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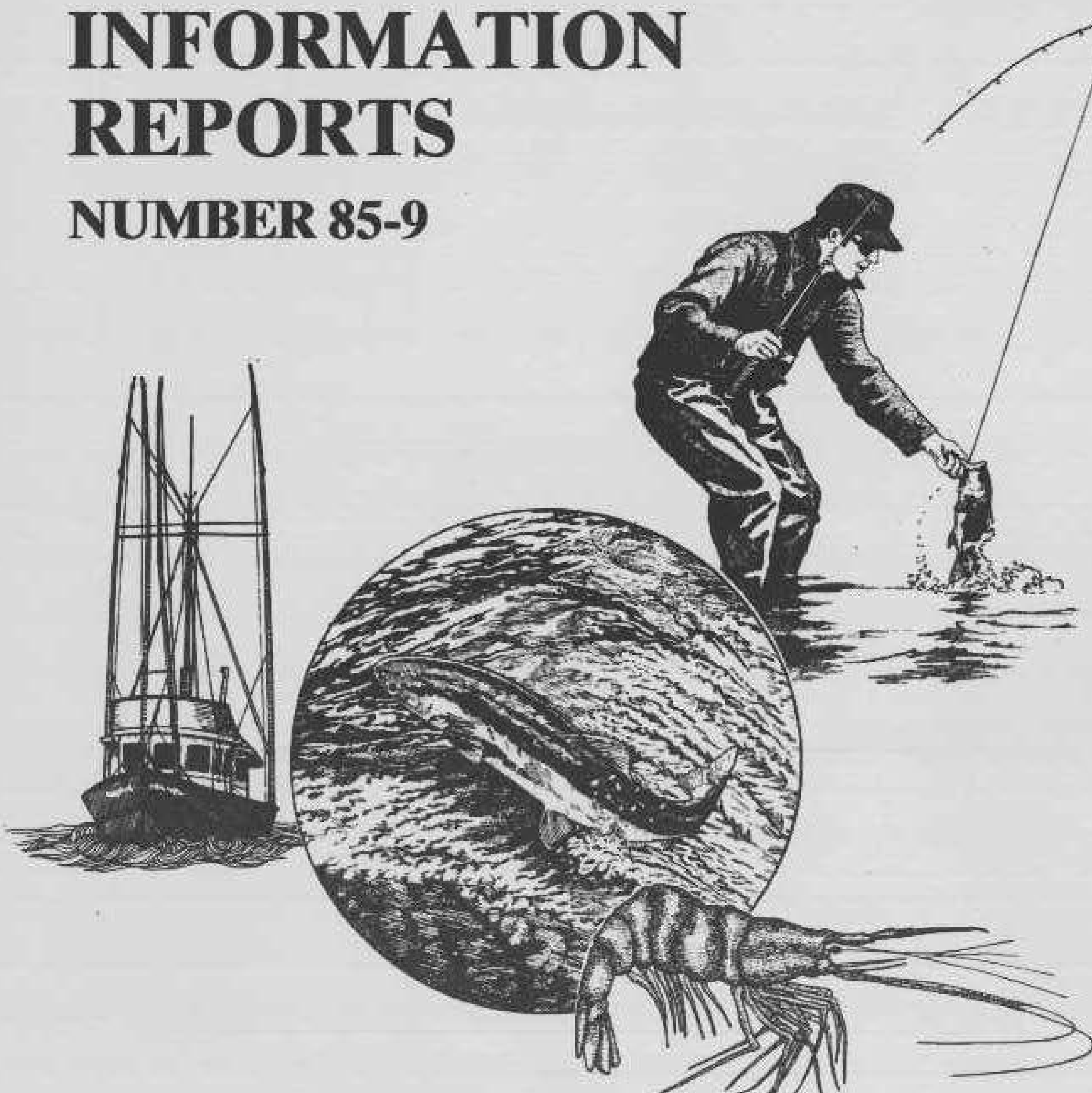

FISH DIVISION

Oregon Department of Fish and Wildlife

Hydroacoustic Estimates of Squid (*Loligo opalescens*) Abundance Off Oregon in 1985

Hydroacoustic Estimates of Squid (*Loligo opalescens*)
Abundance off Oregon in 1985

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ABSTRACT

Quantitative acoustic surveys off the central Oregon coast produced estimates of squid (Loligo opalescens) distribution and abundance from a 10 km^2 area. Squid resided in the middle of the water column early in the study and in the upper one-third later. The center of spawning activity moved southward and shoreward with time. Maximum volumetric densities of squid in any 200 m segment of transect ranged from 2.1 to 83.9 squid/m^3. Maximum areal densities in any file ranged from 8.8 to 178.9 squid/m^2 of surface area. Average areal densities for an entire transect ranged from 0.8 to 19.2 squid/m^2.

Analysis of weight to length ratios of squid commercially harvested in the study area indicated that two different groups of squid entered the study area over the five week study period. The largest school observed covered a surface area of 2.1 km^2 and contained an estimated 31.4 million squid. Biomass of the largest school was estimated to be 1714 mt. Including commercial harvest, the lower and upper biomass estimates were 2108 and 3735 mt, respectively.

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INTRODUCTION

A commercial fishery for Loligo opalescens began off Oregon in 1982 and has expanded each year; landings tripled from 1982 to 1984. Over 400 mt were landed in 1984. The fishery raised questions about the size of the spawning population; squid were known to occur off the coast, but in unknown quantities. The Oregon Fish and Wildlife Commission, responding to staff concerns about the potential for over-harvest given an unknown quantity of squid, enacted stringent harvest guidelines in 1984. Managers were especially concerned about the over-harvest of individual squid schools, and in 1985 recommended fishing on specific schools be suspended after 454 mt were harvested (Starr and McCrae 1985). An accurate biomass estimate is needed to evaluate fishery management strategies and regulations and thus effectively manage the resource. This study was designed to hydroacoustically estimate the biomass of large schools of spawning L. opalescens off the Oregon coast and provide a data base for management of the fishery.

Traditional stock assessment techniques are unsuitable or unreliable for L. opalescens, primarily because of the short life span of the species and the problems estimating parameters such as mortality, annual recruitment, fishing effort, and catchability (Caddy 1983). In the absence of reliable biological data for fisheries modelling, Sato and Hatanaka (1983) suggested direct estimation of stock size by fishing surveys. Direct estimation of school size by fishing techniques has been unsuccessful for L. opalescens and other schooling species, however, because the relationship between abundance and catch per unit effort is often unclear.

The weaknesses inherent in traditional stock assessment methods led researchers to try acoustical techniques which have proven useful for estimating fish abundance (Forbes and Nakken 1972; Ulltang 1977; Burczynski 1979; Craig 1984). Most studies to date have demonstrated the usefulness of acoustics to locate squid, but not to assess squid abundance. Shibata and Flores (1972) and Kawaguchi and Nazumi (1972) suggested acoustic equipment could identify Ommastrephes sloani pacificus. Suzuki (1975) reported the use of echosounders for locating Todarodes pacificus, and Bernard (1980) described the use of echosounders to locate several species of squid off British Columbia, Canada, including L. opalescens.

The most successful studies only identified school shapes and sizes from echograms. Suzuki (1975) suggested a method to roughly estimate squid abundance using an estimate of school size, but Vaughan and Recksiek (1978, 1979) suggested that estimating abundance using school sizes would be difficult because of the small school sizes and patchiness of L. opalescens. Vaughan (1978) reported his target strength estimates could scale echointegrator outputs to estimate abundance.

Jefferts et al. (1984) conducted a pilot study off the Oregon coast to develop appropriate acoustic techniques for calculating squid biomass. The project proved to be successful. They used a dual beam acoustic system to estimate in situ target strength of squid, and used the results to scale integrator outputs. We used similar equipment in 1985 to analyze the distribution and abundance of large (commercially harvestable) squid schools.

Target Strength

Target strength estimates are crucial to the acoustical estimation of squid abundance. Matsui et al. (1972) reported target strength estimates from the dorso-ventral direction of the roll plane in a tethered squid. They insonified a 12 cm long (dorsal mantle length (DML)) Doryteuthis bleekeri with 50 and 200 kHz transducers. Maximum target strengths were -45 dB and -42 dB, respectively. Vaughan (1978; Vaughan and Recksiek 1978) reported dorsal aspect target strengths for L. opalescens ranging from -49.3 dB to -38.8 dB using a 200 kHz transducer. His measurements came from eleven different squid, ranging in size from 4.5 to 16 cm DML, tethered singly in an anechoic tank.

Shibata and Masthawee (1980) went a step further than earlier studies and described target strengths from squid suspended in a field environment. They suspended Loligo formosana squid with monofilament nylon line from a frame attached to a vessel in waters deeper than 20 m. Using a 50 kHz echosounder, the 11 to 19 cm DML squid had target strengths ranging from -47.5 dB to -37.5 dB.

The most important achievement of Jefferts et al. (1984) was an estimation of the in situ target strength of Loligo opalescens. Target strength estimates of L. opalescens provided by earlier studies came from artificial conditions and yielded estimates near that of the reflectivity of a ping-pong ball (-42 dB). Jefferts et al. (1984) reasoned that squid without air bladders should have a much smaller target strength than a ping-pong ball, and suggested that the -56.8 dB value they obtained was more realistic than higher values obtained from Vaughan's (1978) laboratory measurements.

METHODS

Equipment

We chartered a commercial fishing vessel for acoustic surveys. The 18 m long vessel was an active member of the fishing fleet with the electronic capability of locating squid and two purse seines to verify insonified targets. Navigational equipment on board the chartered vessel included radar, satellite navigational systems, and LORAN C. Acoustic equipment included a 50 kHz echosounder with Sitex color display and a Furuno side-scanning sonar. We most often identified acoustic targets by test fishing with a purse seine that was 450 m long by 36 m deep, but occasionally used a smaller seine 275 m long by 18 m deep.

