DETECTION OF MARKET SQUID, *LOLIGO OPALESCENS*, WITH ECHO SOUNDERS

DOUGLAS L. VAUGHAN AND CONRAD W. RECKSIEK
Moss Landing Marine Laboratories
P.O. Box 223, Moss Landing, CA 95039

ABSTRACT

Schools of the squid, *Loligo opalescens,* were located with low (38-kHz) to high (200-kHz) frequency echo sounders in nearshore waters of the Southern California Bight and Monterey Bay during research cruises from May to August 1976. Verification of squid traces on echograms was accomplished by midwater trawling, jig fishing under lights, and visual observation. Two radically different behavior patterns are represented by the echograms: 1) continuous bottom-associated traces which can be resolved over a substantial frequency range (38-200 kHz); and 2) midwater plume-like traces which may be more effectively resolved at higher frequencies.

INTRODUCTION

Echo location of fishable squid concentrations is used in several fisheries. Examples of this include the Japanese fisheries (Flores 1972) of "surume-ika," *Todarodes pacificus*; "kaka-ika," *Sthenotensis bartrami;* "budo-ika," *Loligo budo;* "kensaki-ika," *Doryteuthis kensaki;* "yari-ika," *Doryteuthis bleakeri*; and the California market squid, *Loligo opalescens,* fishery of southern and central California.

Studies of squid aggregations using echo sounders have been carried out in Japanese waters. Shibata and Flores (1972) described echogram traces produced by 50- and 200-kHz echo sounders of various squid species during commercial fishing operations. Echo sounders have been used in describing *Todarodes pacificus* school size, diel behavioral changes, and depth distribution (Kawaguchi and Nazumi 1972; Suzuki et al. 1974).

This paper describes research on the acoustic detection of market squid, *Loligo opalescens*, conducted between May and August 1976. This work consisted of identifying the types of traces that squid produced on echograms from different types of echo sounders. Based on these traces, some aspects about market squid behavior are described.

METHODS AND MATERIALS

Echograms were collected from three separate echo sounders, which varied in frequency from 38 to 200 kHz, throughout the period of May to August 1976. These machines had differences in frequency, pulse length, pulse repetition rate, paper speed, type of paper, beam angle, and time-varied gain adjustments (Table 1).

They were primarily used at various locations between Santa Rosa Island and Santa Cruz, California (Figure 1). The manual gain and white-line settings for each instrument at each location were adjusted for optimal reading of the echograms. Verification that the traces observed were those of *Loligo opalescens* was accomplished through visual observation, midwater trawling, and jig fishing under lights. The traces known to have been caused by this squid species are reproduced herein (Figures 2-6).

RESULTS

A Simrad EK-38 (38 kHz) and a Gemtronics GT-105 (200 kHz) were used simultaneously aboard the California Department of Fish and Game R/V *Alaska* from 28 May 1976 to 20 June 1976 (Cruise 76A4). Echograms that could be attributed to *Loligo opalescens* are

Figure 2 portrays echograms taken with the Gemtronics GT-105 and Simrad EK-38 at a night-light station on 8 June 1976 while at anchor in 29-m depth. The light was switched on at 0055. The ship was positioned at 33° 54.5' N and 120° 0.1' W, which is 2.7 miles southwest of East Point on Santa Rosa Island, California (Location 1, Figure 1). In the two hours spent at this station (0055-0255), 350 market squid were jigged; many squid were observed at the surface, along with occasional sightings of sharks, pelagic polychætes, and salps. Because of the high catch and numerous sightings of squid and the fact that only a few other marine organisms were observed, the traces at this station were assumed to be squid.

The Gemtronics echogram for this station showed dark, closely spaced, feather plume-like traces next to the surface after the night light was turned on (Figure 2-A). These traces remained for approximately 11 minutes, and their occurrence corresponded to visual sightings of squid near the surface. Two additional similar groups of plume-like traces occurred near the surface at various intervals throughout this station. The second group of traces appeared toward the middle of the station and lasted approximately 14 minutes; the third group occurred toward the end of the station and lasted approximately 4 minutes. The vertical extent of these traces over the entire station ranged between 2.3 and 11.3 m. Toward the end of the station, plume traces were also recorded near the bottom (Figure 2-B).

Throughout most of the station, the Simrad EK-38 recorded traces on and near the bottom which ranged in vertical extent from approximately 2 to 14 m. Figure 2-C is an echogram of the largest of these traces recorded.

