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Underwater noise caused by snapping shrimp

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Crangon californiensis

UNDERWATER NOISE

CAUSED BY SNAPPING SHRIMP

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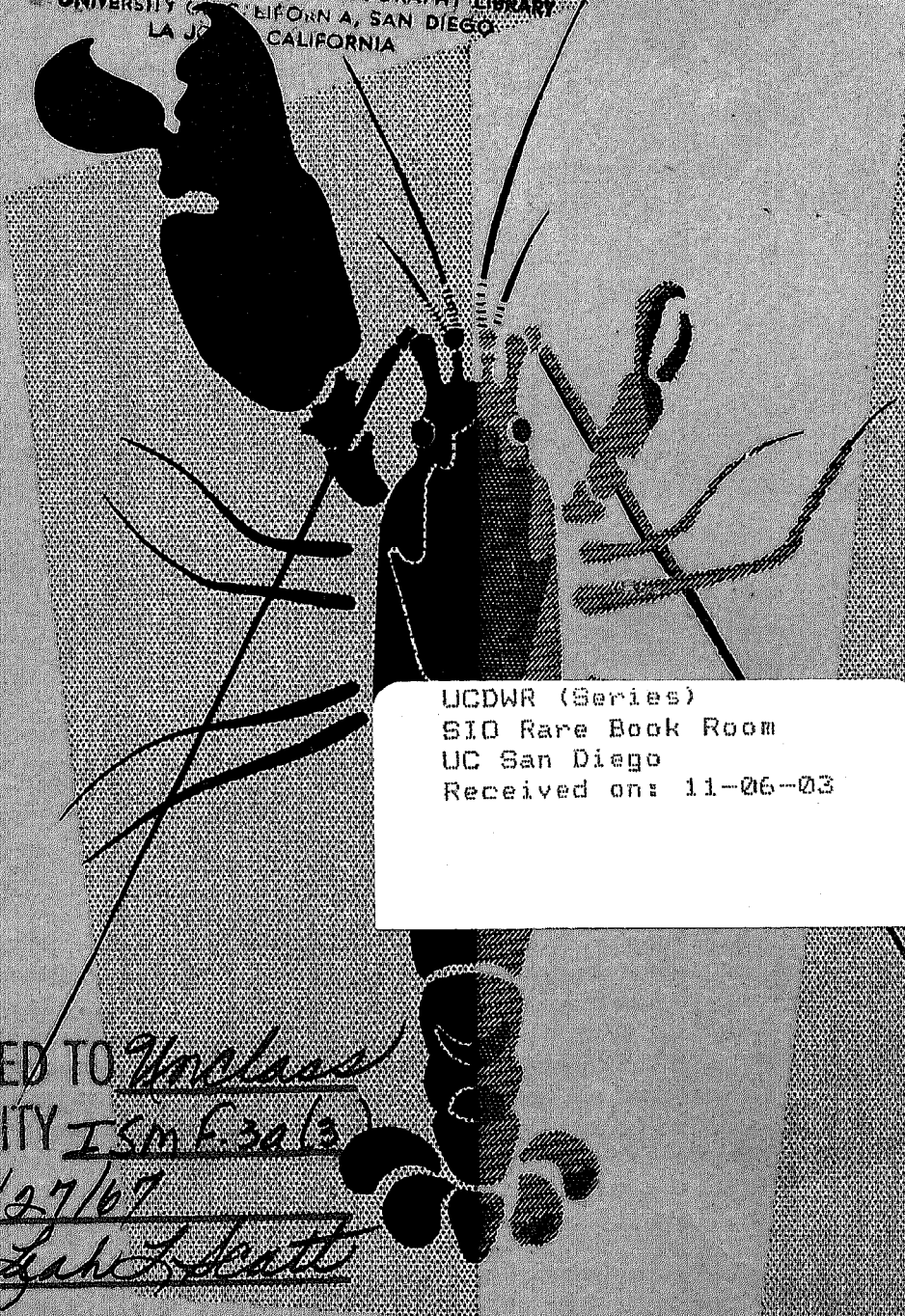
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UNDERWATER NOISE CAUSED BY

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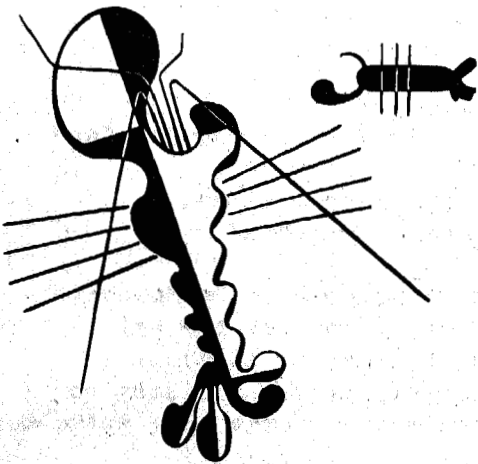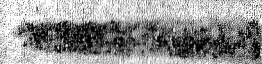
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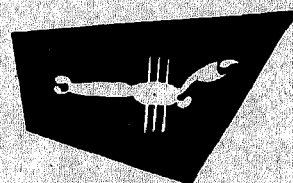
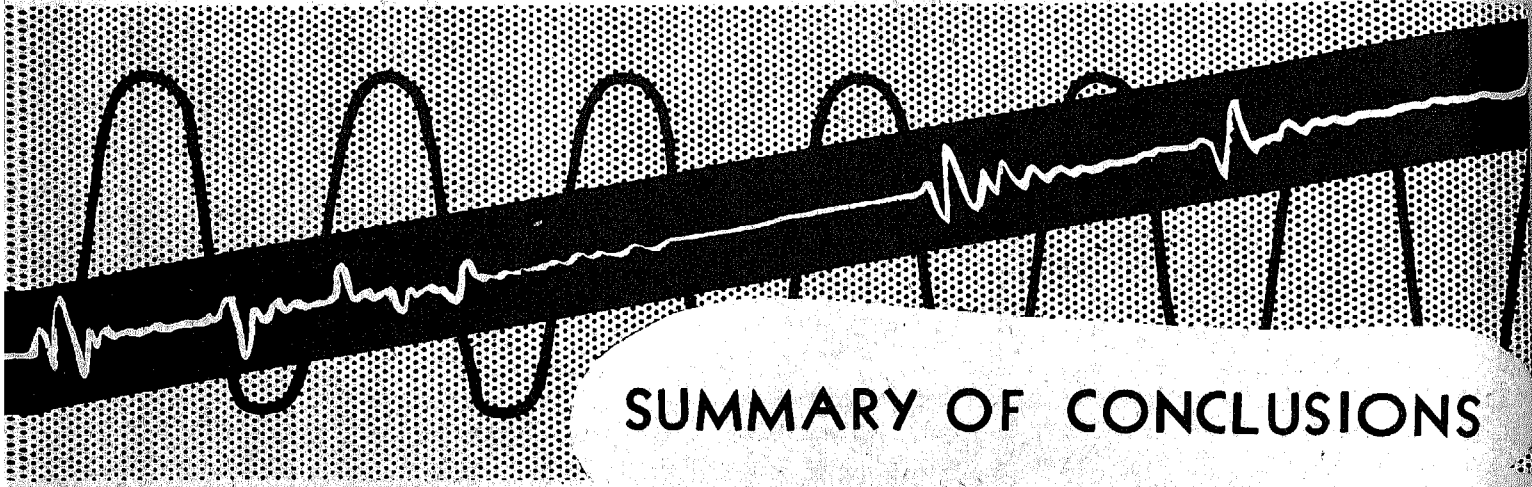NAVY DEPARTMENT • BUREAU OF SHIPS

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SUMMARY OF CONCLUSIONS

THE SNAPPING SHRIMP

1. Crangon (Alpheus) and Synalpheus are the two principal genera of noise-producing shrimp. These animals (not to be confused with commercial shrimp, which are noiseless) are about 3/4 inch to 1-1/2 inches long (Figs. 2 - 5). They have one enlarged claw which produces a vigorous snap when closed. Over a large colony there is a continuous succession of snaps which causes an intense crackling noise resembling the burning of dry twigs. With increasing distance from the shrimp bed, the crackle merges into a sizzle or a hiss.

2. Snapping shrimp can be expected throughout the oceans at locations where environmental conditions are favorable:

(a) Temperature - Limited by the 52° F winter isotherm. Some period of the year with more than 60° F also required.

(b) Geographical Distribution - Tropical and subtropical latitudes shown in Fig. 9; bounded approximately by 35° N and 40° S.

(c) Depth - Generally less than 30 fathoms (180 feet). The highest noise levels appear to occur in water between 30 and 150 feet deep.

(d) Bottom - Rock, coral, shell, weed, or other material providing ready concealment. Relatively uncommon on mud or sand bottoms which are free from sheltering material.

AMBIENT NOISE OVER A SHRIMP BED

3. The average spectrum of noise over a shrimp bed is shown in Fig. 18: At frequencies below 1 - 2 kc, shrimp noise is negligible except for very low sea states (0-½); and the spectrum is determined by water noise. From 2 to 20 kc shrimp crackle is predominant and nearly constant; its spectrum level measured in a 1-cycle band with a non-directional hydrophone is about -34 db above 1 dyne/cm^2 (0.02 dyne/cm^2) with a standard deviation of 5 db. Although no measurements

have been made above 24 kc, shrimp noise has been heard at frequencies up to 50 kc.

4. The noise produced by shrimp is continuous and independent of hydrophone depth. There appears to be no pronounced seasonal variation and but little diurnal variation, the level during the night hours being only a few db higher than during the daytime.

5. The noise level is highest directly over a shrimp bed and drops a few db at the edge. Beyond the edge it falls off rapidly; for a typical bed 1000 to 2000 yards in width, the noise level drops about 20 db in 2000 yards (Figs. 20 - 21). The total ambient noise level, however, includes both shrimp noise and water noise; its change with range therefore depends on frequency and sea state (Fig. 22). The dependence of a typical spectrum on range is shown in Fig. 23.

6. With the exception of sea state, ambient noise levels over and near a shrimp bed are essentially independent of oceanographic conditions.

7. A rough calculation of the transmission, based on certain simple assumptions, shows fair agreement with the observed transmission (Figs. 24-25).

TRANSMISSION OF SHRIMP NOISE

8. Over a typical shrimp bed at least 1000 yards in width, the sound output of a directional hydrophone appears to be independent of the hydrophone orientation, both in the horizontal (Fig. 27) and vertical directions. Indicating that the sound field is isotropic.

9. At the edge of the bed the noise level depends very strongly on the hydrophone bearing, a polar plot of the output showing a large lobe in the direction of the bed (Figs. 27-29).

10. With increasing distance from the edge, the lobe shrinks and narrows rapidly as the shrimp crackle is dominated by water noise. The front-to-back discrimination of a JK hydrophone at 20 kc is shown as a function of range in Fig. 28.

EFFECT OF HYDROPHONE DIRECTIONALITY

11. The critical-band theory of masking applies to shrimp noise as well as to deep-sea background noise and to self noise. Consequently, the spectrum levels of these noises are direct measures of their masking properties at any frequency. That is, the difference in spectrum levels is equal to the difference in recognition levels for a signal at a given frequency, when masked by the various noises. Figure 18, therefore, shows the masking effect of shrimp noise relative to water noise; at 20 kc the masking relative to sea state 2 water noise is about 27 db.

MASKING OF UNDERWATER SOUNDS BY SHRIMP NOISE

A. Sonic Listening*

12. Relative to water noise, shrimp noise over a bed very effectively masks signals above 2 kc. The relative masking is greatest directly over the shrimp bed, decreases rapidly at the edge of the bed, and is negligible 2000 yards or more from the bed. Below 1 kc the masking effect of shrimp noise is negligible except, possibly, for very low sea states (0–½).

13. In the presence of water noise, many ship, submarine, and torpedo signals tend to be recognized by strong components below 1 kc.   Even when recognition does occur at higher frequencies, a small increase in signal level will usually enable the low components to be recognized. In either case, therefore, shrimp noise has little masking effect relative to water noise and may generally be considered unimportant in sonic listening. Should the listening be confined to frequencies above 2 kc, however, shrimp noise will affect the detection of sonic signals very adversely.

14. Self noise on a submarine underway is so strong at the low frequencies that it tends to shift recognition toward higher frequencies. Above 2 kc shrimp noise may produce significant masking relative to low self noise (1 – 2 knots). However, for a creeping submarine most listening contacts are obtained at such long ranges that the greater attenuation at the higher frequencies shifts recognition back to low frequencies where shrimp noise is unimportant. At higher speeds, self-noise increases and at 8 knots the self-noise level is usually above shrimp noise at all sonic frequencies. Thus under most types of listening conditions, shrimp noise probably does not affect maximum sonic listening ranges.

15. Since the recognition of sonic signals tends to occur below 1 kc, a 1.5-kc low-pass filter may at times be advantageously used to exclude shrimp noise at higher frequencies without affecting the recognition of signals. However, these high frequencies, when they can be heard, give the best bearing accuracies; even when shrimp noise is present, high signal frequencies may become audible at short range. For this reason, a low pass filter, while desirable for reducing operator fatigue and in making possible a higher over-all amplification, should not be relied upon to the exclusion of listening without filters.

B. Supersonic Listening *

16. For supersonic listening the masking effect of shrimp noise, relative to other background noise, is given by the difference in their spectrum levels at the main supersonic frequency. Relative levels for shrimp noise, water noise, and self noise are shown in Fig. 33 for JK gear operating at 24 kc.

17. Shrimp noise has a strong masking effect at supersonic frequencies, relative to water noise or low self noise. For fixed listening gear or for a ship listening at low speeds, shrimp noise may therefore be an important factor in limiting maximum listening ranges. At high ship speeds, shrimp noise produces negligible additional masking. At 24 kc, for example, shrimp noise may be neglected at ship speeds above those given in Table VI (page 63).

C. Supersonic Echo Ranging*

18. For supersonic echo ranging from a surface ship at standard search speed, shrimp noise may be neglected, since it is of the same order of magnitude as self noise (Fig. 33). At low speeds or for fixed echo ranging gear, self noise is lower and shrimp noise has the same masking effect, relative to other backgrounds, as for supersonic listening provided the echo is recognized against a background of noise and not reverberation; in general, this will occur only if the echo has a large doppler. For echoes with small doppler (less than 5 knots at 24 kc) the dominant background is bottom reverberation (which is high over areas favorable to shrimp) and shrimp noise is unimportant.

19. The snap of an individual shrimp consists of a single main peak accompanied by several smaller pulses, (Figs. 34 – 36). The whole snap usually lasts from ½ to 1 millisecond. The initial direct snap is followed by a surface-reflected snap of opposite phase.

20. The pressure level of the main peak at 1 yard, measured with a system whose response is flat from 2 to 50 kc, is about 50 db above 1 dyne/cm^2 (300 dynes/cm^2). This is about 40 db above the rms level in the same band, observed over a large shrimp bed.

21. The spectrum of a single snap, derived by a Fourier analysis, agrees qualitatively with the average spectrum over a bed (Fig. 37).

ANAYLSIS OF SINGLE SHRIMP SNAPS

22. Shrimp noise is predictable because: (a) noise-producing species are widely distributed within their geographical range (Figs. 9 – 15); (b) they are confined predominantly to specific bottom types and water depths; (c) the populations are stable; and (d) the noise produced is continuous and of uniform characteristics.

PREDICTION OF SHRIMP NOISE

23. A few other animals are known to make snapping sounds but with few exceptions these are incidental to feeding, creeping, or preening, and the noises are of much lower intensity than shrimp crackle.

BIOLOGICAL SOUNDS SIMILAR TO SHRIMP NOISE

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* SEE FOOTNOTE ON PAGE 6.

7

UNDERWATER NOISE CAUSED BY SNAPPING SHRIMP
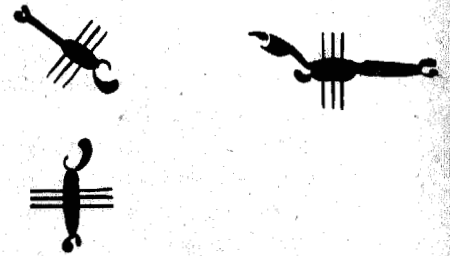
1 INTRODUCTION

One of the factors which limits maximum listening and echo ranges is the background of unwanted sound against which the wanted signal must be detected. In listening, this background is always noise; in echo ranging, it is either noise or reverberation, the latter arising from scatterers at the surface, the bottom, and in the body of the ocean. There are many types of background noise and a brief description of these will be useful in evaluating the importance of shrimp crackle.

1.1 BACKGROUND NOISE IN GENERAL

A convenient classification of background noise is shown in Fig. 1. Airborne noise comprises all unwanted sounds which reach the operator by other means than over the receiving stack. It may consist of speech, noise from other sound gear, gunfire etc. An effective countermeasure is the use of increased gain in the receiver. Amplified noise is delivered by the receiver, along with the wanted sound, and may be divided into two main classes, self noise and ambient noise. Increased gain increases this noise as well as the wanted signal, and is thus not an effective countermeasure.

Self Noise includes (a) circuit noise arising in the equipment itself, (b) noise caused by the motion of the hydrophone through the water, and (c) ship sounds from the vessel bearing the hydrophone.

Ambient Noise is noise from the surrounding ocean, existing independently of the hydrophone and ship. It comprises (a) water noise (surface waves, whitecaps, breakers, surf, etc.), (b) biological noise of which shrimp crackle is usually the most important, and (c) traffic noise, arising from nearby ships, harbor activities, etc.
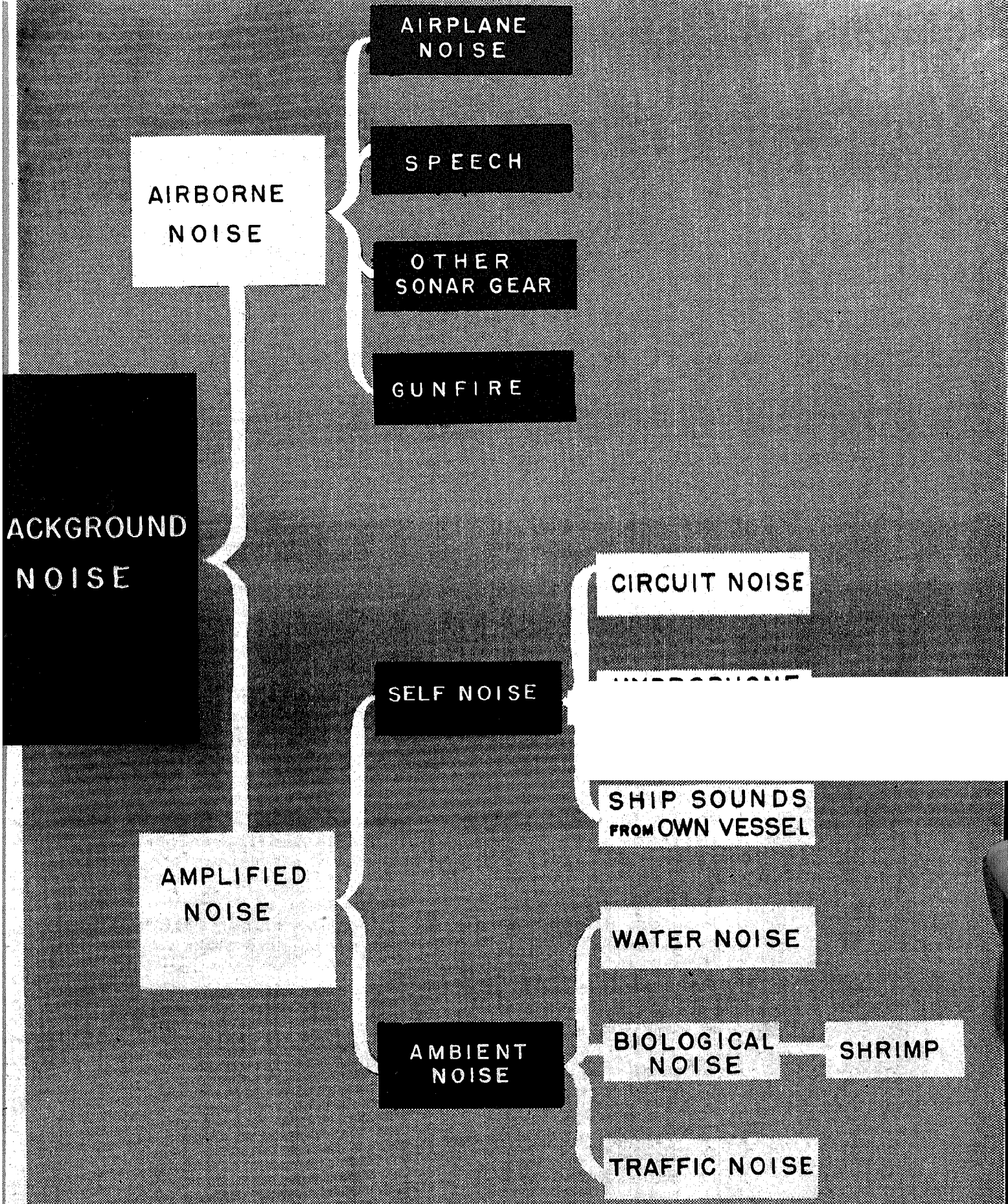
FIGURE I

DIAGRAM OF BACKGROUND NOISE

Various of these noises will be considered later in more detail and compared with shrimp crackle.

1.2
EARLY HISTORY
OF SHRIMP NOISE

Before discussing recent scientific studies of shrimp noise, it is of interest to review briefly some of the early references to this phenomenon:

1. Mariners operating small vessels in tropical waters have sometimes reported hearing strange crackling noises within the hold of their boats. The most common explanation given was that the noise was caused by shipworms (teredos) working in the ship's timbers, or that it was due to superficial fouling growths on the hull. It is now known that the crackle of nearby shrimp populations is audible through the hull and probably forms the basis for these stories.

2. The U. S. Coast and Geodetic Survey encountered troublesome noises while engaged in radio acoustic ranging off Oceanside, California, in 1933-34. The sound was described as being similar to static crashes or to coal rolling down a metal chute (Appendix B of Ref. 6 – see Bibliography, p. 73). No explanation could be found for the noise though efforts were made to correlate it with meteorological and hydrographic conditions, and with road traffic on a highway close to the coast. Subsequent surveys have demonstrated that shrimp crackle is conspicuous in the area where these observations were made and is loud enough in some spots to be audible above the surface during calm water.

3. A U.S. submarine operating in Macassar Strait off Balikpapan early in 1942 circled an area from which a strange crackling noise was emanating (Ref. 2). In reporting this experience, it was suggested that "the Japs may have some newfangled gadget that they drop." Snapping shrimp are common in the Balikpapan region and the type of bottom and depth of water off Balikpapan form a favorable habitat for them. Other reports from submarine officers strongly suggest that noises often encountered in coastal waters in lower latitudes are attributable to shrimp.

4. Sounds were heard through the hull of a small vessel in Beaufort Harbor, N. C., and in calm water off Cape Hatteras. These sounds were described as similar to that produced by "dragging a blackberry vine" (Ref.4) and no doubt were also produced by snapping shrimp. These animals are now known to be very noisy in Beaufort Harbor and occur also in offshore waters at Cape Hatteras (Refs. 7, 14).

To summarize the above as well as other data, it is apparent that the crackling noise has been erroneously attributed to various other phenomena. Some of these are (a) rolling pebbles, (b) surf, (c) volcanic or terrestrial disturbances, (d) shipworms working in a wooden hull, (e) superficial fouling on the hulls of ships, (f) noises due to expansion or contraction of the ship's structure,

and (g) clapping of oyster or clam shells.

Recordings of shrimp noise and other underwater sounds are available for issue. (See Ref. 3 which contains a complete script for such a recording.)

Biological sounds similar to shrimp noise will be discussed in Section 9.

Early in 1942 investigations of underwater sounds were begun by UCDWR in the San Diego region. From the beginning of field tests a characteristic crackling noise of great intensity was observed. It was encountered first at various locations off Point Loma and in the San Diego Yacht Harbor and was later found in coastal waters off La Jolla, Oceanside, and other places on the southern California coast. The origin of the noise was shrouded in mystery during the first year of investigation, though considerable progress was made in determining its spectral characteristics and in establishing its presence in local coastal waters over rock bottoms, around piers, and in harbors (Ref. 3).

Early in 1943 it was finally established through laboratory tests of various animals and through field studies in different habitats, that the crackling noise results from the claw snapping activities of certain small crustaceans known as snapping shrimp (Ref. 6). The snapping shrimp should not be confused with the common commercial shrimp, which is usually much larger and produces no noise. The sharp "snap" produced individually by these animals has long been known but had hitherto been considered only a biological curiosity and not a source of significant underwater background noise.

The sound emitted by an individual shrimp is a single sharp "snap" or "crack" produced only occasionally. It is the combined snapping of the members of a large population that results in a continuous loud underwater crackle. In the sonic frequencies the crackling sound is comparable to the explosive noises produced by brisk burning of large quantities of dry twigs. Similar sounds were obtained by heterodyning supersonic frequencies in the 20-50 kc region down to the audible range. With increasing distance from the source the sounds merge into a sizzle and finally a hiss without distinct cracks.

The explanation of the local mystery also shed light on a number of qualitative reports of the type discussed in the previous section. It ultimately made possible the prediction of this type of ambient noise in other areas.

Surveys of ambient noise made since 1943 in widely separated areas in the Pacific and Atlantic Oceans have confirmed the predicted widespread distribution of shrimp crackle. In addition, local surveys have been made in the San Diego area to establish more

exactly the spectrum and the transmission of shrimp noise. Paralleling the acoustic investigations, biological studies and an intensive survey of the literature have been carried out.

1.4
PURPOSE OF THIS REPORT

This report is a summary of the studies that have been made of the underwater noise of snapping shrimp. The specific objectives of the investigations have been:

1. To identify the origin of the crackling noise.

2. To ascertain its distribution and the factors that control this distribution.

3. To determine its spectral characteristics.

4. To determine its transmission as an underwater sound.

5. To ascertain its predictability in local and remote areas.

6. To determine its masking effect on ship and submarine sounds and on supersonic echoes.

Objective 1 was achieved in 1943 as explained in the Section 1.3. Information on the remaining objectives has been steadily accumulated since then. Many of the results have been reported in detail, together with summaries of the data. References 13, 18, and 19 are of particular value.

The purpose of this report is to provide a general overall summary of the results reached to date in the studies of shrimp noise. Section 2 is concerned with the biology and distribution of snapping shrimp; Sections 3, 4, 5, and 7 describe the acoustic properties of shrimp crackle; Section 6 deals with its masking effects; Section 8 covers the predictability of shrimp noise, and Section 9 describes other similar underwater biological sounds.
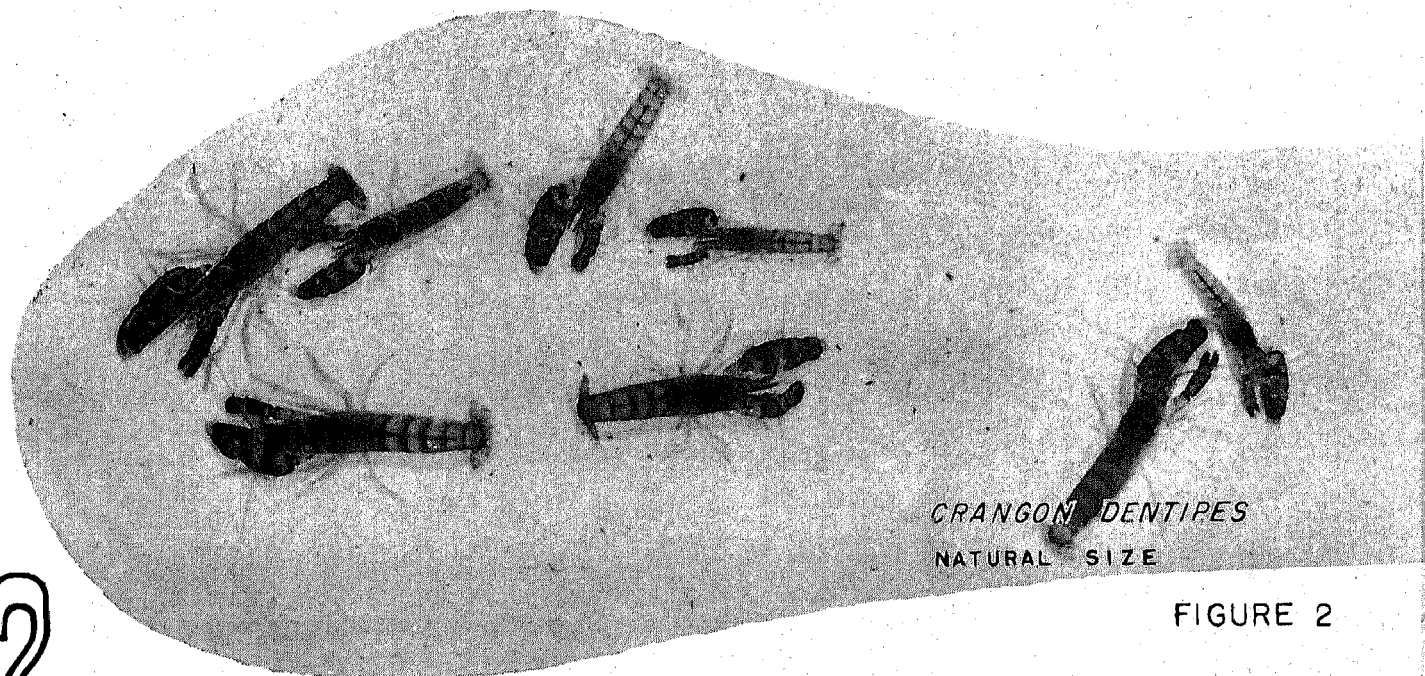
CRANGON DENTIPES
NATURAL SIZE

FIGURE 2

2 THE SNAPPING SHRIMP

2.1 BIOLOGICAL RELATIONSHIPS

Technically, the snapping shrimp are related to the commercial shrimp, which they resemble in general appearance. In life habits and in details of structure, however, they are very different from the common shrimp. The snapping shrimp family (Crangonidae or Alpheidae) comprises about 27 genera and numerous species. Of these, only the species of two genera, viz., Crangon (also called Alpheus by many authors) and Synalpheus are capable of vigorous snapping. In the literature there are recorded about 215 species of Crangon and 150 species of Synalpheus. Three species of these genera are shown in Figs. 2, 3, and 4.

