

Quantitative Sampling of Oceanic Cephalopods by Nets: Problems and Recommendations

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Abstract Three large data sets on cephalopods are critically examined with respect to several sources of error: day-night avoidance, net size, mode of fishing, and patchiness. Catches are low and variable and results only suggest problems with present sampling techniques. Specific field sampling is suggested to quantify several of these sources of error. Volume filtered and time fished are compared as measures of "effort." Variability of volume filtered and net speed within a single tow are examined.

Introduction

The problems involved with sampling cephalopods have long been recognized with respect to the accuracy and precision of various types of sampling devices (Roper, 1977; Clarke, 1977). Two sources

Biological Oceanography, Volume 2, Number 2-3-4
0196-5581/83/010357-00\$02.00/0
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of sampling variation that affect both precision and accuracy are avoidance and patchiness. Temporal and spatial changes in the abundance and species composition of cephalopods are additional sources of variation, but are the "true" patterns (Haury et al., 1978) that biogeographers are attempting to define. The particular problem of avoidance has been dealt with in a general, theoretical manner by Barkley (1964) and in terms of empirical evidence by Fleminger and Clutter (1965), McGowan and Fraundorf (1966) and Murphy and Clutter (1972). A more recent treatment of the avoidance problem by Barkley (1972) has included analyses of several sets of field data to examine the probability of capture, i.e., the probability of catching an organism if it is directly in the path of the net. This is a function of the reaction distance, the animal's escape speed, the mouth size of the net and the speed of the net. Avoidance is influenced by the integrated effects of (1) the differential day-night visual detection of the net due to its presence alone, as opposed to (2) the visual detection of the net due to the bioluminescence it may trigger (Fleminger and Clutter, 1965; Boden, 1969); (3) the noise given off by the bridles, warps ("wire strum") or otter doors, paravanes etc.; (4) the effect of the size and shape of the net opening (and mesh size) (Roper, 1977; Clarke, 1977), (5) the speed and mode of fishing (tows fished on the way up, down, or horizontally); and finally, (6) diel changes in behavioral patterns such as schooling or individual activity levels. It is presently impossible to separate out the effects of each of these possibilities using cephalopod data (or any zooplankton data). Barkley (1972) found minimum probabilities of capture for several species of fishes from a high of 40% to a low of 3% depending on species, net size (1-m net or 3-m IKMT) and towing speed. This means that from 40% to 3% of all individuals in the volume described by the mouth of the net and the tow path are captured.

In addition to the problem of avoidance, the reality of the non-random distribution (i.e. patchiness) of most organisms in the marine environment adds to the constraints on interpretation of cephalopod catch data. Also we must consider that much of our previously collected data are from open nets and are difficult to interpret for several reasons. Finally, we undoubtedly have a seasonal component of variability which is mixed into most of our

treatments of cephalopod data due to the necessity to pool data in order to attain, at best, only moderate numbers of individuals and species.

Our intention in this paper is (1) to examine these separate sources of variation based on previously collected cephalopod data, (2) to rank these sources of variation on the basis of their relative impact on our data collection, and (3) to suggest the most efficient ways to minimize these sources of variation.

Materials and Methods

The data we use come from three separate programs in two widely separated geographical regions. The first is EASTROPAC, a two-year study in the eastern Tropical Pacific in which the micronekton were collected by oblique hauls of a 1.5 m (mouth opening) square net described by Blackburn (1968). The net was 5.8 m long with uniform mesh throughout (5.5 mm \times 2.5 mm). Ship speeds usually were 5 knots, although two of the participating ships towed at 4.0 and 6.4 knots. The tows were designed to reach a depth of about 200 m, although the range was 100–348 (mean = 197 m; standard deviation of 36.4). The volume of water filtered was computed from the distance the ship traveled, the mouth area of the net and an assumed filtering efficiency of 80%. Of the 848 day and night tows, 618 were selected for further study on the basis of availability of ancillary data (i.e. temperature, salinity, nutrients, primary productivity, etc.). Of these, 299 tows were day samples and 319 tows were night samples.

The second program is OCEAN ACRE (OA). The OA study area is located east of Bermuda and encompasses a one-degree square area centered at 32°N, 64°W. Details of the long-term program are given in Gibbs and Roper (1970) and Gibbs et al. (1971). The principal sampling gear was a 3-m Isaacs-Kidd midwater trawl (3-m IKMT) equipped with a codend closing device—a four-chambered, electronically-actuated sampler described by Aron et al. (1964). The apparatus allows collection of three discrete samples at a precise depth and a fourth sample during retrieval of the net from fishing depth to the surface. The gates that separate the chambers are closed by means of a solenoid-actuated triggering mechan-

ism. The mouth opening was 7.44 m²; the entire net was lined with a 6 mm bar measure knotless liner, with a 3 m long codend plankton net of 0.75 mm. The experimental design for OA included a regime of depths and time for seasonal discrete-depth sampling. 12 standard depths were established for sampling the water column during each cruise; each depth was sampled at least once during full daylight hours and once during the night. Trawls that occurred from two hours before to two hours after sunset and sunrise were considered to be twilight tows.

