or strays.

3. *Galeichthys* produced its "percolator" choruses from April through October, with a summer lull in July and August, never earlier than 5:00 P.M. and never continued later than 10:50 P.M., with a duration ranging from nine minutes to four hours.

4. There was a distinct tendency for *Galeichthys* to be more sonic during the period near the new moon, a feature less noticeable in *Opsanus*.

5. Choruses of *Galeichthys* formed only when the water temperature ranged between 74° F. and 89° F. and began only after the light intensity fell to values of from 1 to 1900 foot-candles.

6. *Opsanus* produced its "boat-whistle" sound from March to October, with a summer lull from May through July, most vigorous about the time *Galeichthys* choruses were full, but heard irregularly at all times of day and night.

7. The frequency of the "boat-whistle" of *Opsanus* varied with water temperature, ranging from about 0.93 sound per minute at 74° F. to about 1.92 sounds per minute at 83° F., with none below 73° F. or above 91° F.

8. The third, but unidentified, sound-producer made its peculiar repetitional soft tapping sound from October to June, with a lull from January through March.

9. This third sound occurred in a temperature range of from 64° F. to 83° F. and with light intensities ranging from zero to 150 foot-candles; no clear relationship to moon phases could be established.

10. An Appendix describes the apparatus used and in some cases developed.

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# APPENDIX: EQUIPMENT

For the convenience of the reader, descriptions of the equipment used in these studies have been relegated to this Appendix rather than mixing them with the biological sections.

## Intermittent Tape Recorder

After some preliminary recording of submarine sounds on magnetic tape, it became apparent that, for this project, it was most desirable to develop a simple way to record sound samples around the clock and through an entire annual cycle. Obviously many ways were available, including a literal continual recording, a procedure very costly in time and money. Even were the time spent in listening to the playback reduced by an acceleration of the tape speed to the limit of possible recognition, for the experiments in hand, at least it would still have been too costly in time. Because the preliminary test recordings indicated that the fish choruses proceeded very slowly and changed little over periods as long as an hour, the most practicable procedure seemed to be to arrange the equipment so that it would record samples of sound at intervals for 24 hours. As no inexpensive timer suitable for this purpose could be found on the market, a simple, but completely flexible, control mechanism was constructed which could turn the tape recorder on at a given time and record for any length of time required, repeating its action every hour or any fraction thereof. For much of the work it was found fully adequate to take a five-minute recording every hour through 24 hours or longer. The input of this device accepted a hydrophone (Gulton type) and a battery-driven, fully transistorized "preamplifier." No further amplification was required except that provided in the tape recorder. This input assemblage was used for all the other listening and recording devices that were employed.

The control device providing intermittent tape recording was driven by a good spring clock works, housed in an electronic utility box of suitable size and so arranged as to provide any type of repeatable tape recording that might be required. A spring drive was used in order to avoid any confusion in case of an interruption of electrical service. The clock hands were removed, and a disc was mounted on the minute-hand spindle. On the face of this disc a circular card was marked in minutes. To the rear face of the disc a small piece of thin metal was attached by screws. The shape of this piece of metal determined the length of the recording, which was easily determined by trial. When this piece passed under a light rod it lifted and held it until the end of the piece of metal passed from beneath it. This rod was so attached to a mercury switch, capable of carrying 110 volts AC, that the switch turned on as the rod was lifted by the metal piece on the disc. This action was repeated every hour. A pointer was mounted on the rod as an aid to keeping track of time. (See text fig. 25 for details.)

Because of the time lapse for the heating of the tubes in tape recorders, the circuitry necessary to control one properly for intermittent recording requires more than a simple on-and-off operation, in order to prevent a considerable waste of tape footage while the tubes heat to a functional temperature. This loss was circumvented simply by placing a delay relay in the motor circuit and another in the battery circuit of the amplifier.

## Audiogoniometry

With the equipment described above, it was possible to record conveniently fish sounds over a wide variety of places and times. However, all that this procedure provides is a knowledge that fish sounds are being produced within the range of the listening or recording equipment. Volume changes may suggest that the fish are near or far, but give no indication of direction, nor clear data in terms of distance. Dissatisfaction with this limitation led to the construction of a triangulating device (pl. 19, fig. 3) in order to help to locate the sound-producers, to obtain a measure of the number of groups and the size of each, and to determine their movements, if any. An ultrasonic echo ranger employing the Doppler effect was employed to attempt to estimate the number of silent fishes compared with the sound-producers.