We located squid schools with the ship's electronic equipment, then used a scientific quality echosounding system to collect dual beam and echointegration data. The system included a BioSonics, Inc. 120 kHz dual beam ceramic transducer with nominal beam widths of 10 and 22 degrees, towed in a V-fin body about 2 m below the surface, a BioSonics Model 101 echo sounder with dual 20 log R and 40 log R time-varied-gain (TVG) receiver board, a Tektronix, Inc. oscilloscope, a modified Ross Laboratories, Inc. echogram recorder, and an Apple 1le microcomputer. Additionally, a BioSonics Model 171 tape recorder interface with a Sony digitizer and beta tape recorder system recorded dual beam data. After the field season, BioSonics analyzed the dual beam data with a Model 181 dual beam processor to provide <u>in situ</u> target strength estimates. Specifications of the system are presented in Table 1.

Table 1. Specifications of the acoustic system.

Pulse rate	3.3 pings/sec
Pulse length	0.5 ms
Power	250 w (-6 dB transmit gain)
Bandwidth	5 kHz
Attenuation	120 kHz
Source level	222.3 dB || uPa at 0 dB transmit gain
Receiver sens.	-134.1 dB || uPa at 0 dB receiver gain
Receiver gain	+6 dB for scattered targets 0 dB for small schools -6 dB for dense schools and dual beam work
Digitizing int.	0.14 ms

The Apple lle microcomputer contained a time card, an analoge to digital converter, and echoprocessing, echointegration, and data plotting software designed by CMI-Cascade, Inc. for the Apple lle. The echoprocessing software included a BASIC language driver program for file handling and entry of acoustical sampling parameters and a machine language program that sampled and stored data.

Processed echoes were not integrated in real time; profiles of average echo amplitudes, intensities, and squared intensities were stored as binary files on floppy disk. The sampling scheme and disk storage of data enabled the relatively slow Apple lle to function as an acoustic data processor. Stored echo voltage profiles were integrated in user-defined depth intervals at a later time.

Sampling Design

Acoustic surveys occurred once a week from April 17 through June 16, 1985, in a 10 km^2 area near Heceta Head, Oregon (Fig. 1), that was actively being fished commercially. On each cruise, we used the vessel's echosounder to qualitatively survey for squid while travelling along the 37 m isobath from the home port of Yaquina Bay to the study area. Once in the study area we qualitatively surveyed the area between the 15 and 40 m isobaths from Cape Perpetua to Heceta Head to locate squid schools.

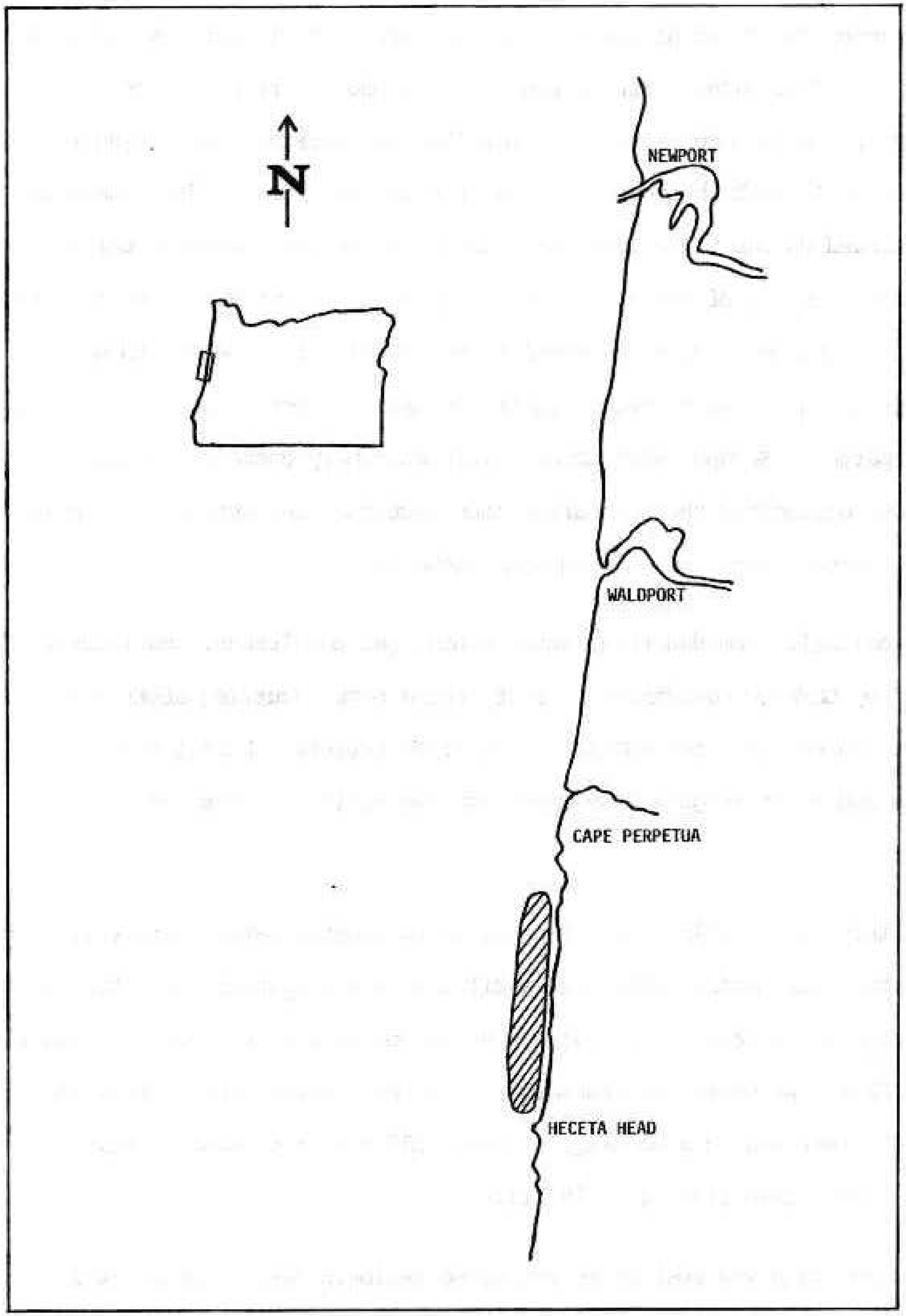

Fig. 1. Location of hydroacoustic surveys, April 25 through May 9, 1985.

We conducted two types of quantitative surveys of squid schools using the scientific echosounder. First, when squid schools were patchy or dispersed, long transects were run parallel to isobaths. Orienting the transect on an isobath reduced bottom tracking problems in data analysis. We continued on the track line until the oscilloscope showed no targets and the vessel was out of the area of observed squid activity. At that point the vessel changed course and moved either shallower or deeper to an adjacent isobath, and proceeded in the opposite direction until no targets were apparent. Second, when schools were extremely dense and compact, transects delineated the boundaries then sectioned the school. In these cases transects were not aligned with isobaths.

We periodically recorded time, water depth, sea conditions, and location as defined by LORAN C coordinates. Purse seine sets occurring after the acoustic survey verified specific insonified targets. Dorsal mantle lengths and whole weights were measured from squid collected on each cruise.

In all surveys we defined file length, or horizontal sample interval, to be 255 pulses, the maximum file size available on the system. At a typical pulse repetition rate of 3.3 pulses per second each file included about 1.3 min of data. We towed the transducer at about 3 meters per second, thus each file represented a coverage of about 200 m of the bottom. Each transect contained from 14 to 191 files.

Transmitter gain was most often set to -6 decibels (dB) relative to 1 micro-pascal, the maximum linear power setting for the Model 101 echosounder with 15 m of shielded cable to the transducer. Echoes were amplified with a 20 log R TVG. Receiver gain was set at various levels so that the receiver output would be about 5-6 volts (RMS) when a dense school was encountered (Fig. 2), or about one-half of the effective dynamic range of the receiver.

Data analysis

The echointegrator converted echo intensities to densities and abundances. It integrated files over selected depth intervals, and produced grand averages and variances of densities and abundances. The echo intensities were converted to squid density by applying a scaling factor that was derived from the calibration constants of the electronic equipment, equipment settings, and the average target strength of squid.

The scaling factors were all known constants except for squid target strength. We taped echoes amplified with a 40 Log R TVG three times on one night for a total of 2 h. Since only individual targets can be used for analysis, we recorded non-overlapping targets by slowly cruising around the perimeter of a large school and by attracting squid to the vessel with lights on a calm night. BioSonics, Inc. analyzed the data using hardware and software described in general by Ehrenberg (1984) and by Jefferts et al. (1984) for Loligo opalescens specifically.

In all files squid echo intensities were integrated over 2 m depth intervals starting 1 m below the transducer. We deleted files that did not reflect squid clusters or aggregations as determined from field notes or verification sets of the purse seine. Total density estimates are thus conservative minimum estimates because only squid clusters were included and sparsely distributed squid may not have been counted.