The third program is the Cold Core Cyclonic Rings Program in the western North Atlantic. These cruises were conducted in the Slope Water Region and the northwest Sargasso Sea. The first four cruises used a 3-m open IKMT fished to 1000 m, while the last four cruises used a modified Tucker Trawl designed to fish five separate nets at an angle of 45° to the vertical. At this angle this net has a 10 m² mouth opening. Each net is 3.18 m wide, 4.0 m high, 13.5 m long and is made of 3 mm knotless nylon mesh. This system, called the MOCNESS 10 or MOC-10 meaning Multiple Opening-Closing Net and Environmental Sensing System, is an enlargement of the 1 m² system described in Wiebe et al. (1976). It is towed on conducting cable and provides real-time information several times a second on fishing depth, temperature, salinity, oxygen concentration, net angle, flow rate, and net fishing status. These data are displayed on a laboratory readout and processed by computer to show cumulative volume and net speed and to plot selected parameters in real time.

The towing regime was arranged to fish the first net open down to 1000 m, then the second net from this depth up to 750 m, and the third up to 500 m, the fourth up to 250 m, and the fifth up to the surface.

Results

Avoidance

Day-night Avoidance

We have data sets of tows that can be used to evaluate the relative importance of differential day-night avoidance compared with diel

vertical migration. The method used is that of Percy and Laurs (1966). This method examines day-night shifts within each of two strata that completely cover the vertical distribution of a species. The best measure of this component of avoidance clearly would be from a synoptic set of samples so that temporal and spatial variation are kept small, but the disadvantage of this is that catch rates of cephalopods are too low using most conventional samplers. Nonsynoptic samples have the advantage of providing larger numbers, but the disadvantage of an unknown amount of temporal and spatial variability.

An example of synoptic data comes from the Cold Core Rings Program. One day-night pair of synoptic stratified tows in the Sargasso Sea had only three species in common (Table 1). If no differential day-night avoidance existed, the N/D ratio for the water column abundance (n/m^2) should equal one. For many fish species this ratio is usually greater than one (Percy and Laurs, 1966). In our data this ratio is less than one for all three species. The results are confusing. We would expect N/D ratios to be greater than one for these three species. We would also expect the D-N (lower level)/N-D (upper level) to fall between 0 and 1.0. One species does; two do not. These results suggest that the numbers of individuals caught are simply too low. It can be argued, however, that for a large number of paired day-night tows, or even oblique tows, the comparison of day-night integrated water column values should follow the binomial with $D = N = 0.5$ if there is no differential day-night avoidance. We have insufficient data to test this hypothesis.

A nonsynoptic set of pooled samples from OA for the two most abundant species is analyzed in Table 2. Although these data represent many discrete tows taken over a 5-year period, we have lumped them into broad depth intervals as delineated in Table 2 to conform to the previous treatment. Tows taken during crepuscular periods between 1600 to 2000 and 0400 to 0800 hours are excluded. The depth intervals include all captures and are continuous, but nonoverlapping. For *Pyroteuthis margaritifera*, the N/D ratio is 0.88 if all negative tows are ignored. Since migration across the 250 m level is complete, the ratio used by Percy and Laurs (1966) is the inverse of the N/D ratio or 1.14. It is possible that the effect of biolumines-

Table 1

Vertical distribution and day-night avoidance analysis of MOC 10-25 (0035 hrs; April 13, 1977) and MOC 10-26 (1400 hrs; April 13, 1977) taken 15 nautical miles apart in the Sargasso Sea.

Species	Number of Specimens		Catch/m ² 0-1000 m		Catch/m ² 0-250 m		Catch/m ² 250-500 m		D-N(250-500 m) + N-D(0-250 m)	
	Day	Night	Night/Day		Night	Day	Day	Night		
<i>Onychoteuthis banksii</i>	2	2	0.77		0.11	0.26	-	0.09		0.58
<i>Brachiooteuthis riisei</i>	4	2	0.39		0.22	0.26	0.29	-		-6.54
<i>Pyroteuthis marginifera</i>	2	1	0.38		0.11	-	0.29	-		2.70

Table 2

Vertical distribution and day-night avoidance analysis of two abundant species from pooled Ocean Acre data (1967-1971). Data are from positive tows only and are in units of catch/hr.

Species	Number of Specimens	Mean Catch/hr	Mean Catch/hr		Mean Catch/hr		D-N (250-500) + N-D (0-250)
		0-500 m Night/Day	0-250 m Night	0-250 m Day	250-500 m Day	250-500 m Night	
<i>Pyroteuthis margaritifera</i>	163	0.88	2.80	-	3.18	-	1.14
<i>Pterygioteuthis giardi</i>	104	2.13	3.20	-	1.50	-	0.47

cence in surface waters at night may make the net more conspicuous due to the strong contrast than during the day in deeper waters.

A similar analysis of data for *Pterygioteuthis giardi* from OA (Table 2) for all positive tows showed nonoverlapping layers of abundance at the 250 m level. The N/D ratio was 2.13 with 47% due to vertical migration and 53% due to differential day-night avoidance. We feel that the variability in trends seen in these examples of this type of analysis is probably due to the low numbers with which we are dealing. This is a serious problem and is not limited to the trawling equipment used in these two programs.