2.2 THE SNAPPING HABIT

Biological studies of most species of these two genera have been based on preserved specimens; consequently the snapping of many species has not been observed directly. The claw structure, however, indicates that all the species do snap to some extent. The species range in size from about three-fourths of an inch to a giant species, C. strenuus, attaining a length of three
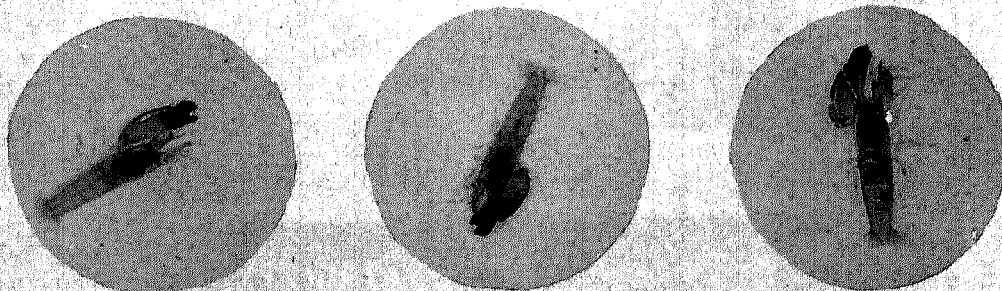
FIGURE 3
SYNALPHEUS LOCKINGTONI   NATURAL SIZE
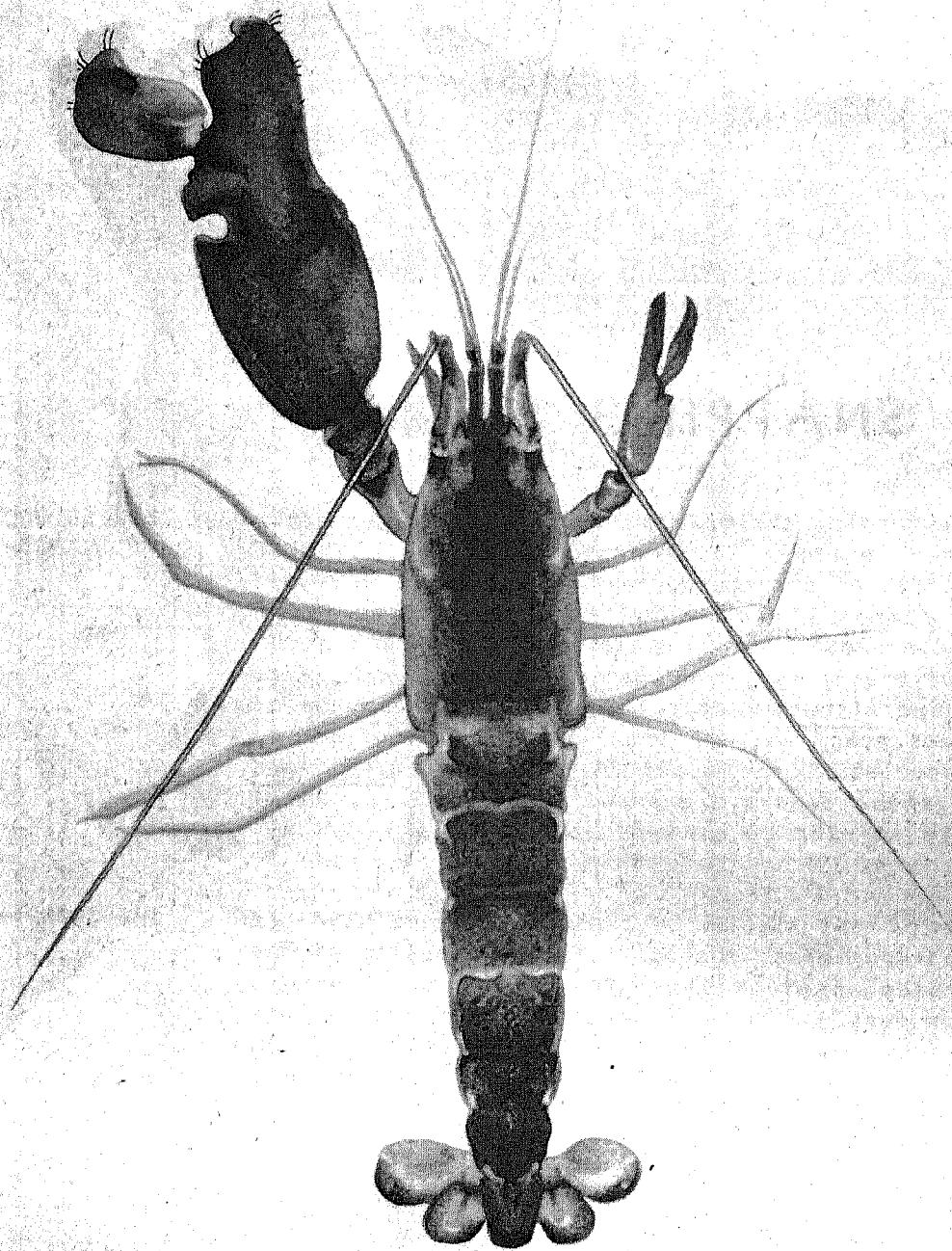
FIGURE 4   Crangon californiensis
4 X

inches, but it is clear that size is not directly correlated
with the intensity of the noise produced. Direct sound measure-
ments of isolated specimens indicate, for example, that
Synalpheus lockingtoni produces a louder snap than its larger
relative Crangon dentipes (see Section 7.3). The habit of
snapping is associated with defensive and offensive activities.
In closing the snapping claw, a vigorous jet of water is pro-
duced by means of a plunger arrangement described in Sec.2.3.

This sudden gush of water serves to frighten away enemies
approaching too near. The antagonist may also be driven away
or sometimes killed by a blow of the small hammer, but the
biological significance of the accompanying loud sound is not
clear.

Shrimp noise is clearly audible to the unaided ear in the air,
when the specimens are dry or in a small amount of water. The
crackle from a shrimp bed can also be faintly heard during a
calm sea. Some idea of the loudness of the snap may be gained
from the following remarks by W. E. Loomis:

"I collected a number of snapping shrimp at a coral reef at
Point Cruz, Guadalcanal. To my inexperienced eye they appear
to be identical to a specimen given to me by Martin Johnson.
When taken their color was brilliant red. They were collected
in a 75 mm shell case and a half a dozen of them in two inches
of water when held at arm's length sounded like corn popping
over a fire. Their activity was truly amazing."

2.3 THE SNAPPING MECHANISM

The sound producing mechanism consists of one disproportionately
large hard appendage comparable to one of the large "claws" of
the lobster. Figure 5 shows an enlarged drawing of the snapping
claw of Crangon californiensis, a vigorous snapper (cf. Fig. 4).
In some species, the snapping claw is nearly as large as the body
of the animal, giving ample room for development of strong
snapping muscles. A movable hard "finger" (c) is jointed near
the outer end of the "palm" (a) of the claw forming a forceps-
like arrangement. The snapping sound is produced by the vio-
lent impact of this finger on the opposing tip of the claw. On
the inner side of the finger is a plunger-like structure (d)
which fits into a socket (e) in the palm. Leading forward from
the socket is a groove through which the water escapes when the
plunger is suddenly forced into the hollow. When the finger is
raised, the plunger is withdrawn from the socket, and it has
been held by some observers that the noise is produced by this
action, similar to the "pop" heard when a cork is suddenly
pulled out of a bottle. The biological function of the plunger-
socket arrangement, however, is the production, not of sound,
but of the water jet mentioned above. It may also aid in pre-
venting dislocation of the finger when it is violently snapped.
The plunger-socket device is present in both Crangon and Synalpheus.

In all species of <u>Crangon</u> there is also a sucking disc on tl
outer side of the finger near its point of attachment (b in Fig.5
When the finger is fully raised, this disc contacts precisely
similar disc on the palm so that the two are firmly in conta(
when the finger is in position to snap.   These suckers serve ;
a trigger to hold the finger back and extra muscular tension mu;
be exerted in breaking the contact.   This in turn increases tl

FIGURE 5
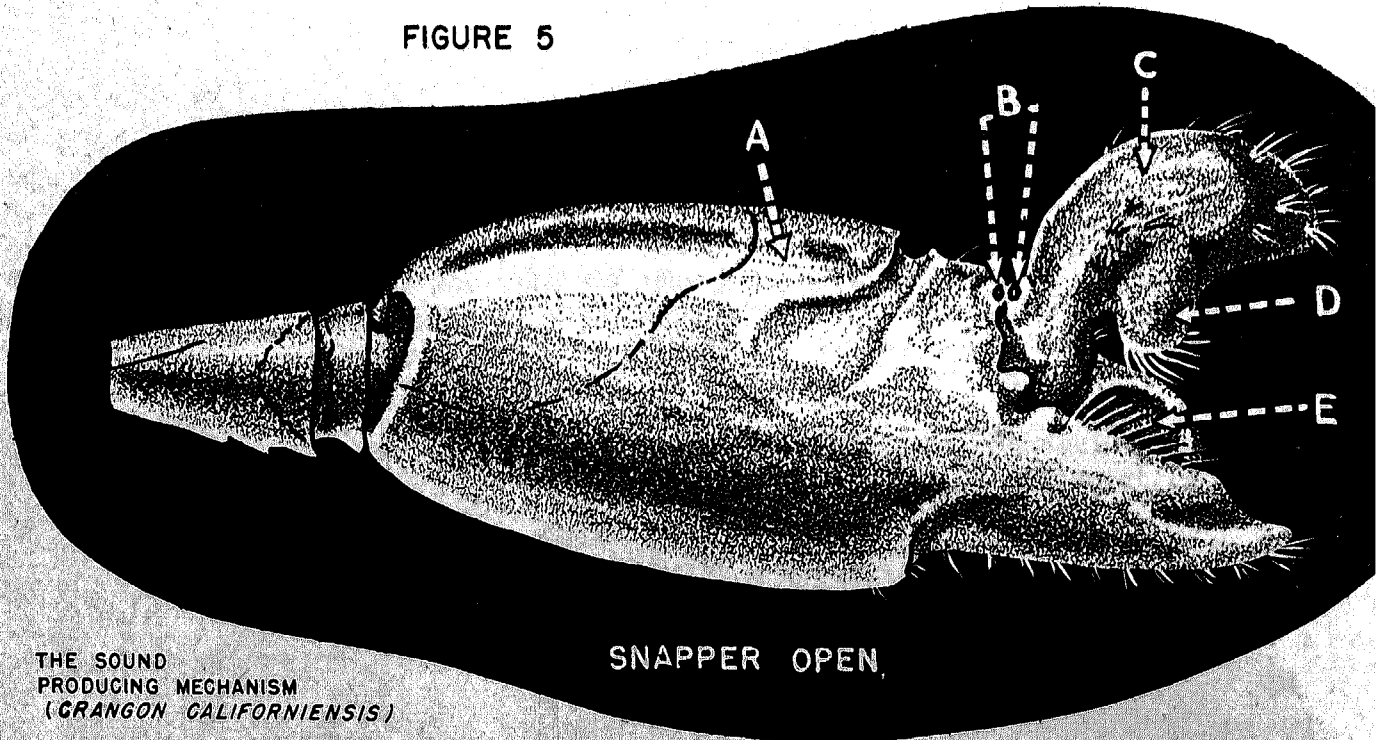
SNAPPER OPEN,

THE SOUND
PRODUCING MECHANISM
(*CRANGON CALIFORNIENSIS*)

A. PALM   D. PLUNGER
B. SUCKERS   E. SOCKET
C. FINGER
  9 Times natural size
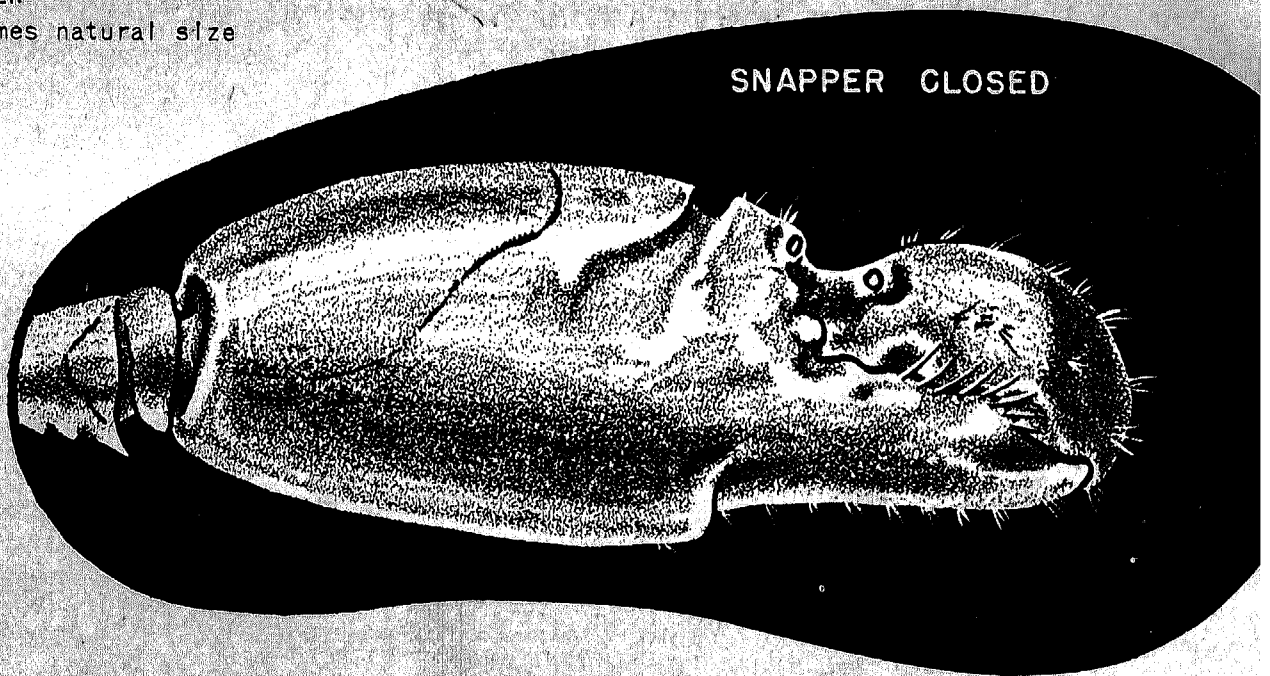
SNAPPER CLOSED

force of the impact. The suckers are absent in Synalpheus, but it is probable that some temporary locking device exists in the hinge.

It is of passing interest to note that the snapping claw may be either right or left. If it is lost through injury the inconvenience is only temporary because a new one is promptly grown at the next moulting when the shrimp sheds its old shell. In this process of renewal, however, the original large claw is replaced by a small one, while the former small pinching claw is enlarged and becomes the new snapping claw.

2.4 LIFE HISTORY

The fertilized eggs of snapping shrimp are carried by the adult until they hatch as free swimming larvae about one-tenth inch in length. After a period of drifting with the water currents, the larvae settle to the bottom and assume the structural characteristics and habits of the adults. No snapping is possible until the adult stage is reached. The free floating period serves to disperse the animals widely and they thrive after settling to a bottom where living conditions are favorable for adults. From what is known of a few species, there appears to be a long breeding season in low latitude waters, but near the higher latitudes the breeding season is shorter.

The duration of life of the individual is not known, but some adults collected at La Jolla, California, in December 1942 and January 1943 were still thriving in an aquarium after 22 months of captivity. These facts are mentioned because the maintenance of overlapping generations is no doubt important in explaining the seasonal continuity of the crackling sound. A short breeding season and a short span of life would result in a considerable variation of the adult population and this in turn would be expected to cause an appreciable seasonal variation in shrimp noise. No seasonal variation of this nature has been observed. It must be noted, however, that a change of only 3 db in sound level may signify a two-fold change in shrimp activity.

Observations have not revealed any swarming or migratory movements such as characterize many other marine animals during the breeding season. The snapping shrimp are gregarious to the extent that large numbers are found within a given area favorable to them, but commonly the members of a given species are found either in pairs or as solitary specimens in isolated retreats within the area. The occupants of these retreats make a noisy protest when an intruder approaches.

2.5 TYPE OF HABITATS

The species of Crangon and Synalpheus are bottom-living animals and, though capable of swimming, they rarely do so in the adult stage. Because of their habit of seeking ready-made or easily maintained burrows, they seek concealment in holes provided by
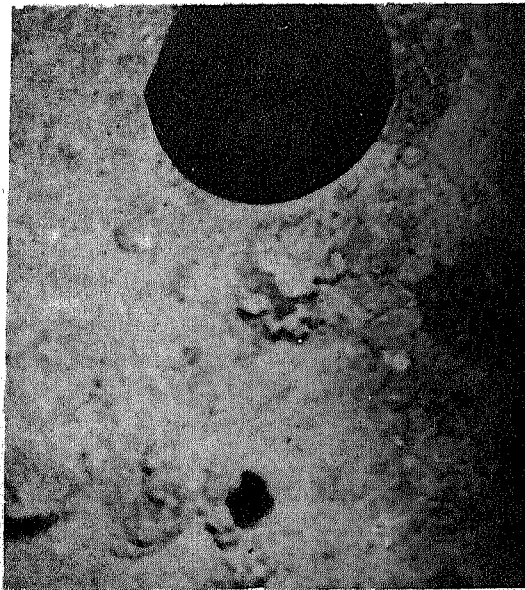
coral, stones, shell, calcareous algae, a d other solid objects (Fig. 6, 7, 8), and are fou d preponderantly on the e bottom types. In the Ea t Indies they are espec - ally fond of bottor s covered by the calcareo s alga Lithothamnion. Th / commonly live among t e branches of sea fans, among the roots of ee grass and other sea weed and among mussels, ba - nacles, and other sub - stantial fouling organ - isms on wharf piles ar other solid structures Some live in the channels and pores of living sponges.

Apparently they do not normally live in any significant number on extensive sand or mud bottoms without some sheltering mat erials. However, some species (for example Crangon califor niensis) tolerate muddy conditions among eel grass, etc., ar have been dredged with mud, particularly in harbors known t be littered with solid debris. Crackling is intensive in som of these situations. A European species Crangon ruber, is sai to be "not uncommon" on the mud bottom off Ram's Head nea Plymouth, England, and in the Mediterranean. It is apparentl a weak snapper.

FIGURE 7
COBBLES AND ROCK   San Diego

COBBLES   San Diego

Some species that normally live on the bottom have been found in masses of floating sea weed. However, it is doubtful whether populations existing under these conditions are large enough to produce continuous crackling noise. One species occurs in clumps of the floating pond weed _Pontederia natans_ where this plant is carried into the sea at the mouths of the African rivers, Leybar, Thiank, and Dakar Bango. Another species (_Crangon pachychirus_) lives in tubes which it constructs from matted threads of algae.

Crangon ruber and _Crangon macrosceles_ have a tendency to desert their burrows to swim freely in the water where they have been caught in trawls. No underwater sound observations have been made of the noise produced by these species.

2.6 DEPTH DISTRIBUTION

Data on hauls of snapping shrimp, taken at various depths, are scattered widely throughout the biological literature (REF. 1). Table I shows the distribution of species of _Crangon and Synalpheus_ reported from five depth zones, 185 different species being represented. The table includes only trawling and dredging collections from the bottom.

TABLE I

DISTRIBUTION OF 185 SPECIES OF CRANGON AND SYNALPHEUS REPORTED FROM FIVE DEPTH ZONES

BOTTOM DEPTH ZONE	NUMBER OF TIMES SHRIMP REPORTED	NUMBER OF SPECIES
0 – 30 fm	418	171
30 – 70	101	59
70 – 100	5	4
100 – 250	14	9
OVER 250	7	4

While most of the species are reported in 0-30 fathom water, it cannot be concluded that Table I gives the actual distribution, since it is not possible to know precisely how uniform the effort and efficiency of collecting have been in various zones. Presumable it has been roughly comparable with respect to number of hauls in the first two zones. This is supported by a summary of 3483 hauls by various expeditions that have contributed to the study of these animals. An analysis shows that 17% and 20% of the hauls were taken respectively in the 0-30 fm and 30-70 fm zones. The remainder were in deeper water. Thus the table gives a rough idea of the depth distribution and indicates that the largest populations are in the 0-30 fathom zone.

Acoustic data discussed in Sec. 3.3 support this belief. It is probable that the deeper ranging species also have their maximum concentration in depths less than 30 fathoms and that the typically deep water forms do not occur in sufficient concentrations to produce a continuous crackle like that heard in shallow water. A very sparse population of shrimp would make itself known only by intermittent cracks that fail to enable a sustained sound measurement.

2.7 GEOGRAPHICAL DISTRIBUTION

The species of Crangon and Synalpheus are confined to coastal or shallow water throughout the tropical and subtropical regions (Fig. 9). This type of distribution (REf. 13) is no doubt governed by water temperature but precisely how this operates is not yet clear. In general, the 52°F winter surface isotherm marks the approximate northern and southern limits of their continuous range. The thermal control of distribution must, however, be a complex one. It is not accomplished simply by the temperature dropping to 52°F but rather by the duration of temperatures at or below this level during the winter. Certain critical periods of life such as spawning and larval development appear to require a considerable period of warmer temperatures, near or above 60°F during the summer. The isolated populations lying outside of the 52°F isotherms are probably governed by favorable local conditions. Examples of this sort are seen at the north end of of Honshu near Vladivostock and along the coast of Ireland (Figs. 10 and 13).

Figures 10 - 15 show the localities where snapping shrimp have been collected one or more times. The data presented on these charts are compiled from all available publications dealing with snapping shrimp and show the widespread distribution of the animals. (See Ref. 1 for an extensive bibliography dealing with snapping shrimp.) The arrows denote specific localities where species of either Crangon or Synalpheus (or both) have been reported but do not necessarily indicate concentration of populations. In the strictly tropical and subtropical waters, the distribution of shrimp is believed to be continuous within the areas where depth and type of bottom are favorable. This belief is supported

GEOGRAPHICAL RANGE OF SNAPPING SHRIMP *(CRANGON and SYNALPHEUS)*

SHRIMP ARE FOUND WITHIN THE SHADED AREA WHERE DEPTH AND BOTTOM CONDITIONS ARE FAVORABLE.
THE ARROWS DENOTE LOCALITIES WHERE AMBIENT NOISE HAS BEEN MEASURED.

FIGURE 9

FIGURE 10
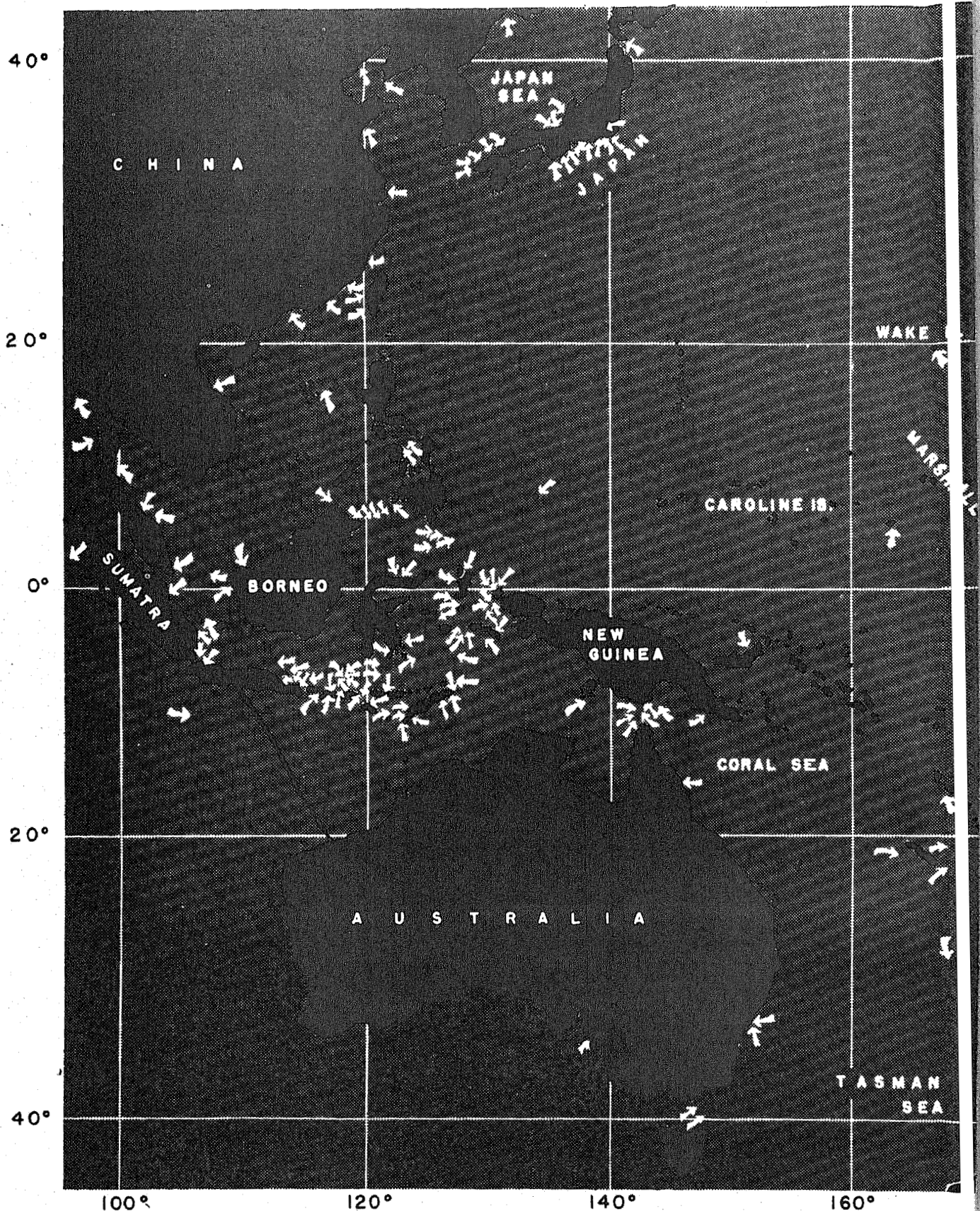
LOCALITY CHART SHOWING SHRIMP RECORDS—EAST INDIES AREA

THE ARROWS ON THIS AND THE FOLLOWING MAPS INDICATE LOCATIONS WHERE NOISE-PRODU
SNAPPING SHRIMP (SPECIES OF *CRANGON* AND *SYNALPHEUS*) ARE KNOWN TO OCCUR.