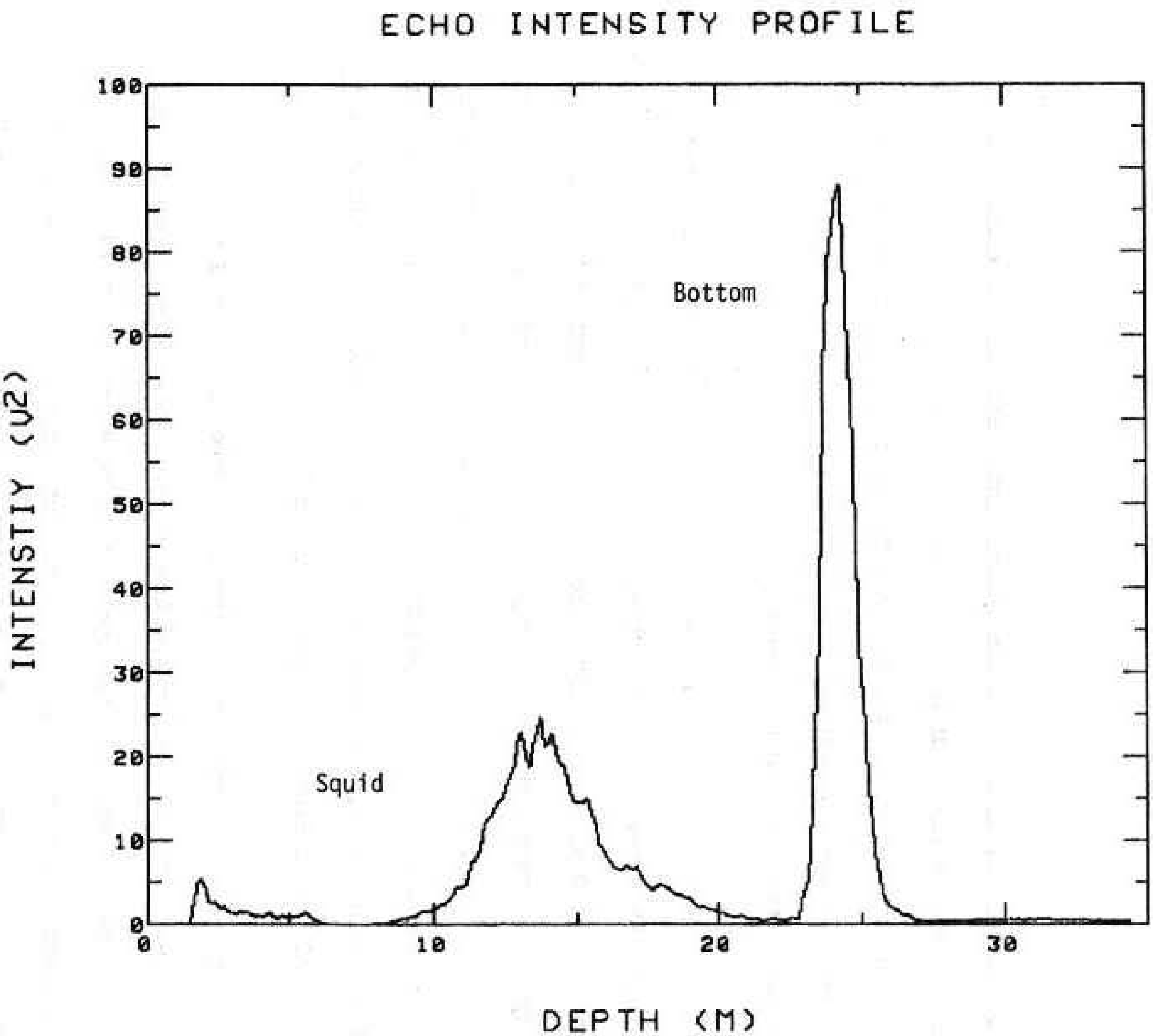

Fig. 2. Echo profile of file 2, transect TR5.2.B. The transducer is about 2 m below the surface, and sampling began 1 m below the transducer.

The integrator converted squid volumetric densities to areal densities by multiplying the mean density of each depth stratum by the depth extent of the stratum. The areal densities of each stratum were then summed to the bottom to provide a cumulative areal density for each file. The resulting values were plotted on a chart of the transects. We then drew generalized boundaries around files containing similar densities. Chart depths were adjusted to mean lower low water (MLLW) using local tide tables.

Areal densities of all files in a transect were averaged and converted to abundance by multiplying the average areal density by the surface area encompassed by the transect. Abundance estimates were converted to biomass using the average weight of the squid collected on the day of the transect.

RESULTS

We collected a total of about 2 h of dual beam data and 23 h of echointegration data from five cruises over a five week period off Heceta Head. An exploratory cruise from Newport to the Columbia River provided additional qualitative information. The five cruises off Heceta Head yielded abundance estimates from eight transects. Squid schools were not located or positively identified on the first and last cruises, and the rest of the transects from the middle three cruises were not analyzed due to lack of squid, adverse weather and sea conditions, or because we were experimenting with gain settings.

Integrator scaling variables came from the dual beam data and the biological characteristics of squid caught on each cruise. Target strength estimates ranged from -55.0 dB to -56.8 dB (Table 2). Overall *in situ*

Table 2. Biological, physical, and acoustical estimates of parameters sampled from April 25, 1985 through May 9, 1985.

Cruise No.	2	2	3	3	3	4	4	4
Transect	TR 4.25.D	TR 4.26.A	TR 5.1.A-F	TR 5.2.A	TR 5.2.B	TR5.8.A	TR 5.8.AX	TR 5.9.A
Date	4-25-85	4-26-85	5-1-85	5-2-85	5-2-85	5-8-85	5-8-85	5-9-85
Avg. wt. of squid (gm)	54.7	54.7	46.4	46.4	46.4	40.9	40.9	40.9
Time of day	2310-2345	0525-0725	1513-1914	0200-0455	0955-1030	1903-2221	2325-0030	0609-0829
Mean depth (m)	24	26	24	25	22	20	22	22
Area ($m^2 x10^6$)	1.4	2.1	3.7	7.2	0.4	6.7	0.6	4.3
Areal density (#/m^2)	7.15	14.64	1.06	.83	19.62	4.18	32.19	7.17
Random 95% CI (±#/m^2)	2.18	2.37	.24	.22	4.22	.93	7.98	1.28
Cluster 95% CI (±#/m^2)	6.87	7.44	1.14	.39	4.14	2.35	15.63	2.84
Peak areal density (#/m^2)	27.18	153.0	8.8	9.5	71.9	81.4	178.9	75.7
Peak vol. density (#/m^3)	3.26	17.53	2.1	2.5	26.2	17.9	83.9	11.1
Abundance (million)	9.7	31.4	4.0	6.0	8.7	28.2	19.9	31.1
Biomass (mt)	532	1714	183	278	404	1154	817	1275

<u>Target Strength Estimates</u>

Date	5-8-85	5-9-85	5-9-85
Time	2225-2325	0230-0300	0320-0350
Mode	Cruising	Drifting	Drifting
No. of targets	2663	6415	2557
Avg. TS (dB)	-56.4	-55.0	-56.8
95% CI (±dB)	0.2	0.1	0.2

target strength averaged -55.7 dB. The average weight of squid decreased during the study period from a high of 54.7 gm to a low of 40.9 gm (Table 2). Thus, the value used to transform squid abundance to biomass changed from 18.3 squid per kilogram early in the study to 24.4 squid per kilogram for later transects.

The first cruise took place on April 17. One long zig-zag transect line began in the late afternoon near Heceta Head and ended 4 h later near Cape Perpetua. The track line covered a depth range of 18 to 45 m. Integrator files were not summed because we did not positively identify squid in any location.

We located two large schools of squid on separate transects on the second cruise, April 25 and 26. In both transects we first delineated the school dimensions then bisected it to obtain density estimates (Table 2). TR 4.25.D, the fourth transect of April 25, provided a nighttime estimate of squid distribution. Squid were clustered in the northern and southern portions of the transect (Fig. 3) with 50% of the integrator files containing areal densities of 5-20/m^2 of surface area .

Maximum average volumetric densities in TR 4.25.D occurred between 17 and 22 m (Fig. 4), and the peak squid density in any file occurred at a depth of 18 m. Most squid resided in the mid to lower third of the water column (Fig. 5). Multiplying the average areal density by the transect area produced an abundance estimate of 9.7 million squid and a biomass estimate of 532 mt (Table 2).

TR 4.26.A covered an extremely large school in the early morning hours of April 26. This transect contained the largest area of concentrated squid