Size and Shape of Net

Because of the large difference in mesh size, we will not consider the comparison of a 3-m IKMT (6.0 mm mesh) with an Engels Midwater Trawl (101 mm mesh tapered to 38 mm) presented by Roper (1977). It can be stated that larger mouth-area nets catch larger individuals (Roper, 1977) though not necessarily more individuals per unit volume. This is partly due to escapement through the larger mesh of large nets and partly due to the lower avoidance of large mouth-area nets. In addition, it is difficult to compare two different nets with respect to size frequency of catch unless they are towed fairly close together in time and space. Therefore we selected a series of paired tows with a 3-m IKMT (6.0 mm mesh) and an open MOC-10 (3.0 mm mesh) taken on KNORR 58-3 (Fig. 1).

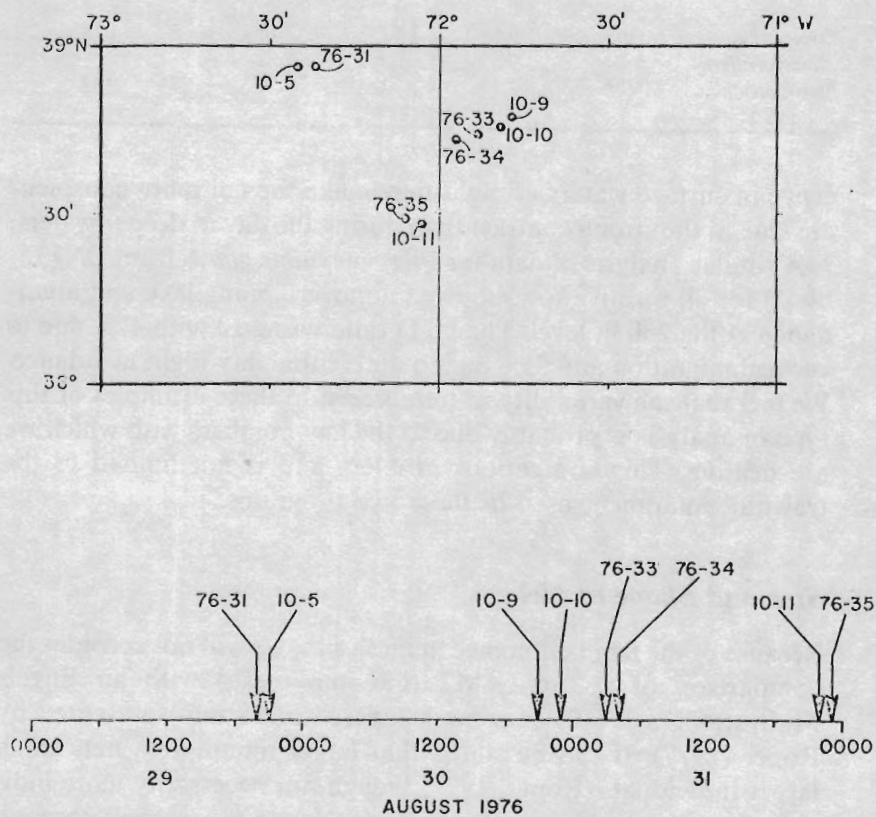


Figure 1. The locations of paired IKMT - MOC-10 tows in space and time.

Table 3
Abundance comparisons for paired IKMT - MOC-10 tows

Tow	IKMT (JEC 76-31)	MOC 10-5	IKMT (JEC 76-33)	MOC 10-9	IKMT (JEC 76-34)	MOC 10-10	IKMT (JEC 76-35)	MOC 10-11	
Time	2020	2148	0035	2145	0200	2300	2315	2200	
Depth Sampled (m)	0-250-0	0-250-0	0-60-0	0-60-0	0-115-0	0-115-0	0-250-0	0-250-0	
Duration (min)	80	72	75	65	65	75	55	60	
Volume (m³)	23,700	27,400	28,100	33,000	33,400	50,700	25,700	32,000	
Speed of Tow (Knots)	1.27	1.27	1.61	1.69	2.20	2.25	2.0	1.78	
Species (n/10*m³)									
<i>Pterygoteuthis geminata</i>	0.84	<	12.10	<	5.99	>	1.56	>	0.93
<i>Pyroteuthis</i>									
<i>margariifera</i>	—	—	1.07	>	0.91	<	4.73	>	0.62
<i>Abrolopsis pfefferi</i>	—	—	1.07	<	1.21	>	1.18	>	0.31
<i>Onychoteuthis banksii</i>	—	0.36	—	—	—	—	—	—	—
<i>Cranchia scabra</i>	—	—	0.36	—	—	0.20	—	—	—
<i>Phasmotopsis oceanica</i>	—	—	0.36	—	—	—	—	—	—
<i>Selenoteuthis scintillans</i>	—	—	0.36	—	—	—	—	—	—
<i>Egea inermis</i>	—	—	—	0.30	—	—	—	—	—
<i>Helicocranchia pfefferi</i>	—	—	—	—	0.30	0.20	—	—	—
<i>Rossia equallis</i>	—	—	—	—	—	0.20	—	—	—
<i>Tremoctopus violaceus</i>	—	—	—	—	0.30	—	—	—	—
<i>Brachioteuthis riisei</i>	—	—	—	—	—	—	0.39	—	—
<i>Octopoteuthis megaptera</i>	—	—	—	—	—	—	—	0.31	—
<i>Pyroteuthinae larvae</i>	—	—	—	—	—	—	1.56	—	—
<i>Pterygoteuthis giardi</i>	—	—	—	—	—	—	1.17	0.31	—