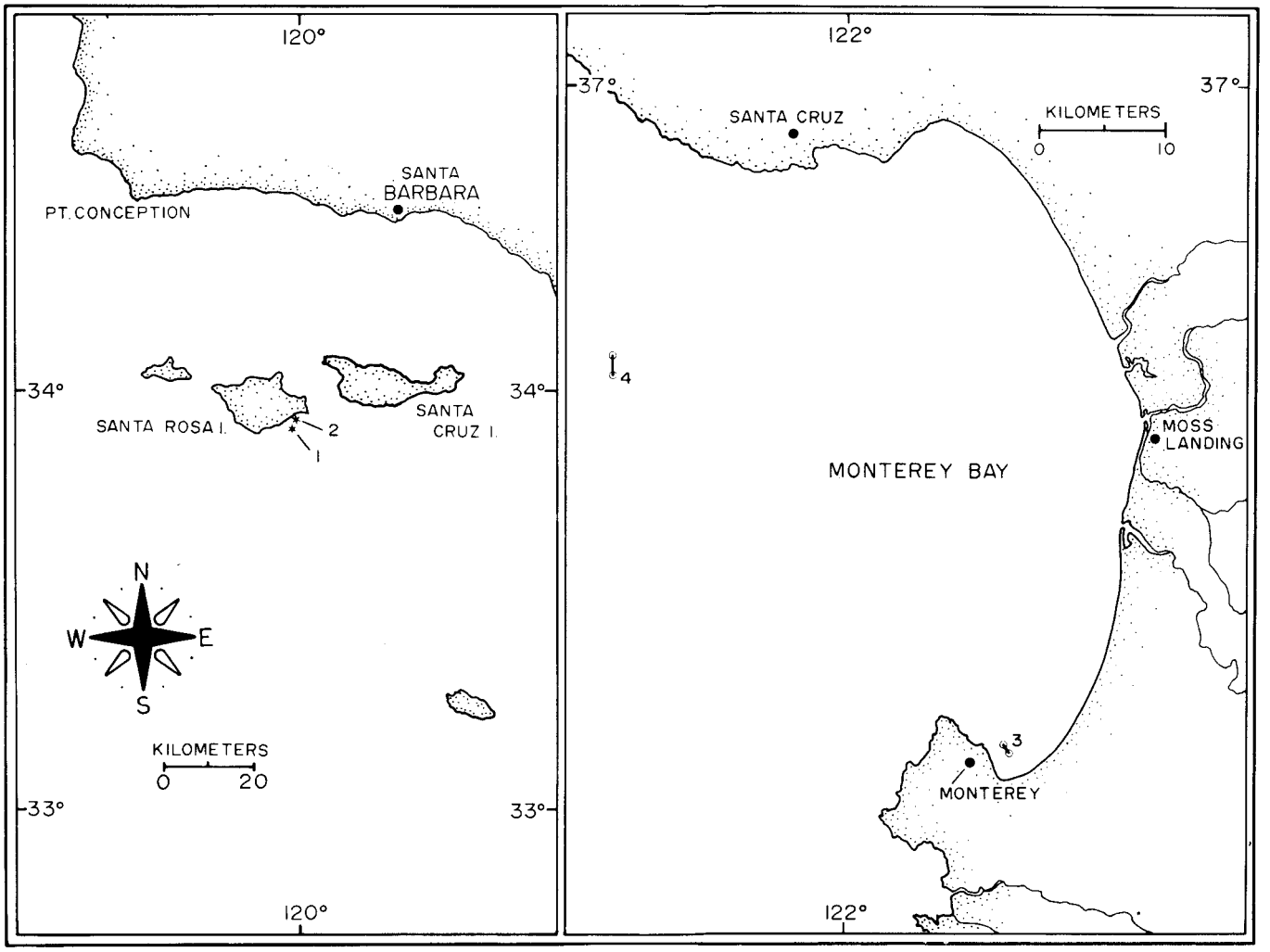


Figure 1. Midwater trawls (3, 4) and night-light stations (1, 2) where echo sounders were used in the detection of market squid May through August 1976.

Unlike the Gemtronic echo sounder, no large traces were recorded near the surface.

Figure 3-A and B are traces taken simultaneously with the Gemtronics and the Simrad EK-38, respectively, when the R/V *Alaska* was searching for squid at an estimated speed of 2 knots next to Santa Rosa Island. The mark with the letter "A" adjacent to it was made at the same time for both units. The primary trace represented a concentration of animals which was approximately 0.5 km long and extended from 2.3 to 14.5 m off the bottom. The ship's position at the time of the trace was approximately 33° 55.7' N and 120° 0.5' W (Location 2, Figure 1). After passing over the school once, the vessel doubled back over it, anchored, and the night light was switched on. Squid were caught soon after jigs were lowered to the bottom. This station began at 0340 on 8 June 1976 over a depth of 27.4 m. Figures 4-A and B show respective traces for the Gemtronics and Simrad EK-38 taken at the beginning of the night-light station.

After the light was on for approximately five minutes, plume-like traces on the Gemtronics were appearing to rise toward the surface (Figure 4-A). By 0410, this sounder was recording a continuous bottom trace, which was about 3.7 m in height, and numerous "speckled" traces (Figure 4-C). These speckled traces were recorded as almost saturating the water column. At this time, adult squid were being jigged at a relatively fast rate; 500 were caught during the station. They were also visible in heavy concentrations at the surface and many were seen copulating. Other marine organisms visible were spiny dogfish, unidentified sharks, and pelagic polychætes.

The EK-38 recorded dark bottom traces at times during the station and very faint traces in the water column above the bottom (Figure 4-B). Traces off the bottom were resolved to a much lesser degree than Gemtronics traces taken at the same time. Scattering was recorded