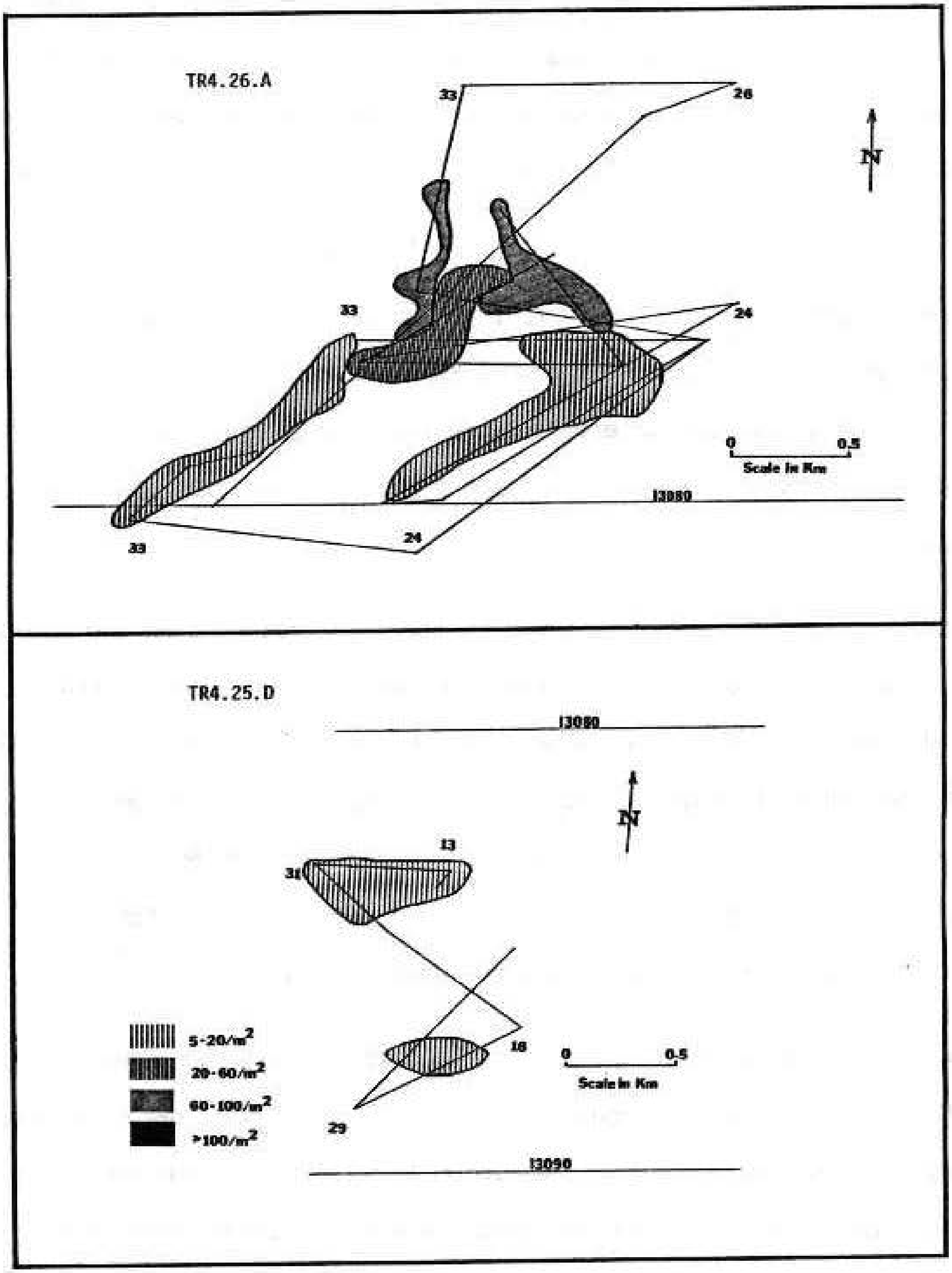

Fig. 3. Distribution and areal densities of squid insonified on April 25 and 26, 1985. General boundries were drawn around files with similar density intervals. Track lines and depth (m) at selected locations are displayed with LORAN C lines of position.

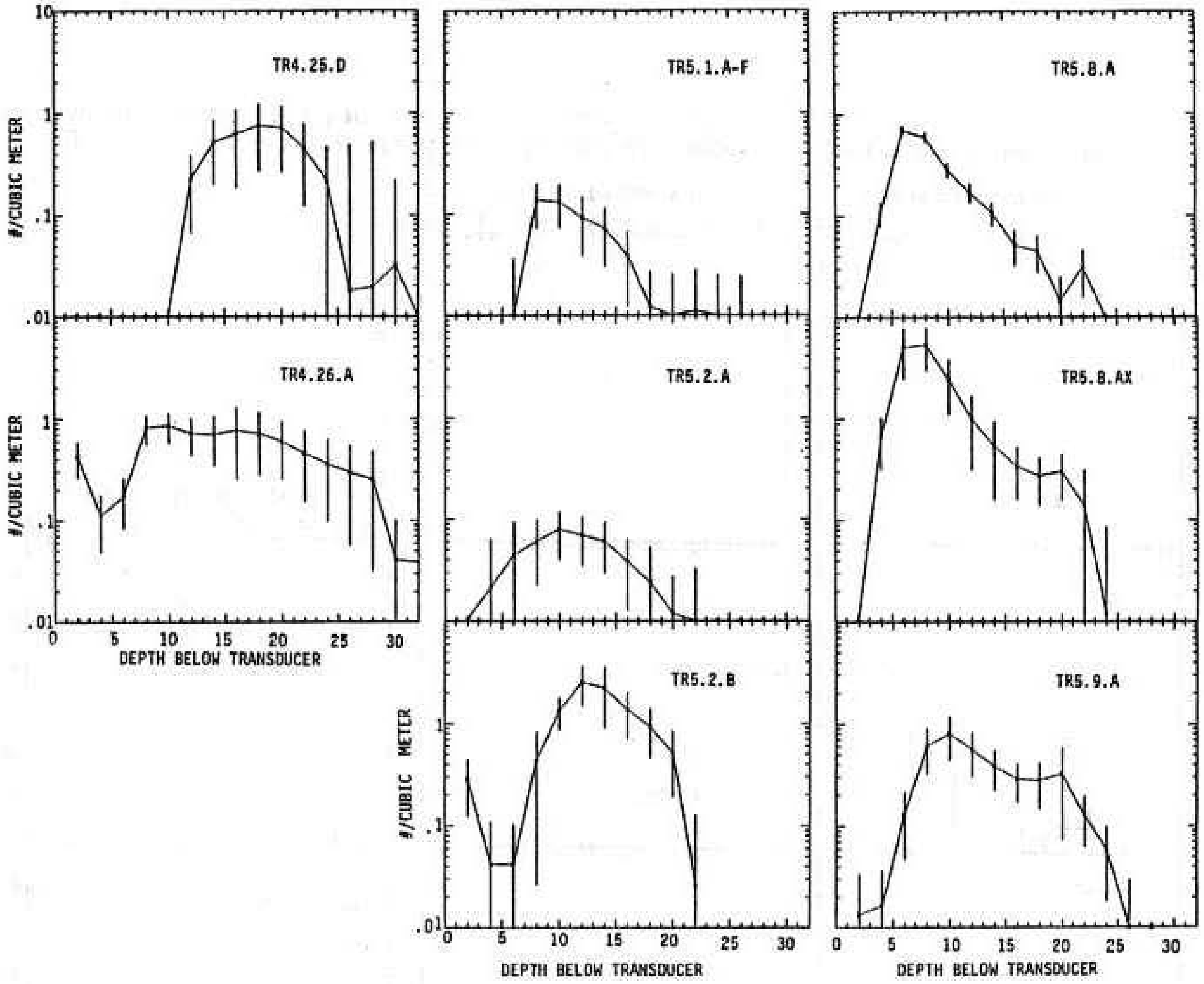

Fig. 4. Average squid volumetric density and variance as a function of depth from transects conducted April 25 through May 9, 1985.

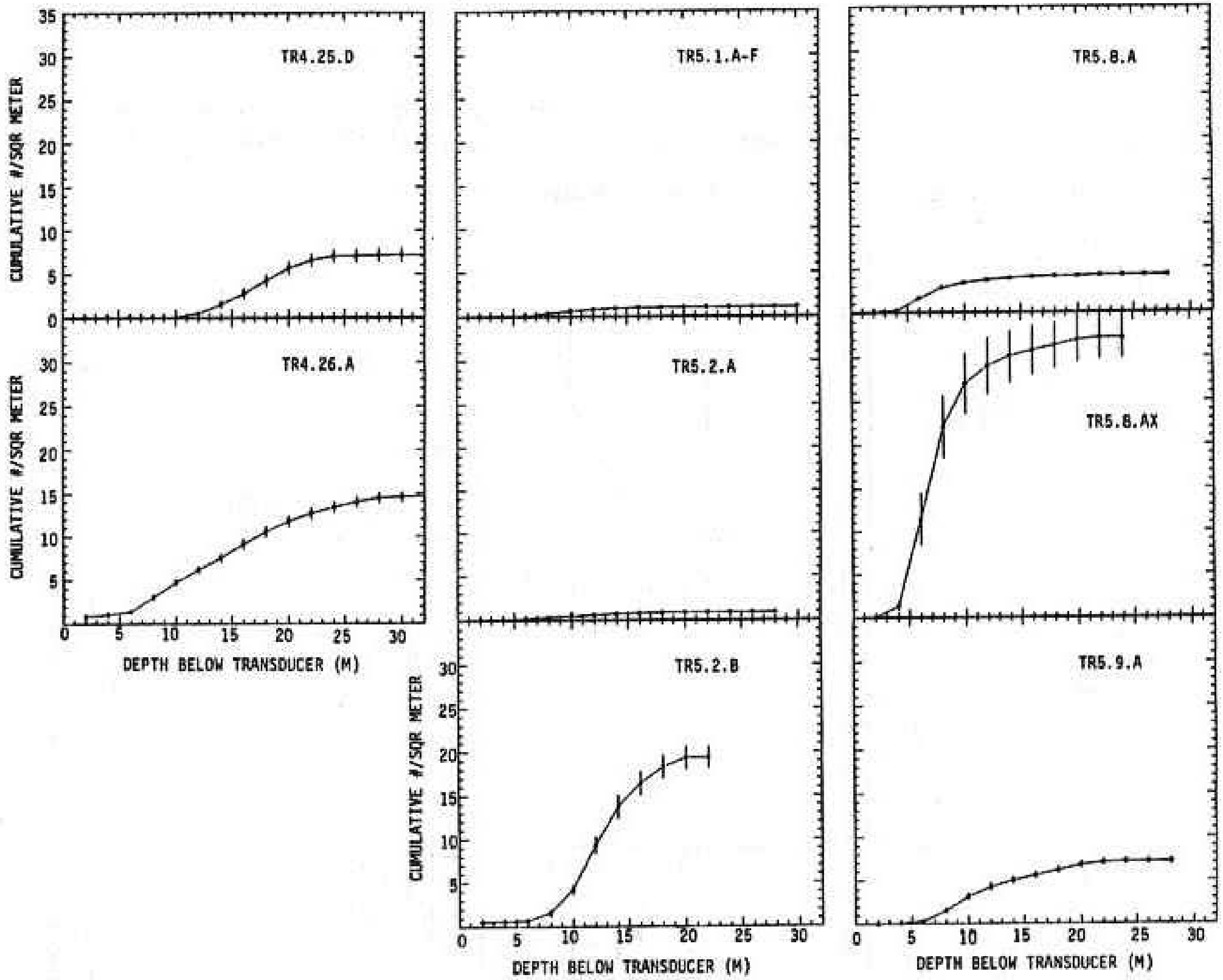

Fig. 5. Average squid areal density and variance as a function of depth from transects conducted April 25 through May 9, 1985.

that fishermen have seen since commercial fishing for squid off Oregon began in 1982. About 10% of the integrator files contained areal densities as high as 60 to 100 squid/m^2 (Fig. 3). This transect produced the second highest peak areal density for a file and the third highest peak volumetric density.