The equipment herein described operates

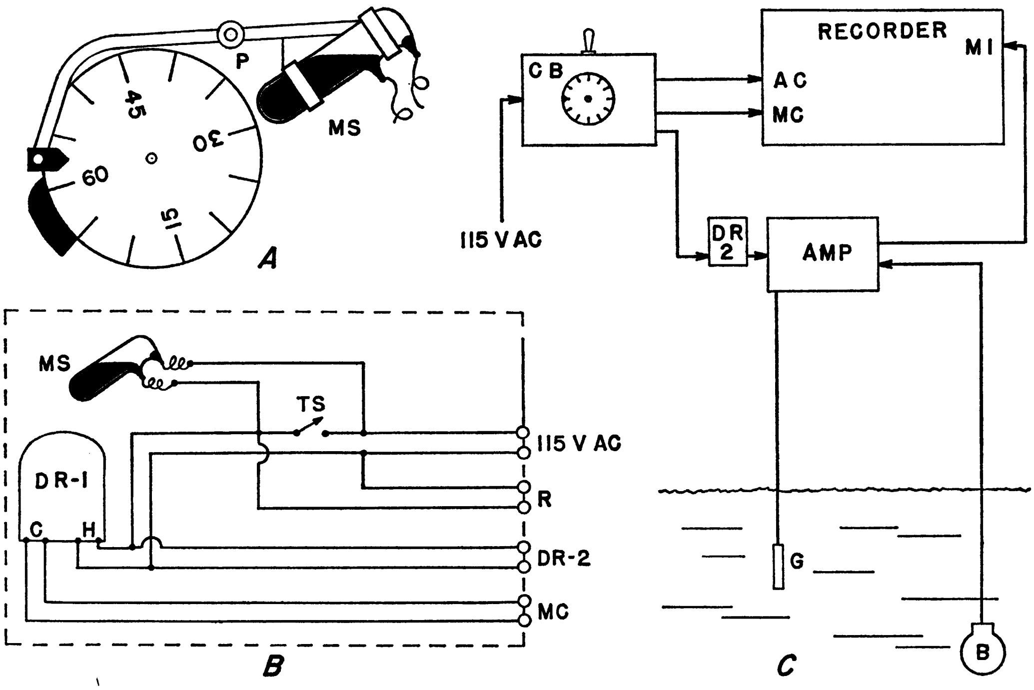


FIG. 25. Control device for intermittent recording. A. Control-clock switching mechanism. B. Schema of interior circuitry of control box. C. Block diagram of components.

*Symbols:* AMP, amplifier; B, barium titanate hydrophone; C, relay contacts; CB, control box; DR, thermostatic delay relay, 115 volts, normally open 30 seconds, 30-ampere contacts; G, German silver ground; H, heating element; MC, motor circuit; MI, microphone input; MS, mercury switch, 125 volts @ amperes, 20-degree tilt; P, pivot; R, magnetic tape recorder, TS, toggle switch, single pole, double throw, 115 volts @ 3 amperes.

as does a surveyor who, having a known side of a triangle, then measures the two angles it makes with the other two sides. The extent to which this instrument was useful and the cases in which it was not are fully discussed in the main section of the paper. Thus far it has been used at a permanent base, on a dock, but there is no reason why it could not be used from a semi-permanent base or even as a portable device that could be adapted to a properly anchored small boat.

A binaural VU meter was used to insure that the volume of sound delivered to each ear was matched and that the sounds on one night were on the same level as those on another.

Most of the mechanical details of this device are shown in plate 19, figure 3. The wooden frames which serve as supports for the vertical standard may be made in any convenient manner. Those here employed tipped up, so that the normally submerged hydrophones could be raised for servicing, by being swung to the left on hinges that attach it to the base board. The standards themselves are made of half-inch iron pipe, galvanized, and heavily painted on the submerged parts with a rubber-based paint. At the upper end a T joint was placed, which carries two short lengths of pipe; these are capped on their outer ends and act as a handle for rotating the vertical pipe. This carries the hydrophone assemblies on its lower end by means of a similar arrangement of pipes but uses longer cross pieces so that the hydrophones rotate on a circle 4 feet in diameter. The caps on the handle ends can be removed for sighting through the pipes to align this horizontal segment at right angles to the submerged support for the two hydrophones. Otherwise the handle is normally used to rotate the hydrophone assembly for balancing the sounds coming through the hydrophones to the corresponding ear.

The manner in which the hydrophones are attached to their support is shown in plate 19, figure 4. The rear side of the hydrophone is blocked out, as well as possible, by a thick piece of foam rubber. Although not clearly evident in the photograph, the hydrophone is turned away from the supporting arm by nearly 45 degrees, which helps to accentuate the separation of the sounds in each ear when one is ranging for a true bearing.

The calibration of this device was accomplished by securing a convenient under-water source of sound to a long pole which could be planted vertically in the bottom so that the source was submerged and stationary. This source was a common doorbell, with the gong removed. The actuator with its clapper was sealed in a jar so that the clapper struck the jar wall. Wires to the modified bell were brought through a seal in the jar cover which was properly weighted so that it would sink. The sound was a distinctive broad-band noise, with a large component near the frequencies produced by the fishes. Sighting the pole supporting the sounder through the "handle" of the triangulating unit and adjusting its position to the hydrophones, taking an aural bearing on the sound-producer easily adjusted the device as to its bearing, so that when a reading was made the handle pointed toward the source. An audiogenerator was used in this connection in order to determine the frequencies that were damped seriously under the conditions of this specific set-up.