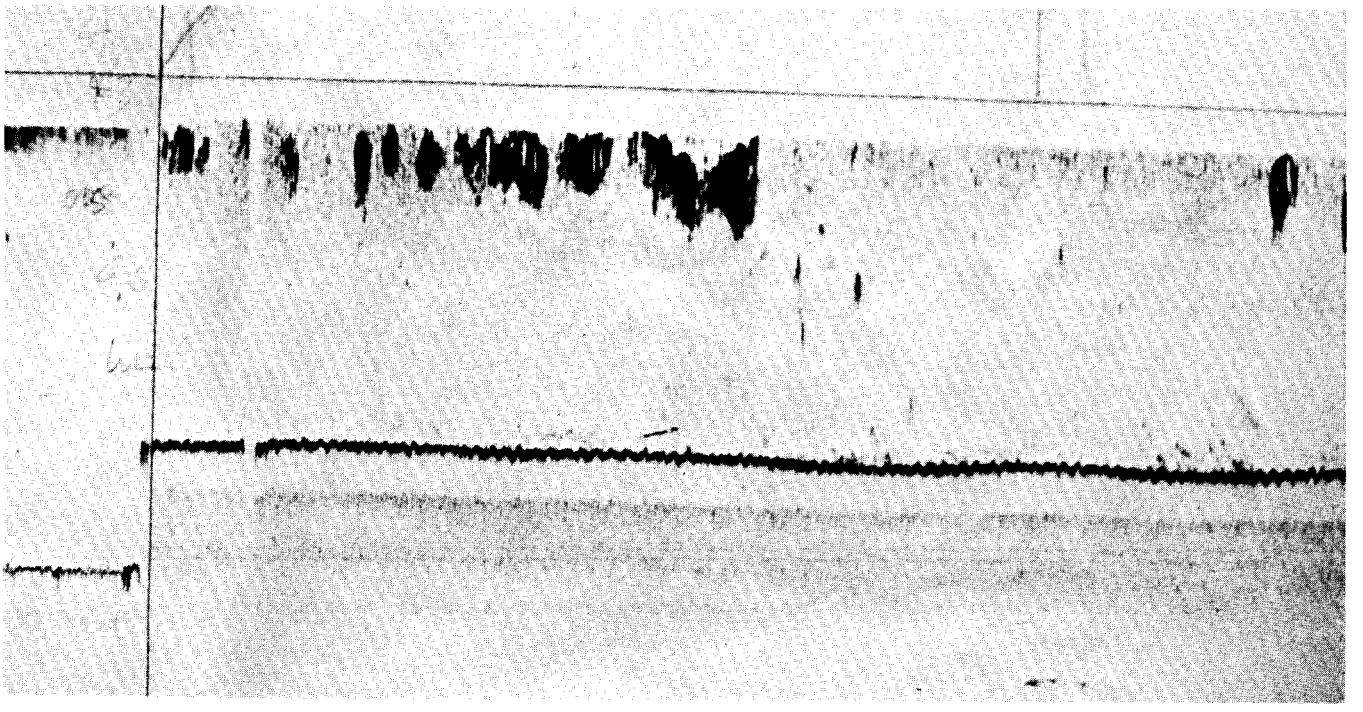
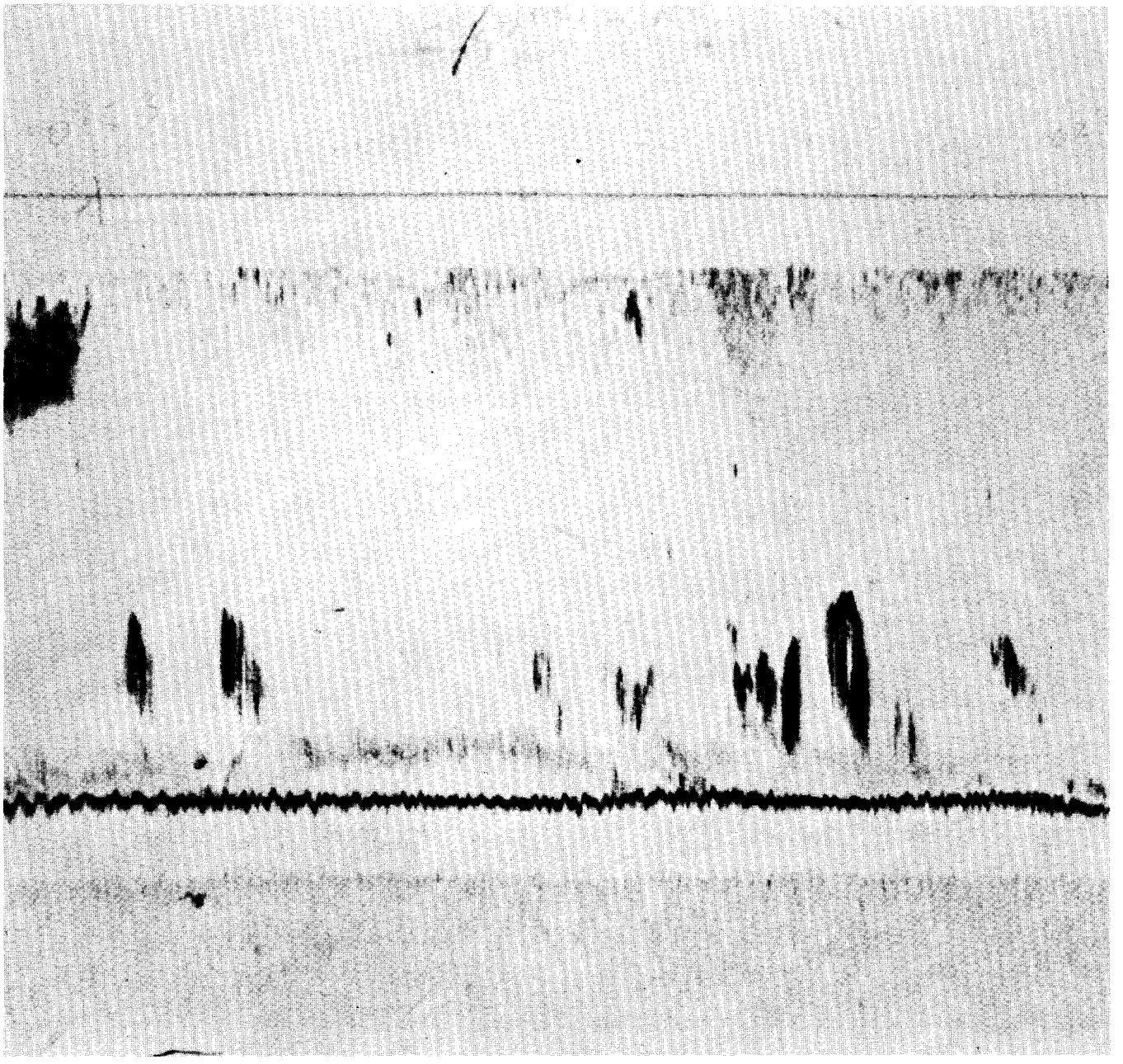
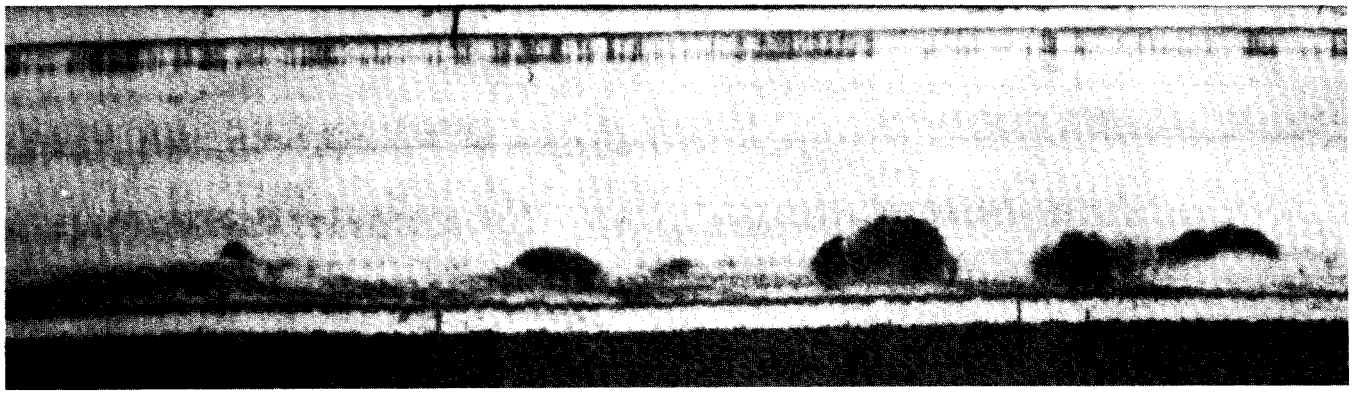


Figure 2. Echograms of market squid traces taken from the R/V *Alaska* 8 June 1976 at a night-light station near Santa Rosa Island (33° 54.5' N, 120° 0.1' W, depth 29 m), taken with A. 200-kHz Gemtronics GT-105, showing plume-like traces near the surface, recorded at the beginning of the station (approximately between 0055 and 0106 hours); B. 200-kHz Gemtronics GT-105, showing plume-like traces near the bottom, recorded midway through the station (approximately between 0150 to 0200 hours); C. 38-kHz Simrad EK-38, showing bottom traces assumed to be market squid.