Each pair of tows sampled to the same depth. A comparison of four of these pairs is shown in Table 3. For the most abundant species, *Pterygioteuthis gemmata*, the IKMT out-caught the MOC-10 in half of the tows, but all possible comparisons of the paired tows for the three most abundant species show the IKMT higher in 6 out of 10. If we assume these nets to be of equal effectiveness, we could look at these results only in terms of which net caught more using the binomial. The binomial probability of 6 of 10 is 0.20. This says that these two nets are not significantly different from each other at the 0.05 level in terms of capturing abundant cephalopods.

Mode of Fishing

The use of open-closing net systems provides a choice not only of depths to be sampled, but of whether to sample while the net is descending, stable at depth, or ascending. While the net is descending it approaches a stationary animal from above, precedes the warp and travels somewhat slower than on the retrieval portion of the tow. This is due to the horizontal component of the speed of paying out the warp, reducing the effective forward speed of the net. On the retrieval, these two components are additive. Based on this difference in speed alone (often 0.5 knots), one might expect the ascending nets to catch more effectively. The difference in approach of the net to the animal may, however, be significant. We have selected some MOC-10 tows to compare the catches of Net 0 (the descending net) to those of Nets 1-4 (the ascending nets).

Since integrated water column abundances (n/m^2) are based upon a summation of water column concentrations and these concentrations are determined by the number of specimens captured and the volume of water filtered, we adjusted the concentrations in Net 0. If only one individual was caught, it could only have been caught in one of the four depth intervals fished by Nets 1-4. To divide by the total volume of water filtered in the 0-1000 m column would clearly give us a biased underestimate. Assuming each 250 m interval was fished evenly on the way down, we divided the one specimen by one-fourth of the volume of Net 0. If two specimens were caught, the most conservative assumption was that they were

caught in separate intervals and were divided by one-half of the volume of Net 0 (it should be pointed out, however, that the results of this analysis are unchanged if Net 0 catches are *not* adjusted in this manner).

The only obvious pattern that is seen in Table 4 is that in every tow in which a species is caught in Net 0, the integrated value is greater than that of Nets 1-4. This is due to the greater volume usually sampled by each of Nets 1-4 (one specimen in any one of Nets 1-4 gives a lower concentration than one specimen in Net 0). Using the binomial and assuming Net 0 catch = Nets 1-4 catch, we find that in 12 out of 33 cases in which either is a nonzero catch, Net 0 is greater than that of Nets 1-4. The hypothesis can be rejected at the 0.05 level ($p = 0.041$). This suggests that nets have a greater probability of catching squid while being retrieved. This is most likely due to the greater volume of water Nets 1-4 filter which increases the probability of capturing specimens. A large number of tows (15-20) to a constant depth, close together in time and space and filtering volumes from about 10,000 to 40,000 m³ would be necessary to test this hypothesis. We do not have these data.

Patchiness

The tendency of species to occur in patches certainly influences our ability to sample them precisely and accurately. One index commonly used to estimate the type of distribution is the index of dispersion (ID). It is simply the s^2/x ratio. If the organism is patchy, the ID is much greater than 1.0. A random distribution shows an ID approximately equal to 1.0 and an even distribution of less than 1.0. We have calculated indices of dispersion for a number of species from the various data sets. There are a large number of zeros (negative tows) in the data. Another way to show patchiness is to look at frequency of capture (number of positive tows/total number of tows), as shown in Table 5. These data clearly show that within depth strata where these species are known to occur, the frequency of capture is always less than 50% and coefficients of dispersion are usually > 1.0 , indicating that most distributions are strongly patchy.

Table 4
Abundance comparisons for the oblique net (0-1000 m) and the four discrete nets from the Sargasso Sea and Slope Water Region; n/m^2 .