22
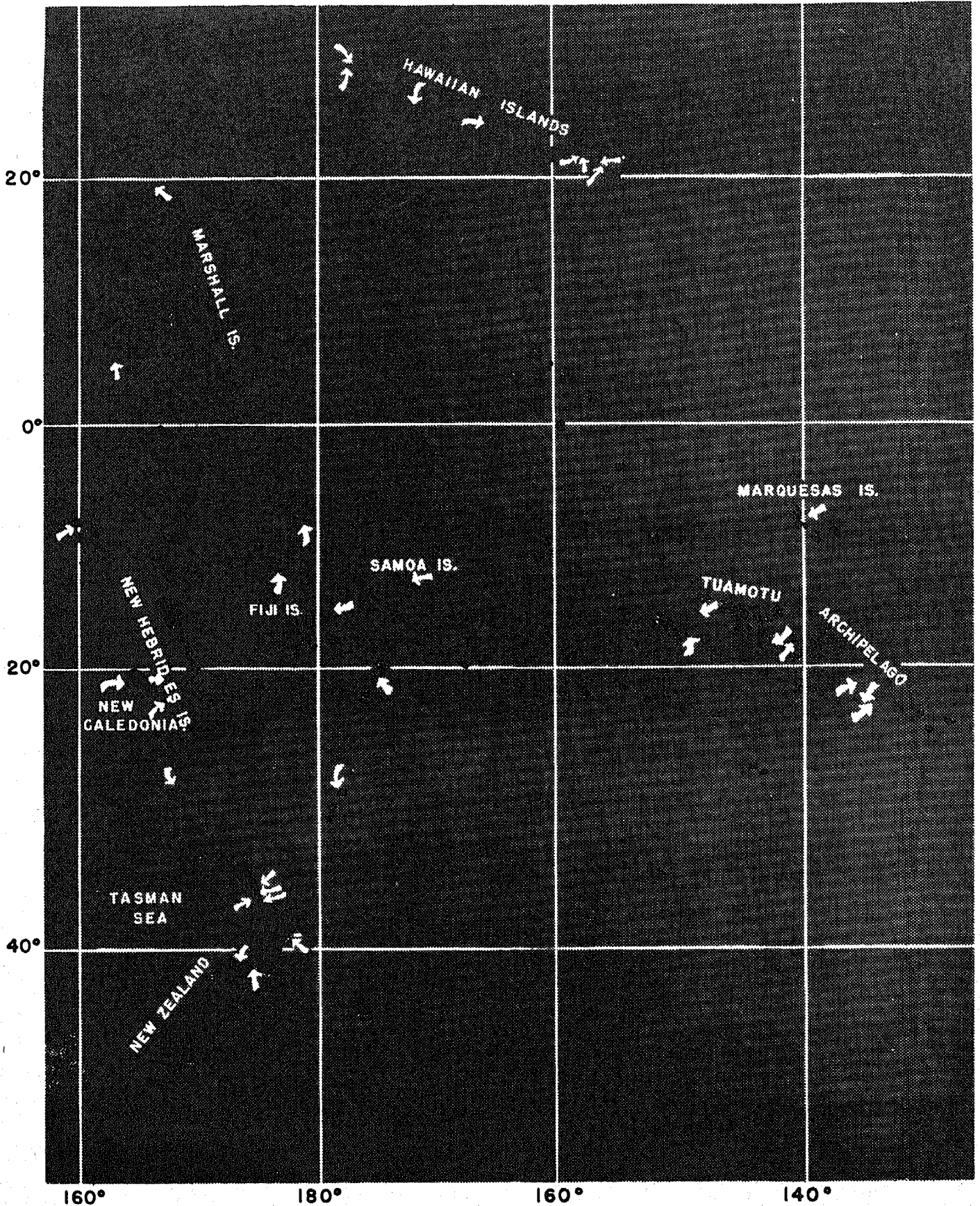
FIGURE 11

LOCALITY CHART SHOWING SHRIMP RECORDS—CENTRAL AND SOUTH PACIFIC AREA

FIGURE 12
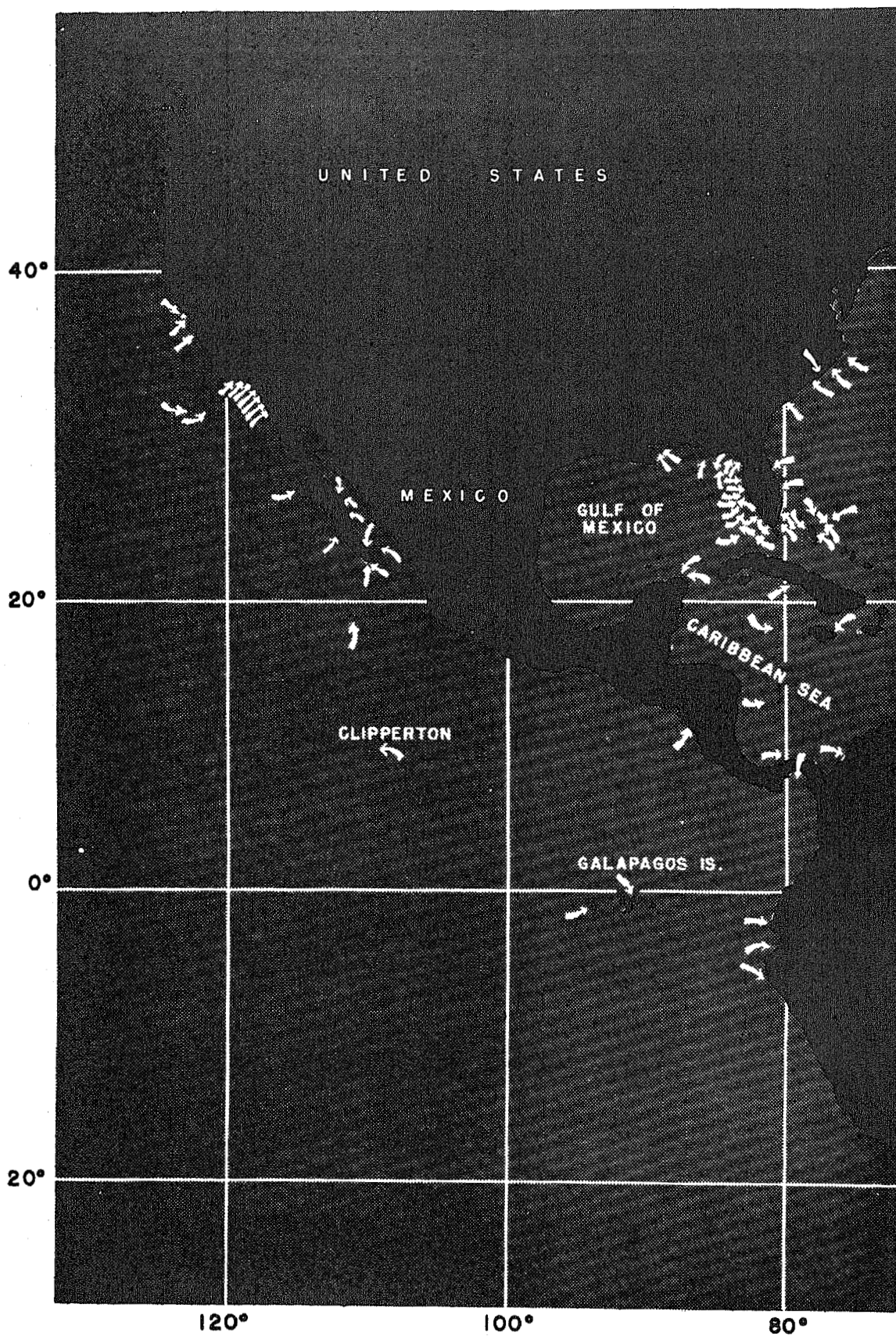
LOCALITY CHART SHOWING SHRIMP RECORDS-AMERICAN AREA
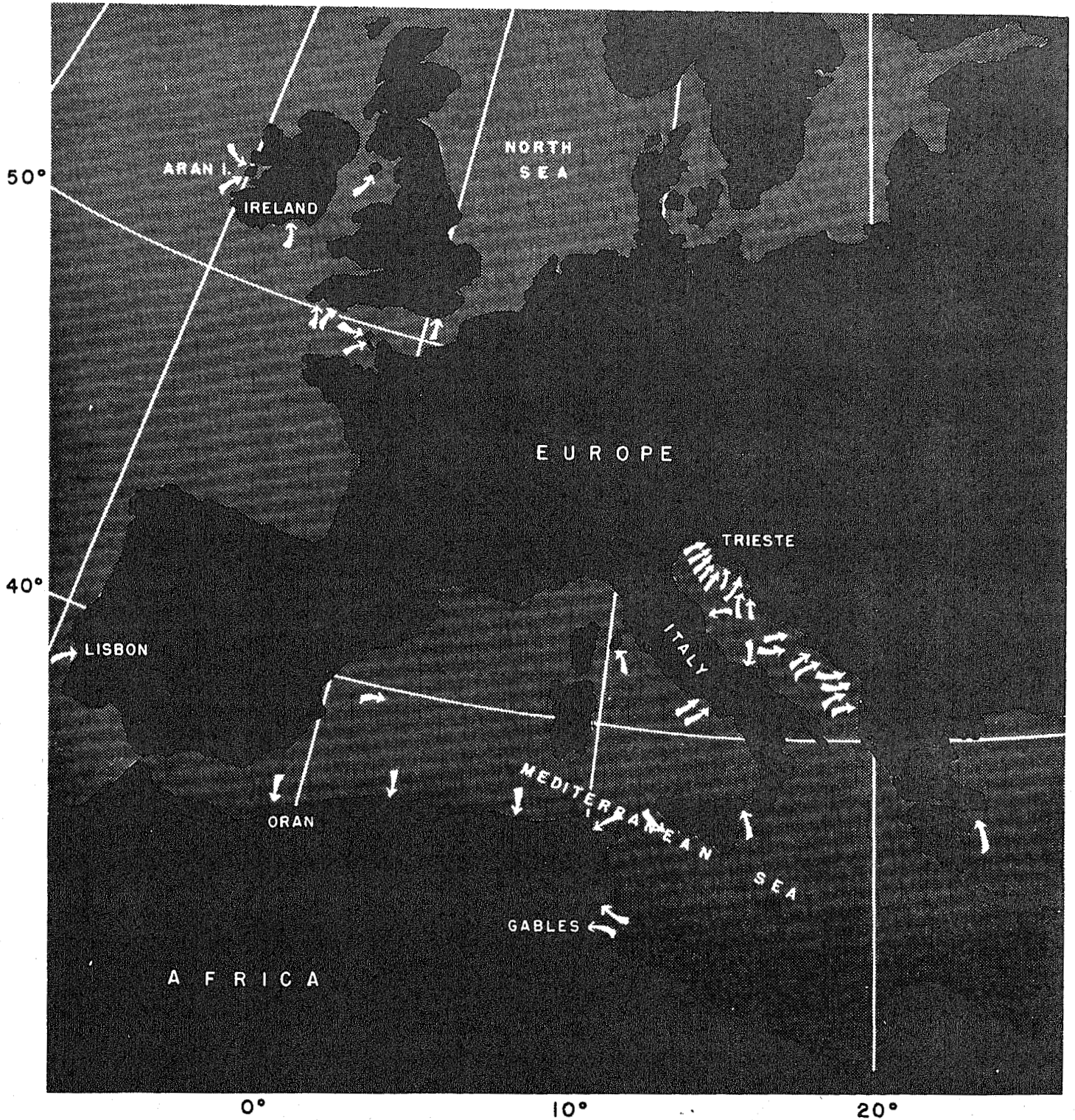
FIGURE 13

LOCALITY CHART SHOWING SHRIMP RECORDS—EUROPEAN AREA

FIGURE 14
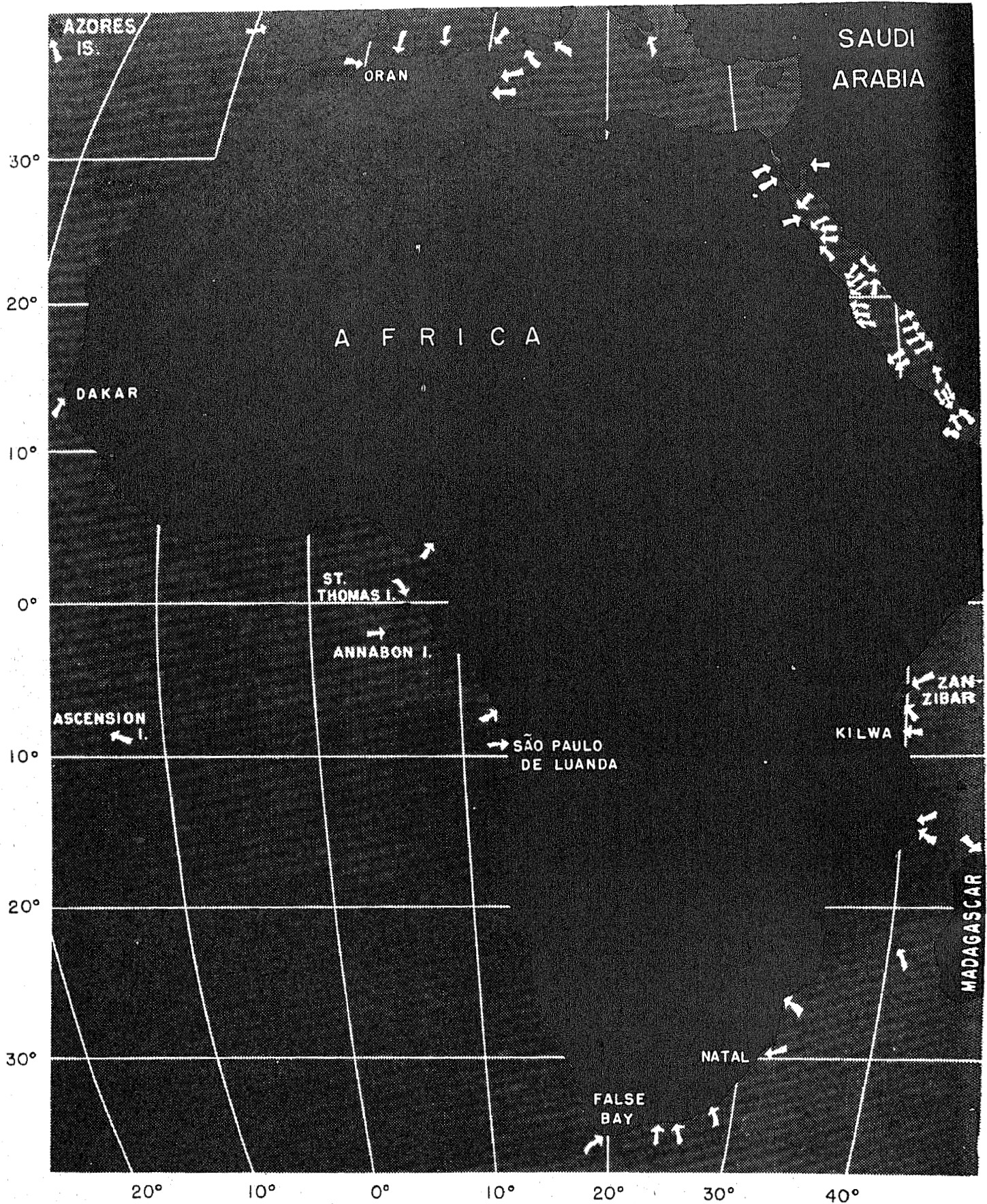
LOCALITY CHART SHOWING SHRIMP RECORDS—AFRICAN AREA

FIGURE 15
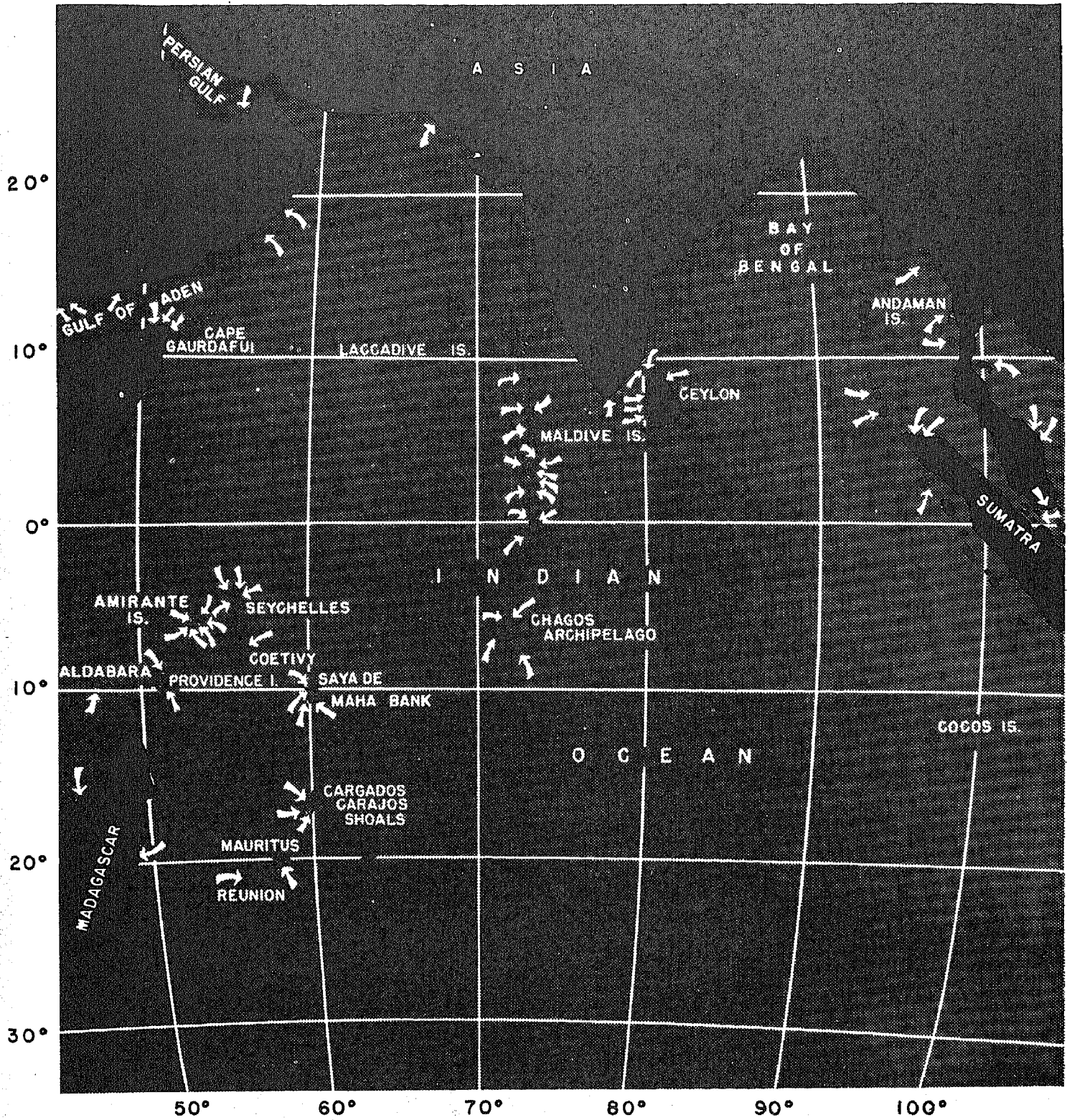
LOCALITY CHART SHOWING SHRIMP RECORDS—INDIAN OCEAN AREA

by the available acoustic data from sound surveys made in various parts of the world (see Bibliography).

There is but little quantitative information on geographical distribution. The animals are as a rule difficult to collect in representative numbers because of their habits of seeking retreats in hollows and crannies of rock, coral, etc. It seems clear, however, that the greatest number of individuals as well as species occur in tropical waters among coral and the alga Lithothamnion. The northern and southern boundaries of continuous distribution along the open coast are no doubt transition zones in which the populations become progressively sparser, but how wide these zones are is not known. However, the animals are known to be quite abundant at Beaufort, N. C. and at Monterey Bay, California, and listening tests in these areas show shrimp crackle to be pronounced, though exact measurements are not available. Between Cape Lookout and Wimble Shoales and in the San Franciso region sparse crackle has been heard but sound measurements fail to show the characteristic spectra of shrimp noise. Acoustically, there must be a certain concentration of shrimp in a given area before an rms reading of the snapping sound can be obtained (see Sec. 7). Sound measurements from latitude 9°S to 33°N indicate about the same levels over shrimp beds irrespective of latitude.

A few of the species are circumtropical, or nearly so, while others are restricted to specific regions. The greatest number of species occur in the tropical Indo-Pacific, but large numbers are also found in the West Indies. Many species also occur in the Red Sea, and in Southern Japan. For Japan as a whole there are at least 23 species of Crangon and 7 species of Synalpheus. Of these, ten species of the first and two species of the second occur in Tokyo Bay. Fewer species are reported from elsewhere in the world where comparable biological studies have been made. For example, there are totals of only 4, 2, and 7 species, respectively, in the Mediterranean, Southern England, and Southern California regions.

3 AMBIENT NOISE OVER SHRIMP BEDS

Measurements of shrimp noise level and spectra were made between February 1942 and July 1944 in the four general areas shown in Table II (see Bibliography). The table also shows the approximate latitude of the various localities at which the data were taken; all lie within the shrimp belt of Fig. 9. It should be noted that a few sound measurements are available from outside the shrimp belt, but no characteristic shrimp spectra were obtained.

TABLE II

AREAS WHERE SHRIMP NOISE HAS BEEN MEASURED

Area and Locality	Approximate Latitude
A. Southern East Coast of U.S.A.	
Florida and Bahamas	$24^{\circ}N - 28^{\circ}N$
B. Southern West Coast of U.S.A.	
San Diego	$33^{\circ}N$
C. Central Pacific	
Hawaiian Islands	$21^{\circ}N$
Midway Island	$26^{\circ}N$
D. Southwest Pacific	
Ellice Islands	$9^{\circ}S$
New Caledonia	$22^{\circ}S$
Russell Islands	$9^{\circ}S$
Guadalcanal Island	$10^{\circ}S$

FIGURE 16

SOUND LEVEL
INDICATOR

HALF-OCTAVE
FILTER

HYDROPHONE
AND
PREAMPLIFIER

NON-DIRECTIONAL
HYDROPHONE

SHRIMP BED

TYPICAL PROCEDURE AND EQUIPMENT
USED IN MEASURING SHRIMP NOISE
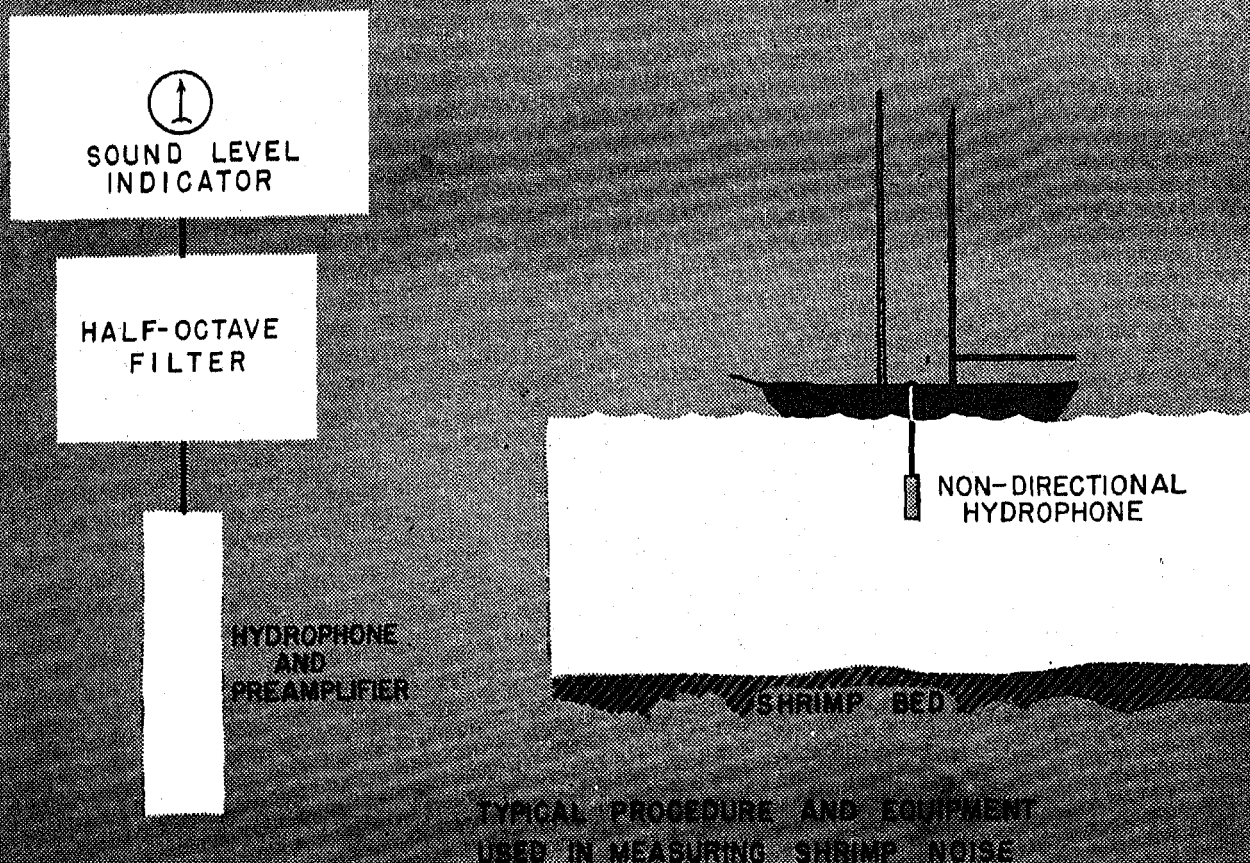
Ambient noise was recorded at a number of stations in eac
locality, both over shrimp beds and at distances up to 12,00
yards away. Water depth varied from 20 to 200 feet for the in
shore stations to depths as great as 1000 fathoms at some of th
offshore stations. Bottom samples were taken at most of th
shallow stations and these, together with hydrographic charts
sufficed to establish the bottom character with fair accuracy

Various measuring systems were used and no attempt will be mad
here to describe these in detail. (See Refs. 3, 18, 21.)
typical system is shown in diagramatic form in Fig. 16. A
essentially non-directional hydrophone at a depth of 10 to 6
feet was usually employed. Ambient noise in the water was picke
up and amplified by a pre-amplifier located in the hydrophone
case. This signal was fed into a sound analyzer which filtere
out the noise in particular frequency bands (usually 50-cycl
or half-octave). The noise level of the selected band was ther
read on a sound level indicator or recorded on tape. By se-
lecting various frequency bands from 100 cycles to 24 kc, the
spectrum of ambient noise could then be determined.

Deep Water - No Shrimp

Average spectra of deep-sea ambient noise measured with a non-directional hydrophone are shown in Fig. 17 as a function of sea state (Ref. 18). These spectra furnish a convenient measure of the ambient noise levels to be expected in the absence of shrimp noise (traffic noise will be neglected). The spectrum level* decreases with frequency at the rate of 5 db/octave. The standard deviation of observed levels with respect to these values is about 5 db.
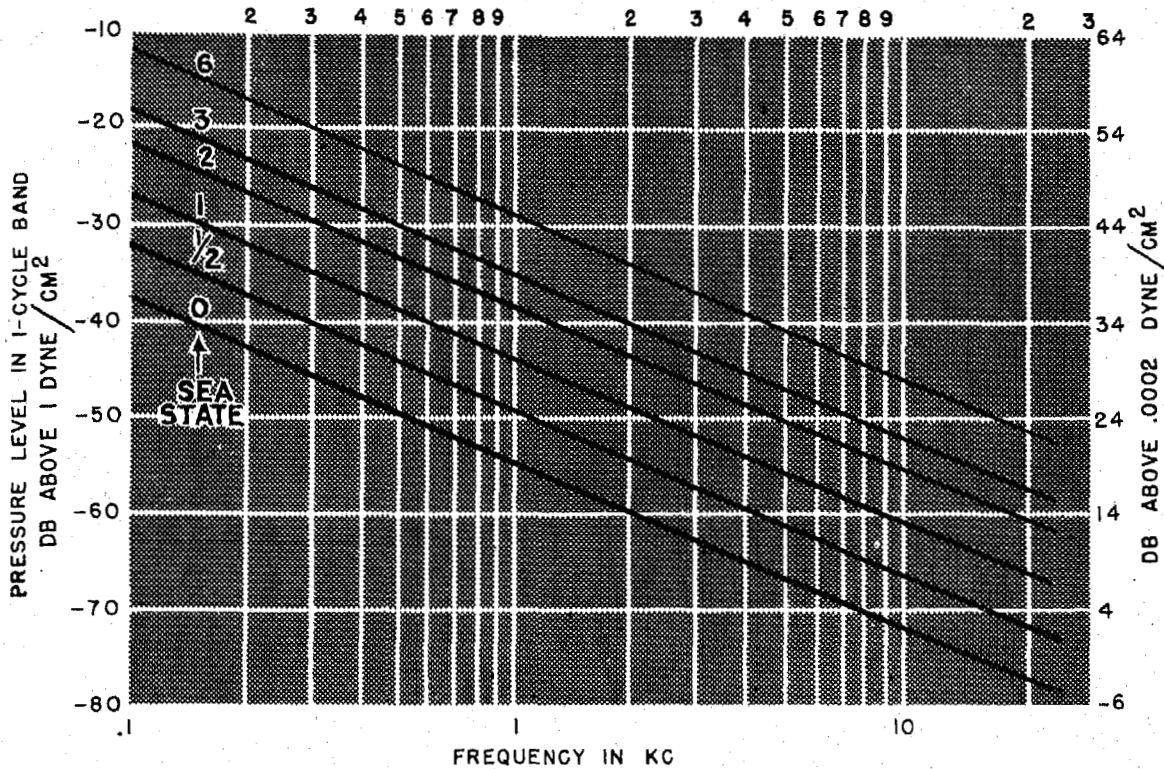
FIGURE 17 – AVERAGE WATER NOISE SPECTRA IN DEEP WATER

Shallow Water - Over Shrimp Bed

Shrimp crackle changes the ambient noise very markedly. Fig. 18 shows the average spectrum levels for various sea states, measured with a non-directional hydrophone directly over a large shrimp colony. Below 1 kc shrimp noise is negligible, but above 2 kc it completely dominates water noise. At 10 and 20 kc, for example, shrimp crackle is about 26 db above water noise for sea state 2. Between 2 and 20 kc, shrimp noise is nearly constant, its spectrum level in a 1-cycle band being about -34 db above 1 dyne/cm^2.