Maximum average volumetric densities occurred between 10 and 20 m (Fig. 4), and the peak squid density in any file occurred at a depth of 16 m. Squid were spread throughout the water column starting about 6 m below the surface (Fig. 5). The area encompassed by transect TR 4.26.A contained an estimated 31.4 million squid, representing a biomass of 1714 mt.

The third cruise took place on May 1 and 2, and yielded three useful transects. The first two transects were long transects run over small patches of squid schools. The third transect covered a small but very dense concentration of squid.

The first long transect, TR 5.1.A-F, occurred in the afternoon on May 1. Squid were patchily distributed in small groups straddling the 24 m isobath (Fig. 6). Maximum average volumetric densities occurred between 10 and 14 m (Fig. 4), but there were few squid in the water column (Fig 5). The maximum squid density in a given file occurred at a depth of 8 m. This transect contained the lowest peak file density (Table 2). Abundance was estimated to be 4.0 million squid, and biomass 183 mt.

Before dawn on May 2 we completed TR 5.2.A, the longest transect of the study. This transect was the longest and also contained the least amount of squid. The average density profile indicates that the few squid encountered were located between 10 and 15 m deep (Fig. 4). The maximum

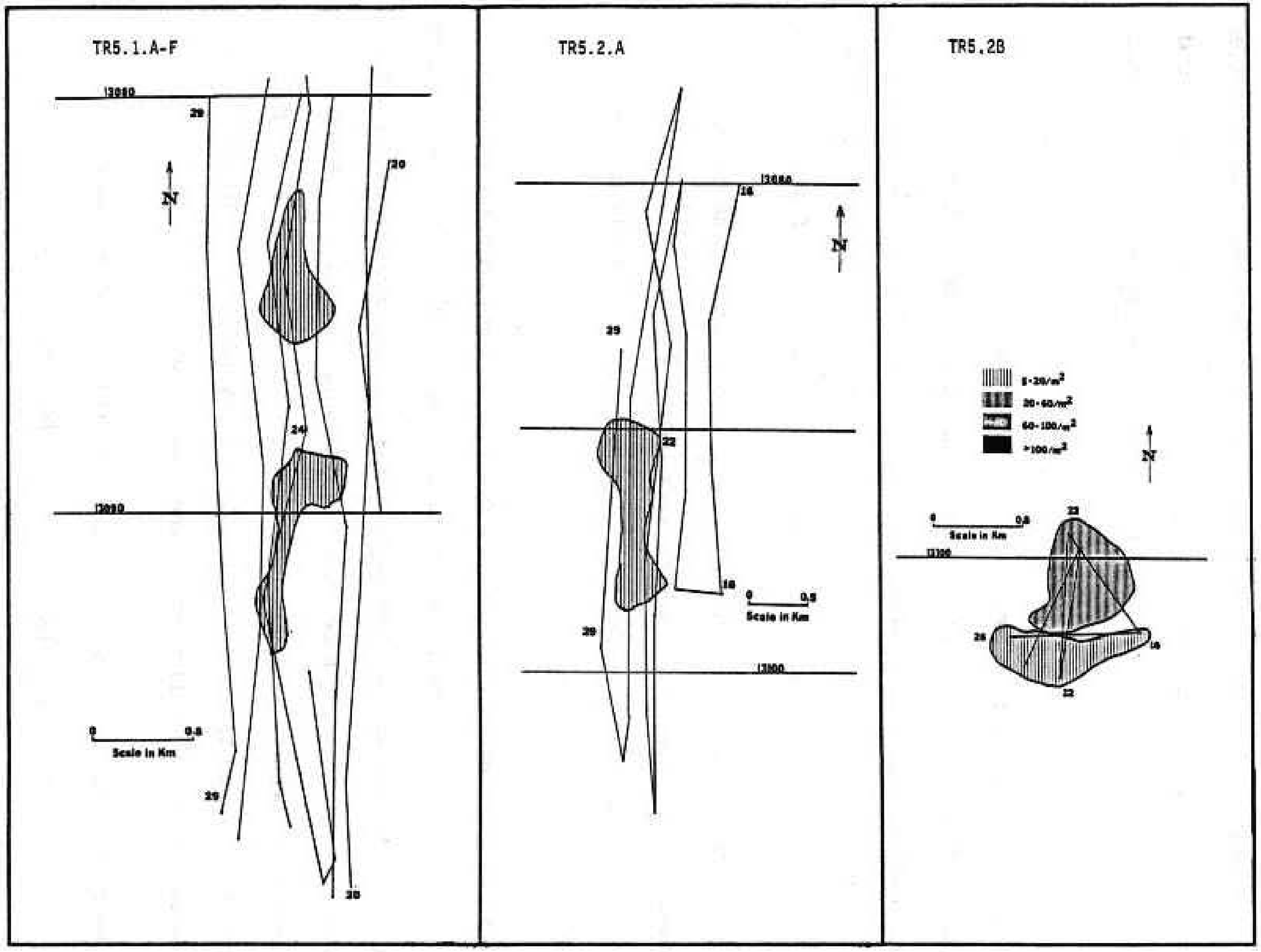

Fig. 6. Distribution and areal densities of squid insonified on May 1 and 2, 1985. General boundries were drawn around files with similar density intervals. Track lines and depth (m) at selected locations are displayed with LORAN C lines of positions.

squid density in any file occurred at a depth of 8 m. The few squid aggregations that were observed were also situated along the 24 m isobath (Fig. 6).

The density of TR 5.2.A was the lowest of any transect, but multiplying the low density by the large area of the transect yielded an abundance estimate of 6 million squid. The resulting biomass of 278 mt is larger than the biomass estimate from TR 5.1.A, although it came from a density estimate that was 20% lower.

The third productive transect on this cruise was the shortest of the study. In the morning on May 2 we surveyed a very dense school. Over one-half of the files in the transect contained squid areal densities of 20-60/m^2 (Fig. 6). Squid again resided in the middle of the water column (Fig. 4), but were tightly packed, and provided a mean areal density larger than any measured on the second cruise. Maximum density in a given file occurred at a depth of 14 m. Although the surface area covered by TR 5.2.B was only 6-11% that of the two longer transects on the third cruise, the estimates of abundance and biomass were the highest of the cruise.

The fourth cruise, on May 8 and 9, again yielded three useable transects. On May 8 squid schools were relatively dense but widely distributed. In the late afternoon a long transect run parallel to the shore delineated the entire group of schools. That night we echointegrated a particularly dense school, and the following morning again surveyed a relatively large school.

TR 5.8.A took place just before dawn on May 8. Squid were closer to the surface (Fig. 4), in shallower water (Fig. 7), and further south than on any of the previous cruises. The average areal density was a somewhat

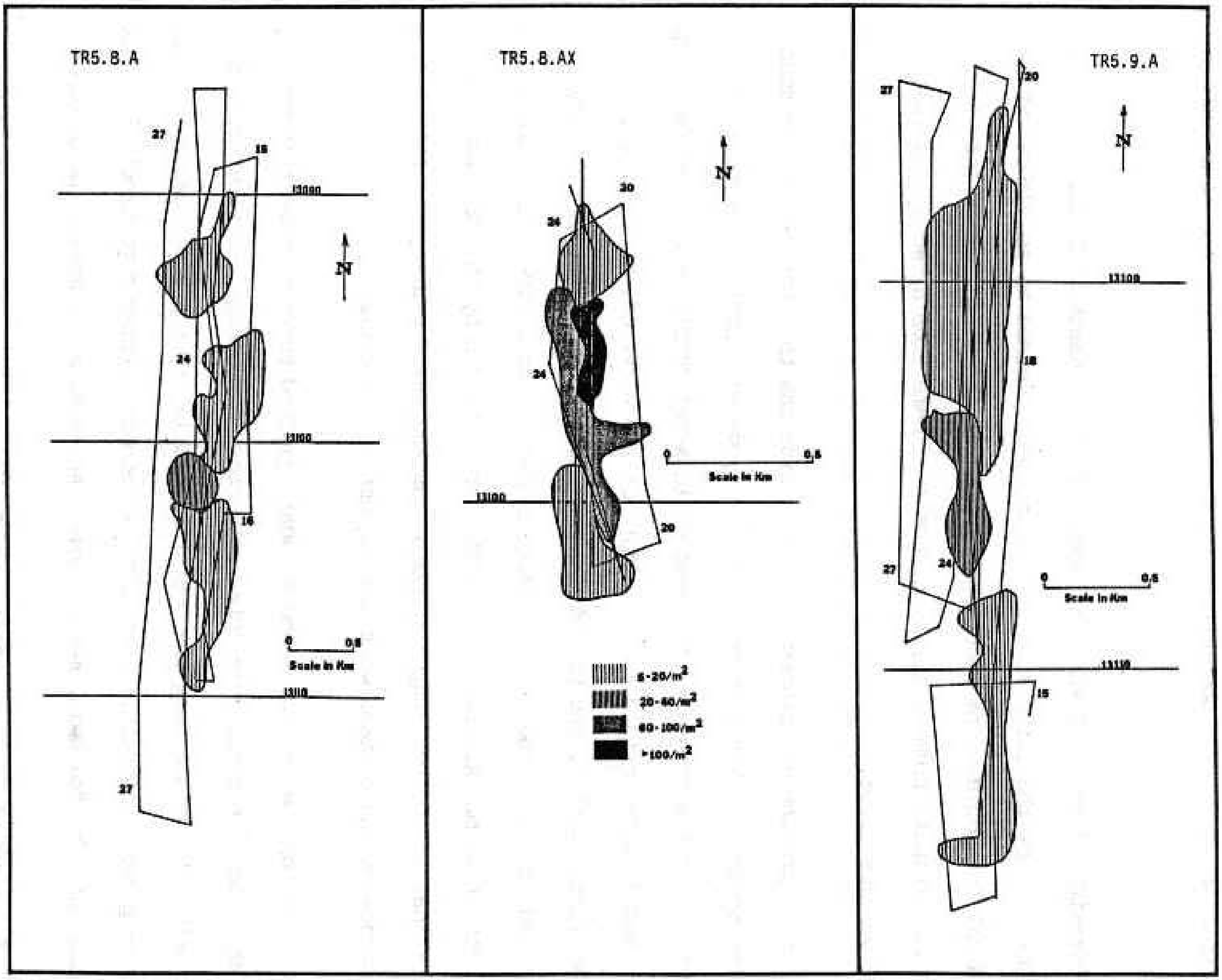

Fig. 7. Distribution and areal densities of squid insonified on May 8 and 9, 1985. General boundries were drawn around files with similar density intervals. Track lines and depth (m) at selected locations are displayed with LORAN C lines of positions.

higher value than those obtained from the long transects of May 1 and 2, but still not as high as values from the transects that bisected dense squid schools. Maximum volumetric density occurred at a depth of 8 m. Although squid density was relatively low on TR 5.8.A, the abundance estimate of 28.2 million squid was high because this transect was the second largest transect of the study.