Environment	SARGASSO SEA (NIGHT)		SARGASSO SEA (DAY)		SARGASSO SEA (NIGHT)	
Tow	0	10-1000	0	10-1000	0	10-1000
Net	1-4	1000-0	1-4	1000-0	1-4	1000-0
Depth	0	1000-0	0	1000-0	0	1000-0
Species	SARGASSO SEA (NIGHT)		SARGASSO SEA (DAY)		SARGASSO SEA (NIGHT)	
	MOC 10-25	MOC 10-63	MOC 10-26	MOC 10-67	MOC 10-68	MOC 10-68
	0	1000-0	0	1000-0	0	1000-0
<i>Pyrosoma margaritifera</i>	2.5	>0.109	>0.294	-	<0.504	-
<i>Pyrosoma giardi</i>	5.0	>	-	-	-	-
<i>Histioteuthis dofteni</i>	-	<0.449	-	1.82	>0.109	-
<i>Ctenopteryx sicula</i>	-	<0.307	-	-	<0.300	-
<i>Onychoteuthis banksii</i>	-	<0.198	<0.263	-	<0.133	-
<i>Japetella diaphana</i>	-	<0.089	-	-	-	-
<i>Brachioteuthis risiei</i>	-	<0.218	<0.557	-	-	-
<i>Mastigoteuthis magna</i>	-	-	-	1.82	>0.109	-
Environment	SLOPE (DAY)		SLOPE (NIGHT)		SLOPE (DAY)	
Tow	0	10-1000	0	10-1000	0	10-1000
Net	1-4	1000-0	1-4	1000-0	1-4	1000-0
Depth	0	1000-0	0	1000-0	0	1000-0
Species	SLOPE (DAY)		SLOPE (NIGHT)		SLOPE (DAY)	
	MOC 10-36	MOC 10-57	MOC 10-57	MOC 10-67	MOC 10-68	MOC 10-68
	0	1000-0	0	1000-0	0	1000-0
<i>Histioteuthis larvae</i>	1.54	>	<0.326	-	-	-
<i>Teuthowenia megalops</i>	1.54	>0.370	-	-	-	-
<i>Mastigoteuthis magna</i>	-	<0.200	-	<0.193	-	-
<i>Pyrosoma gemma</i>	-	<0.093	-	-	-	-
<i>Rhynchoteuthis</i>	-	<0.185	-	-	-	-
<i>Histioteuthis reversa</i>	-	1.67	>	<0.093	0.93	>0.083
<i>Abdriopsis</i> sp.	-	<0.109	<0.109	-	-	-
<i>Leachia</i> sp.	-	-	-	1.54	0.93	>
<i>Thelidoteuthis allessandrini</i>	-	-	-	<0.093	-	-
<i>Onychoteuthis banksii</i>	-	-	-	<0.125	-	-
<i>Illex</i>	-	-	-	-	0.93	>
<i>Liocranchia pfefferi</i>	-	-	-	-	<0.093	<0.083
<i>Gonatus</i>	-	-	-	-	-	<0.083

Table 5

Day-night values for frequency of capture (F), abundance (A), and index of dispersion (ID) for abundant species.

EASTROPAC	F_D	F_N	A_D	A_N	ID_D	ID_N
<i>Abraliopsis affinis</i>	0.22	0.47	0.31*	1.12	2.3	3.5
<i>Liocranchia reinhardtii</i>	0.38	0.37	3.08	1.72	74.9	14.3
<i>Pyrogopsis schneehagenii</i>	0.26	0.32	0.47	0.52	2.1	2.6
<i>Onychoteuthis banksii</i>	0.29	0.21	0.42	0.28	2.6	1.8
<i>Pterygioteuthis giardi</i>	0.04	0.34	0.20	1.88	31.4	90.2
OCEAN ACRE						
<i>Pyroteuthis margaritifera</i> (Day 300-550; Night 50-250)	0.46	0.56	1.46**	1.64	3.98	4.06
<i>Pterygioteuthis giardi</i> (Day 250-500; Night 50-200)	0.31	0.42	0.62	1.33	2.85	4.23
<i>Abraliopsis pfefferi</i> (Day 100-650; Night 50-550)	0.09	0.13	0.13	0.15	1.34	1.16
<i>Onychoteuthis banksii</i> (Day 50-100; Night 0-150)	0.63	0.24	0.91	0.40	0.98	2.08
<i>Helicocranchia pfefferi</i> (Day 100-200; Night 100-200)	0.50	0.58	1.05	0.79	3.14	0.93
<i>Leachia</i> (Day 50-800; Night 50-250)	0.15	0.33	2.78	1.87	96.36	18.50

* = $n/10^4 \text{ m}^3$

** = catch/hr

Time and Flow as Units of Effort

Catch per unit of time is sometimes used to standardize fishing effort. Since organisms are distributed in some nonuniform concentration, actual volume of water filtered by a sampling device is a more effective way to express effort. Figure 2 shows the relationship of volume filtered (as measured by a flowmeter in the mouth of the trawl) to time (duration) of tow for 44 3-m IKMT's taken in the Slope Water Region and the northwest Sargasso Sea. The regression line is highly significant, but the variability is also large. For example, based only on time, three tows of 208 min each filtered from 86,000 m^3 to 182,000 m^3 , or a factor of 2.12 times the smaller volume. Data from MOC-10 tows also show a significant regression for Nets 1-4, also with large variability (Fig. 3). These results strongly suggest that calculating abundances based on time fished rather