---

* THE SPECTRUM LEVEL AT EACH FREQUENCY IS THE RMS PRESSURE LEVEL IN A 1-CYCLE BAND EXPRESSED IN DB ABOVE 1 DYNE/CM^2.

Although shrimp crackle has been heard at frequencies u
50 kc (by heterodyning to the audible range), no quantita
measurements have been made above 24 kc. If the ave
spectrum in Fig. 18 is extrapolated, using a 5 db/octave sl
its level at 100 kc is −46 db above 1 dyne/cm^2. This is a
12 db below the level obtained by a "flat" extrapolat
assuming shrimp noise to be constant above 20 kc.
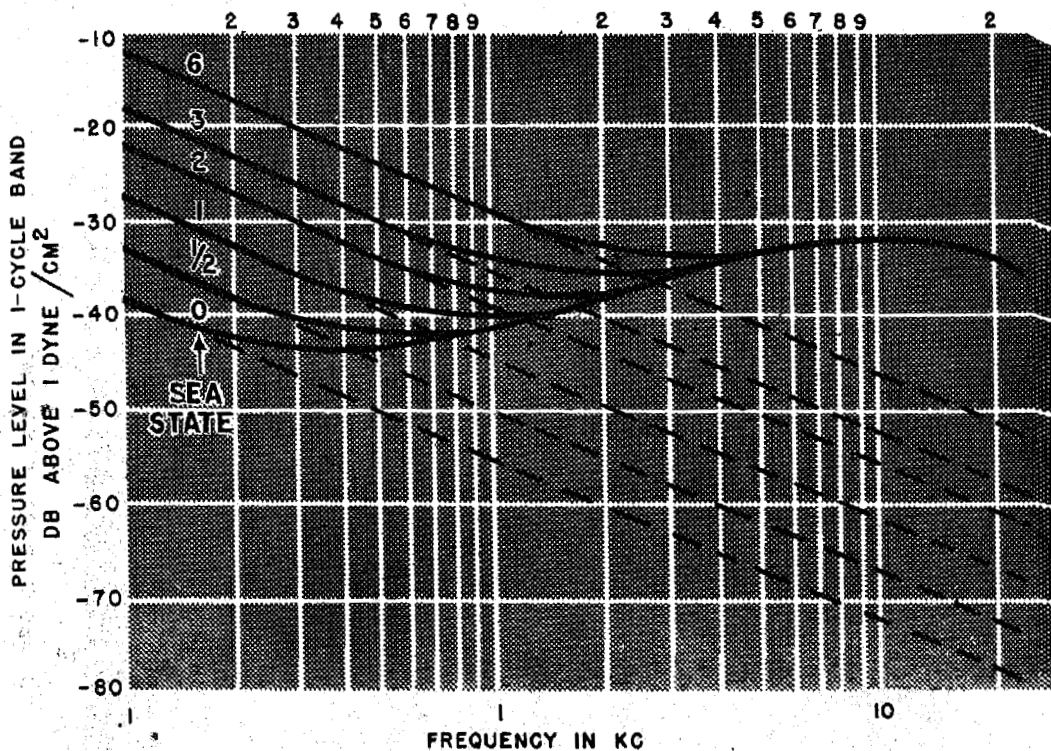
FIGURE 18   AVERAGE AMBIENT NOISE SPECTRA OVER SHRIMP BED

Variability of Shrimp Spectra

In general, comparison of the spectra of shrimp noise fr
different areas shows only minor differences. Figure l
illustrates the general agreement between the average spect
measured at San Diego, Pearl Harbor, and in the Southwe
Pacific. It is not certain that the variations in shape a
real; they may be due to differences in the measuring equipme
employed, particularly above 10 kc, although the shape
the spectra measured with given equipment in one area show
a high degree of consistency.

In some cases, however, spectra differing markedly from the avera
have been obtained. Two of these are shown in Fig. 19B. Spect
A agrees well in shape but has a general level about 20 db high
than the average; it was measured with the hydrophone a few fe
away from the pier in Kaneohe bay (Hawaiian Islands). The h
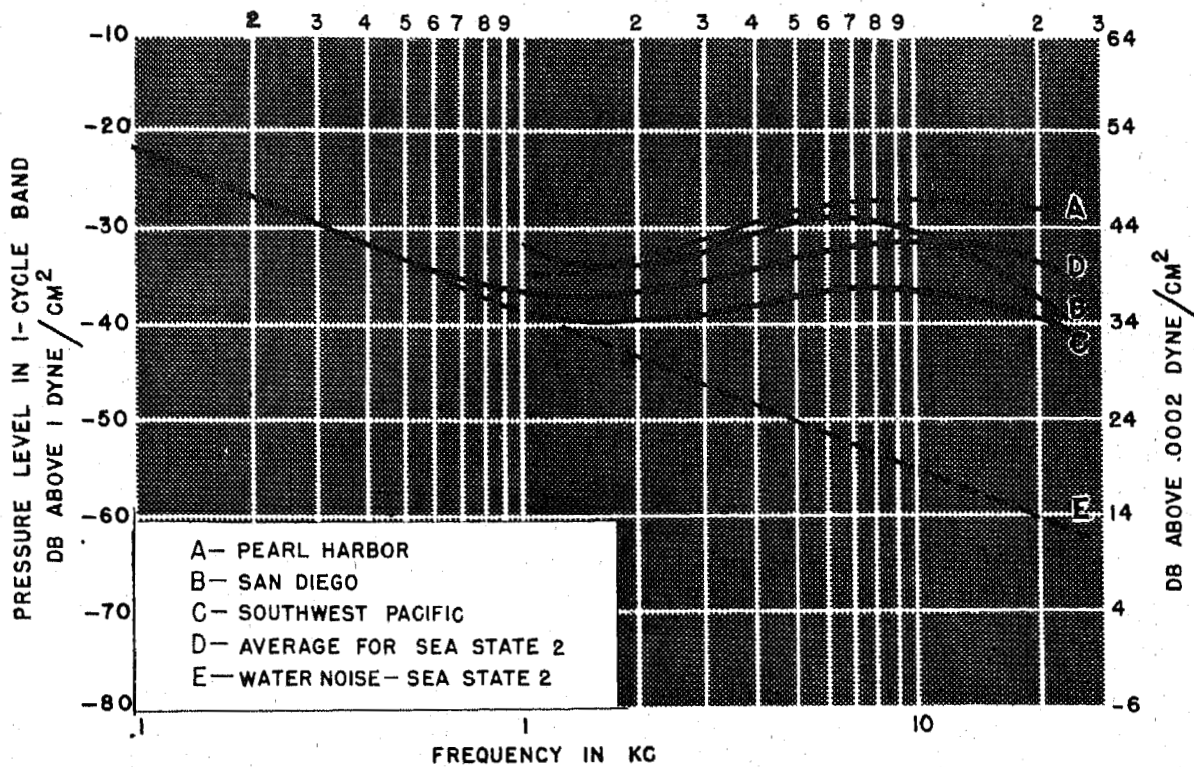
FIGURE 19 A. TYPICAL SHRIMP NOISE SPECTRA
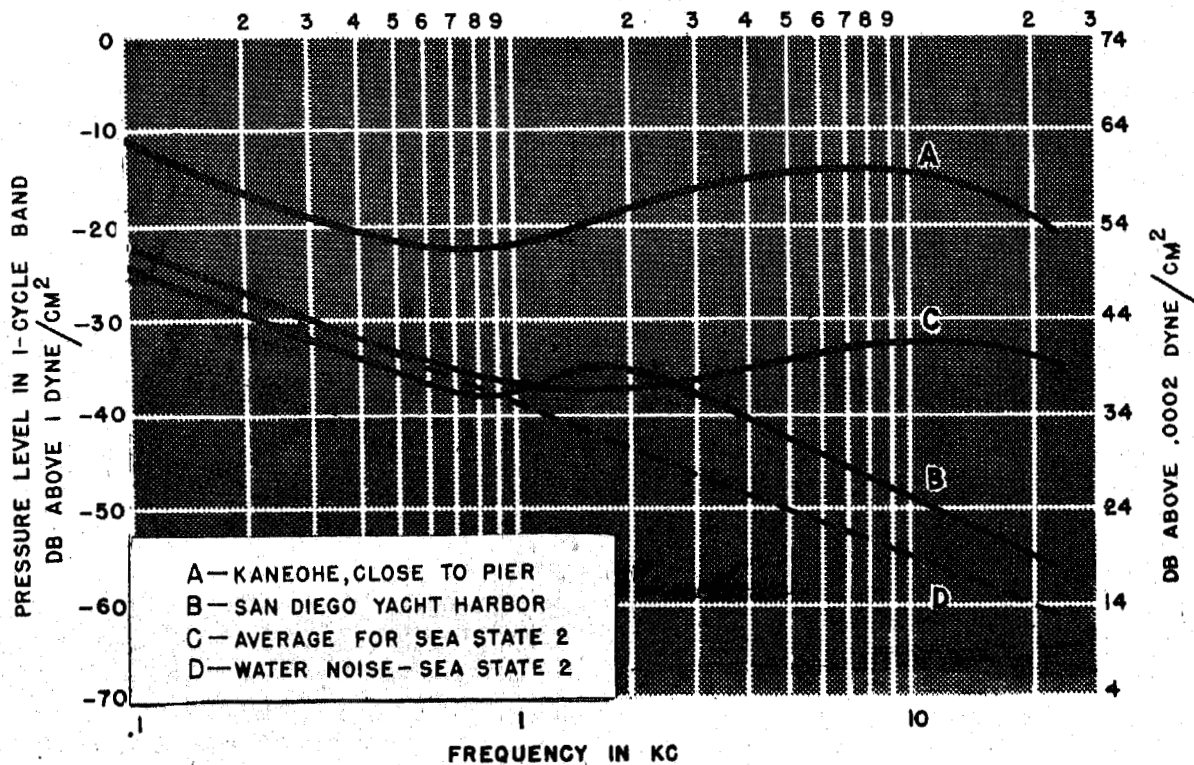
FIGURE 19 B. EXAMPLES OF UNUSUAL SHRIMP NOISE SPECTRA

level is caused by snapping shrimp living in the fouling material on the pilings; 20 feet away from the pier the spectrum level was 10 db lower.

Spectrum B was obtained in San Diego Yacht Harbor. Although shrimp crackle was loud at this location, the spectrum is quite different in shape from the average spectrum obtained outside the harbor. The different spectrum may have been caused by a species of shrimp (Crangon californiensis) found in this location but not in the outside areas.

3.3
SHRIMP NOISE LEVELS

In order to discuss the general level of the spectrum of shrimp noise, it is convenient to use the average of the spectrum levels at 3, 5, and 10 kc. This index of shrimp noise is essentially that used in the Survey Report No. 3 (Ref. 18). It is independent of water noise and includes the region of sonic frequencies where shrimp noise is most important. Table III shows this average for the various spectra in Fig. 19.

TABLE III
SONIC NOISE LEVELS OVER A SHRIMP BED –
NON-DIRECTIONAL HYDROPHONE
(AVERAGE SPECTRUM LEVEL IN 1-CYCLE BAND AT 3-5-10 KC)

	db above 1 dyne/cm^2
Average Spectrum	-34
Typical Spectra	
A. Pearl Harbor	-29
B. San Diego	-31
C. Southwest Pacific	-38
Unusual Spectra	
A. Kaneohe (Near Pier)	-14
B. San Diego Yacht Harbor	-42
Water Noise – Sea State 2	-52

Except for a few unusual spectra, the measured levels over shrimp beds have a standard deviation of about 5 db with respect to the average.
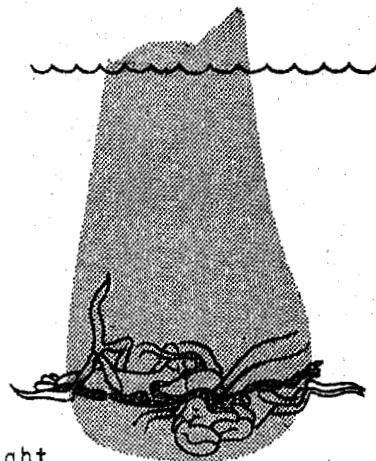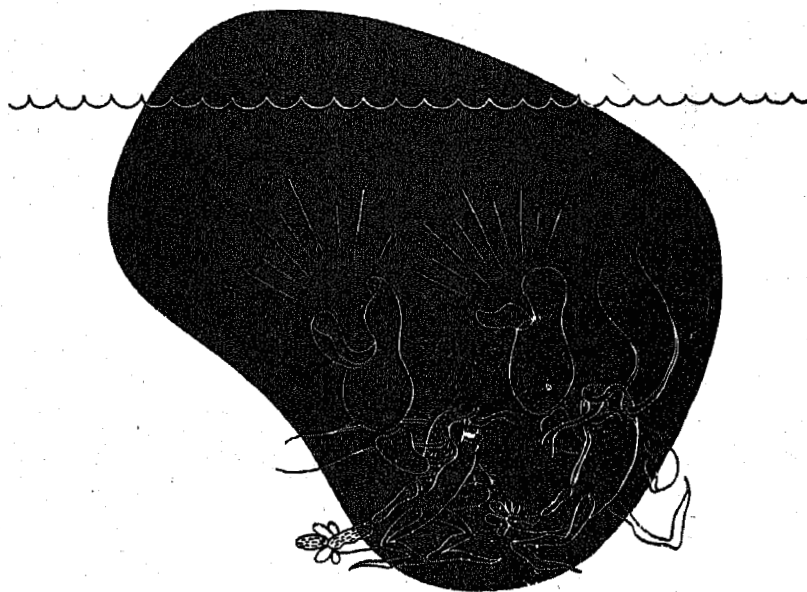
Diurnal Variation

There is a small diurnal variation in shrimp noise. At night
the levels are 2 to 5 db higher than in the daytime. In
addition, there is a slight peak in the noise level shortly
before sunrise and after sunset. The effect is probably
caused by increased activity of the shrimp at these times.

Observations made so far have indicated no appreciable seasonal
variation in shrimp noise, in agreement with the known sta-
bility of the adult population discussed in Section 2.4.
This result may not apply near the edge of the shrimp belt,
however, or at unusual localities inside the belt having
large seasonal variations in water temperature.

Dependence On Hydrophone Depth

Tests were made in the Florida-Bahamas area to see whether
shrimp noise levels depend on the depth of the hydrophone.
Spectra were measured over a shrimp bed 42 feet deep with a
non-directional hydrophone suspended at half water depth and
also mounted on a tripod at the bottom. The spectrum levels at
the two depths were nearly identical, indicating that shrimp
noise is independent of the hydrophone depth (Refs. 18 and 21).
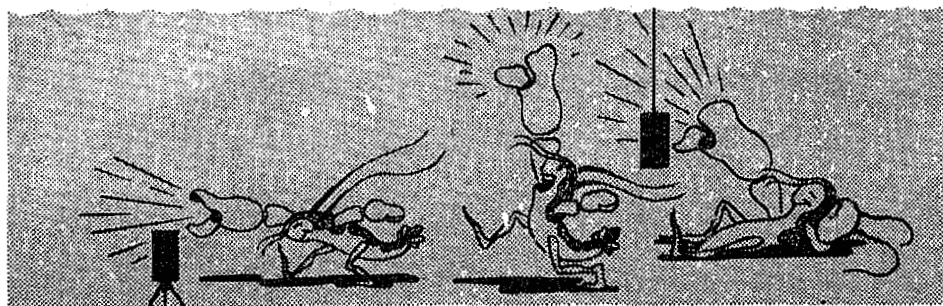
This result is consistent with the observation that shrimp noise is the same in all directions (see p. 46 below). At Kaneohe, on the other hand, the noise level was abnormally high near the pier, but dropped 10 db when the hydrophone was moved 20 feet away. The Kaneohe measurements can be interpreted as resulting from a small highly concentrated region of shrimp. The high concentration caused the abnormally high level, while the small size of the shrimp-infested area caused the shrimp level to decrease rapidly with increasing hydrophone distance. Similarly, if a shrimp bed were only a few feet wide, the measured level would drop rapidly as the hydrophone was raised above the bottom to a height larger than the width of the bed.

Dependence On Water Depth

The average spectrum of shrimp noise shown in Fig. 18 is representative of the levels measured over or near shrimp beds in open water up to 150 feet in depth. In water depths greater than 200 to 300 feet, shrimp noise is unlikely to be present except as transmitted from nearby shallow areas (see Sec. 4).

Near San Diego, for example, measurements of shrimp noise in 10 - 20 fathom water near shore showed characteristic high levels over nearly all extensive rock and cobble areas. Over very rocky off-shore banks 40 - 60 fathoms deep, on the other hand, there was observed only a very weak crackle, characteristic of barnacles and small crabs (see Sec. 9). Thus the acoustic evidence indicates that, in general, shrimp crackle is high only in shallow water 0 - 30 fathoms deep.

Dependence On Bottom Character

In the discussion of habitats in Sec. 2.5, it was pointed out that snapping shrimp seek out bottoms that provide sheltering material for concealment. These favorable bottoms include coral, rock, stone, shell, etc. With few exceptions this is well substantiated by the acoustic data: Within the 0 - 30 fathom depth zone about 80% of the high levels (above -44 db) have been observed over favorable bottom types. In contrast, about 90% of the low levels (below -44 db) for this depth zone were over unfavorable bottom types. Considering the difficulty in establishing bottom character, this correlation is surprisingly good.
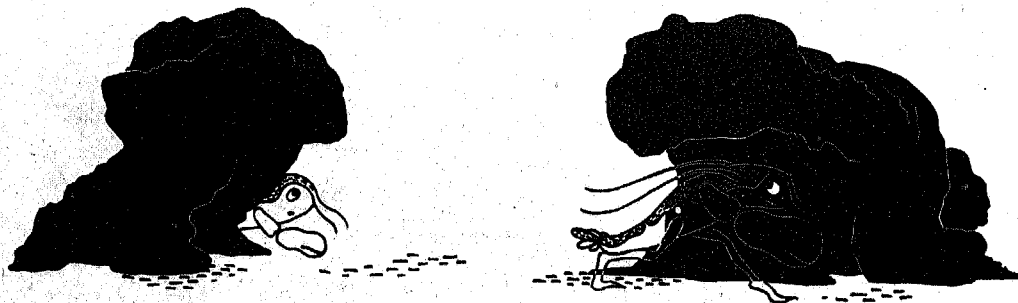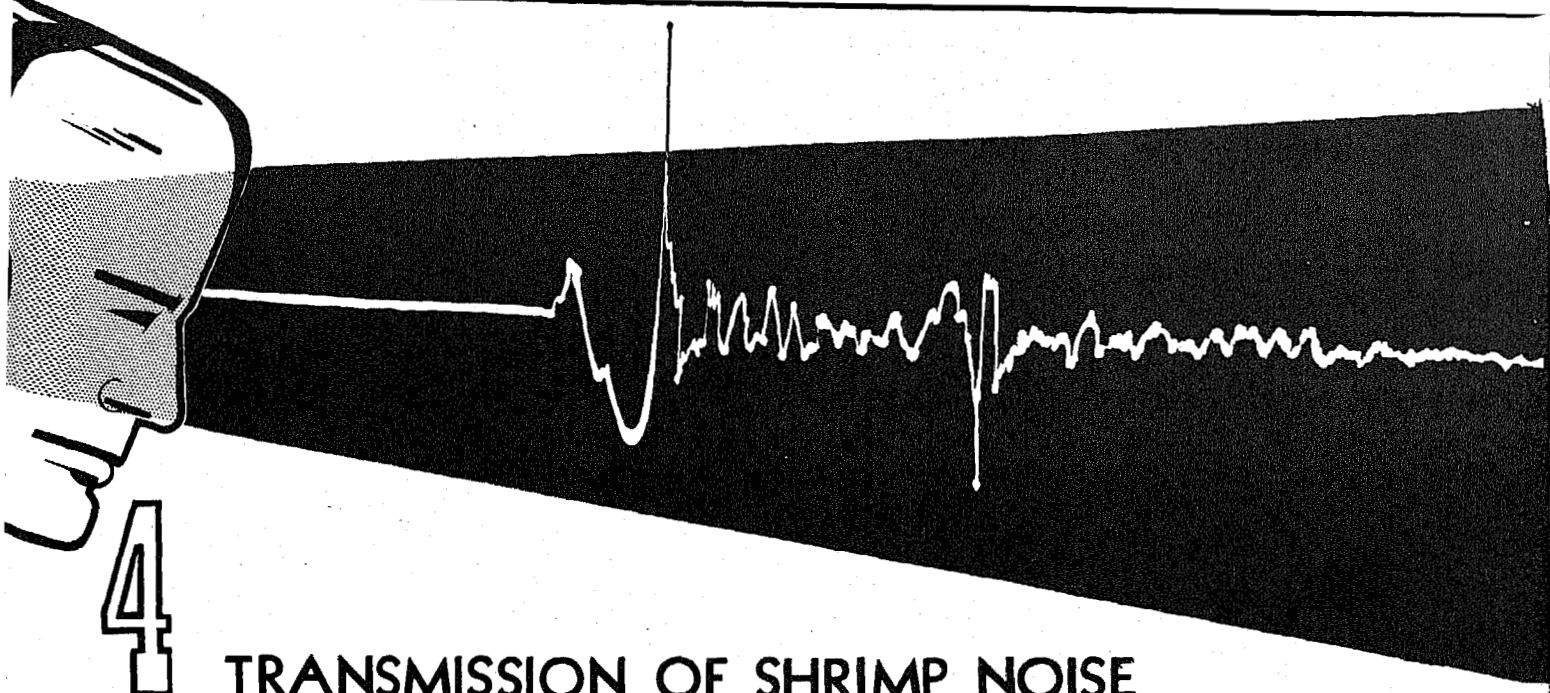
4 TRANSMISSION OF SHRIMP NOISE

The spectra and noise levels discussed in the previous section
were measured either at long ranges from shrimp beds, where
water noise alone was found, or over the beds, where shrimp
noise dominated the spectrum above 2 kc. Between these two
extremes there is a gradual transition from one spectrum to the
to the other. The purpose of this section is to discuss: first,
the average transmission of shrimp noise beyond the bed; second,
the change in the spectrum with range; third, the effect of
oceanographic factors on the transmission; and fourth, the
calculated transmission for several idealized cases.

Figure 20 shows typical noise levels (average of 3-5-10 kc)
measured at various points on a traverse crossing a shrimp bed.
The data were taken in the San Diego area, about two miles south
of Point Loma. The bottom character is well established. There
is a band of rock and shale running north and south; this is
bounded on the east by a sand area and on the west by sand and
mud, both unfavorable bottoms for shrimp. Water depth along the
traverse varied from 10 fathoms at the east end to 45 fathoms at
the west end; over the shrimp bed in the rock and shale area the
depth was 15 - 20 fathoms.

The measured levels along the traverse (shown by the points in
Fig. 20B) were obtained with a non-directional hydrophone at a
depth of 10 feet. Over the bed, which is about 1200 yards wide,
the level reaches a peak of -32 db. Beyond the edge of the bed
it falls off rapidly, and at 4000 yards has dropped some 20 db
and is about equal to water noise for sea state 1 - 2.