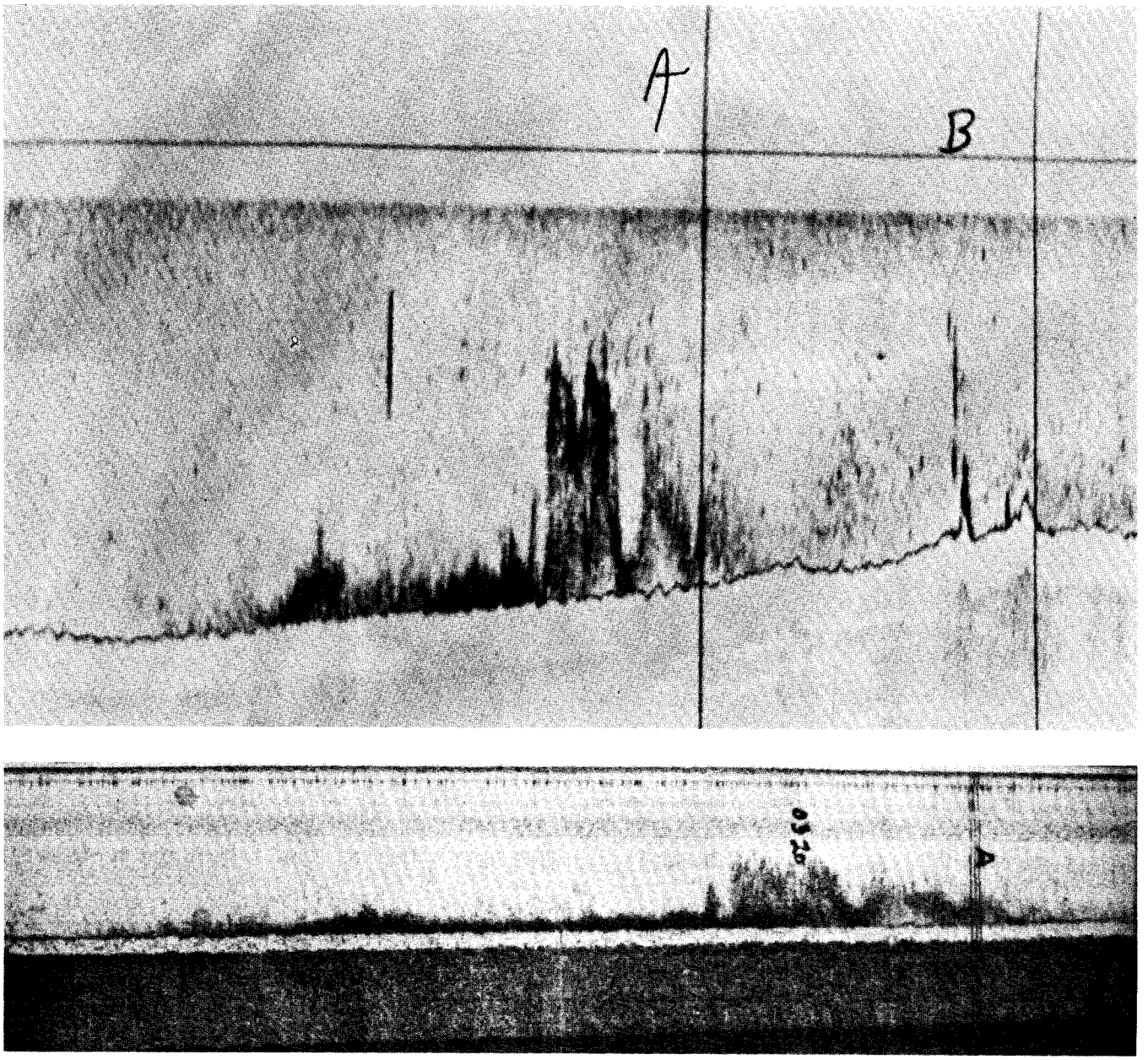


Figure 3. Echograms of market squid taken from the R/V *Alaska* traveling at an approximate speed of 4 knots while searching for squid next to Santa Rosa Island 8 June 1976. At Mark A on both echograms, the ship's approximate position was 33° 55.7' N, 120° 0.5' W; time was 0320 hours; A. taken with the 200-kHz Gemtronics GT-105 echo sounder; B. taken with the 38-kHz Simrad EK-38 echo sounder.