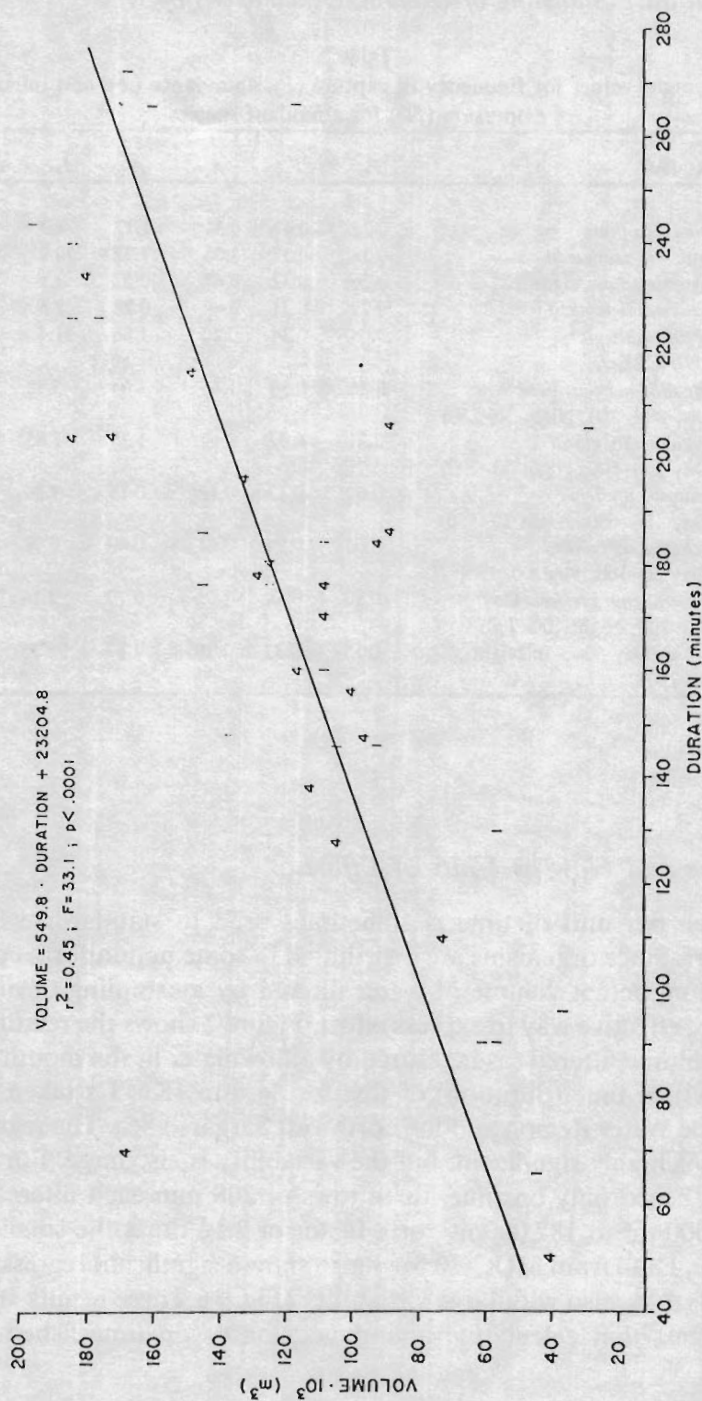


Figure 2. Volume filtered as a function of time for tows to 200–1250 m using a 3-m IKMT (4 = Sargasso Sea tows; 1 = Slope Water Region tows).