The solid curve in Fig. 20B is the average level for similar data
taken along several traverses in the San Diego area; it fits the
data just discussed to within a few db and is typical of the
transmission measured in other areas with low sea states. Figure
21 shows the noise levels measured during one off-shore run at

4.1 DEPENDENCE OF SHRIMP NOISE LEVEL ON RANGE
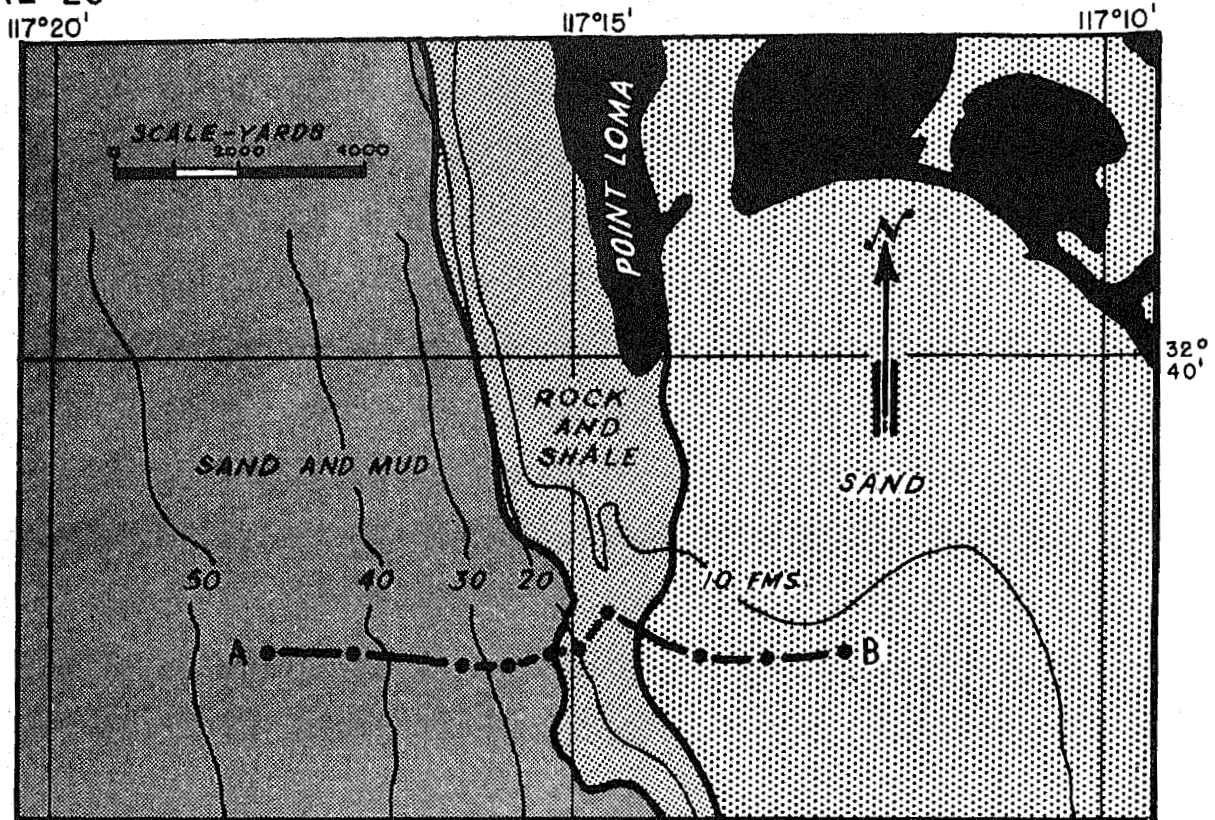
FIGURE 20

A. SHRIMP STATIONS IN SAN DIEGO AREA
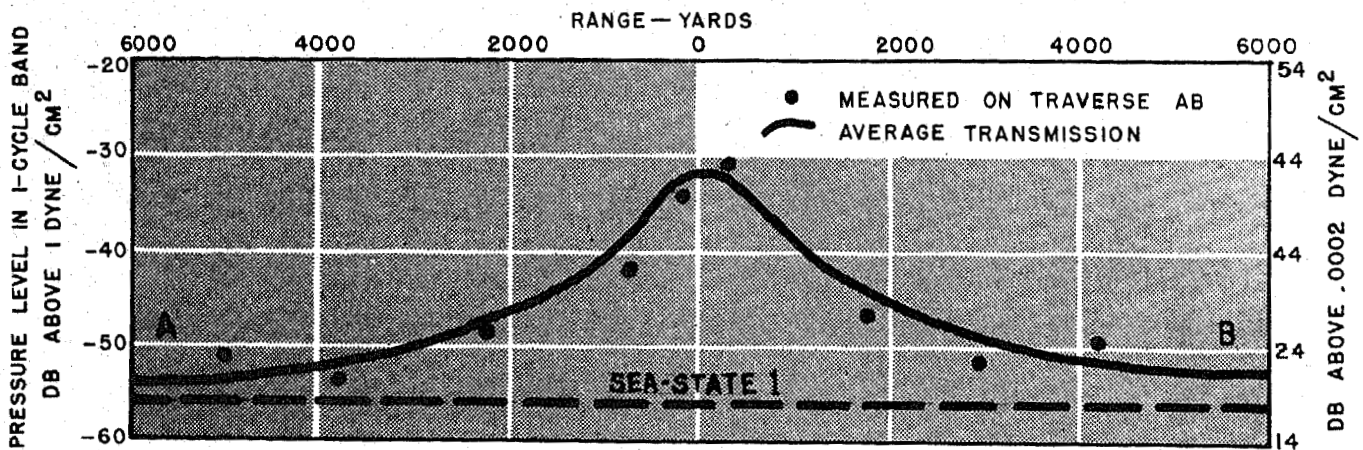
B. SHRIMP NOISE LEVEL— AVERAGE OF 3-5-10 KC
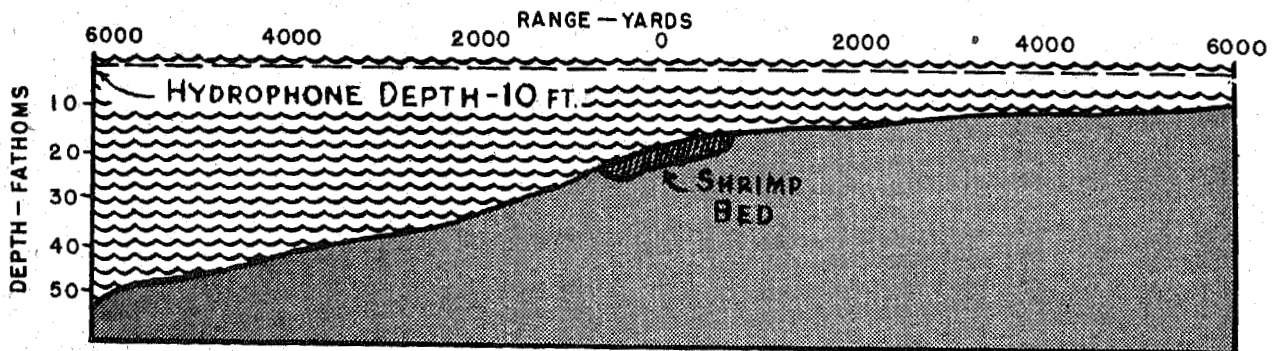
C. BOTTOM PROFILE— CROSS SECTION ALONG TRAVERSE

DEPTH — FATHOMS

SHRIMP NOISE LEVELS AND BOTTOM PROFILE
NON-DIRECTIONAL HYDROPHONE—SEA STATE 0-1

FUNAFUTI ISLAND
SOUTHWEST PACIFIC AREA

PRESSURE LEVEL IN 1- CYCLE BAND
DB ABOVE 1 DYNE/CM^2

○ AVERAGE: 10-15-20 KC
● AVERAGE: 3- 5-10 KC

RANGE—YARDS

DB ABOVE .0002 DYNE/CM^2

FIGURE 21

39
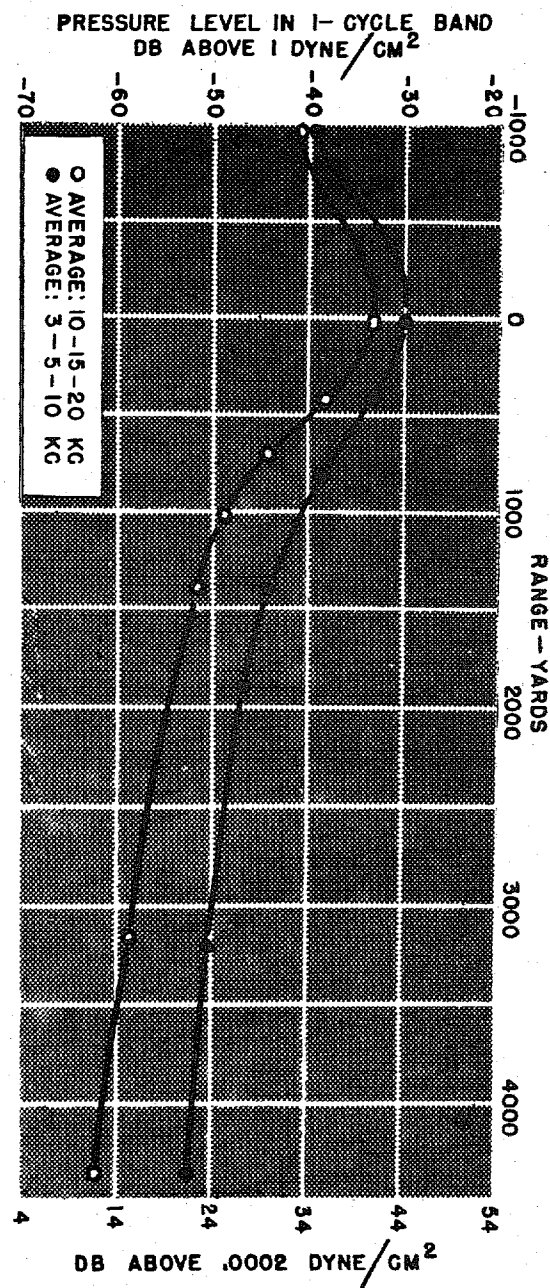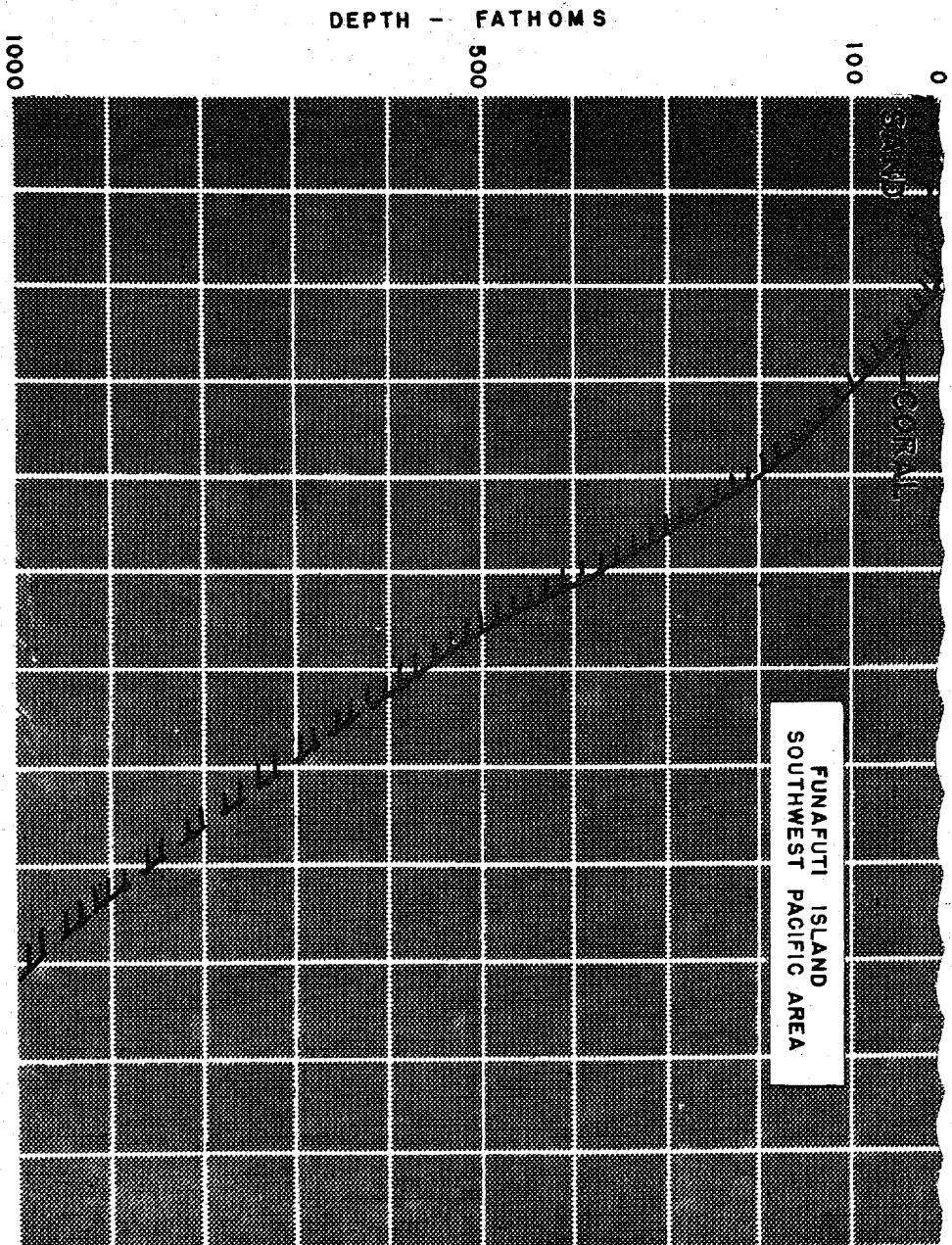
Funafuti in the Ellice Islands; the curves are typical of the
Pacific transmission measurements made for the most part with
deep (200 feet) mixed layers. The (upper) sonic curve is com-
parable to the San Diego average. The lower curve is the average
of the supersonic components at 10-15-20 kc; it is seen to drop
off more rapidly than the sonic curve. At long ranges it is lower
because of the lower water noise level at the high frequencies.

Table IV summarizes the average transmission of the sonic fre-
quencies for sea states 1 and 2 as a function of range from the
edge of the shrimp bed. The entries for sea state 6 were
estimated and are included for comparison. A standard devia-
tion of the order of 5 db is to be expected between observed
values and the averages.

TABLE IV

SONIC AMBIENT NOISE OVER AND NEAR SHRIMP BED

NON-DIRECTIONAL HYDROPHONE
(Spectrum Level in a 1-Cycle Band in db above
1 dyne/cm^2 – Average of 3-5-10 kc)

Sea State	Over Bed	Edge	Range from Edge – Yards			
			500	1000	2000	4000
1	-31	-35	-40	-44	-50	-54
2	-31	-35	-40	-44	-47	-49
6	-31	-34	-37	-39	-40	-41

For low sea states it is seen that shrimp noise is important
only within about 2000 yards of the boundary of the bed, while
for high sea states it is appreciable only within 1000 yards.

These results apply only to the average (3-5-10 kc) ambient
noise. The transmission of the various spectral components of
shrimp noise will now be discussed.

4.2 CHANGE OF SPECTRUM WITH RANGE

Figure 22 shows the transmission of shrimp noise at 3, 5, 10,
and 20 kc as a function of range. The curves are averages of
data taken with a non-directional hydrophone in the San Diego
area with sea state 1 – 2. They are typical of the decrease of
shrimp noise with range observed in other areas.

The peak levels over the bed are those shown in the San Diego
spectrum of Fig. 19A. Beyond the bed the noise level decreases
rapidly with range and flattens off into water noise. The decay
is more pronounced at the high frequencies since the peak level
at 20 kc is about 25 db above water noise, as compared with about
18 db at 3 kc.

FIGURE 22
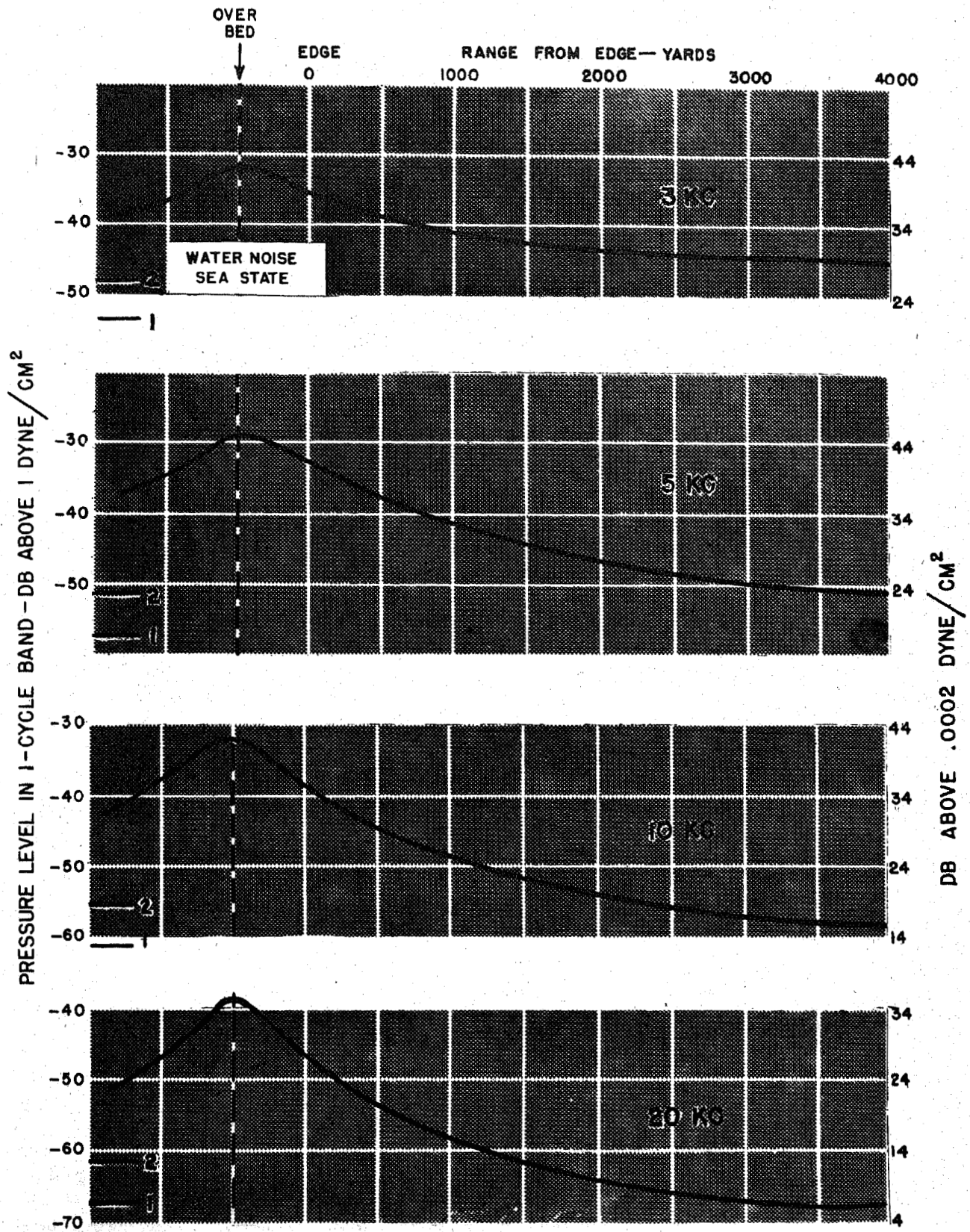
TRANSMISSION OF SHRIMP NOISE IN SAN DIEGO AREA
NON-DIRECTIONAL HYDROPHONE — SEA STATE 1 or 2

Figure 23 shows the corresponding spectra at six positions, starting over the bed and running out to 4000 yards. The spectra change successively from the typical spectrum of shrimp noise over the bed to the water noise spectrum for sea state 1 – 2 at 4000 yards.

FIGURE 23
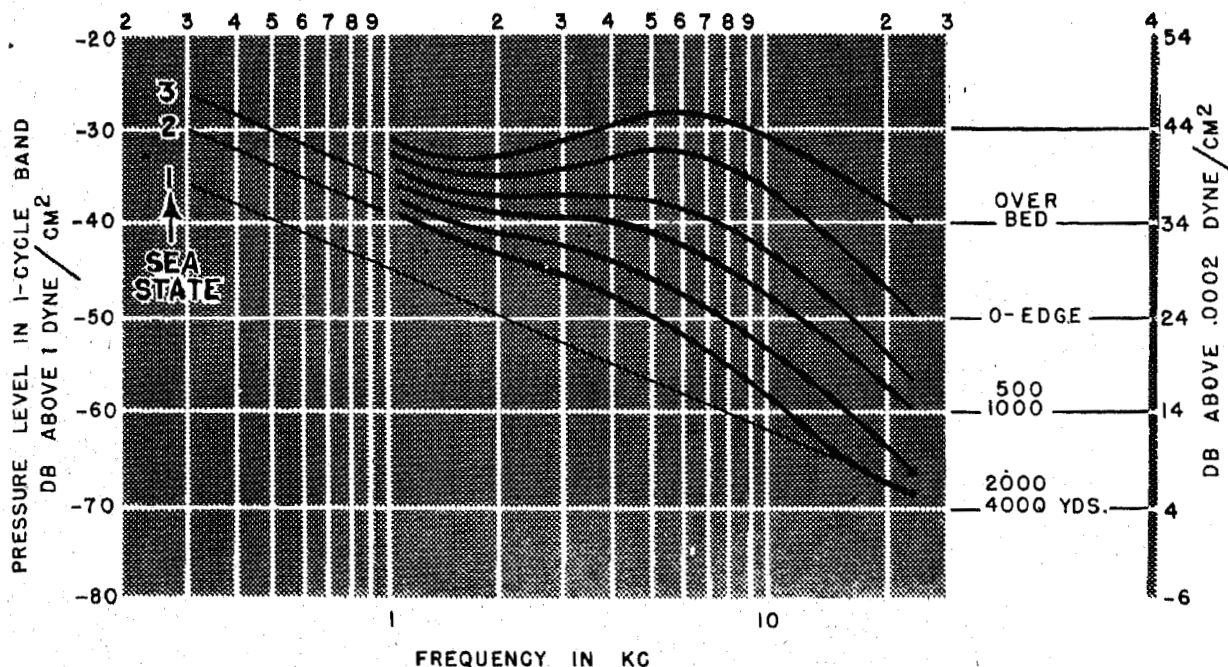
CHANGE IN SPECTRUM WITH RANGE – SAN DIEGO AREA

NON-DIRECTIONAL HYDROPHONE – SEA STATE 1 or 2

4.3 EFFECT OF OCEANOGRAPHIC CONDITIONS

Oceanographic factors which might be expected to affect the transmission of shrimp noise include the sea state, the character and profile of the bottom, and temperature gradients. Since most of the measurements of shrimp noise have been made with sea states of 2 or less it is not known how surface roughness influences the transmission curve. It is obvious, of course, that the major effect will be to increase water noise and thus shorten the range at which the curve flattens off, as indicated by the levels in Table IV for sea state 6.

The absence of data taken with strong negative temperature gradients precludes a check of the effect of refraction. The effect of bottom type on transmission is beyond the scope of this report,

but is probably not large at high sonic and supersonic frequencies in the absence of sharp negative temperature gradients.

In spite of the absence of experimental data, however, it is possible to estimate the importance of oceanographic factors on shrimp noise. The curves of Fig. 22 show that even under good transmission conditions the level of shrimp crackle drops almost to water noise within about a mile of the bed. With rare exceptions, however, oceanographic factors do not affect the transmission very greatly at ranges inside 1000 or 1500 yards. It appears probable, therefore, that even with poor transmission conditions the curves of Fig. 22 will be affected only to the extent of dropping off more rapidly beyond the bed and will fall into water noise at slightly shorter ranges.

To summarize: With the exception of sea state, ambient noise levels over and near a shrimp bed are usually independent of oceanographic factors.

4.4 CALCULATED TRANSMISSION

Present data do not justify a detailed theory of the transmission of shrimp noise. Nevertheless, it is of interest to examine the general nature of transmission for several idealized situations. Four cases were studied and these will now be discussed and compared with the observed transmission.

Two shrimp beds of widely different shapes were assumed: the first is an infinite strip 1200 yards wide and approximating the San Diego bed in Fig. 20A; the second is a circular bed 1200 yards in diameter. The water depth was assumed to be 100 feet and the hydrophone depth 10 feet, corresponding to the conditions shown in Fig. 20C.

The shrimp were considered as point sources uniformly distributed over the beds. Two cases were then distinguished; in the first, each point source was assumed to emit sound equally in all directions (isotropic source). In the second case, the intensity in a given direction is proportional to the cosine of the angle between the vertical and this direction (cosine source). Thus, the intensity from the cosine source is greatest directly above the source and drops off to zero in the horizontal direction.

The hydrophone was assumed to be non-directional and to move outward from the center of the circular bed and across the infinite strip bed. At each position, the intensity at the hydrophone due to each source was assumed to vary inversely as the square of the distance to the source. The total intensity was found by summing the individual intensities, surface reflection and background noise being neglected.

Table V summarizes the salient features of the transmission as a function of range (R) in the four cases. They are compared graphically in Fig. 24.

TABLE V

SUMMARY OF CALCULATED TRANSMISSION CURVES

Shape of Bed	Type of Source	Center of Bed	Intensity — db above Peak Intensity at Center of Bed		Law at Long Ranges
			Edge of Bed		
			True	Apparent	
1. Infinite Strip	Isotropic	0	−2	−6	R^{-1}
2. Circular	Isotropic	0	−3	−8	R^{-2}
3. Infinite Strip	Cosine	0	−3	−15	R^{-2}
4. Circular	Cosine	0	−5	−16	R^{-3}

The four calculated curves in the upper part of Fig. 24 reach a peak over the center of the bed; at the edge of the bed, the intensity drops off 2 to 5 db. Beyond the edge, the four curves diverge rapidly, spreading over 20 db at 2000 yards. The dependence on range is brought out more clearly in the lower part of Fig. 24 by plotting the intensity logarithmically against the range. Two range scales are shown: The upper scale, suggested by the theory, is the range from the center of the bed in units of 600 yards (the half-width of the bed). The lower scale shows the equivalent range in kilo-yards from the edge of the bed. The intensity is plotted in db above the peak intensity over the bed.

FIGURE 24

SHRIMP BED

RANGE FROM EDGE— YARDS

CASE
1
2
3
4

EDGE

RANGE FROM CENTER IN UNITS OF BED HALF-WIDTH (600 YDS)

CASE
2
3
4

RANGE FROM EDGE— KYDS.

CALCULATED LEVEL— DB ABOVE PEAK INTENSITY OVER BED
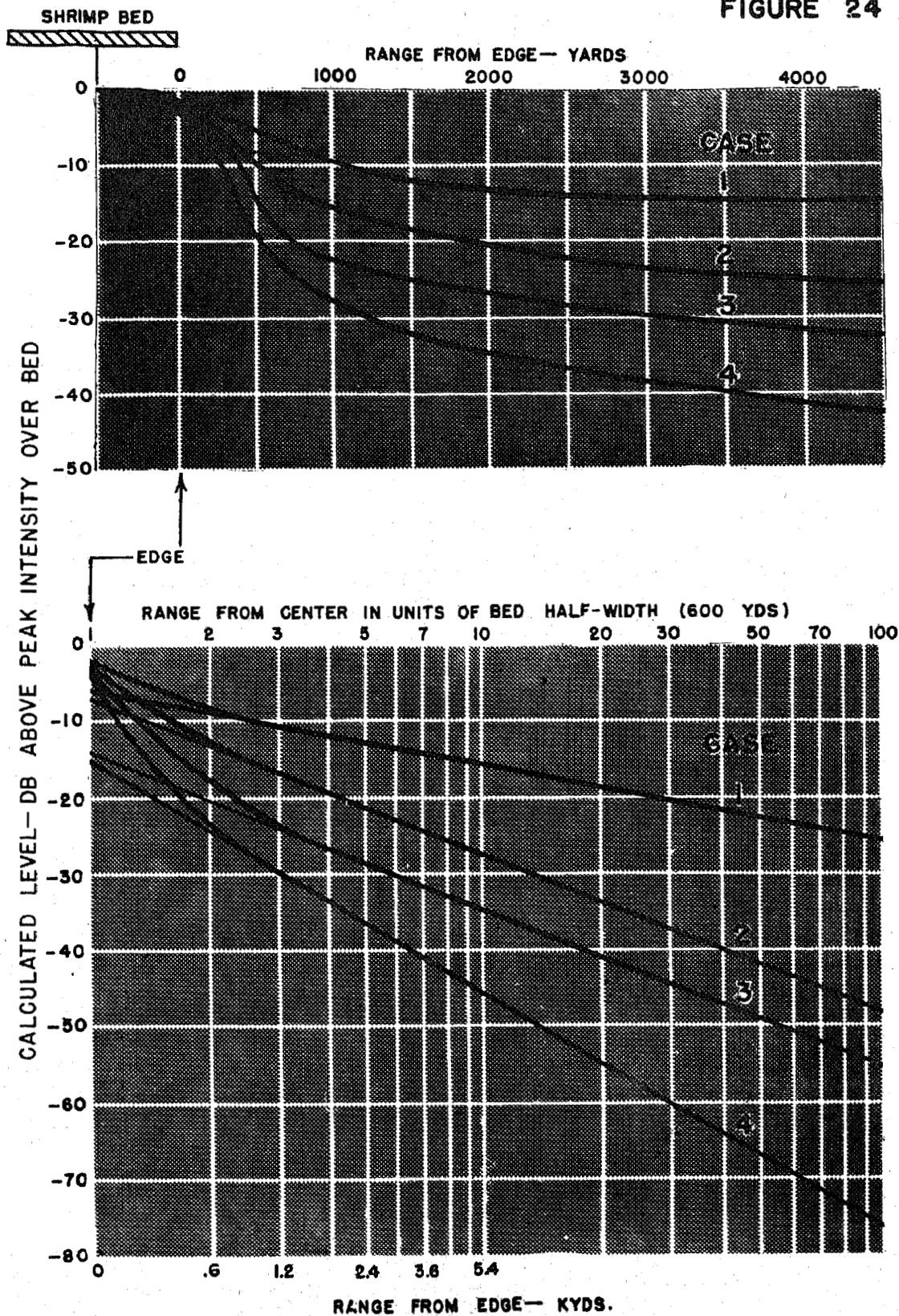
CASE 1 :	INFINITE STRIP — ISOTROPIC SOURCE
CASE 2 :	CIRCULAR BED — ISOTROPIC SOURCE
CASE 3 :	INFINITE STRIP — COSINE SOURCE
CASE 4 :	CIRCULAR BED — COSINE SOURCE

CALCULATED TRANSMISSION OF SHRIMP NOISE

At long ranges, each of the curves asymptotically approaches a straight line, indicating a dependence varying inversely as a power of the range as indicated in the last column in Table V. These straight lines, when extended back to the edge of the bed (unit distance on the upper scale) determine the "apparent" intensities given in Table V. Thus, at long ranges, the infinite strip bed with isotropic sources may be considered as a line source with an inverse first power dependence on range, and an intensity at "unit" distance (600 yards) which is 6 db below the actual peak intensity over the bed. In the same way the circular bed may be replaced by a point source with an inverse square law, whose intensity at "unit" distance is 8 db below the actual peak intensity. These results for the isotropic case would be changed considerably by assuming the surface to be a perfect reflector: because of the mathematical complexities involved, however, it was not felt that this calculation was justified.

The transmission with cosine sources drops off more rapidly beyond the boundary. In this case the intensity at the hydrophone (at any range) is proportional simply to the solid angle subtended by the bed. This quantity decreases rapidly with range beyond the edge of the bed, resulting in an inverse square dependence on range for the infinite strip and an inverse cube dependence for the circular bed.

Comparison Of Observed And Calculated Transmission

Figure 25 shows three curves; curve A is the observed transmission at 10 kc (Fig. 22). This curve was selected because it is less affected by water noise than those at the lower frequencies and provides a better comparison with the calculated levels. The 20 kc curve was not used because it is much more affected by attenuation, a factor not included in the calculations.

The second curve (B) shown in Fig. 25 is the calculated transmission for the case of the infinite strip with cosine sources (Case 3 in Fig. 24). This case was chosen for three reasons:

(1) The shape approximates the effective shape of the actual shrimp beds.

(2) The cosine source assumption, because of the solid angle relation, implies that the intensity over the shrimp bed is essentially the same in all directions, an effect which is observed over actual shrimp beds when a directional hydrophone is employed. (This will be discussed in more detail in Sec. 5.)