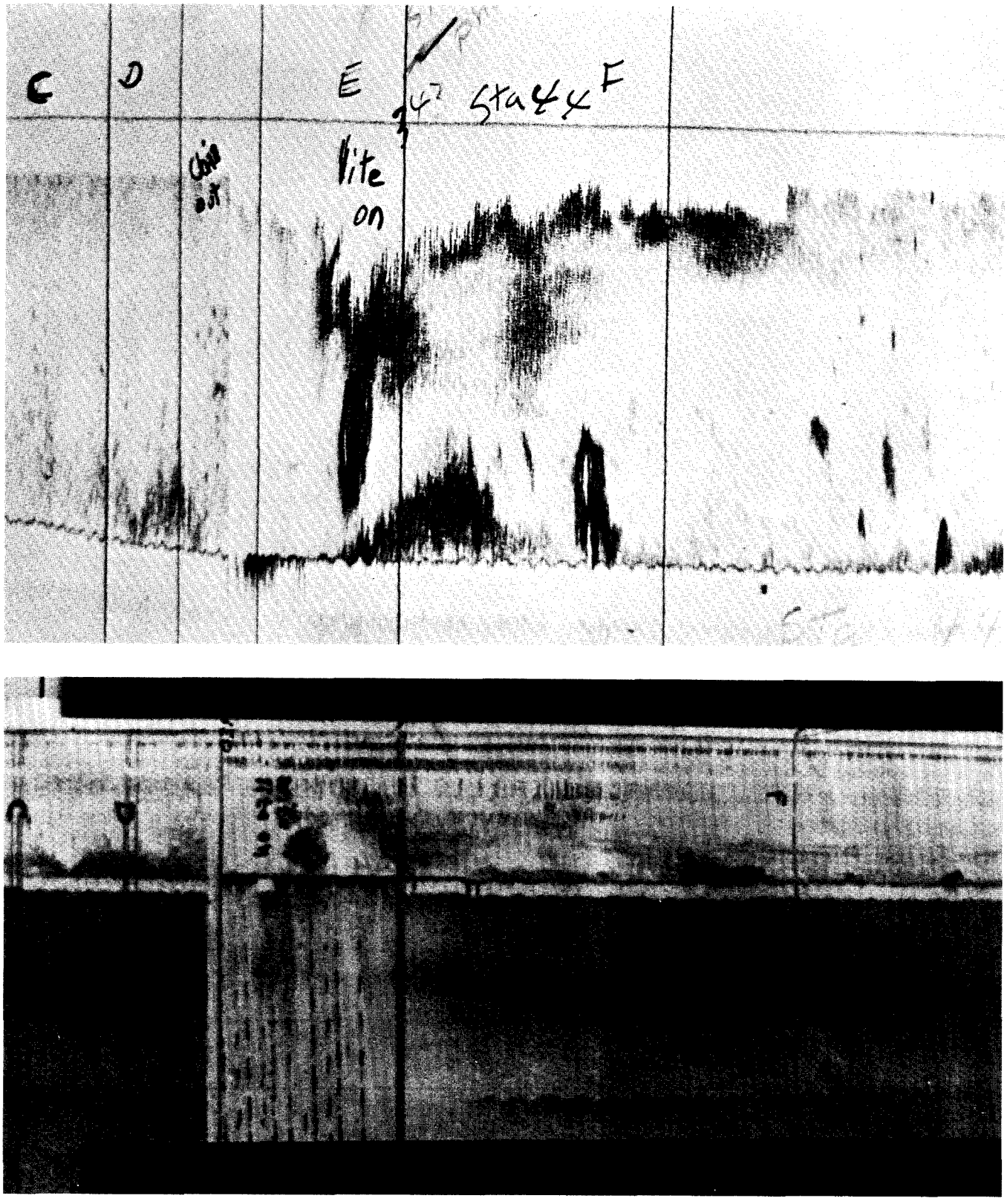
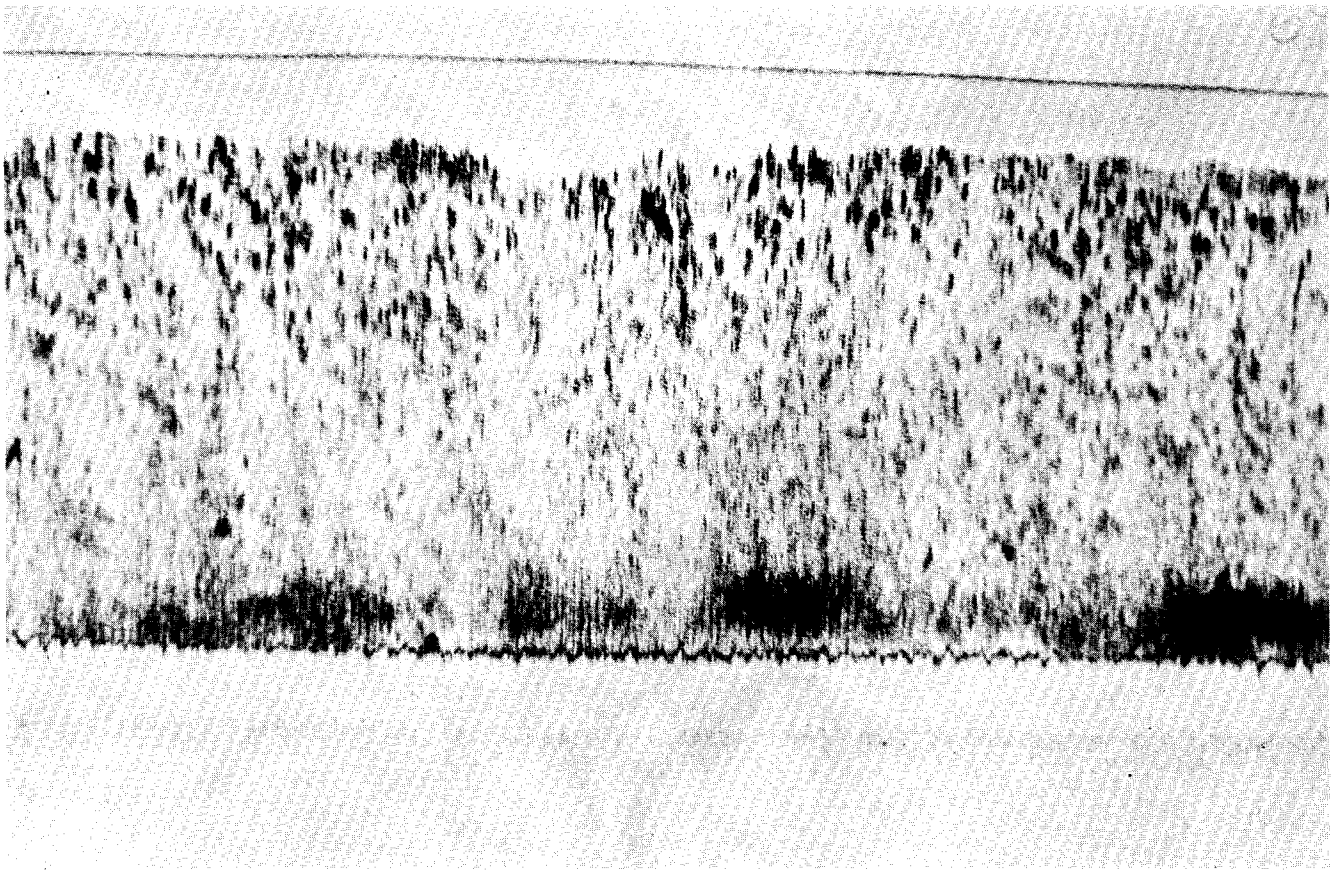
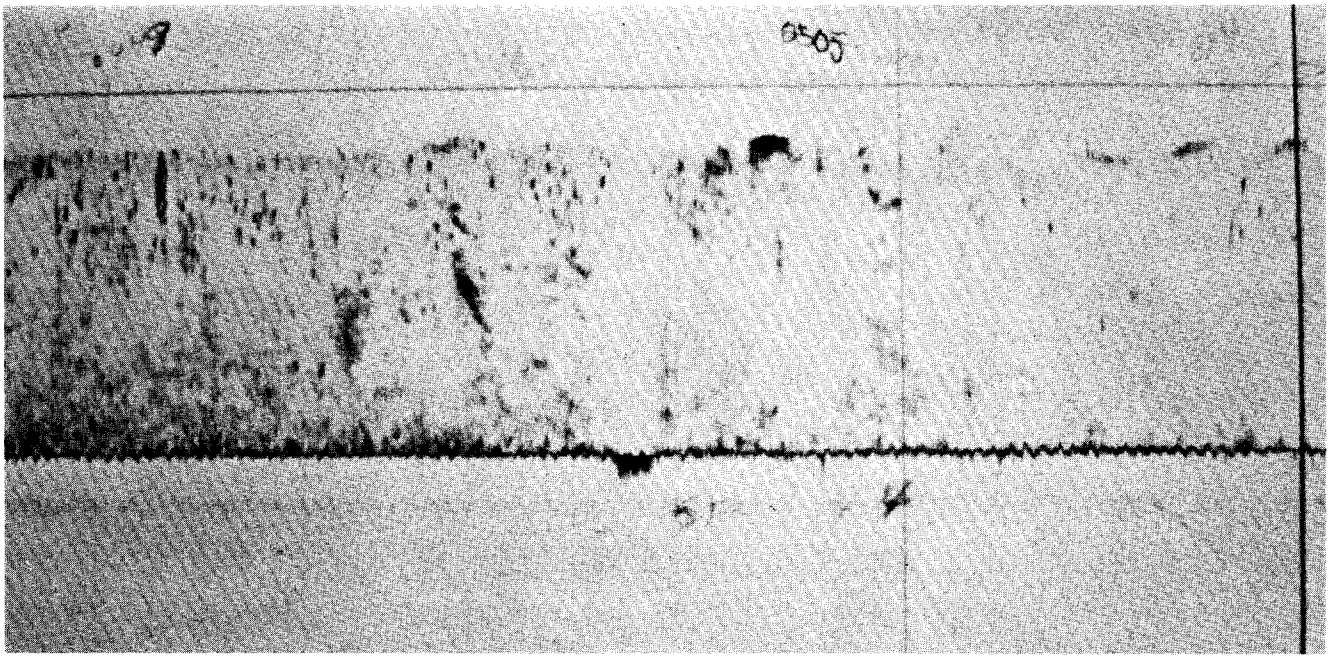


Figure 4. Echograms of market squid taken from the R/V *Alaska* 8 June 1976 at a night-light station near Santa Rosa Island (33° 55.7' N, 120° 0.5' W, depth 27.4 m): A. 200-kHz Gemtronics GT-105, taken at the beginning of the station, showing continuous squid traces along the bottom and plume-like squid traces rising toward the surface. The light was turned on at approximately 0340 hours (Mark E); Mark F was made at approximately 0344. The large dark trace that extends throughout the water column under the words "lite on" was caused by anchoring. B. 38-kHz Simrad EK-38, taken at the beginning of the station. Marks E and F were made at the same time as those shown on the Gemtronics in A. The continuous traces next to the bottom between these two marks were assumed to be market squid. Most of the scattering recorded above the bottom next to Mark E was caused by anchoring. C. 200-kHz Gemtronics GT-105, taken approximately between 0405 and 0433 hours, showing "speckle" traces almost saturating the water column and a continuous trace lying along the bottom. D. 200-kHz Gemtronics GT-105, taken between 0449 and 0510 hours, showing less traces as dawn approached.