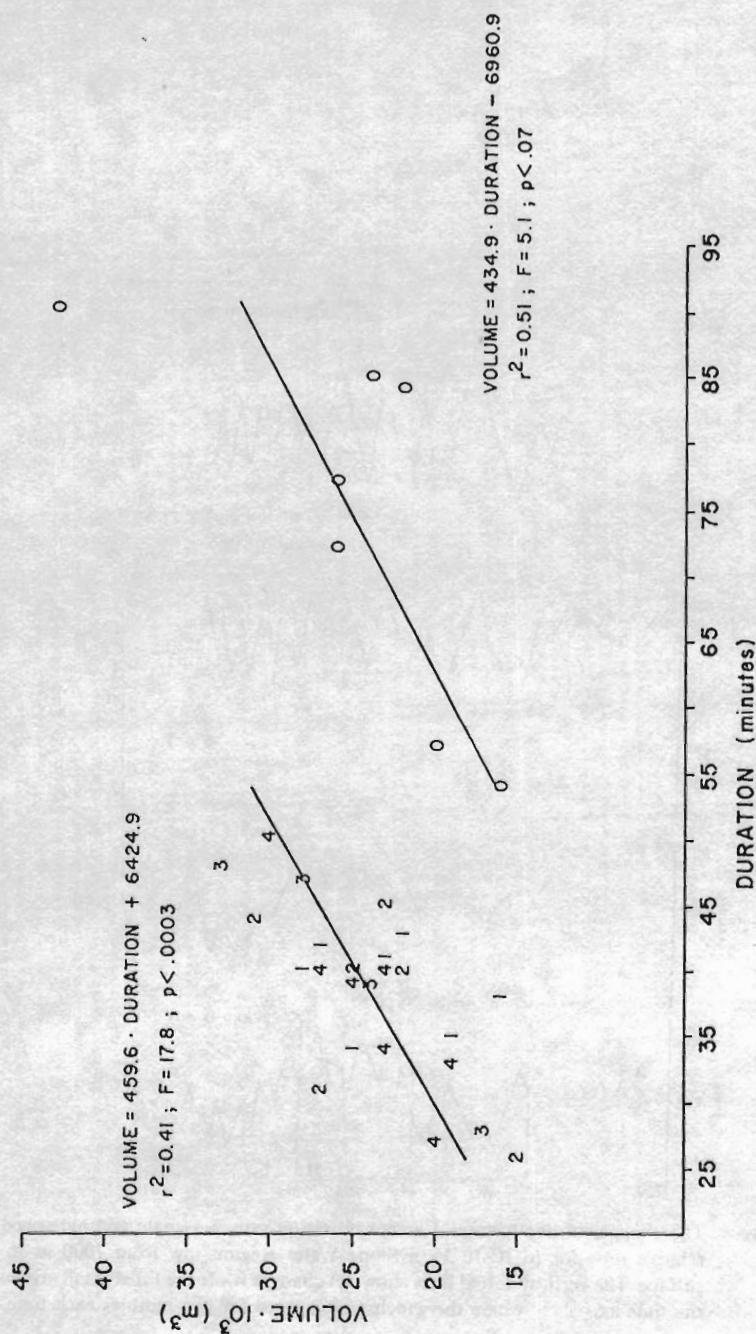


Figure 3. Volume filtered as a function of time for tows from 1000-0 m in discrete 250-m layers and for open nets from 0-1000 m separately. The numbers represent net numbers: 0 (0-1000 m), 1 (1000-750 m), 2 (750-500 m), 3 (500-250 m) and 4 (250-0 m).

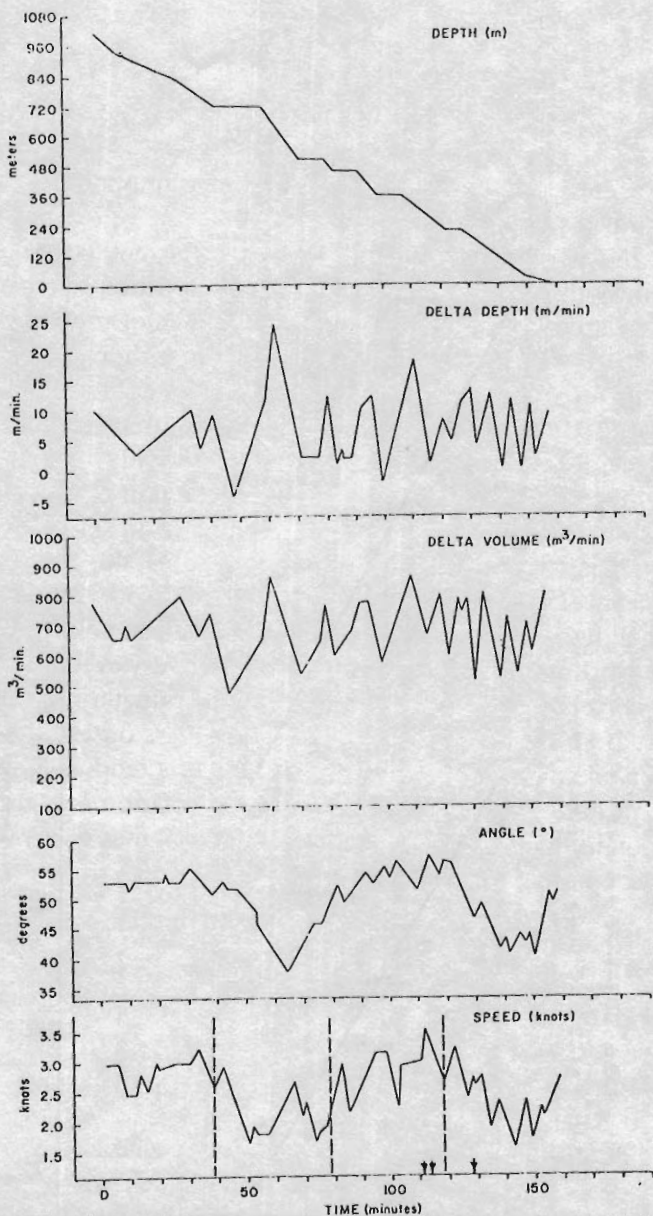


Figure 4. The changes in depth, rate of ascent, filtration rate, net angle and net speed vs. relative time for MOC-10-36, a Slope Water Region tow from 1000 m to the surface. The vertical dotted lines show net changes while the three small arrows on the time axis show where the winch was stopped for two minutes each time.

than actual volume filtered may introduce a large amount of "artificial" variation into the data.

Even within a single tow the behavior of the net is variable. Figure 4 shows the changes in the ascent rate, filtration rate, speed through the water and net angle over time for each of the four nets in a MOC-10 tow in the Slope Water Region. Although the tow starts off quite evenly at 1000 m, the amount of water filtered within small intervals (on the order of 25 m) becomes quite variable. This tow was designed to fish each 250 m interval evenly in terms of time. We had to adjust winch speed for about 2 min each on only three occasions. Otherwise, no changes were made in ship speed or wire speed. The times fished for Nets 1-4 were 39, 40, 40, 40 min and volumes were 27,900; 24,600; 27,900; and 26,500 m³, respectively. The difference was only 13% from the smallest volume to the largest, but within intervals the "effort" was not very evenly distributed. The correlation coefficients for all four parameters are shown in Table 6. If species are thinly stratified in layers on the order of 100 m (as some data suggest), our present efforts tend to under or overestimate abundance due to this source of variation. In addition, the variation in the net speed (from 1.5 to 3 knots) may significantly affect the catchability of specimens during a tow at various depths.