(3) Only the cosine source gives an intensity which does not depend on the depth of the receiver when over a large bed. With an isotropic source, the intensity increases logarithmically with decreasing height above the bed. Thus the assumptions made in the calculation

FIGURE 25
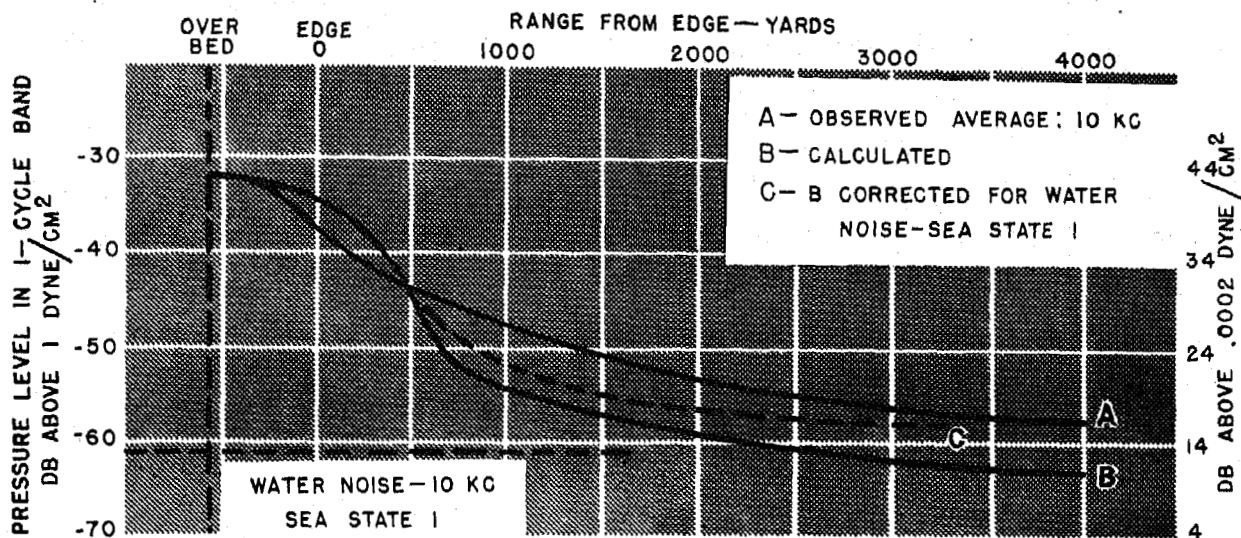
COMPARISON OF OBSERVED AND CALCULATED TRANSMISSION

of curve B as to the shape of the bed and the type of source are in rough agreement with typical shrimp beds where curve A was observed.

Beyond the edge it is seen that the calculated curve drops off more rapidly than the observed curve. At ranges greater than 500 yards from the boundary the two curves are parallel, with the observed values about 6 db above the calculated.

The separation is reduced if the calculated values are corrected for water noise as shown by the dashed curve. The agreement is good in view of the approximations in the theory and the uncertainties in the boundary of the actual beds. The actual transmission will differ from the theoretical curve B because of multiple reflections between surface and bottom. Sound arriving over these additional paths will tend to increase the intensities above the levels computed, especially at the longer range, and might bring the experimental and theoretical curves into even closer agreement. It may be remarked that curve I of Figure 24, computed for an isotropic source, would disagree seriously with the experimental observations.

5 EFFECT OF HYDROPHONE DIRECTIVITY

The discussion of shrimp noise has thus far been restricted to levels measured with a non-directional hydrophone. With increasing frequency, however, particularly in the supersonic region above 10 kc, hydrophone directivity becomes increasingly important; in supersonic listening and echo ranging, highly directional hydrophones are used almost exclusively. This section deals with the effect of hydrophone directivity on the ambient noise level at various positions over, near, and far from a shrimp bed.

5.1 GENERAL DISCUSSION

The response (or sound output) of a non-directional hydrophone is independent of the direction of the incident sound. This results in a spherical beam pattern in space, shown in cross-section in Fig. 26.

A directional hydrophone, on the other hand, is most sensitive to sounds which are incident along its axis. This results in a beam pattern as shown in Fig. 26 for a typical directional hydrophone (JK) at 20 kc. The hydrophone discriminates strongly against sounds received outside the main lobe, as shown by the low response in these directions. The beam pattern shown was measured in the horizontal plane; in space this pattern subtends a solid angle which is only about 1/200 that of the spherical non-directional pattern.

Now suppose the two hydrophones are used to measure water noise at a point far from a shrimp bed, where crackle is negligible. Since water noise is known to be incident on the hydrophones from all directions, it is clear that the response of the JK will be only about 1/200 that of the AX58. The JK output level due to water noise must therefore be corrected by adding 23 db; it is then equal to the output level of the AX58.

At positions near the bed where shrimp noise is louder, the output level of the AX58 is shown by the transmission curves in Figs. 20 – 22. The JK output will depend on the bearing. If the beam is trained on the bed, the output level will be high. If it is trained away from the bed, the low response in the rear hemisphere will discriminate against shrimp noise and the output level will correspond to water noise alone. Finally, over the shrimp bed, the output level of the JK, although it will not depend on bearing, will be lower than the output level of the AX58.

With regard to shrimp noise, therefore, two questions may be asked:

(1) How should the sound output from a directional hydrophone over a shrimp bed be corrected to give the level which would be observed if a non-directional hydrophone were used?

(2) How does the sound output of a directional receiver change
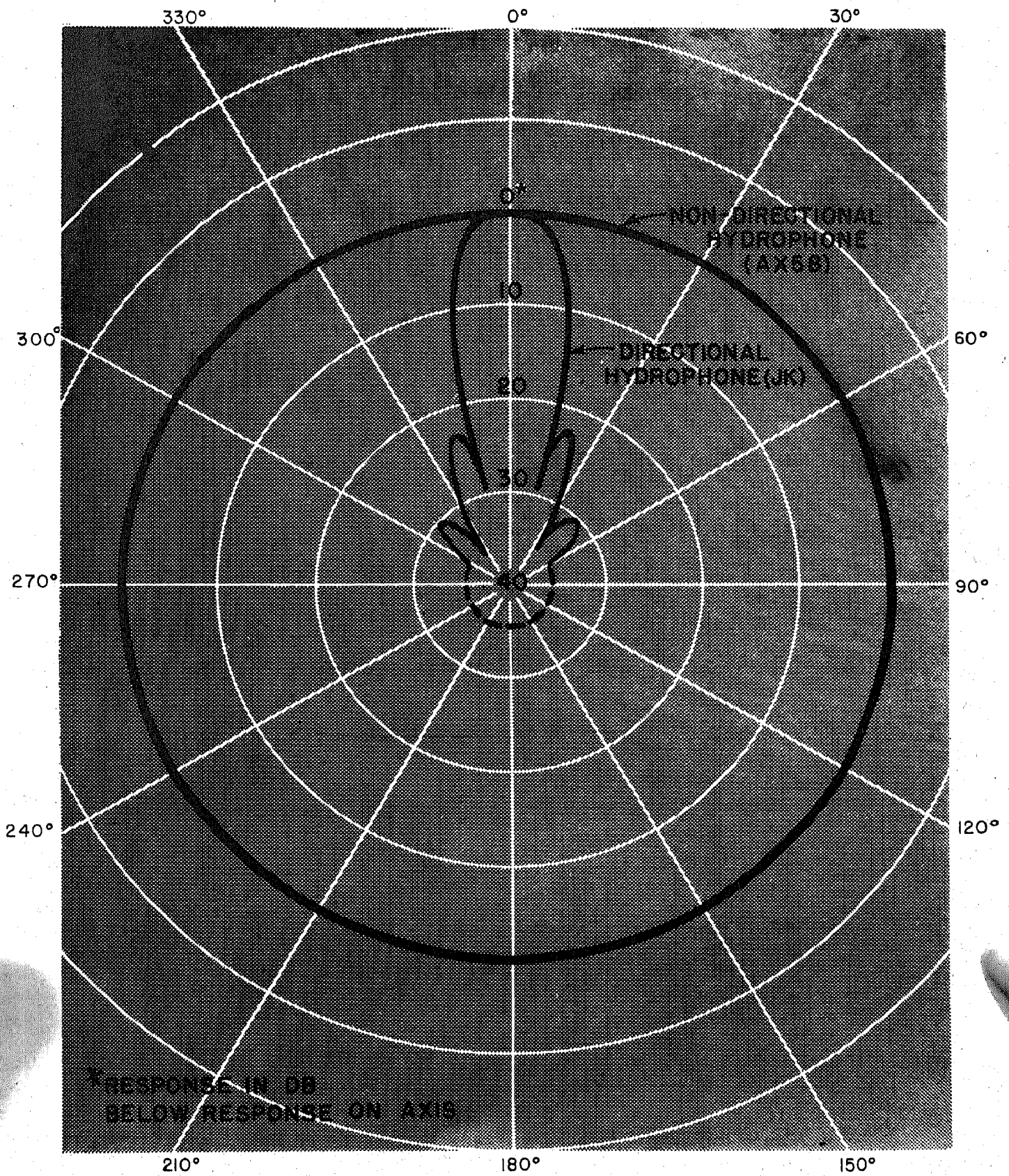
BEAM PATTERNS FOR DIRECTIONAL AND
NON-DIRECTIONAL HYDROPHONES — 20 KC

FIGURE 26

with bearing when located near the edge or in the vicinity of a shrimp bed, but not over it?

5.2
DEPENDENCE OF NOISE LEVEL ON BEARING OF DIRECTIONAL HYDROPHONE

To answer these questions, measurements of shrimp noise were made simultaneously at about 20 kc with the JK and AX58 hydrophones. The data were taken in the San Diego area during five days in the spring and summer of 1944. About forty stations were occupied. At each station the JK hydrophone, its beam horizontal, was rotated through one or more revolutions in steps of a few degrees. At each bearing the sound level was recorded. Sea state was 1.

Figure 27 shows the average polar noise patterns at various positions along a traverse about a mile north of traverse AB (Fig. 20) and parallel to it. For each pattern the level in a given direction is the pressure level of an equivalent plane sound wave, which, incident along the axis of the JK, would produce the observed response.

Over the bed the shrimp noise level is independent of the hydrophone bearing. This is true only for a large bed, however; over small scattered beds the uneven distribution of shrimp results in various uneven patterns (egg-shaped, double-lobed, etc.). At 4000 yards the water noise pattern is likewise the same in all directions and about 27 db lower. At the edge of the bed the noise pattern exhibits a marked dependence on bearing, as would be expected, the level of the large lobe in the direction of the bed being about 15 db above the level away from the bed. With increasing range the lobe narrows and shrinks rapidly, and at 2000 yards it is only 7 db above the water noise pattern.

5.3
COMPARISON OF DIRECTIONAL AND NON-DIRECTIONAL HYDROPHONES

In Fig. 29 the polar noise patterns at 20 kc are compared for the directional (JK) and non-directional (AX58) hydrophones. The latter are of course circles at each position. Over the bed the AX58 level is -40 db, as shown in the 20 kc curve of Fig. 22, while the JK level is about 22 db lower. Within experimental error the two output levels differ by the same amount as in deep water (4000 yards). This answers the first question above.

These observations might be explained in either of the following two simple ways. On the one hand, the shrimp noise could be the same in all directions, from those above as well as from those below. On the other hand, the noise could be coming only from below, with equal intensity in all solid angles below the projector. Over a bed whose dimensions are large compared with the water depth, it may be expected that sound reflected from the surface will have approximately the same intensity as sound coming up from the bottom. Thus one may conclude that over such a bed the shrimp noise is actually the same in all directions. It may be noted that this conclusion is consistent with the assumption of cosine sources discussed in the section on transmission.
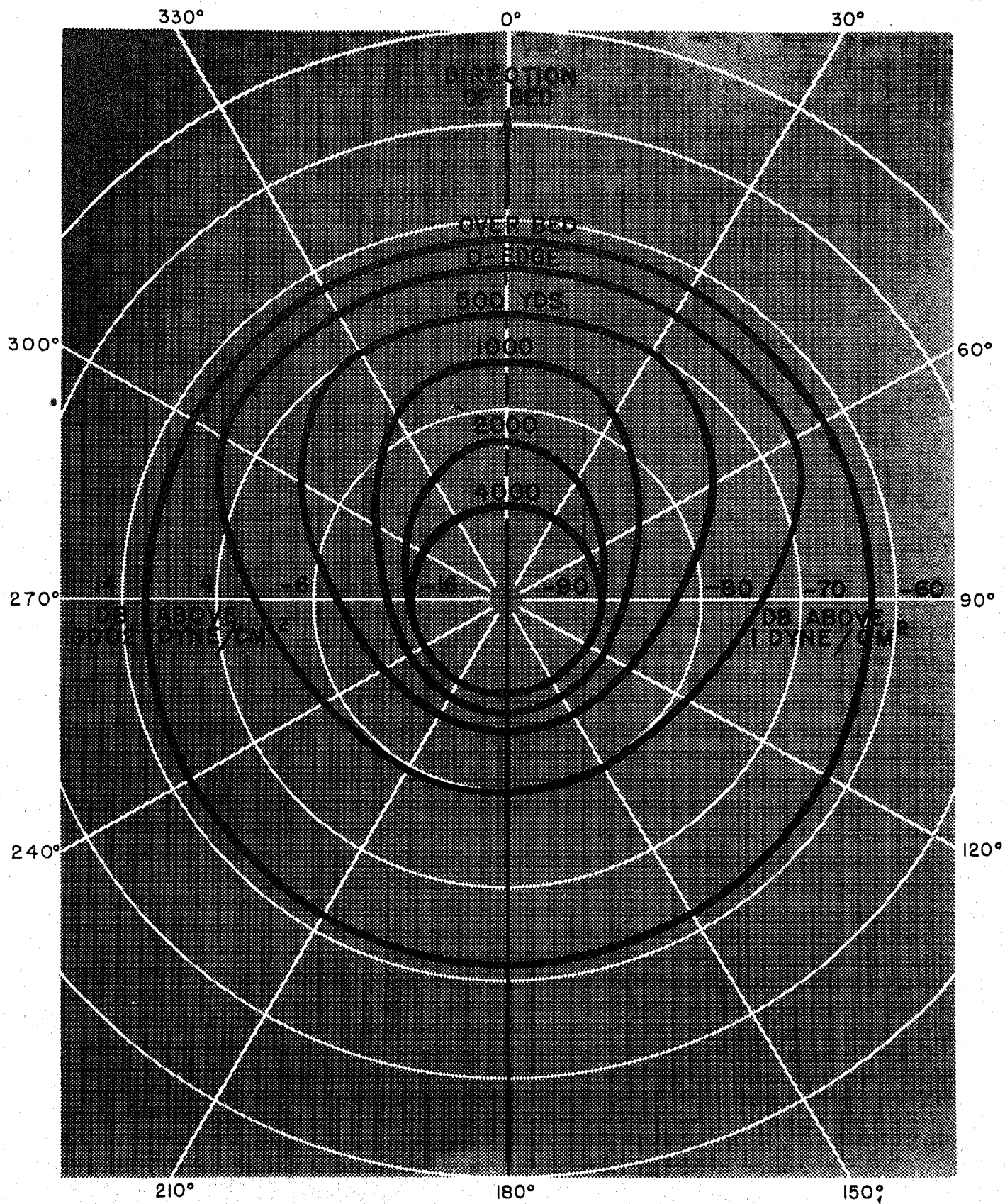
NOISE PATTERN AT 20 KC ON DIRECTIONAL (JK) HYDROPHONE
OVER AND NEAR SAN DIEGO SHRIMP BED
(PRESSURE LEVELS IN 1-CYCLE BAND)

FIGURE 27

Casual observations made independently during reverberation
studies over shrimp beds support this conclusion. No sig-
nificant change in shrimp noise at 20 kc was noticed when the
directional receiver was aimed up 30°, down 30°, or directly
downward. It therefore appears that over a large bed no
reduction in shrimp noise can be gained by changing the bear-
ing or tilt of a directional hydrophone.

The answer to the second question is provided by the noise
patterns of Fig. 29, results of which are summarized by the
three curves of Fig. 28. Curve A is the 20 kc curve of Fig.
22. Curves B and C show the maximum and minimum JK levels
from Fig. 27. The difference between the two bearings near
the edge of the bed is strikingly brought out.

Near the edge it is seen that the JK level toward the bed is
about 15 db below the AX58 level. This difference is to be
expected because the AX58 beam subtends the whole of the long
bed, while the narrow JK beam subtends only a small section.
If the shrimp colony were confined to a very small area, on
the other hand, the theory for Case 4 (circular bed for iso-
tropic sources) indicates that the AX58 level would drop
off more rapidly beyond the edge, while the JK, with its beam
subtending the whole bed, would not be much affected. In this
case, therefore, the two levels would agree more closely near
the edge. At long ranges, where shrimp noise cannot be heard,
the two outputs would of course still differ by 23 db, since
water noise is non-directional.

OVER
BED

FIGURE 28

EDGE   RANGE FROM EDGE OF SHRIMP BED — YDS.
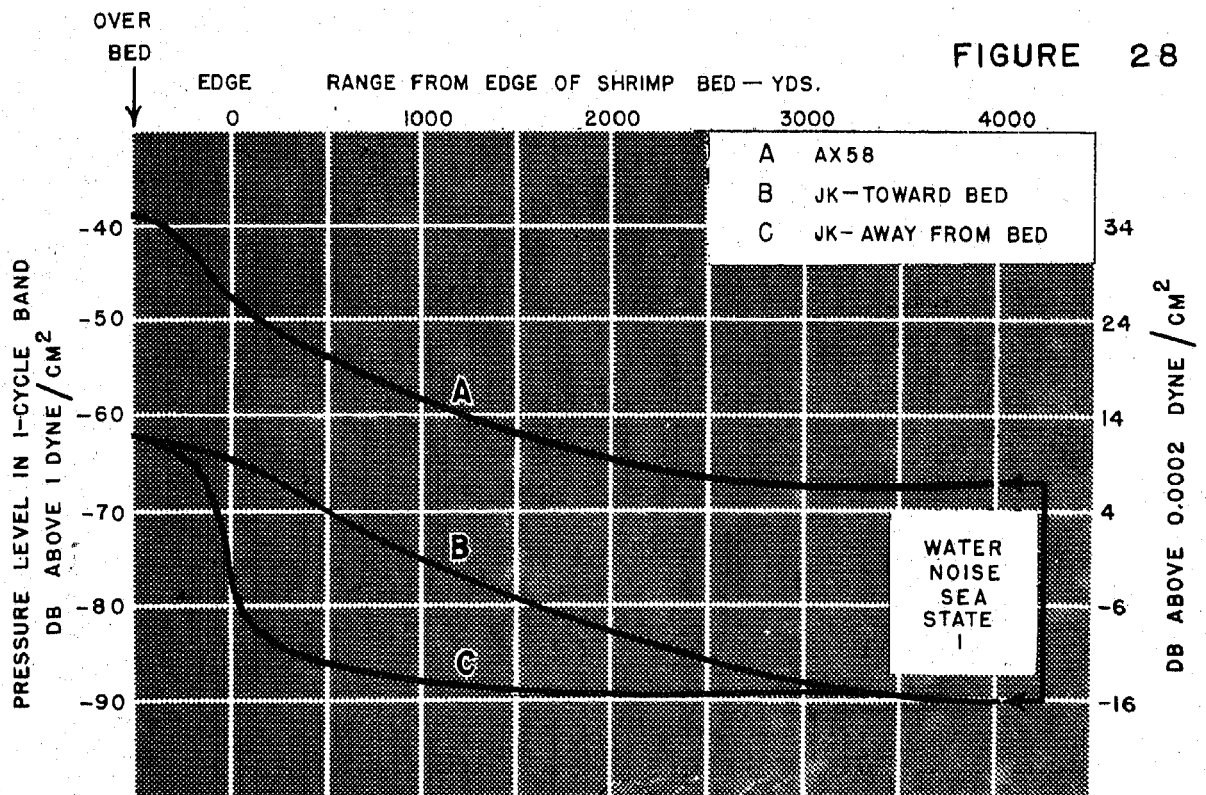
COMPARISON OF DIRECTIONAL (JK) AND
NON-DIRECTIONAL (AX58) HYDROPHONES AT 20 KC

FIGURE 29

NOISE PATTERNS AS A
FUNCTION OF BEARING AND RANGE
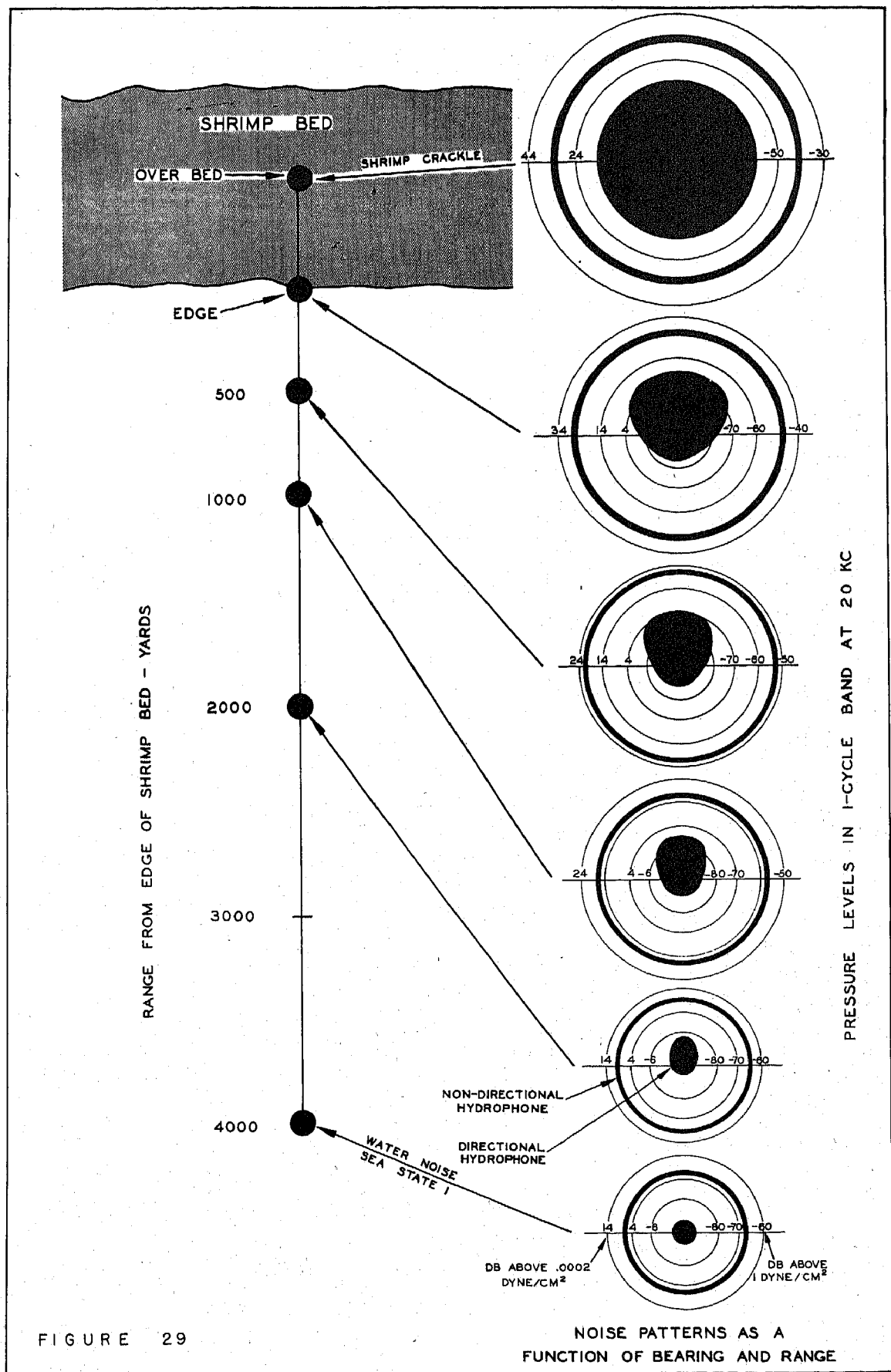
EFFECT OF HYDROPHONE DIRECTIVITY AT 20 KC

MASKING OF
UNDERWATER SOUNDS BY SHRIMP NOISE

The detection of a wanted signal against an unwanted background depends on the character of the signal, the background, and the detecting device. Only recognition by ear will be considered here, although many of the results are applicable to other types of detection. The manner in which the ear recognizes a signal will first be discussed briefly; the results will then be used to illustrate the masking effect of shrimp noise, as compared with other backgrounds, in sonic listening and supersonic listening and echo ranging. The conclusions regarding these effects are based on rather scanty ship-noise measurements, which vary considerably from ship to ship. Further research or changes in ship design may alter the relative importance of shrimp noise.

6.1
RECOGNITION OF
SIGNALS BY THE EAR

The ear is a frequency-discriminating device. In the presence of a background such as water noise or shrimp noise, it behaves as though provided with a set of fairly narrow band-pass filters. These enable the ear to hear a desired sound in one of the pass bands (usually called the "critical bands") without interference from noise outside the band. The width of the critical band depends on the frequency. From the idealized graph in Fig. 30A, the critical-band width is seen to be about 50 cycles between 0.1 and 1 kc; above 1 kc it increases with frequency and at 10 kc is about 600 cycles.

Experience has shown that underwater sounds radiated by ships, submarines, and torpedoes can be heard in the presence of wide-band noise when the signal/noise ratio approaches unity in at least one of the critical bands (Ref. 17). The relation between the critical-band spectra* of noise and signal, when the latter is detectable half the time, is shown in Fig. 30. The signal in Fig. 30B has a low-frequency peak, such as is found in machinery noise; Fig. 30C shows a signal composed of a continuous spectrum below 1 kc (typical of propellor or cavitation noise) and a broad peak at about 6 kc.

The role of the critical band in recognition is as follows. Consider the signal in Fig. 30B. If the signal level were lowered by a large amount, the signal would be completely masked by the relatively intense noise and could not be detected. Now suppose the signal level is increased; at first the signal will be detected only occasionally, say 10% of the time. As the level is raised, detection occurs more frequently; when the signal and noise levels in the critical band around the signal become equal, the signal is detected 50% of the time and recognition is said to occur. Thus recognition first occurs at frequency F_1 when the critical band spectra of the signal and noise become tangent. Similar remarks apply to the signal and noise in Fig. 30C where recognition occurs at the frequency F_2.

---

* CRITICAL BAND SPECTRA REPRESENT THE FREQUENCY DISTRIBUTION OF RMS POWER IN THE SIGNAL OR NOISE AS MEASURED WITH FILTERS OF BAND-WIDTHS EQUAL TO THOSE OF THE EAR AT THE CORRESPONDING FREQUENCIES. CRITICAL-BAND LEVELS ARE THUS TO BE DISTINGUISHED FROM SPECTRUM LEVELS, WHICH REFER TO THE RMS ACOUSTIC POWER CONTAINED IN 1-CYCLE BAND.

6.2 INTERFERENCE IN SONIC LISTENING

Comparison Of Shrimp Noise With Water Noise and Self Noise

Figure 31A shows the recognition of sonic signals against shrimp noise and water noise. The critical band spectra were derived from the average curves of Fig. 18 for a non-directional hydrophone with sea state I. The signals are idealized peaks at frequencies F_1 and F_2.

Below I kc it is seen that shrimp noise produces no impairment in the recognition of the signal F_1. Above I kc, however, the presence of strong shrimp crackle necessitates a large increase in the signal level for recognition. This increase measures the masking effect of shrimp noise and amounts to about 28 db at F_2. On the average, therefore, the masking of shrimp noise relative to water noise at sea state I is 28 db at 8 kc.

This result could have been obtained directly from the average spectra of shrimp noise and sea state I water noise shown in Fig. 18 because the <u>relative</u> levels of the two spectra at any given frequency are unchanged by plotting them as critical band spectra. The important conclusion follows: At a particular frequency the masking of shrimp noise relative to any other wide band noise is given by the difference in the spectrum levels of the two noises. Negligible additional masking is produced by shrimp noise if its spectrum level is lower than that of the reference noise.

Applying this result to Fig. 18, it is seen that above 2 kc shrimp noise produces strong masking relative to water noise, the amount depending on the frequency and sea state. Below I kc shrimp noise produces negligible masking except at very low sea states ($0-\frac{1}{2}$).