0505

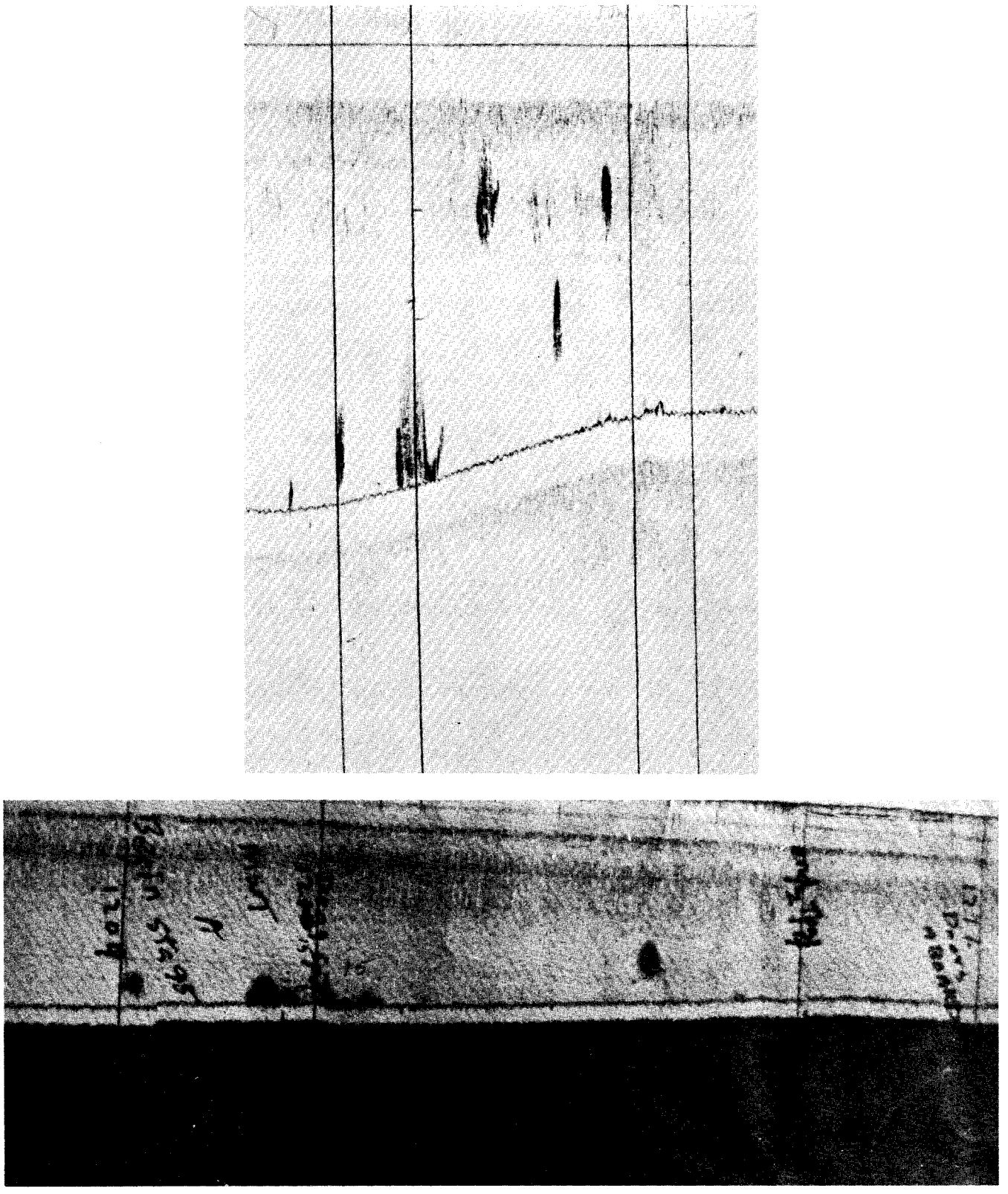


Figure 5. Echograms taken in Monterey Bay during a midwater-trawl station from R/V *Alaska* traveling at an approximate speed of 3 knots 20 June 1976 between 1215 and 1219 hours (36° 37.3' N, 121° 53.5' W to 36° 37.1'N, 121° 53.4' W). Marks correspond to stages in fishing the net: first mark shooting (1209); second mark to third mark trawl speed; fourth mark hauled (1226). A. 200-kHz Gemtronics GT-105. The three large plume-like traces are assumed to represent market squid. B. 38-kHz EK-38. The large plume trace within the trawl speed marks is assumed to represent squid and was recorded at the same time as the middle plume trace on the Gemtronics sounder in A.

throughout the water column; however, the scattering off the bottom did not look much different from the normal background that accompanies traces of most of the Simrad EK-38 echograms collected even when there were no squid. The light was turned on at approximately 0340; mark "E" on the echogram corresponds to this time. Mark "F" was made at approximately 0344. The continuous traces next to the bottom between these two marks were assumed to represent market squid.

As dawn approached this station and it became progressively lighter, less traces were recorded until almost none were on the echogram (Figure 4-D); less squid were caught with the fishing gear and less were observed on or next to the surface. At dawn, squid were no longer detected under the vessel.

Daytime traces of market squid were collected with the Gemtronics and Simrad EK-38 echo sounders (Figures 5-A and B, respectively) in Monterey Bay on 20 June 1976. These traces were recorded while the *Alaska* was towing a midwater trawl moving at a speed of approximately 3 knots (36° 37.3' N, 121° 53.5' W; 36° 37.1'N, 121° 53.4' W; Location 3, Figure 1). The trawl's head rope was at an estimated depth of 11 m, and its ground rope was estimated at 29 m. The catch was 1,646 market squid, 1 *Torpedo californica,* 1 *Pelagia,* 1 *Chrysaora,* 3 unidentified jellyfish, and 1 unidentified crab. The market squid had a mean dorsal mantle length of 117.6 mm with a standard deviation of 12.59 mm. The Gemtronics echogram for the trawl showed three large, dark, plume-like traces (Figure 5-A). The first one to appear made a trace that began at 7 m and continued to 14.1 m. The middle trace ranged from 16.4 to 23.5 m,