Discussion

While our data from small nets suggest that cephalopods are low in abundance when viewed on a tow by tow basis, data from cephalopod predators suggest otherwise (Clarke, 1977). In these two extremes we have a nonselective "predator" and a very selective predator; both introduce opposite bias in their characterization of cephalopod abundance. Our inability to do much with statistical treatment of cephalopod data stems from low catches per unit effort by nets. Data from cephalopod predators suggest we could improve our catch rates.

The most serious problem to assess is that of avoidance. Barkley (1972) suggested that avoidance and mesh losses of larval and juvenile skipjack may be as high as 99% using a Cobb Trawl of about 670 m² mouth opening, suggesting that even a large net towed at 2-3 knots may successfully capture only 1% of the individuals in its

Table 6

Correlation coefficients for parameters monitoring net performance during an upward oblique tow with a MOC10. Number of Observations is 155.

	<i>Delta volume</i>	<i>Angle (°)</i>	<i>Speed (kts)</i>
Delta depth (m/min)	.66	-.29	.35
Delta volume (m ³ /min)		.18	.66
Angle			.64

($p < 0.022$ for all values.)

tow path. This "poor" performance is because large nets usually (if not always) have correspondingly larger mesh and, therefore, smaller individuals pass through the meshes. Poor performance may also be due to the greater distance ahead of the net at which an individual senses its approach (8.3 m for a 3-m IKMT vs. 3.3 m for a 1-m net), thereby partially offsetting the apparent advantage of large size (Barkley, 1972). The ability to offset this disadvantage is proportional to a faster towing speed which clearly has an upper, practical limit (of perhaps 5–6 knots). Data from Murphy and Clutter (1972) show little or no significant increase in catches/volume between a 3-m IKMT and a 1-m net for anchovy larvae (using the same mesh size).

Our ability to quantitatively assess the importance of cephalopod avoidance is presently nonexistent. Because cephalopods have strong similarities with fishes in terms of vision and swimming ability, fish studies should provide useful information. Barkley's (1972) results suggest avoidance was over 90% in most cases for the fish data he examined. This degree of avoidance means that an increase in population abundance of an order of magnitude could be masked in a relative sense by an increase of only 9% in the ability to avoid. Several factors associated with sampling may easily add this much variation: the effects of bioluminescence, differences in net configuration, physiological changes in the cephalopods and perhaps others.

Patchiness presents a different type of problem and is second to avoidance. It can be compensated for by taking larger volume tows. This becomes expensive, but makes the data collected more valua-

ble. Seasonal variation within most regions probably ranks lowest of the factors considered in this paper, except for highly migratory species.

Recommendations

It is obvious from our attempts to analyze cephalopod data that the low numbers we catch present problems. Two solutions are suggested: the use of larger trawls (at least 100 m² in mouth area) and longer tows in layers inhabited by cephalopods. In the future these layers may be identified by acoustical techniques. These larger trawls should have mesh sizes comparable to smaller trawls for comparative purposes and mouth shapes that can be monitored. Flowmeters should always be used to measure "effective" distances traveled at a minimum and actual volume filtered at best. Research should be done on the avoidance reaction of cephalopods (i.e., circular net mouths may be less easily avoided than rectangular mouths). It is, of course, possible that there may be almost as many reaction patterns as there are species of cephalopods.

The effects of patchiness on sampling have been well studied in zooplankton (Haury et al., 1978). In essence, the suggestions to overcome patchiness are to take long tows, filter large volumes of water per unit distance traveled and to take replicates. The first two suggestions have to be evaluated relative to the size and abundance of the organisms we are attempting to sample. If we are dealing with highly clumped organisms with average abundances of one individual per 10,000 m³, we could do some modeling to estimate patch densities and patch distributions so that simulated sampling in the model would produce results similar to observed values. We feel that this is important.

Finally, whenever samples are taken, we recommend at a minimum, monitoring of depth, flow, temperature, and net speed. A series of samples needs to be taken to assess the relationship between volume of water filtered and catch. This would best be done with a multiple series of samples at a depth horizon of known high relative abundance for the most common species, filtering volumes ranging from 20,000 to 200,000 m³ or more if time allows and with some replication. If no trends are suggested with any level of cer-

tainty, then our sampling should be drastically altered before we can reasonably expect reliable data on cephalopod distributions and abundances. Until we can convincingly put some reasonable confidence limits on our abundance estimates, we cannot really distinguish presence from absence.

Acknowledgments

We would like to express our sincere gratitude to C. Lea, Texas A&M University, and M. J. Sweeney, Smithsonian Institution, for assistance in the field and in the lab with processing the samples and with gathering and analyzing the resulting data. One of us (JHW) would like to acknowledge NSF Grant GA 31095 to J. A. McGowan for support of the EASTROPAC work and ONR Contracts N00014-75-C-0537 and N00014-80-C-0113 for support in the Cold Core Rings Program. One of us (CFER) would like to acknowledge the Fluid Research Fund, Smithsonian Institution, for support to attend the Micronekton Workshop and support of the Ocean Acre program from the U.S. Navy Underwater Systems Center through C. L. Brown (Contract N00140-73-C-6304).

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