A dial and pointer on top of the supporting wood frame gave a reading in degrees of angle from the base line connecting the two triangulating stations. A plumb-bob hung from the sighting handle enabled a close adjustment of the pointer over the dial above noted, which was a draftsman's cardboard compass card of 360 degrees, treated with plastic because of its exposed position. The pointer was a heavy plastic strip, with a dark line engraved on its lower surface for close reading. It was attached to a machinist's shaft collar for connection with the vertical support. Another shaft collar was attached to this support which rested on a bearing on the lower board of the wooden support, allowing smooth and easy turning of the whole rotatable assembly (pl. 19, fig. 3).

It was found that the two hydrophones, each feeding its output to the proper earphone of a binaural, ear-muffed headpiece, could be better balanced as to volume by ear than by a binaural VU meter.

Finding the position of a single sonic source by means of the audiogoniometer is sufficiently evident from the description of the device and operates on well-known principles. The data obtained from a multiple source or a wide sonic front, however, present a series of somewhat complex problems, the understanding of which bears heavily on the degree of success possible with this instrument. These involve both the position of the sonic source and the structure of the source, in addition to the frequency of the generated sound, the degree of its attenuation, and the degree of distortion inherent in any given location.

Obviously this device could not distinguish between a globular source and the end of a long-drawn-out one except by the backward displacement of the sound center, because, in ranging, the instrument would sense at least one side of the long mass. If the mass was at such an angle that only one station would range down the side of the mass, that one would range to its end or to the limit of the ability of the system to detect sound. This is very limited at the frequencies necessarily involved in this work based on fish-produced sounds.

Often, as would be expected, the sonic center is just halfway between the upper and lower limits of range, which suggests an essential uniformity throughout the sonic mass. When the sonic center is not so situated, it usually implies that some part of the mass is delivering more volume than the rest, which in turn implies an other-than-random distribution of the sound-producers. Possibly two or more groups producing sounds arranged in a certain configuration could, however, lead one to misinterpret the data as merely showing an ordered arrangement within one mass, whereas, in fact, there might be a number of fully separate groups. Such eventualities must always be guarded against when one is interpreting data supplied by such an instrument, and they indicate one of its limitations.

It should be borne in mind that the above discussion is based on a situation in which the edge of the sound production is reasonably abrupt. If, however, it is diffuse, the effect noted will not be found, and the whole point may be indeterminate. The appearance of a very sharp "end point" is in itself indicative of clear-cut limits to the sonic mass.

If the audiogoniometer is rotated beyond the positions under discussion, so that it faces away from the sonic mass, the sound may be heard again in both ears. If so, there should be no difficulty because, in addition to a slight reduction in intensity, the effects are quite different and the situation can be recognized by the following circumstances. When the hydrophones face the sound source and the standard is turned to the left or to the right, the sound delivered by the hydrophone that is approaching the source will become louder while the one retreating from it will become fainter, just as with a pair of human ears when the head is turned. When the hydrophones are facing away from the sound source however, the situation is reversed, so that the left earphone is being fed by the hydrophone on the right, and vice versa. Although the two hydrophones have changed their positions and because it is difficult to range with the low frequencies put out by fishes that are slightly directional, there is a certain advantage in this condition. These shifts are quickly and fully recognizable and constitute a useful check on the general location of very faint, hardly audible sounds.

Such complications as those described here are intensified when other positions or shapes of the sonic mass occur. There are, in fact, certain positions in which the sonic mass cannot be found from a fixed installation. If, for example, the sonic mass is below one or both of the triangulation stations, little can be done other than shifting to a more remote location. Also, if the sonic mass forms an annular band around one or both stations a similar difficulty is established.

The above account deals with hypothetical considerations. Such conditions, when they appear in encounters with real groups of sonic fishes and become problems, are discussed in the main body of the text, and some solutions are described.

## Exploratory Listening and Recording Devices

Handy portable equipment can be made of components that are used for the devices that are described above. The same hydrophone and the small, fully transistorized preamplifier, with a self-contained battery, and a pair of stethoscope earphones can be stuffed in a pocket for instant use. Two of the preamplifiers, in their boxes within the larger box to the rear, are shown in plate 19, figure 1, as components of the audiogoniometer receiver unit. The box measures 5 inches by $2\frac{1}{4}$ inches by $2\frac{1}{4}$ inches. The amplifier is a five-transistor audio-amplifier employing three stages of audio, driving a push-pull output stage, with a rated output of 360 milliwatts, powered by one 9-volt transistor battery. The output from the hydrophone goes to a subminiature jack via a shielded cable on the aluminum shielding box housing the amplifier and battery. Mounted on this box is an on-off switch, with volume control and an output jack into which the earphone plugs. A ground wire from the box, attached to a short rod of German silver, to be dropped overboard abolishes interference. As an alternate the earphone jack will accept an input plug from a small battery-operated tape recorder.

## Under-Water Speakers

Submersible speakers, such as are often used to pipe music into swimming pools, were used to deliver output from the audiogenerator when the transmission qualities of the area in respect to various frequencies were examined.