Figure 31 B shows signal recognition against shrimp noise, water

FIGURE 30
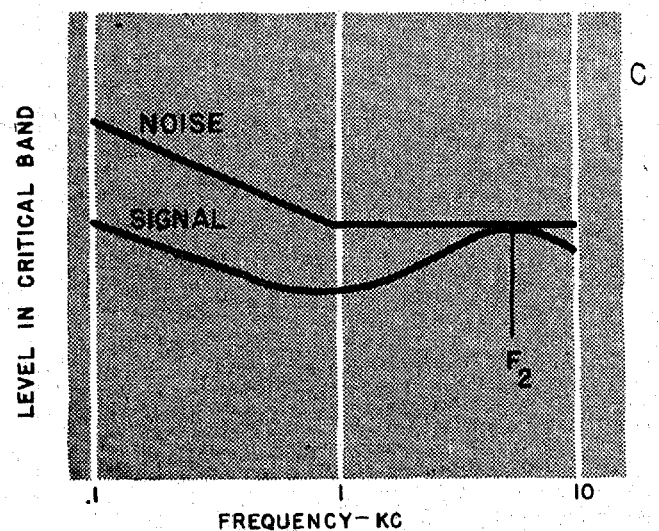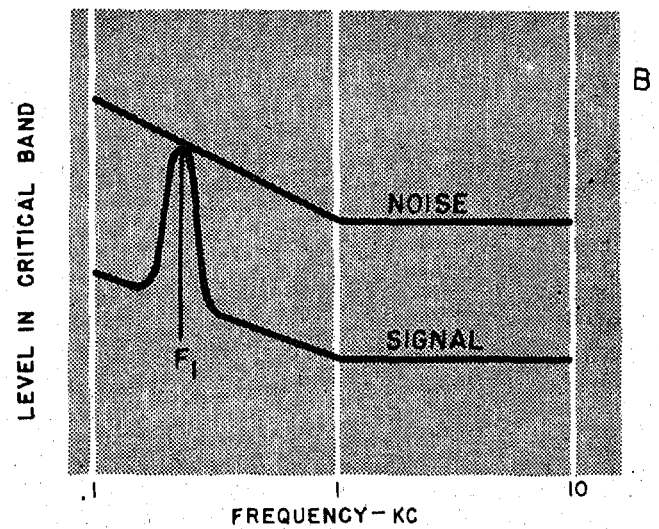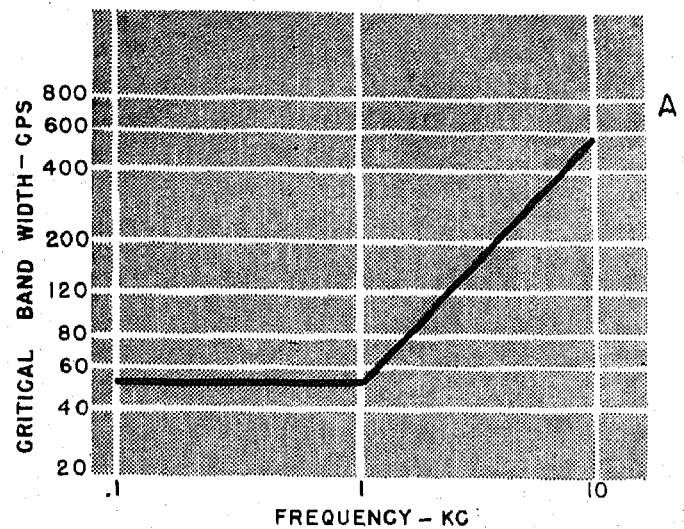
APPLICATION OF CRITICAL BANDS
TO SONIC RECOGNITION

55

FIGURE 31
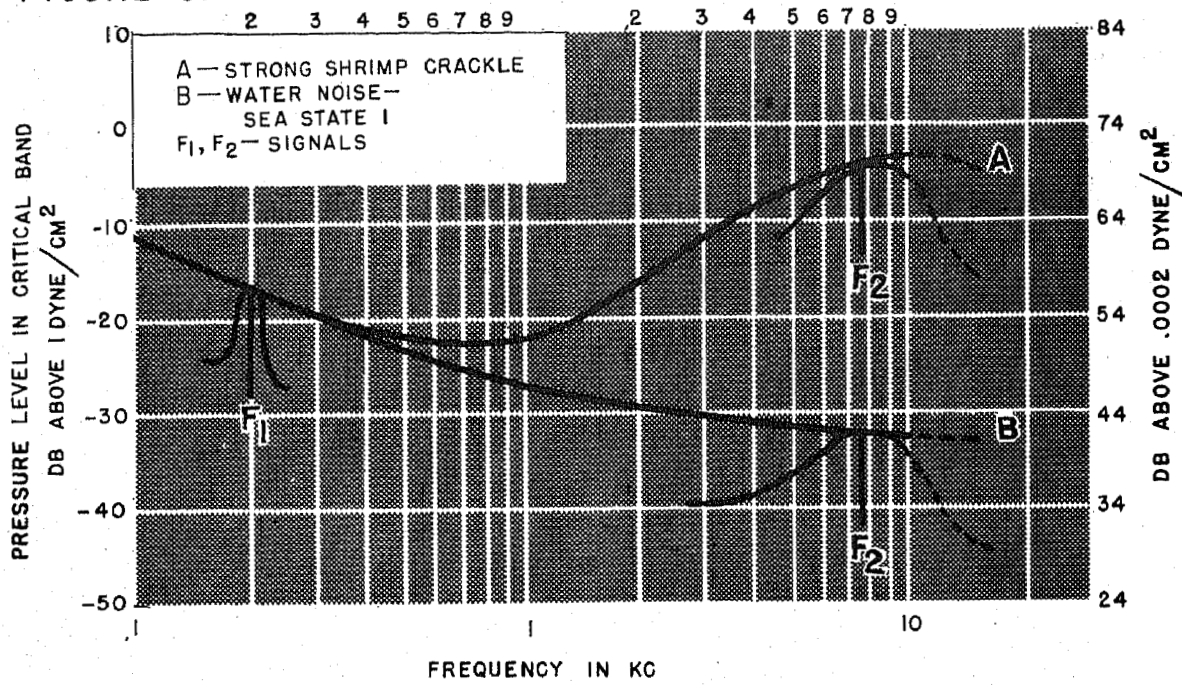
A. SIGNAL RECOGNITION AT SONIC FREQUENCIES
NON-DIRECTIONAL HYDROPHONE

B. SIGNAL RECOGNITION AT SONIC FREQUENCIES
DIRECTIONAL HYDROPHONE ON FLEET TYPE SUBMARINE

noise and low self noise with sea state I, representative of
listening conditions on a Fleet-type submarine employing a
standard JP-I hydrophone. Curves A and B are somewhat lower
than in Fig. 31A, as a result of slight hydrophone direct-
ivity[1]. Curve C is the spectrum of self noise for a 2-knot
Fleet submarine at periscope depth.[1] It is seen that shrimp
noise has the same masking effect relative to water noise as
for non-directional gear.

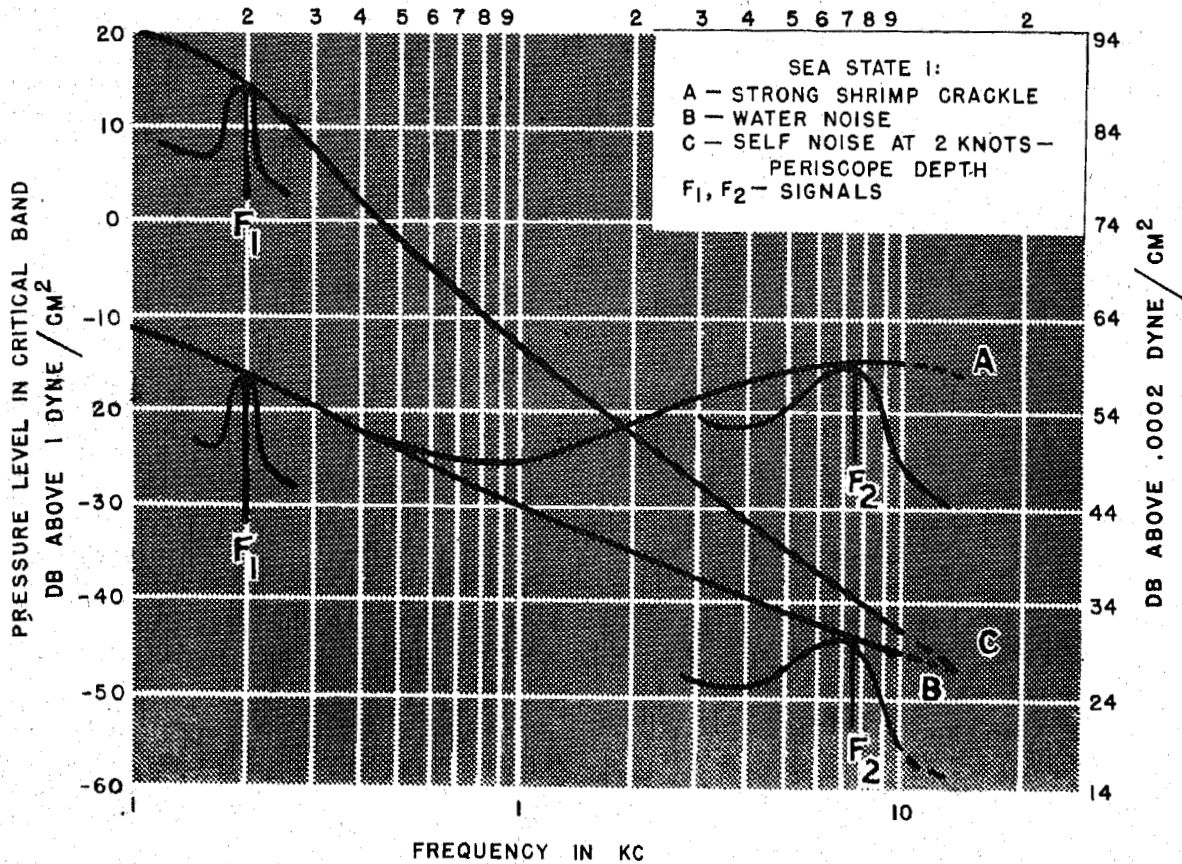Above 2 kc shrimp noise is also higher than 2-knot self noise,
the relative masking at 8 kc being about 25 db. With increas-
ing speed the self-noise curve is shifted upward; for 8 knots
the shift amounts to about 22 db and the self noise curve lies
almost entirely above shrimp noise. Above speeds of about 8
knots, therefore, shrimp noise produces negligible masking
relative to self noise.

Below I kc, self noise, even at the low speed of 2 knots, is
considerably above sea state I water noise; at F_1 (200 cycles)
for example, it produces an added masking of 30 db. This has
a considerable influence on the importance of shrimp noise,
as will be shown below.

The spectrum levels of shrimp noise shown in Fig. 31 are found
directly over the bed and illustrate, on the average, the max-
imum possible masking by shrimp crackle. At the edge of the
bed the masking effect decreases rapidly; the average trans-
mission curves at 3, 5, and 10 kc (Fig. 22) indicate that in
general shrimp noise produces negligible additional masking
of sonic signals at positions 2000 yards or more from the
bed. If a highly directional hydrophone is used, the masking
effect of shrimp noise beyond the edge of the bed will depend
on the bearing of the hydrophone. This is discussed more
fully under supersonic listening (Sec. 6.3).

Importance Of Masking By Shrimp Noise

Operationally, the importance of shrimp noise in masking a given
signal depends on the increase in signal level necessary for
recognition, since this change can be directly related to shorter
listening ranges. For the single-peak signal F_2 in Fig. 31 the
large increase of 28 db (above the audible level for water noise)
would considerably shorten the maximum listening range; for such
a signal, therefore, shrimp noise would be an important factor.

In general, however, a ship signal does not consist of a single
high-frequency peak. This is illustrated by Fig. 32, which
shows the critical-band spectra of the measured signals from
a 15-knot destroyer and a 5-knot submarine at periscope depth.
Both are seen to contain prominent low-frequency peaks. The
two background spectra (shrimp noise and water noise) are those
of Fig. 31 for JP-I listening gear on a Fleet submarine.

The destroyer signal in Fig. 32A has a peak at 250 cycles and
its audibility is unaffected by the presence of shrimp noise.
As in the case of the peak F_1 in Fig. 31B, however, this signal
would be strongly masked by self noise if the listening sub-
marine were underway at 2 knots.

The spectrum of the submarine signal in Fig. 32B is somewhat
different; it has a strong component at 7 kc accompanied by
some rhythmic cavitation noise. In the presence of shrimp
noise, this peak would require an increase of some 27db for
audibility. An increase of only about 10 db in the signal
spectrum, however, is sufficient for the peak at 0.5 kc to
become audible. In this case, therefore, the masking effect
of shrimp noise is about 10 db relative to water noise at
sea state 1.

Both of these examples demonstrate that the importance of
shrimp noise in masking the signal depends critically on the
distribution and level of the peaks. Unfortunately, ship
signals have usually been measured with wide bands which ob-
scure the peaks, so that little is known of this detailed
structure. Available evidence, however, indicates that most
ship and submarine signals are similar to the destroyer sig-
nal in Fig. 32A, with predominant peaks below 1 kc, probably
due to machinery noise (Ref. 24). Other factors such as at-
tenuation also tend to weaken the high-frequency end of the
signal spectrum and emphasize the low-frequency peaks.

Similar remarks apply to other signals. Cavitation noise,
rich in the higher frequencies, has a spectrum similar to
that of water noise, so that if recognition against water
noise does occur first at a high frequency, a slight increase
in signal level when shrimp noise is introduced is sufficient
to make the lower frequencies audible. Finally, torpedo noise
levels are so high that in the presence of water noise they
can usually be heard at great ranges, where, because of sel-
ective attenuation at the higher frequencies, recognition
occurs at low sonic frequencies (Ref. 22). For sonic lis-
tening in the presence of water noise, therefore, it is pro-
bable that recognition of ship, submarine, and torpedo signals
will occur below 2 kc and will be affected only slightly by
shrimp noise.

For sonic listening on a submarine underway, it would appear
that shrimp noise again does not usually affect maximum ranges.
The high self-noise below 2 kc, pointed out in the discussion
of Fig. 31B, would by itself tend to shift recognition to
high frequencies. However, the increased attenuation of
these higher frequencies has the opposite effect, and at
ranges greater than 5000 yards, a target is usually first
audible at low sonic frequencies. At low submarine speeds,
ranges greater than this are common, while at high submarine
speeds self-noise is in any case above shrimp noise. At a
submerged speed of 8 knots, for example, self-noise on JP-1
gear is above shrimp noise at frequencies up to about 8 kc.

While most sonic listening ranges are therefore probably un-
affected by the presence of shrimp noise, the accuracy of
bearings obtainable with sonic gear is much reduced when
shrimp are present.
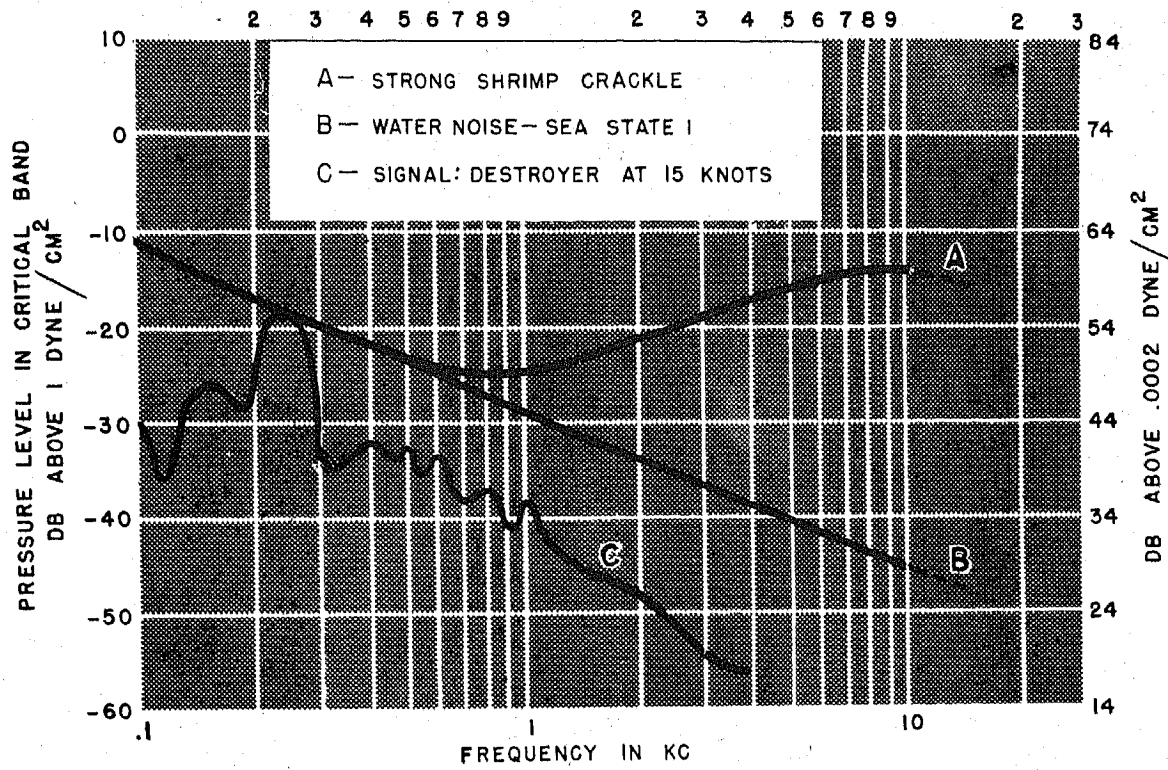
A. SONIC LISTENING—DIRECTIONAL HYDROPHONE
ON FLEET TYPE SUBMARINE
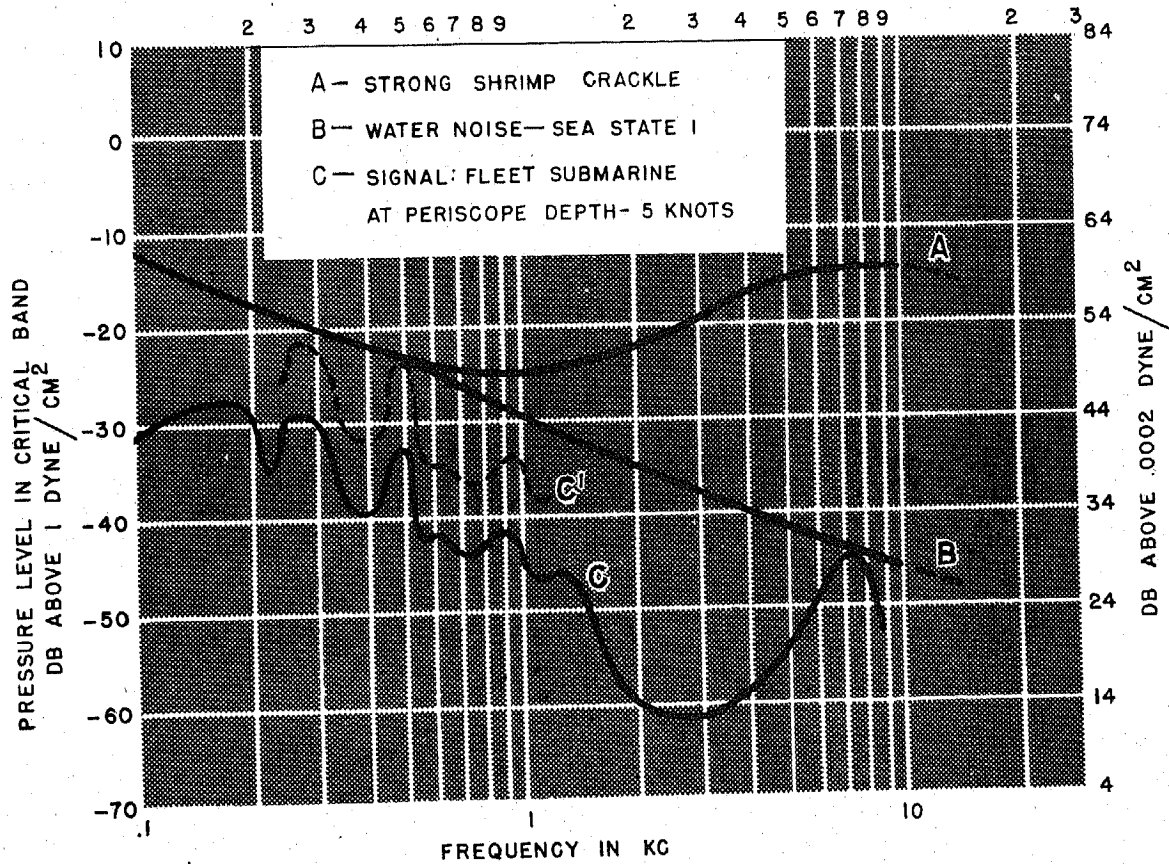
B. SONIC LISTENING—DIRECTIONAL HYDROPHONE
ON FLEET TYPE SUBMARINE

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With JP-1 equipment, for example, good bearings can be obtained
at intermediate ranges by listening to the high sonic frequencies.
When shrimp are present, these frequencies cannot be heard except
at very close ranges, and at the unmasked low sonic frequencies
only a very approximate indication of bearing can be obtained.

Effect Of Filters

From the preceding discussion it is clear that in sonic listen-
ing over a shrimp bed most signals will first be audible at
frequencies below 1 or 2 kc. Especially with gear such as the
JP-1, whose response increases with increasing frequency, elimi-
nation of these high frequencies by low pass filters may actually
improve listening in the presence of shrimp noise for two reasons:

(1) Elimination of frequencies above 1.5 kc reduces the loud-
ness of shrimp noise to such a degree that over-all system
amplification may be increased without listening to uncom-
fortably loud noise levels. This will improve listening condi-
tions at the lower frequencies where the sensitivity of the ear
is low; it also reduces the possibility that desired signals
will be masked by room noise.
(2) Elimination of frequencies above 1.5 kc reduces the loud-
ness of the shrimp noise and consequently tends to reduce
fatigue effects, which decrease the efficiency of the sound
operator. Many listeners seem annoyed and irritated by the
particularly "sharp" character of the shrimp noise.

A further use for low pass filters is suggested in connection
with sound measurements in areas where shrimp noise is en-
countered. In measuring submarine sounds, for example, ex-
perience has shown that a 1-kc or 1.5-kc low-pass filter is
needed to reduce shrimp noise.

It is to be emphasized that the use of these filters is recom-
mended primarily as a supplement to ordinary listening without
filters; in the presence of shrimp noise, listening both with
and without filters should always be tried. Especially at
close range, for example, where the higher signal frequencies
may be audible, listening to these frequencies is desirable
for accurate bearings.

Conclusions For Sonic Listening

For sonic listening with a non-directional or only slightly
directional hydrophone (JP-1):

1. Relative to water noise, shrimp noise over a bed very
effectively masks signals above 2 kc. The relative masking is
greatest directly over the shrimp bed, decreases rapidly at the
edge of the bed, and is negligible 2000 yards or more from the
bed. Below 1 kc the masking effect of shrimp noise is negligible
except, possibly, for very low sea states (0-½).

2. In the presence of water noise most ship, submarine, and

torpedo signals tend to be recognized by strong components below
1 kc. Even when recognition does occur at higher frequencies,
a small increase in signal level will usually enable the low
components to be recognized. In either case, therefore, shrimp
noise has little masking effect relative to water noise and may
generally be considered unimportant in sonic listening. Should
the listening be confined to frequencies above 2 kc, however,
shrimp noise will affect the detection of sonic signals very
adversely.

3. Self noise on a submarine underway is so strong at the low
frequencies that it tends to shift recognition toward higher
frequencies. Above 2 kc shrimp noise may produce significant
masking relative to low self noise (1 - 2 knots). However,
for a creeping submarine most listening contacts are obtained
at such long ranges that the greater attenuation at the higher
frequencies shifts recognition back to low frequencies where
shrimp noise is unimportant. At higher speeds self noise
increases and at 8 knots the self-noise level is usually above
shrimp noise at all sonic frequencies. Thus under all types
of listening conditions, shrimp noise is usually unimportant
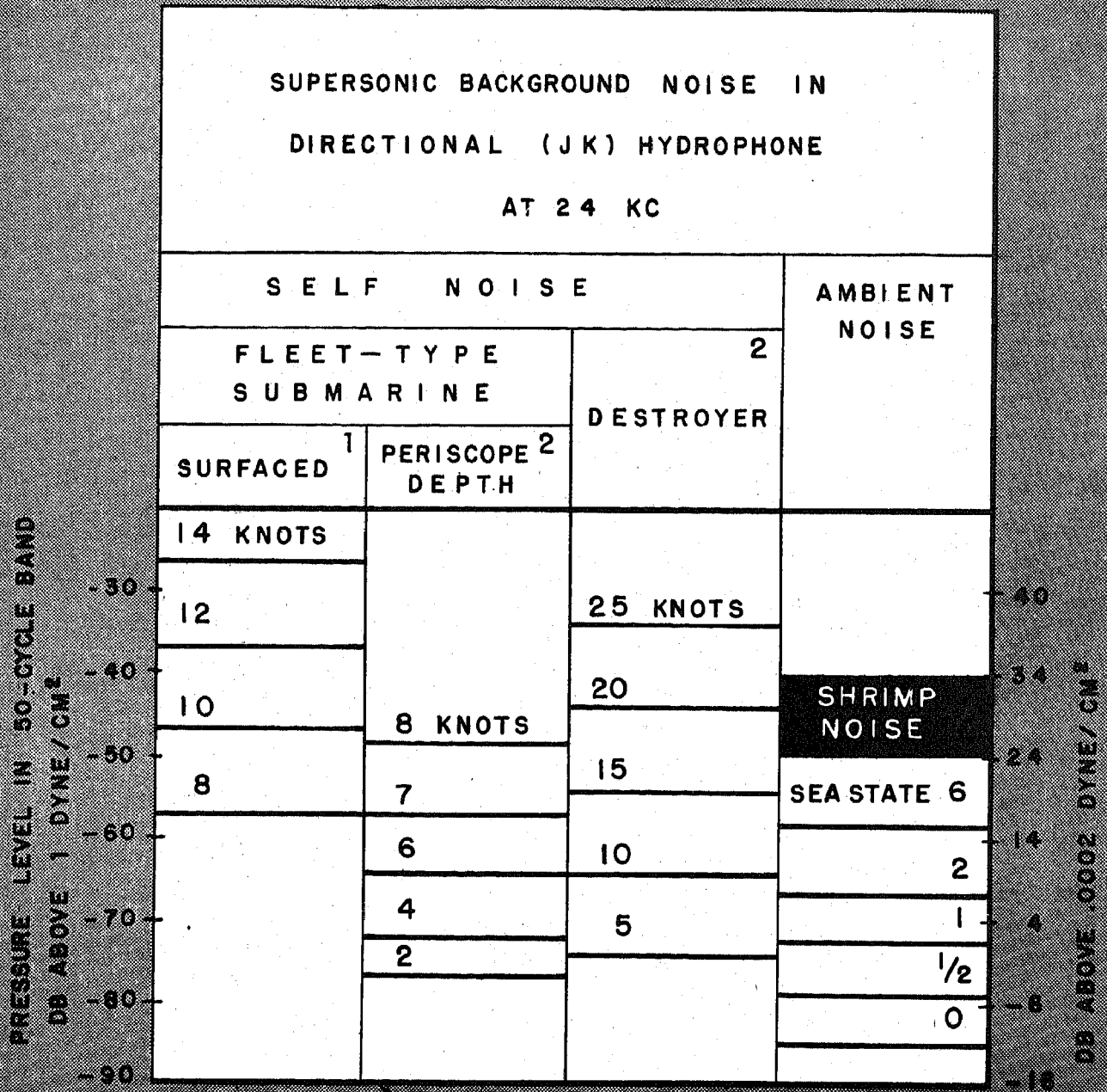for sonic listening.

4. Since the recognition of sonic signals tends to occur below
1 kc, a 1.5-kc low-pass filter may at times be advantageously
used to exclude shrimp noise at higher frequencies without
affecting the recognition of signals. However, these high
frequencies, when they can be heard, give the best bearing
accuracies; even when shrimp noise is present, high signal
frequencies may become audible at short range. For this reason,
a low-pass filter, while desirable for reducing operator fatigue
and in making possible a higher over-all amplification, should
not be relied upon to the exclusion of listening without filters.

6.3
INTERFERENCE IN
SUPERSONIC LISTENING

In supersonic listening a relatively narrow band of sound,
centered at a high frequency, is heterodyned down to an audible
band of the same width centered at about 1 kc. For listening
gear used with the JK hydrophone, the main frequency is about
24 kc and the band width is about 1500 cycles.