After collecting dual beam information on May 8 we acoustically surveyed a dense school. TR 5.8.AX covered a small area, but this transect contained the densest concentration of squid observed during the study. The average areal density was 60% greater than the highest average density of the previous week. The vertical distribution of squid was similar to that of TR 5.8.A; squid were densest in the upper third of the water column (Fig. 4).

Maximum volumetric density of any one file was the highest recorded and occurred at a depth of 6 m. The peak areal density was also the highest recorded in this study. Over 15% of the integrator files generated in this transect contained areal densities greater than $100/m^2$ of surface area (Fig. 7). Although TR 5.8.AX contained the densest school of squid, it was a small transect and produced an intermediate abundance estimate of 19.9 million squid, resulting in a biomass estimate of 817 mt.

In the early morning on May 9 we duplicated the southern portion of the previous night's long transect. Squid were well distributed on TR 5.9.A; 23% of the integrator files contained squid areal densities of $5-20/m^2$, 8% displayed densities of $20-60/m^2$ (Fig. 7). Squid resided deeper in the water column than the previous night (Fig. 4), but were less dense. The maximum volumetric density of any one file occurred at a depth of 20 m.

TR 5.9.A produced the second largest abundance estimate of 31.1 million squid, resulting in a biomass estimate of 1275 mt.

The last cruise in the Heceta Head area produced no useable data. We echointegrated targets in a dense band close to the bottom from 0345 h to 0600 h on May 16. Test fishing proved that the targets were small fish. We searched for squid in the normal study area and up to 8 km south of the area, but located no squid.

The two day exploratory cruise between Yaquina Bay and the Columbia River did provide useful information. Small schools suspected to be squid appeared on the chromoscope off most of the headlands. More importantly, however, the cruise stressed the need to verify acoustic data. On one occasion we acoustically surveyed a dense band of targets for 2 h, only to catch small fish in the verification sets. On a second occasion a dense school of jellyfish produced echo profiles very similar to those obtained from loose aggregations of squid. The test fishing again prevented an erroneous calculation of squid abundance. and emphasized that acoustic surveys without target verification are highly suspect.

DISCUSSION

Distribution and movements

We observed no consistent pattern of squid distribution relative to time of day, but in all the cruises squid densities were generally high in the early morning and generally low in the afternoon. Nighttime densities were variable. The vertical distribution of squid, however, did change with time. During the April 25 and May 2 cruises squid resided primarily in the middle of the water column. By May 8 and 9 the highest squid densities occurred in the upper one-third of the water column. The location of squid schools also changed, the center of activity moved approximately 5 km south and 1 km shoreward from the 26 m to 20 m isobath over the two week period between the second and fourth cruises (Fig. 8).

The movement of the center of squid concentration may have been due to the influx of a new school of squid into the study area. In 1984 squid biological characteristics indicated a progression of spawning in a school (Starr and McCrae 1984). The sex composition of fishery market samples changed from predominately females to males as females spawned then died. The percentage of spawned females in the samples smoothly progressed from 0-100% in about 12-15 d. With the increase in percentage of spawned females came a corresponding decrease in the weight to length ratio of females. Using the percentage of spawned females and the average weight to length ratios, Starr and McCrae (1984) identified the influx of three separate groups of spawning squid into an area.

In 1985 we again observed evidence of several groups of squid entering the study area at different times (Starr and McCrae 1985). The sex composition changed with time; the samples contained primarily males towards the end of the season. The percentage of spawned females fluctuated early then gradually increased with time. Just before the samples contained 100% spawned females, the spawning curve quickly declined and began another increase (solid line, Fig. 9.B). The shape of the curve can be explained by an initial small group of squid moving into the area to spawn followed shortly by a much larger influx of a new group of squid. Just prior to the completion of spawning of the first two groups a third group moved in to

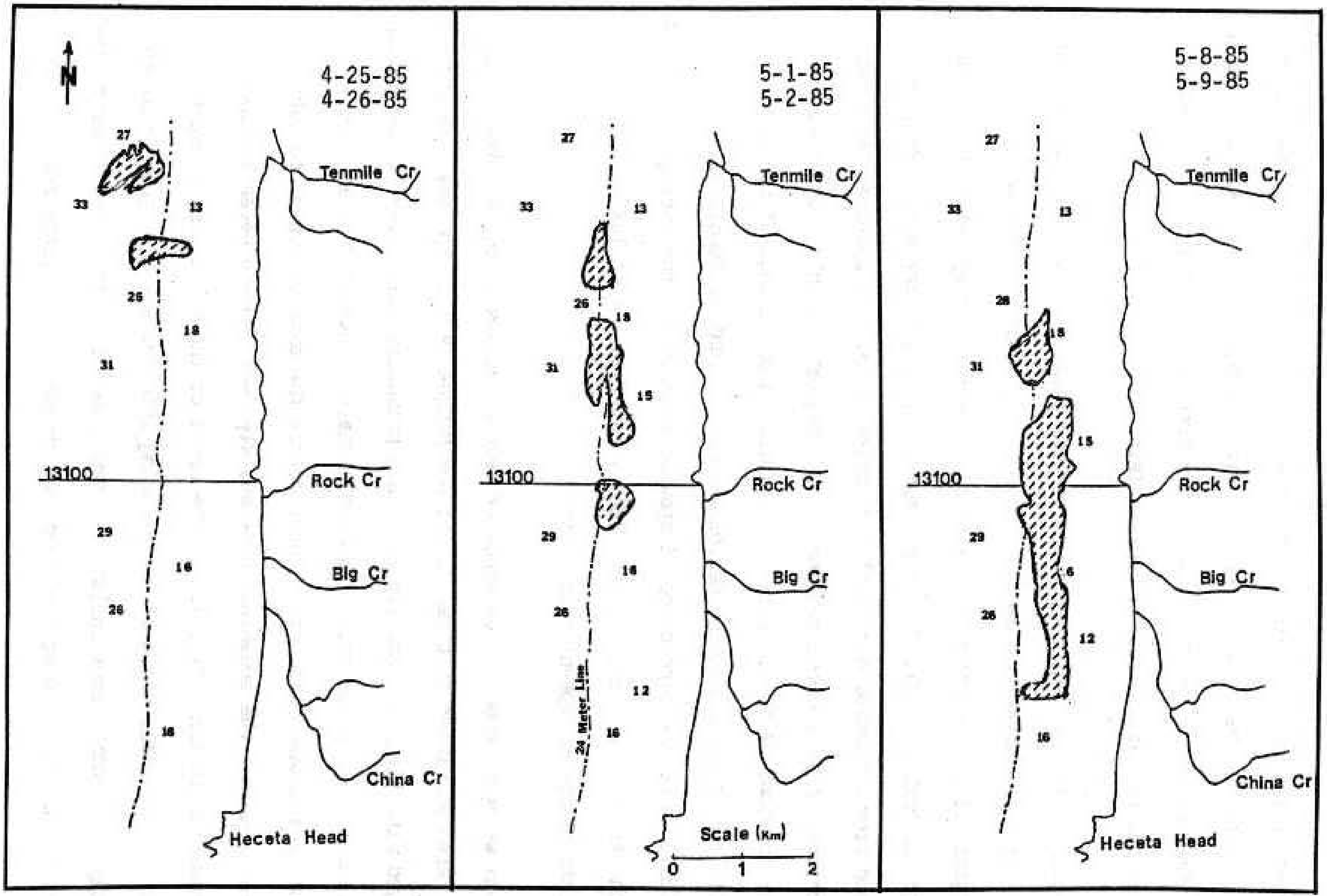

Fig. 8. Distribution of squid schools insonified on three cruises from April 25 - May 9, 1985. Depth (m) is shown at selected positions with LORAN C lines of position.