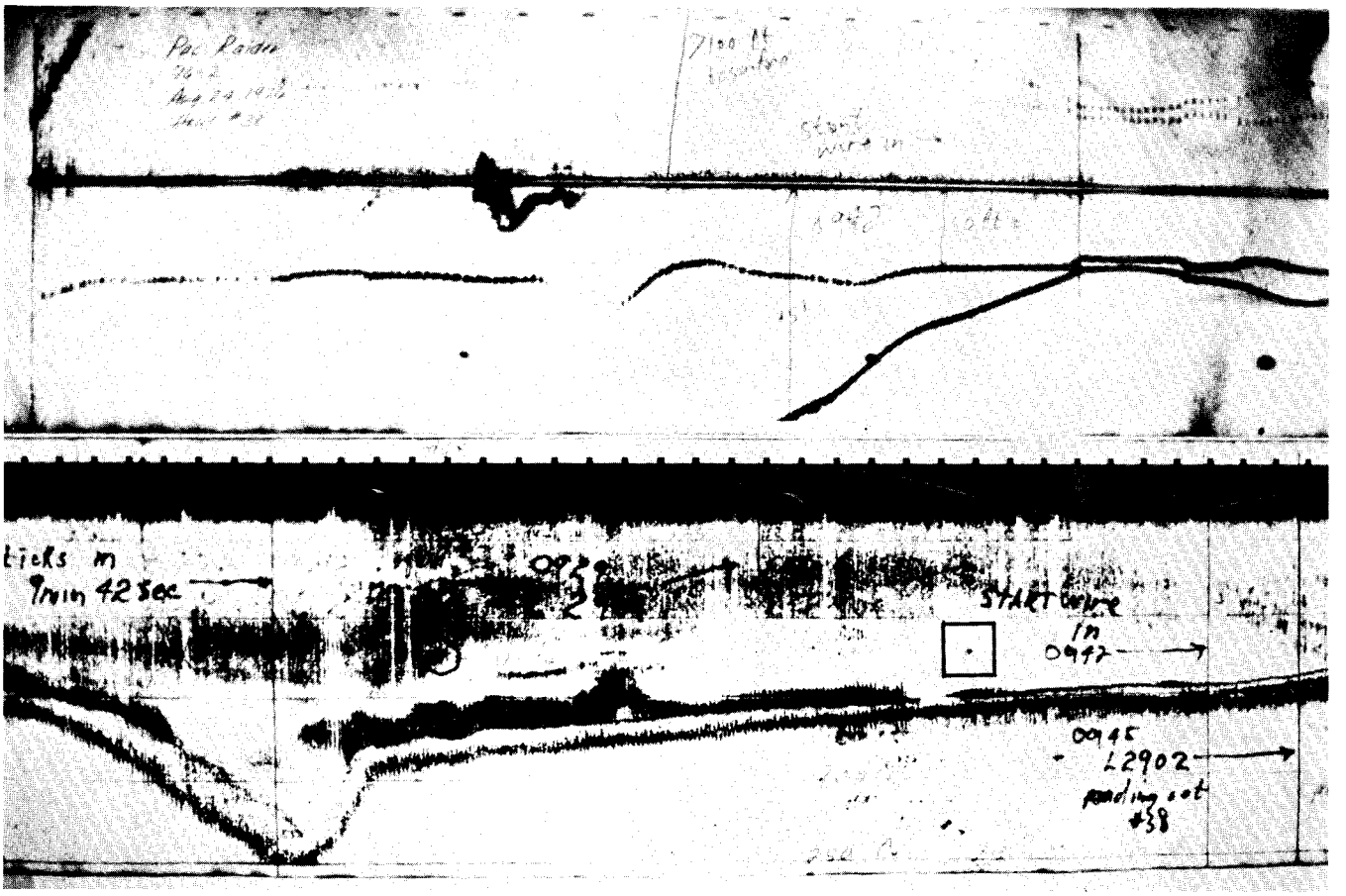


Figure 6. Echograms taken from the National Marine Fishery Service chartered R/V *Pacific Raider* while midwater trawling in Monterey Bay on the morning of 24 August 1976 (36° 50.5' N, 122° 9.5' W to 36° 49.8' N, 122° 9.5'W). Upper, taken from a Furuno net sounder (Model No. FNR-400). The head rope was recorded as the double black line toward the vertical middle of the echogram. The bottom line of the trawl was recorded as the black line underneath the head rope trace, and the ocean bottom can be seen as the rising black trace at the lower right hand side. The black trace toward the middle of the picture, which is between the head rope trace and the bottom line trace, is assumed to be squid. Lower, taken with a 50-kHz Japanese Radio Company zoom echo sounder (Model No. NJA-310). The area within the square to the right shows where the net was fishing in the water column at the time a large trace was recorded entering the net by the net sounder. The trace within this area is assumed to be squid.

TABLE 1

Specifications for Echo Sounders* Used in the Detection of *Loligo opalescens*.

Echo Sounder	Research Vessel	Frequency (kHz)	Pulse Length (msec)	Pulse Repetition Rate (/min)	Beam Angle @ -3 db Loss	Paper Speed (mm/min)	Type Paper	Time-Varied Gain	Mounting
Gemtronics GT-105	*Alaska*	200	0.85	180	**	8	dry	no	side
Simrad EK-38	*Alaska*	38	3.0-0.3	96	20° alongship; 13° athwartship	25	wet	yes	hull
Japan Radio Co. NJA-310	*Pacific Raider*	50	1-3	**	22°	~10	wet	no	hull

*These machines may possess mutiple specifications for the parameters listed. The specifications in this table hold for the echograms discussed in this paper.

**unavailable

and the last trace ranged from 8.4 to 14.1 m. Because of the high catch of squid and low numbers of other species found in the net, these traces were assumed to represent squid. The Simrad EK-38 recorded one major plume between 14.9 and 27.4 m (Figure 5-B). The target making this trace was assumed to be the same as the target causing the middle trace on the Gemtronics. Both occurred at a similar depth range and both took place 2 minutes, 48 seconds after the onset of the trawl.

Figure 6 shows echograms taken from a 50-kHz Japan Radio Company zoom echo sounder (Model No. NJA 310) during a midwater trawl operation and an echogram from a Furuno net sounder (Model No. FNR 400), which was operating simultaneously. The unit of the net sounder that was placed on the head rope of the midwater trawl consisted of an upward- and downward-facing transducer that operated at 75 kHz and a transmission transducer that operated at 50 kHz. Consequently, targets which passed into the net were detected at 75 kHz and received by the recording unit at 50 kHz. Both sounders were used aboard the National Marine Fishery Service chartered R/V *Pacific Raider* while midwater trawling in Monterey Bay on 24 August 1976 between 0934 and 0942 (36° 50.5' N, 122° 9.5' W; 36° 49.8' N, 122° 9.5' W). During the tow, the net sounder recorded a large, dark trace entering the net (Figure 6, top). At the time this trace was recorded, the net was assumed to be fishing at 125 fathoms. A square surrounds the trace of the JRC echo sounder echogram of what was presumed to be the catch entering the net (Figure 6, bottom). The entire catch consisted ot more than 200 squid, averaging a dorsal mantle length of 83.7 mm with a standard deviation of 7.98 mm, and four medusae. A continuous trace along the bottom, which extended between 20 and 60 m above the bottom, was recorded by the echo sounder as well.