The audio spectrum presented to the ear depends primarily on
the equipment employed, since the actual noise spectrum at the
main supersonic frequency is relatively constant throughout the
band. The audio spectrum for heterodyned shrimp noise is there-
fore the same as for water noise or self noise received through
the same gear. Laboratory tests on the recognition of heterodyned
screw sounds in the presence of heterodyned shrimp noise showed
the same relative recognizability as for water noise. It may
be concluded, therefore, that the added masking caused by shrimp
noise at a given supersonic frequency is the same as the increase
in the background spectrum level at that frequency, due to shrimp
noise. From the spectra of Fig. 18, it is seen that at 24 kc
the masking of shrimp noise relative to sea state 1 water noise
is about 30 db.

FIGURE 33

SUPERSONIC BACKGROUND NOISE IN DIRECTIONAL (JK) HYDROPHONE AT 24 KC

SELF NOISE			AMBIENT NOISE
FLEET—TYPE SUBMARINE		DESTROYER	
SURFACED [1]	PERISCOPE DEPTH [2]		
14 KNOTS			
12		25 KNOTS	
10	8 KNOTS	20	SHRIMP NOISE
8	7	15	SEA STATE 6
	6	10	2
	4	5	1
	2		½
			0

Left axis: PRESSURE LEVEL IN 50-CYCLE BAND DB ABOVE 1 DYNE/CM² — values: -30, -40, -50, -60, -70, -80, -90

Right axis: DB ABOVE .0002 DYNE/CM² — values: 40, 34, 24, 14, 4, -6, -16

1. BEARING 090 or 270
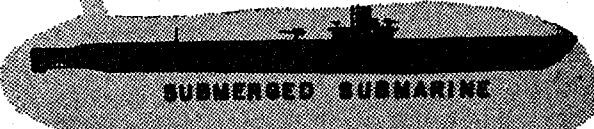2. ALL BEARINGS EXCEPT 20°–30° SECTOR INCLUDING PROPELLORS

This result can also be obtained from Fig. 33 which compares shrimp noise with water noise and self noise in a JK hydrophone at 24 kc.* The levels given are for a 50-cycle band, which is essentially the critical band width at the audio frequency (1 kc) at which the noises are presented to the ear. These are, therefore, the levels at which a 24-kc signal will be recognized. The three left columns in Fig. 33 show self-noise levels at various speeds for a submarine at the surface and at periscope depth and for a destroyer. The right column shows the levels for shrimp noise and water noise.

For listening vessels underway, self noise increases rapidly with speed and soon becomes the dominant background. Table VI shows the approximate speed at which self noise on a destroyer or submarine becomes equal to strong shrimp noise at 24 kc. At speeds approaching these values, shrimp noise, even over a bed, may be neglected in supersonic listening.

TABLE VI

SPEED AT WHICH SELF NOISE EQUALS SHRIMP NOISE OVER SHRIMP BED

(JK HYDROPHONE AT 24 KC - FROM FIGURE 33)

VESSEL	SPEED — KNOTS
DESTROYER	18 – 23
SURFACED SUBMARINE	10 – 12
SUBMERGED SUBMARINE	8 – 9

At low speeds, however, the masking effect of shrimp noise may be very large. This is particularly true for fixed listening equipment (barge-mounted or harbor-detection) where water noise is usually the dominant background. It is clear from Fig. 18 that even for high sea states shrimp noise produces serious additional masking. Shrimp noise may therefore be an extremely important factor in supersonic listening.

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* SEE REF. 22. IT MAY BE NOTED THAT THE AVERAGE SHRIMP NOISE LEVEL IN FIG. 33 IS 5 DB LESS THAN THE AVERAGE GIVEN IN TABLE III, TO TAKE ACCOUNT OF THE FACT THAT THE LISTENING SHIP, IN MOST PRACTICAL SITUATIONS, IS NOT LIKELY TO BE DIRECTLY OVER THE BED. A 10-DB CORRECTION FOR THIS EFFECT WAS MADE IN REF. 22.

These remarks apply to shrimp noise near a bed. Well beyond
the edge of the bed the noise level (and therefore the masking
affect) depends on the range and bearing of the hydrophone as
shown in Figs. 27 - 29 for an extended bed. At 1000 yards, for
example, the relative masking at 20 kc in the direction of the
bed is about 15 db above sea state 1 water noise; in the op-
posite direction it is only 2 db above the water noise, a
decrease of 13 db in the masking effect. At 2000 yards the
relative masking, even in the forward direction, is very slight.

Conclusions For Supersonic Listening

1. The critical-band theory of masking is valid for super-
sonic listening. It follows that the masking effect of shrimp
noise relative to other background noise, is given by the
difference in their spectrum levels at the main supersonic
frequency.

2. Shrimp noise has a strong masking effect relative to water
noise or low self noise and may therefore be an important factor
in limiting supersonic listening ranges for fixed echo ranging
gear or for low speeds of the listening ship.

6.4
INTERFERENCE IN
SUPERSONIC ECHO RANGING

The recognition of an echo differs from that of a wide-band
signal, since an echo is essentially a signal at a single fre-
quency. The critical band criterion states that for audi-
bility the power level of the echo must equal that of the
background noise in the critical band. Since the band presented
to the ear is centered at about 1 kc, the width of critical
band in question is about 50 cycles. The conclusion follows
that for audibility the power level of the echo must equal
the level of the masking noise in a 50-cycle band. Strictly
speaking, this result is true only for steady echoes having
a constant amplitude. Actual echoes require a further in-
crease in power to become audible because of the finite re-
sponse time of the ear; in addition, the fluctuation in actual
echoes may modify the required level.

In any case, shrimp noise has the same masking effect relative
to other backgrounds as in supersonic listening, the relative
masking being given by the difference in spectrum levels at
the main supersonic frequency. If the echo is heard against
a background of self noise or ambient noise at 24 kc, therefore,
Fig. 33 may be used. From this it follows immediately that
shrimp noise has a negligible effect in echo ranging from a
submarine or a destroyer at speeds above those in Table VI.

In general, however, the most important background in shallow
water is not self noise but bottom reverberation. This is
caused by high backward scattering of the ping when it strikes

the bottom and is most intense over rock and coral. Since these bottom types are also the most favorable for shrimp, it is probable that high bottom reverberation will occur over most shrimp beds.

The intensity of bottom reverberation changes with range. At short ranges it is very high, being far louder than either self noise or shrimp noise. From this high level the reverberation decreases with range, dropping very rapidly at first and then more gradually. At long ranges it falls into the background noise level. Thus the dominant background is bottom reverberation at short ranges and noise at long ranges.

From this discussion it would appear that over a shrimp bed, bottom reverberation and not shrimp noise is usually the masking background. This is indeed true for echoes having little or no doppler.

An echo having a high doppler, however, is shifted away from the reverberation, which is largely concentrated at one frequency. This causes most of the reverberation to lie outside the critical band around the echo and decreases its masking effect. At 24 kc, for example, the masking effect of reverberation drops about 12 db for an echo having 5 knots of doppler (80 cycles) and about 18 db for 10 knots (Ref. 23).

This decrease in the masking effect of reverberation shortens the range at which noise becomes the dominant background. If self noise is low, shrimp noise may then mask the echo, the amount of the masking relative to water noise or low self noise being given by Fig. 33. This situation may occur in echo ranging on a fast target with fixed echo-ranging gear (such as Herald) used in harbor defense.

For a submarine echo ranging on a surface ship, target noise, produced by the ship's screws, may be the dominant background noise, making shrimp noise an unimportant factor. If target noise (and self noise) is not high, however, the discussion in the preceding paragraphs applies.

Conclusions For Supersonic Echo Ranging

1. For echoes with a doppler of less than 80 cycles (5 knots at 24 kc) bottom reverberation is the masking background over shrimp beds and shrimp noise has a negligible effect on maximum echo ranges.

2. If the echo has a high doppler, the masking background is noise and the masking effect of shrimp noise relative to other background noises is given by the increase in the spectrum level due to shrimp noise.

HYDROPHONE

7 ANALYSIS OF SINGLE SHRIMP SNAPS

Shrimp noise over a bed is a continuous background crackling sound with occasional loud "snaps" or "cracks" resembling the sound of burning twigs. In the usual measurements of shrimp noise made with a sound level meter or recorder, it is the root-mean-square (rms) level of this background which is recorded and which has been described in the preceding sections.

In design of acoustic mines, however, it is of interest to know not only the rms level, but also the peak levels of ambient noise which may be expected (Ref. 20). Measurements of single shrimp snaps were therefore made by UCDWR. This study, while exploratory and limited in scope, gave several interesting results concerning the spectrum and transient characteristics of the snaps as well as their peak level; these results will now be described.

FIGURE 35
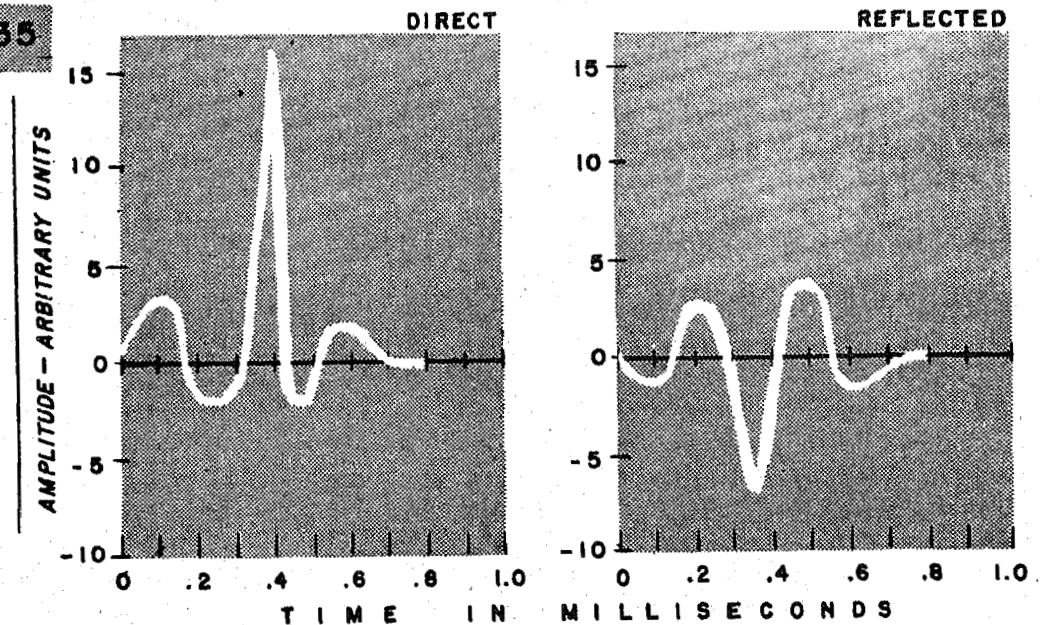
DIRECT AND SURFACE-REFLECTED COMPONENTS
OF A SINGLE SHRIMP SNAP

Oscillograms of single shrimp snaps were recorded on 35-mm
film using a C-10 hydrophone, a wide-band amplifier essentially
flat between 2 and 50 kc, and a General Radio high-speed moving-
film camera. Several reels of film were taken at random times
at Scripps Pier, La Jolla, and at the U. S. Navy Electronics
Laboratory pier in San Diego Harbor. The shrimp were living
in their natural habitat during these tests and probably
consisted of a mixed population of Synalpheus and Crangon.

In taking oscillograms of the sounds from isolated identified
specimens a different procedure was necessary since the shrimp
may not "snap" for long periods of time when kept in captivity.
Several specimens of one genus were removed from sea water and
exposed to fresh water in Sweetwater Lake, near San Diego.
This stimulated them to snap and the photographs were made.
The shrimp died after a few minutes' exposure to the fresh water.

Attempts were also made to measure snaps produced by single
species in the laboratory acoustic tank. The tests were
unsuccessful because of reflections and cavity resonance effects
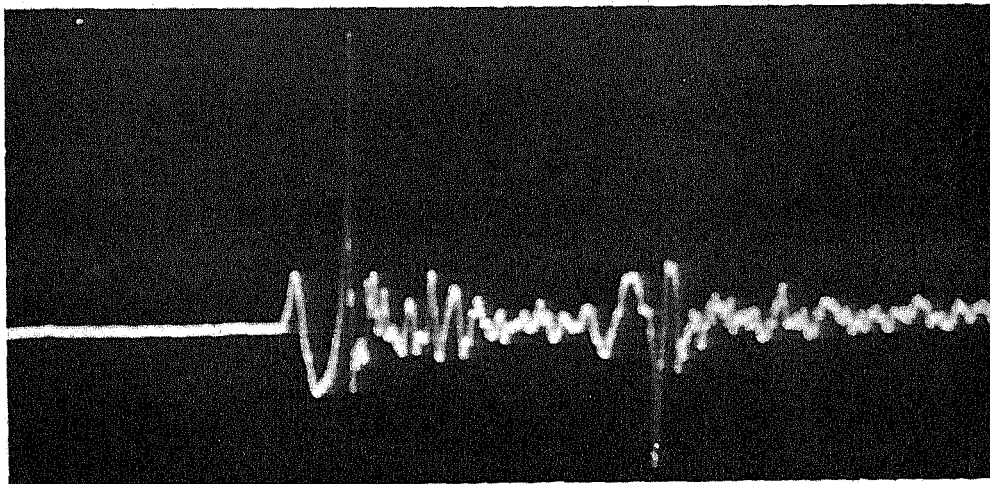from the tank and the rubber bucket in which the shrimp were
lowered.

FIGURE 36
OSCILLOGRAM
SHOWING SINGLE
SHRIMP SNAP

Figure 36 shows the oscillogram of a snap from a single shrimp.
The direct component on the left is followed by the surface-
reflected component of smaller amplitude and opposite phase
(Fig. 34). The time between the direct and surface components
of the snap shown in the oscillogram is about 1.5 milliseonds
and is determined by the geometry of the experiment. Figure
35 shows a slightly idealized tracing of the same two peaks,
plotted in arbitrary amplitude units against time.

The direct component consists of a small initial compression,
a larger rarefaction, and then a very sharp positive pulse,
comprising the main peak. The pulse then dies out in several
damped oscillations, the whole snap usually lasting from 1/2
to 1 millisecond. With the exception of the main peak, the
various pulses comprising the snap have a build-up time of
the order of 0.1 millisecond and are reliably recorded. The

7.2
CHARACTERISTICS
OF SHRIMP SNAPS

main peak, however, rising almost vertically, has a build-up time of the order of 0.01 milliseconds and the band-width (2-50 kc) of the recording system may be inadequate to record its full amplitude. However, any non-resonant acoustic device whose response does not extend beyond 50-70 kc should show peaks no greater than those found in the present work.

The reflected component of the snap shown in Figs. 34, 35, and 36 is nearly a mirror image of the direct component. This is typical of the records obtained when the surface was very smooth. With a rougher surface, the direct component is, of course, unchanged but the reflected snap is usually greatly distorted.

The shape of the snaps from Crangon and Synalpheus, recorded in the lake, showed slight differences. In general, however, the snaps recorded in sea water at the two piers and in the lake were all roughly similar in shape and indicate that the snap of Figs. 34, 35, and 36 may be taken as representative.

7.3 RATIO OF PEAK TO RMS LEVEL

In the Sweetwater test the shrimp were placed about five feet from the hydrophone. Correcting the results to pressure levels at 1 yard, it was found that the average peak level was about 45 db above 1 dyne/cm^2 for Crangon and about 54 db for Synalpheus. The standard deviation of the individual peaks is probably about 5 db. The difference between the two genera is believed to be real although the reliability of the measurements is somewhat lessened by the possible inclusion of weak snaps emitted by the fatigued and dying shrimp.

In order to compare the peak level with the background, the average San Diego spectrum for Fig. 19A was used. This indicates an rms level of about 10 db above 1 dyne/cm^2 for the broad band (2-50 kc) used in the peak tests. Thus the average peak level of a single snap from a shrimp a yard away is about 40 db above the rms level of shrimp noise over a bed. A rough check on the order of magnitude is given by measurements made at Scripps Pier. These data showed occasional single snaps with peak pressures of about 1000 dynes/cm^2, 50 db above the background, probably caused by nearby shrimp on the pilings.

7.4 FOURIER SPECTRA OF SNAPS

In order to determine the spectra of individual shrimp snaps, sixteen representative records were selected. After enlargement and tracing they were subjected to Fourier analysis[1] by an Henrici harmonic analyzer at the Case School of Applied Science, Cleveland, Ohio.

Figure 37A shows the resulting amplitude spectra for the snap of Figs. 34, 35, and 36. The direct and reflected spectra agree quite well.

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1. R. S. SHANKLAND, "THE ANALYSIS OF PULSES BY MEANS OF THE HARMONIC ANALYZER." J. ACOUS SOC. AM., V. 12, 3, 383-386; JAN. 1941.

and are typical of the spectra obtained from most of the snaps. Figure 37B shows the direct spectrum levels in db compared with the average spectrum obtained over shrimp beds in the open sea near San Diego. The agreement is reasonably good, indicating that the spectrum of a single snap is essentially the same as that resulting from the superposition of a large number of individual snaps, as would be expected.

D— DIRECT
R— REFLECTED
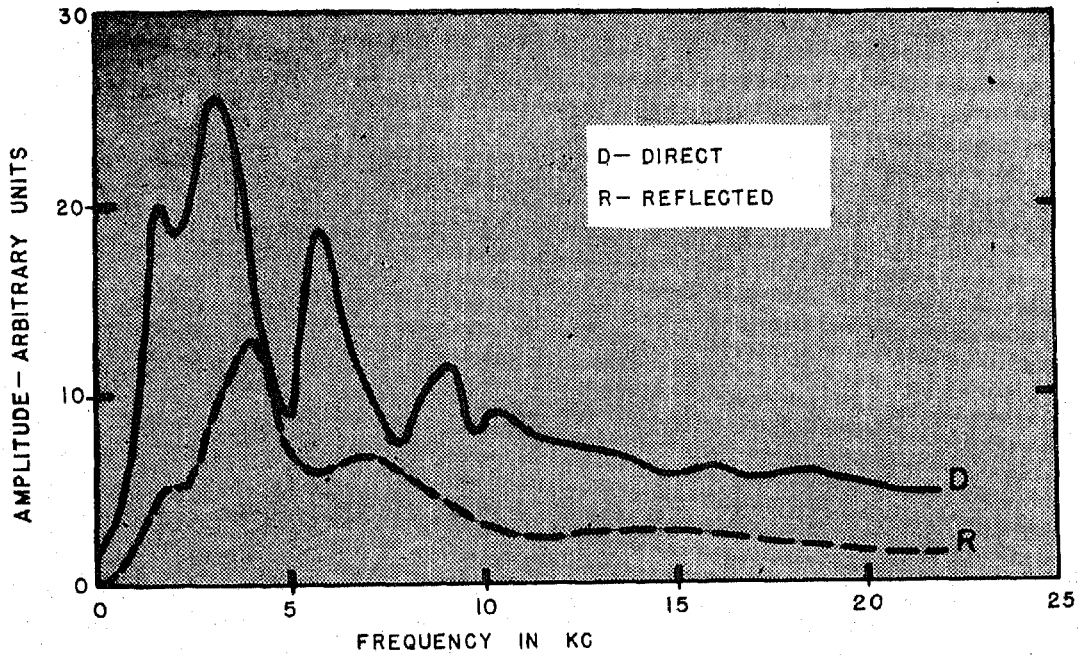
A. SPECTRA OF SINGLE SHRIMP SNAP

FIGURE 37

A— DIRECT COMPONENT OF
SINGLE SNAP
B— AVERAGE OVER
SAN DIEGO BED
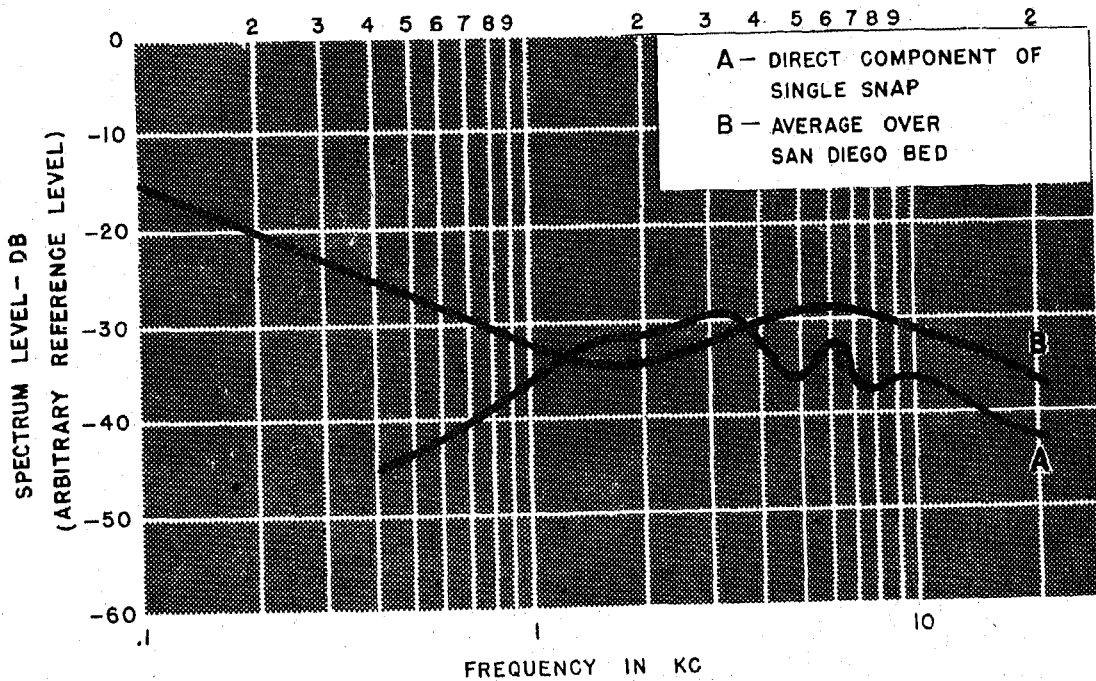
B. COMPARISON OF OBSERVED AND SYNTHETIC SPECTRA

PREDICTION OF SHRIMP NOISE

Shrimp crackle is the most widespread of marine animal noises thus far studied and it is, with two local exceptions*, the most disturbing noise encountered in shallow water. Unlike most other marine animal sounds, however, shrimp noise can be predicted, making it possible to avoid the noise or to plan operations advantageously. Rules for this prediction and their validity are discussed in this section.

8.1 FOR PREDICTING SHRIMP NOISE

The prediction of shrimp noise is rendered possible by several factors. First of all, snapping shrimp are widely distributed within the shrimp belt, as shown by the locality charts. Second, within this belt, shrimp are confined almost wholly to specific bottom types and within specific depths of water. Third, shrimp are non-migratory and may be considered as a constant characteristic of any region in which they have once been found. Finally, the noise produced by shrimp is continuous and has a relatively uniform intensity and spectrum. Consequently, knowing their habits, it is possible to predict areas of probable high shrimp noise level within the geographical range of the animals, provided accurate information is available on the type of bottom and depth of water. Information on these factors can be obtained from bottom sediment charts published by the Hydrographic Office.

Rule 1: Occurrence

Snapping shrimp can be expected throughout the oceans at locations where environmental conditions are favorable. These conditions are:

(a) Geographical Distribution: Tropical and subtropical latitudes, shown by the shrimp belt of Fig. 9; bounded approximately by 35° N and 40° S.

(b) Water Depth: Generally less than 30 fathoms (180 feet). The highest sound levels appear to occur in water between 30 and 150 feet deep.

(c) Bottom Type: Rock, shell, coral, weed, or other material providing ready concealment. Relatively uncommon on mud or sand bottoms which are free from sheltering material.

*IN ISOLATED PLACES ALONG THE ATLANTIC COAST A VARIETY OF DRUM-FISH, KNOWN AS CROAKERS, CAUSE A SERIOUS UNDERWATER DISTURBANCE DURING THE EVENING HOURS IN THE EARLY SPRING AND SUMMER MONTHS. SIMILAR FISH OCCUR ELSEWHERE IN TROPICAL AND SUB-TROPICAL WATERS. A SECOND UNDERWATER NOISE OF DISTURBING MAGNITUDE IS THE SO-CALLED 'EVENING NOISE' WHICH IS OBSERVED OFF SOME ISLANDS IN THE HAWAIIAN CHAIN.

RULE 2:

(a) Spectr...
kc; above

(b) Level:
with a non
-34 db ab

RULE 3:

The noise
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RULE 2: Noise Levels Over Shrimp Beds

(a) Spectrum: Depends primarily on water noise below 1 - 2 kc; above 2 kc shrimp crackle is predominant (Fig. 18).

(b) Level: Between 2 and 20 kc the average spectrum level with a non-directional hydrophone is nearly constant at about -34 db above 1 dyne/cm^2 with a standard deviation of 5 db.

RULE 3: Transmission Of Shrimp Noise

The noise level is highest directly over the bed and a few db lower at the edge of the bed. Beyond the edge it decays rapidly, dropping about 20 db within a distance of 2000 yards from the edge (Fig. 22).

Regarding Rule 1(a), there are few known exceptions to the prediction that shrimp will be found within the belt where the bottom type and water depth are favorable. Near the northern and southern limits of the belt, it is probable that local conditions, rather than the exact value of the latitude, determine whether or not shrimp will be found (see Sec. 2.7). At locations far outside the belt, Puget Sound (Fig. 9) for example, weak crackle due to other causes could be heard (see Sec. 9). Rule 1(b) concerning the dependence of shrimp on water depth is supported by both biological and acoustic data. Although this evidence is not conclusive, the 30-fathom rule is believed to be reliable as a rough guide. Rule 1(c) is based on biological knowledge of the habitat requirements and is strongly supported by the fact that most of the high levels were observed over favorable bottom types while most of the low levels occurred over unfavorable bottoms (see Sec. 3.3).

Rules 2 and 3 are essentially summaries of the available acoustic data and it is impossible to check them by an independent comparison with observations. Some indication of their validity, however, is given by the following remarks:

Rule 2 is consistent with nearly all spectra taken over shrimp beds in numerous locations (Table II). With few exceptions the spectra from all areas are remarkably uniform in both shape and level (Fig. 19A) and agree well with the average.

Rule 3 gives the range dependence of ambient noise in the vicinity of a bed for frequencies between 5 and 20 kc with sea states 1 - 2 and represents the available transmission data from various areas reasonably well. The decrease is less rapid below 5 kc and for higher sea states.

BIOLOGICAL
SOUNDS SIMILAR TO SHRIMP NOISE

Among the known animals producing noises that may be confused with shrimp crackle or that may in a minor way contribute to the ambient noise are the following:

Gonodactylus oerstedii (and perhaps other species of this genus), a crustacean generally known as "mantis shrimp" or "squillid" makes a clicking sound when striking out with its claws. Like the snapping shrimp, this animal has a wide tropical distribution and lives in similar habitats.

At least two species of the Coralliocars shrimp, C. graminea, and C. wilsoni, are capable of snapping by means of a structure similar to that used by regular snapping shrimp. They are not known to be abundant and apparently have a geographic and habitat range falling within that of the snapping shrimp.
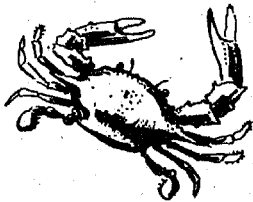
Typton spongicola of the Mediterranean and Pontonia pinnae of East Africa are species of crustacea said to be capable of snapping. They are not considered numerous.

The larger crabs such as Cancer and Portunus have been observed to make noises sounding like the individual crack produced by Crangon and Synalpheus, but the noise is incidental to the cracking of brittle shells of small clams, etc., for the food within the shell. Crackling from this source can of course be present only so long as shell food is being eaten. Other animals, including fishes, which occasionally crack shells for food would also fall into this category of incidental noise makers. To produce the volume of crackling that occurs continuously over shrimp beds, would, however, very quickly exhaust all available shells. Hence cracking of shells is believed to be a very small contribution to the ambient noise.
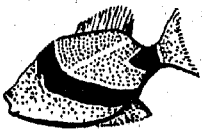
The trigger fish is said to be capable of making a clicking sound by means of the joints of some of the fin spines; and the mackerel by means of its pharyngeal teeth.

Populations of barnacles produce very weak crackling sounds, barely audible at very close range. Barnacles and perhaps other crustacea (preening their shells or feeding) appear to be the cause of these very faint noises sometimes heard, when the hydrophone is within a few feet of the shore, in quiet waters north of the geographic range of snapping shrimp.

In the Hawaiian area, a very troublesome raucous noise with a sharp high peak at 3 kc has been encountered. This has been called "evening noise" in view of its regular occurrence each evening between about 7:30 p. m. and 10:00 p. m. In one harbor, this caused a 10 db rise in overall level of the ambient noise during the evening hours. The origin of the noise was not determined but the possibility of its being somehow associated with increased shrimp activity in the evening has been suggested.

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