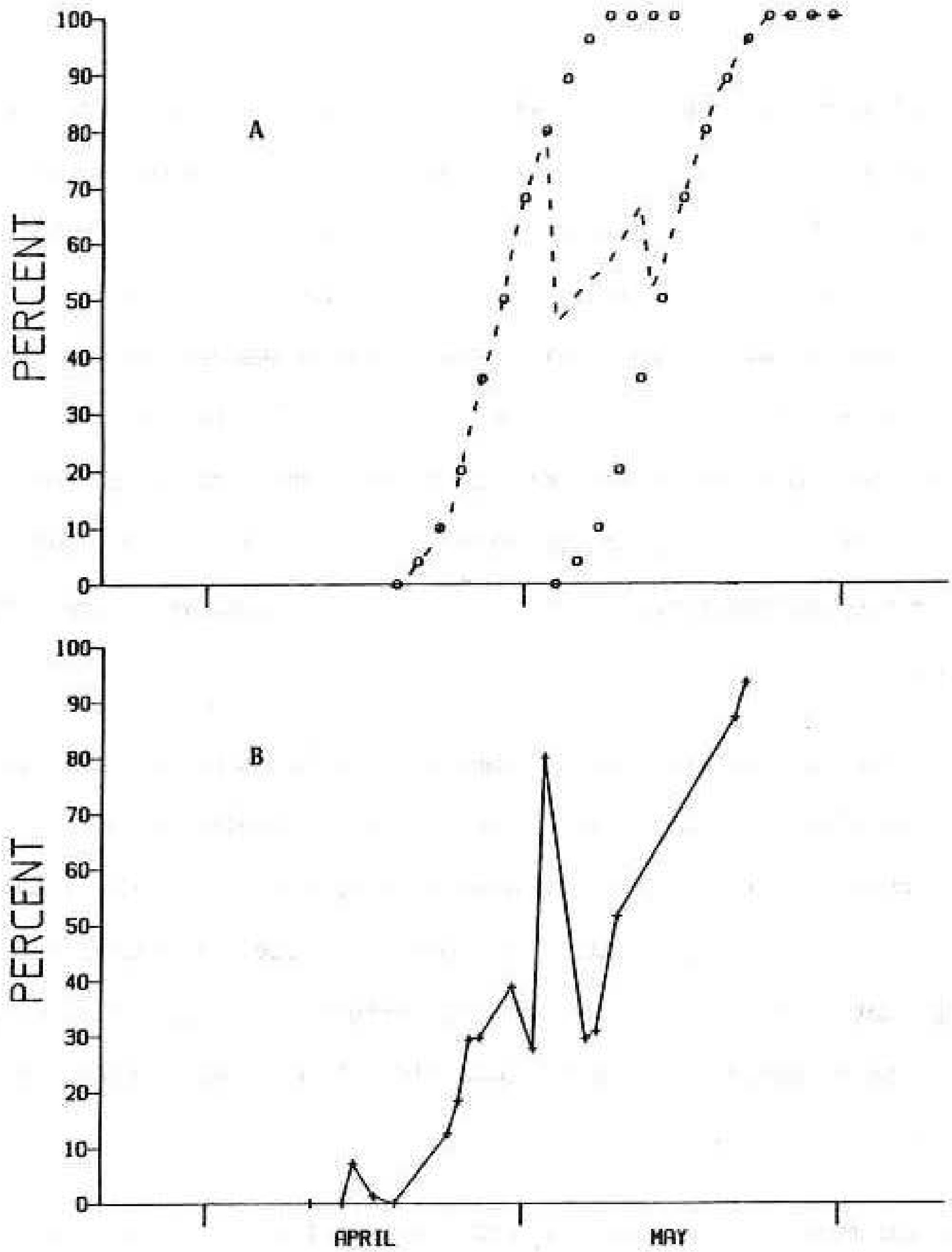

Fig. 9. A. Hypothetical curve of percent spawned female squid over time showing an influx of two groups of animals. B. Observed percent of spawned females from samples collected in 1985 (standardized to purse seine gear only).

the area to spawn. This scenario is graphically presented by the circles in Fig. 9.A.

To strengthen the hypothesis that three groups moved into the study area to spawn, we plotted the average weight to length ratios of female squid in each sample (Fig. 10). From an analysis of morphometric relationships Starr and McCrae (1984, 1985) determined that spawned squid have significantly smaller weight to length ratios than unspawned squid. This relationship is true for all squid larger than about 95 mm. As the percentage of spawned squid in the population increases, the mean weight to length ratio decreases. Thus, an increase in the mean weight to length ratio of a sample indicates that squid in an earlier spawning stage moved into the area.

The weight to length relationships of females only are used because Fields (1965) reported that for larger squid, males have a greater weight to length ratio than females. Using the average ratios of all animals to explain differences in the percentage of spawned females in a sample would thus bias the data. An increase in the mean weight to length ratio could be attributed to a change in spawning condition when it was really due to a change in the sample sex ratio.

If no new squid move into an area one would expect the weight to length ratios to gradually decrease with time. If a new group of squid enters an area, however, one would expect the sample ratios to gradually decline then quickly increase as squid in an earlier spawning stage appear in the samples. The mean sample ratios should subsequently decline at approximately the same rate as the initial group. If a third group of

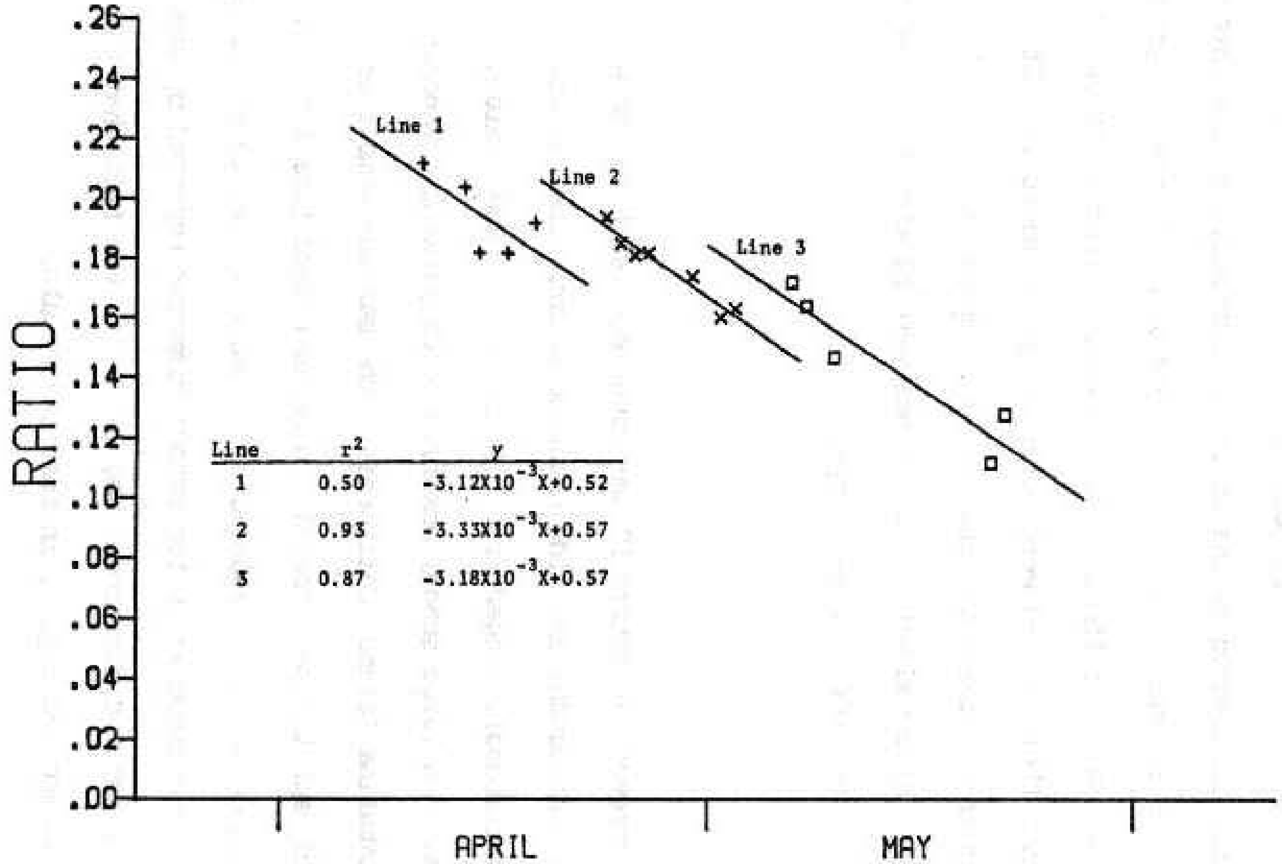

Fig. 10. Average ratio of mantle weight to dorsal mantle length for samples collected in 1985, showing three groups of squid in the sample ares (standardized to purse seine gear only).

squid enters an area the mean ratio would again increase, then begin to decrease as the new squid spawned.

The result should be three relatively parallel lines or curves that would be offset by a factor influenced by the amount of new squid moving into an area, and the relative spawning states of the existing and entering groups of squid. The offset parallel lines of mean weight to length ratios in Fig. 10 indicate that there indeed were three groups of squid in different spawning conditions that entered the study area to spawn at different times. Only samples collected with purse seines were plotted to avoid bias introduced by the use of different gear types.

Density

We qualitatively surveyed the entire 10 km^2 study area each cruise with the chartered vessel's echosounder and side scanning sonar. The surface area of the densest squid schools ranged from 0.3 km^2 to 3.75 km^2, values similar to the area of a large school observed by Cailliet and Vaughan (1983) off Santa Catalina Island, California. The maximum number of contiguous files in each transect containing squid ranged from 4 to 12, representing a distance of 800 to 2400 m. This value is two to six times larger than the 450 m maximum value for school diameter reported by Vaughan and Recksiek (1978), but the difference may be due to the fact that the schools we measured were rectangular instead of circular.

The average and peak volumetric densities measured this year compare favorably with the densities reported by Vaughan and Recksiek (1978) and Cailliet and Vaughan (1983). They estimated average squid densities to be 26.5/m^3 in dense areas and 3.2/m^3 on the fringes of the school on one night, and 7.3/m^3 without lights and 99.6/m^3 with lights on a second night. Similarly, our estimates of average densities ranged from 0.4 to 16.9 squid/m^3, and peak density was 83.9 squid/m^3.

Few researchers have reported squid densities in terms of areal densities. In this study, average areal densities ranged from 0.8 squid/m^2 of surface area over extremely small and patchy clusters of squid to 32.2 squid/m^2 over dense concentrations. The average areal density estimate reported by Jefferts et al. (1984) for a similar study area was comparable to the lowest mean density estimate we obtained on a long transect on May 2 over extremely small and patchy clusters of squid.