DISCUSSION AND CONCLUSIONS

Schools of market squid were shown to produce three distinct type of traces on echograms. The first was a feather plume-like trace that appeared when schools were pelagic (Figure 2-A, 2-B, 4-A, 5-A, 5-B). The second type was a more-or-less continuous bottom trace that appeared when schools were on or near the bottom (Figures 2-C, 3-A, 3-B, 4-A, 4-B, 4-C). The continuous trace recorded along the bottom in the lower portion of Figure 6 may be squid as well. In the latter case, the net was fishing close to the shoal represented by this trace when two hundred squid were captured. The third type of trace consisted of "speckles" scattered throughout the water column when squid were attracted toward the surface at a night-light station when the ship was anchored (Figure 4-C). At the time these latter traces were recorded, squid were viewed from the surface to be in large numbers, some of them copulating. Therefore, each of these speckles probably represented individual squid, a copulating pair, or a small aggregation. Squid aggregated too close together to be resolved as individuals in the continuous and plume traces. The entire surface area on the echogram of most of these traces known to be squid was darkened.

Plume-like traces on echograms are caused by schools being less than the diameter of a cross-section of the acoustic beam and by the schools being more or less elipsoidal in shape (Cushing 1973). A continuous trace is made when targets remain under an echo sounder beam for a relatively long period of time. This trace can be caused by the ship being stationary over a stationary target or a ship moving on top of a large school or scattering layer (Cushing 1973). Usually, the horizontal distance of the school is much larger than the cross-sectional diameter of the acoustic beam at that depth. Consequently, this study has found squid to aggregate either in large numbers close to the bottom or in smaller numbers in pelagic schools.

The traces that market squid have been shown to make in this study resemble those that other researchers have found. Shibata and Flores (1972) using 200-kHz and 50-kHz echo sounders have shown plume-like traces for various species of squid caught in Japanese waters off a moving boat and when squid were rising to the light at a night-light station. Kawaguchi and Nazumi (1972) have shown similar plume-like traces taken in the day for *Todarodes pacificus* with 200- and 75-kHz echo sounders. Mais (1974), using the 38-kHz sounder described in this paper, has shown *Loligo opalescens* to make a more-or-less continuous layer which appears next to the bottom.

Market squid were detected with 38-kHz, 50-kHz and 200-kHz echo sounders. The 38-kHz Simrad EK-38 and the 200-kHz Gemtronics GT-105 recorded squid traces both in the day (Figure 5) and night (Figures 2 through

4). The "speckle" traces that appeared on the Gemtronics echogram during a night-light station (Figure 4-C) were not apparent on the Simrad EK-38 echogram when these units were operating simultaneously. More plume traces of market squid appeared on echograms of the Gemtronics than the Simrad EK-38 when both were operating simultaneously. At the first night-light station discussed (Location 1, Figure 1), the Gemtronics recorded many plume traces (as the ones shown in Figure 2-A); the EK-38 recorded none. The Gemtronics recorded three plume traces during the midwater trawl in Monterey Bay (Figure 5-A) while the EK-38 recorded only one trace (Figure 5-B).

In this study, it is difficult to determine whether the Gemtronics has superior specifications, such as higher frequency, to the EK-38 for locating small pelagic groups of squid, or whether the difference in the amount of traces on echograms was due to the different locations of the transducers. The transducer of the Simrad EK-38 was located on the hull, whereas the transducer of the Gemtronics was located on th hull, whereas the transducer of the Gemtronics was located amidships on the port side during midwater trawling operations and amidships on the starboard side under the light during night-light stations. It is likely that the Gemtronics picked up more squid plumes because squid schools were more likely to be insonified at light stations by a transducer which is next to an attracting light, squid schools were closer to the Gemtronics' transmission axis during the midwater trawl, and small squid aggregations were better detected with the higher frequency echo sounders. Suzuki et al. (1974) found that a 200-kHz echo sounder recorded squid more clearly than a 75kHz sounder; and Kawaguchi and Nazumi (1972) concluded that the optimum specifications of an echo sounder for squid detection were a frequency between 75 kHz and 200 kHz, narrow beams, and a minimum pulse length.

- Echograms at night-light stations demonstrated the fact that lights attract market squid during the night (Figures 4A and C). At dawn, the light lost its effectiveness to attract squid, as demonstrated by the lack of targets recorded in Figure 4-D. Therefore, either the squid scattered, moved as a school to a different location, or moved so close to the bottom that they became undetected by the sounders. Light attraction is a common phenomenon for several commercial squid species. Kawaguchi and Nazumi (1972) have demonstrated with echo sounders that *Todarodes pacificus* is lured to lights at night; and Shibata and Flores (1972) showed the same thing to occur with other species of squid caught in Japanese waters.

The description of traces on echograms caused by market squid was needed before echo sounders could be considered a useful tool in deriving information about this species. Therefore, this work is considered to be ar essential precursor to acoustic management and behavioral studies conducted on market squid. The results in this study indicate that at least two behavioral modes can be resolved with echo sounding equipment from a moving ship. Extensive, continuous bottom-associated traces, which Mais (1974) and we have observed, probably represent concentrations that may develop only at certain times of the day, seasons, prey densities, maturity, etc. We are reasonably certain that they may occur in shallow (20-m) or deep (< 150-m) water. Once located, concentrations or shoals or this sort offer some prospect of being surveyed with a view toward determining biomass. The pelagic behavioral representations we have observed, i.e. plume traces, appear to represent small, perhaps feeding, groups of swiftly-moving animals. These squid schools are apparently quite difficult to sample and identify acoustically and offer less hope of usefulness for biomass estimating.

ACKNOWLEDGMENTS

We thank J.R. Raymond Ally, Fisheries Biologist, California Department of Fish and Game, Chief Scientist for the 1976 California Fish and Game market squid survey conducted aboard the R/V *Alaska* (Cruise 76A4), during which time most of the echograms used in this study were collected. We also thank James Mason, NMFS Fishery Biologist, who supplied us with a photograph of two of the echograms used in this study.

This work is the result of research sponsored by NOAA Office of Sea Grant, Department of Commerce, under Grant No. NOAA 04-6-158-44110, Project Number R/F-15. The U.S. Government is authorized to produce and distribute reprints for governmental purposes, notwithstanding any copyright notations that may appear hereon.

REFERENCES

Cushing, D. 1973. The detection of fish. Pergamon Press, Oxford, New York. 200 pp.

Flores, E.E.C. 1972. Handline fishing for squid in the Japan Sea. FAO Fish. Circ. No. 142: 1-6.

Kawaguchi, T., and T. Nazumi. 1972. Echo-traces of squid, *Todarodes pacificus,* in the central waters of Japan Sea. FAO Fish. Circ. No. 142: 15-25.

Mais., K.M. 1974. Pelagic fish surveys in the California Current. Calif. Dept. Fish Game, Fish Bull. No. 162.

Shibata, K. and E.E.C. Flores. 1972. Echo-traces typical of squids in waters surrounding Japan. FAO Fish. Circ. No. 142: 7-13.

Suzuki, T., M. Tahiro, and U. Yamaguchi. 1974. Studies on the swiming layer of squid, *Todarodes pacificus* Steenstrup as observed by a fish finder in the offshore region of the northern part of the Japan Sea. Bull. Fac. Fish. Hokkaido Univ. 25(3): 238-246.