Our results suggest that to obtain accurate estimates of density and abundance of spawning schools, it is imperative to intensively survey schools in an area. A large zig-zag transect is useful for identifying presence or absence of squid in a large area, but has only a small chance of locating and adequately quantifying large schools (Vaughan 1978, Shotton and Bazigos 1984). We conducted a zig-zag transect on our first cruise, and although the average density estimates were essentially zero, we knew squid were in the study area because we were able to attract them to lights at night. Later we observed that squid clusters were oriented parallel to isobaths and decided that shorter and closer transects, parallel to isobaths, better sampled spawning schools.

Also, to estimate maximum density and abundance, it is important to sample repeatedly over the spawning period. Dense squid aggregations were not apparent at all times on each cruise and could easily be missed without repeated acoustic coverage of an area. For instance, taken by itself the density estimate of the May 2 searching survey would have underestimated the highest average squid density by 39 times, and underestimated peak abundance by a factor of five.

Thus, if the study objective is to estimate maximum density and abundance of spawning schools, then the best acoustic sampling design contains a qualitative survey of a large area and a quantitative survey of squid schools. Surveys should be conducted repeatedly during the spawning season. An intensive survey of a known squid school also helps alleviate the acoustic problem of discriminating fish from squid. This problem is virtually eliminated in compact spawning schools that are almost 100% squid.

For these reasons, the density estimates provided by Jefferts et al. (1984) are probably not good indicators of the peak density of spawning squid off Heceta Head in the 1984 spawning season. They covered a large area with a broad zig-zag pattern and did not have the time or money to adequately replicate their survey. Also, despite multiplying the mean areal density by a large survey area, their estimate of abundance probably does not accurately reflect the peak number of spawning squid. Nevertheless, their survey design was fine for developing methods, and is useful if the project objective is to estimate squid density in a large area.

Abundance

The five cruises completed in the Heceta Head area produced eight different non-zero estimates of abundance. For resource management, only one estimate of the range of total abundance is desirable, however. A logical way to reduce the number of estimates from eight to three is to lump the transects from each cruise to provide one peak abundance estimate for each week.

Nielson and Geen (1981) presented one method of evaluating abundance estimates of fish on spawning grounds. The method essentially integrates a curve described by estimates of abundance to derive a total number of fish-days. The total number of fish-days is divided by the average number of days an individual stays in the spawning locale to arrive at a total number of fish that spawned. The technique has proven useful for salmonids (Beidler and Nickelson 1980), but depends heavily upon a large number of data points and an accurate estimate of the time of residence on the spawning grounds. Unfortunately, the three non-zero and two null data points derived from this study were not sufficient to obtain a meaningful estimate using the area-under-the-curve technique.

We can assume there were at least as many squid in the study area as were harvested and as were counted on any given day. Therefore, an estimate of the minimum biomass of squid present in the study area can be obtained by adding the peak estimate of biomass from any of the cruises to the amount of squid commercially harvested prior to that time. A transect on April 26 produced the largest acoustic biomass estimate of 1714 mt. The acoustic estimate combined with the 394 mt of squid landed before that date provides an overall minimum biomass estimate of 2108 mt. Similarly, a second estimate of the minimum biomass comes from a transect on May 9. It provided a peak estimate a little lower than the transect on April 26, but with the addition of 746 mt tons landed by that date resulted in a minimum estimate of 2021 mt.

A maximum estimate of overall squid abundance can be obtained by assuming that the two peaks of abundance measured represent two different groups of squid. The biological data collected during the season indicate that there were at least two groups of squid in the area with different morphological characteristics. Assume the first group arrived on April 18, stayed on the spawning grounds about 15 d, then died before the May 9 acoustic survey. Next, based on the biological data, assume the second group entered the study area sometime after the April 26 survey and again stayed on the spawning grounds 15 d before dying. If we assume the acoustic biomass estimates of April 26 and May 9 represent the peaks of abundance of the two groups of spawning squid, and no squid were counted twice, then a biomass estimate can be obtained by adding the amount of squid counted on those two days with the amount of squid landed prior to those days. The result is a biomass estimate of 3735 mt. This value should be treated as a conservative maximum estimate of abundance in the study area during the study period.

Variance

It is important to have an understanding of the accuracy and precision of the biomass estimates if they are to be used for managing the resource. Bias and variability come from electronic, acoustic, biological, and data expansion sources (Ehrenberg and Lytle 1977). Total variance can be quite large, and is the subject of attention of a number of researchers. Bazigos (1975, 1981), Shotton (1981), and Shotton and Bazigos (1984) provide excellent summaries of concerns to be addressed in acoustic study design and ways to evaluate and reduce variation. A number of scientists are working to reduce bias by creating new acoustic equipment and methods to increase the precision of estimates (Craig 1984). Also, several papers have been published which discuss the statistical aspects of variability in acoustic biomass assessment (Lozlow 1977; Bodholt 1977; Kimura and Lemberg

1981; Williamson 1982). It is beyond the scope of our study to thoroughly quantify all aspects of variation in our biomass assessment, but a general discussion of variability is warranted.

Variation inherent in the electronic equipment is probably the smallest component of variability. Electronic errors generated by sea conditions, the ship's electrical field, and ambient noise were minimized by transmitting at a high power.

Acoustic error introduced by the variation in the random scattering process may be large. Large variations can occur in the phase relationships between echoes from individual targets (Bodholt 1977). This variation in the sound intensity received by the transducer may be caused by the change in orientation or character of the reflecting surface (squid), by transducer side-lobe reflection, or by shadowing or additive effects of targets densely schooled.

The target strength estimates have associated error values. One source of error is caused by reflections from side-lobes of the transducer. This error is minimal with the BioSonics transducer since it has small side-lobes. Another source of target strength variation is that the insonified squid vary in size and aspect so the reflective surfaces are not identical. Several investigators have suggested that instantaneous mean target strength of schooled fish may vary ± 1-2 dB due to variations in size and aspect (Craig 1984). A 2 dB uncertainty in target strength translates to a +50% or -37% uncertainty in an abundance estimate.

Some sources of acoustic variation are uncontrollable, but we minimized error by transmitting a signal at high power in shallow water with a high pulse repetition rate. Collecting a large number of targets for target strength analysis also helped reduce variation. In this study the average target strength had a narrow 95% CI of ± 0.2 dB, indicating that target backscattering cross sections changed little while we were collecting dual beam data. A species composition of almost 100% squid in the schools insonified also helped reduce variation in estimates of target strength.

Variability associated with the spatial distribution of squid is undoubtedly a large component of error. Variability is inherent in random sampling of contagiously distributed animals. This error was minimized by using Bazigos' (1975) and Kimura and Lemberg's (1981) suggestion that the precision of sample estimates could be increased by decreasing the distance between transects. Collecting large amounts of data by limiting file sizes to just over one minute also increases precision. Because of the frequent sampling rate we assume variation within files is small. A bias is introduced at times; however, because the echoprocessor does not collect data when the computer writes to a disk, a process that occurs about 10% of the time.

Between file variation was quantified and presented in the form of estimates based on both random sampling theory and cluster sampling theory. The random sampling estimates provided a smaller coefficient of variation than the cluster sampling estimates, but Williamson (1982) postulated that when files are highly correlated the random sampling estimate method underestimates variance. He suggested that when serial correlation is high, cluster sampling estimates of the variance are more appropriate.

In the long transects with sparsely distributed schools, serial correlation was high and the cluster sampling method of estimating the 95% confidence interval may indeed be more appropriate. However, the transects that circumscribed, then bisected, dense squid schools may be more appropriately designated as random samples of one aggregation rather than being treated as a group of squid clusters. In either case the random sampling estimate provides a liberal estimate of variation and the cluster sampling estimate provides a conservative estimate of variability.

A source of error exists with the expansion of sample summaries as well. LORAN C lines of position may be up to several hundred meters off depending upon equipment used and location (especially in nearshore areas), thus influencing the precision of the value of the area used to transform density estimates to abundance estimates. Error is added because the average weight of squid used to transform abundance to biomass has a coefficient of variation on the order of 15%. A possible additional source of variation is due to the fact that the target strength estimates came from the end of the field season when squid mean lengths were a little smaller and mean weights were considerably smaller than in the beginning of the season. Smaller squid may have had a lower backscattering cross section, resulting in an underestimate of squid abundance early in the season.

SUMMARY

Approximately 23 h of acoustical survey information collected over a 5 week period yielded estimates of squid abundance from a small area off the central Oregon coast. The best survey design included a qualitative survey of the entire study area using a wide beam transducer with a color video display, followed by quantitative acoustic surveys using a scientific echosounder and echoprocessor. Intensive surveys of discrete squid schools provided the highest estimates of squid density. Long, widely spaced or zig-zag transects underestimated school abundance. Test fishing verified that the targets insonified were squid; it is important to sample with nets during acoustic surveys to avoid misinterpreting echoes.

Maximum volumetric densities of squid in any 200 m segment of transect ranged from 2.1 to 83.9 squid/m^3. Maximum areal densities in any file ranged from 8.8 to 178.9 squid/m^2 of surface area. Average areal densities for an entire transect ranged from 0.8 squid/m^2 to 19.2 squid/m^2. The largest school observed covered a surface area of 2.1 km^2 and contained an estimated 31.4 million squid. Biomass of the largest school was estimated to be 1714 mt.

We chose the peak abundance estimate from each cruise to reduce the number of biomass estimates from eight to three, and suggested three methods of obtaining an overall estimate of squid abundance. Adding the biomass estimate from the largest school insonified to the amount of squid commercially harvested prior to that day provided a minimum biomass estimate of 2108 mt. Biological information collected indicated that two

groups of squid occupied the study area at different times. We obtained a maximum biomass estimate of 3735 mt by adding the two peak estimates of abundance and by assuming they represented different groups of squid.

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