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Variability in Abundance and Mean Length of a Marine Fish Larva (Sebastes sp.) Sampling During 24-h at a Single Station on Flemish Cap

by

J. T. Anderson

Fisheries Research Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland, Canada A1C 5X1

and

I. Webster

Department of Physics, Memorial University of Newfoundland
St. John's, Newfoundland, Canada A1B 3X7

Abstract

As a measure of variability in fish larval abundance and estimates of mean length for the Flemish Cap bank a single station was sampled every two hours over a 24 hour period. Larval redfish abundances ranged from 22.4 to 115.6 larvae/m2 (CV=45.3%) while mean length varied from 9.2 to 10.9 mm (CV=4.7%). There were significant between-station differences in larval abundance but not in mean length. A negative relationship between volume of water filtered and numbers of larvae per m2 indicated a bias in estimates of standardized larval abundances. This bias was attributed to a discontinuous distribution of redfish larvae confined to surface waters and the presence of strong subsurface tidal currents on Flemish Cap. Corrected estimates of larval redfish abundance were lower by a factor of 1.4 and densities higher by a factor of 7.2. There were no clear relationships between variations in abundance or size of redfish larvae and zooplankton abundance or species composition.

SPECIAL SESSION ON RECRUITMENT

INTRODUCTION

Plankton surveys designed to estimate the abundance of fish eggs and larvae have been carried out for decades. As part of these surveys certain assumptions concerning the spatial-temporal distributions of the data are made (Smith and Richardson 1977). The surveys themselves are usually carried out based on a grid of stations covering the area of interest. This approximates a systematic stratified sampling design in two dimensions (Cochrane 1977), assuming the initial station (i.e. grid coordinate) is random. It is further assumed that variation in egg and larval densities are homogenous within each strata and data from each survey are assumed to be synoptic within the sampling period. Finally, samples are intergrated throughout the water column to some maximum depth, with the assumption all ichthyoplankton are sampled representatively from this depth range with no day/night differences. Sampling variability has long been recognized as a source of error in plankton survey data (Winsor and Walford 1936, Winsor and Clarke 1940), yet few sampling programs based on standard grid survey designs directly measure this source of error or test the survey assumptions.

Ichthyoplankton surveys were carried out on Flemish Cap in recent years to measure abundance, distribution and growth of

redfish (Sebastes spp.) larvae (Anderson 1984). These surveys covered a large oceanic area ($4.1*10^{10}$ m2) with each station representing approximately $1.4*10^{9}$ m2 (37 km station spacing). Sampling was carried out over a 6-day period with the assumption that sampling was synoptic during this time. From each survey there are two basic data outputs: total estimated abundance for the survey area, and mean larval length. Both are derived from the 42 stations sampled during each survey.

As a measure of within-station variability in plankton abundance and mean larval length, replicate sampling was carried out over a 24-h period on Flemish Cap at a single station, immediately following a 42-station grid survey in May 1980 (Figure 1). This study was designed to measure the degree of variation in icthyoplankton abundance and mean length that could occur at the scale of a single sampling location within one day. Secondly, it was intended to relate this variation to changes in physical oceanography, invertebrate zooplankton abundance and species composition routinely sampled during our surveys and thought to be relevant factors that might relate to measures of larval abundance and mean length.

The paper is presented in two parts. The first reports observations from the sampling program. From these data we observed a negative relationship between standardized larval abundances and volume of water filtered by the bongo sampler, which was contrary to expectations. In the second part we examine the hypothesis that a surface water distribution of redfish larvae and tidally driven variations in subsurface currents (i.e. > 30-50 m depth) were responsible for this observation. The degree to which such conditions can bias standardized estimates of ichthyoplankton abundance is addressed.

MATERIALS AND METHODS

Following a standard ichthyoplankton survey on Flemish Cap, a single station (47°N 46°W) was sampled every two hours over a 24-h period during 26-27 May 1980. The sampling location was chosen to be >200 m water depth in an area of presumed mixed water between Flemish Cap and the Labrador Current. Abundance measured during a routine grid survey on Flemish Cap immediately preceeding this study indicated this was an area of average larval redfish abundance at this time (Anderson 1984). At each two-hour sampling interval plankton and physical oceanographic samples were collected. Plankton data were collected using 0.61 m bongo nets fitted with 0.333 mm mesh cylinder-cone nets, General Oceanics flow meters and a pressure sensor transmitting depth information in real time. The nets were towed at 1.2 m/s (2.5 knots) obliquely from maximum depths of 200 m, with payout and retrieval rates of 0.83 and 0.33 m/s, respectively. Each sampling period began with a CTD cast using a Guildline Mark IV probe fitted to a 60 Rosette sampler.

To obtain a measure of the approximate depth distribution of redfish larvae a series of tows were carried out at 47°20'N 46°W, 37 km north of this location, during late June 1981. In this case a tow was first done to 200 m depth following the procedures already outlined. Following this tow the ship returned to station and tows to 100 m and 50 m were done in succession along the same direction as the initial tow done to 200 m. Sampling started at 0747 GMT and repeated every two hours for a total of five sets of observations, starting in daylight and ending before sunset.

Ichthyoplankton samples were processed as described by Anderson (1984). Abundance was calculated as number of larvae per square meter:

$$N = CD/\pi r^2 L$$

where C is the number of larvae collected, D is the maximum sampled depth (m), L is the length of the tow path (m), and r is the radius of the net opening (m). Volumes filtered are expressed here as an average of left and right bongo nets.

Zooplankton species abundances were determined from one side only. Subsampling of 500-1000 individuals was done using a Motoda splitter from which individuals were speciated, with staging of the most abundant three species in any one sample. Where one species dominated, counting and staging of other species was done at a lower split such that 30-40 of the next two most abundant species were counted. Plankton displacement volumes were determined, after removing non-gelatinous invertebrates > 2.0 cc, by allowing the sample to drain through a piece of 0.256 mm mesh netting until no more than one drop of preservative per minute remained. The plankton sample was then re-emersed in a known volume of water and the displacement measured.

Temperature, salinity and density data were collected using the CTD system. Salinity calibration was done on water samples from a known depth using a Guildline Autosal. Salinity (‰) was calculated from the conductivity ratio using Bennett's (1976) equation and density was calculated as sigma-t. Calculation of the mixed layer depth (MLD) was based on the 26.5 sigma-t isocline (Figure 3c), demarcating the top of the pycnocline. Standard meteorological observations were also made at each sampling time.

Community structure was analyzed using Detrended Correspondence Analysis (DECORANA) run on the CEP-40 program (Hill 1979). Analyses of plankton data were run using statistical packages from the Statistical Analysis System (SAS 1982) and Hewlett Packard's VisiCalc PLUS program.

RESULTS AND DISCUSSION

Part 1: General Observations

Physical Oceanography

The sampling period began at 1435 GMT on 26 May 1980 and continued for a 24-h period. Dusk occurred between stations 4 and 5 and dawn between stations 9 and 10. During the initial stages of the sampling period winds peaked at 8.5-10.5 m/s (Beaufort Scale 5), remained high until station 7 and then decreased steadily to zero by station 13. Water temperatures in the top 30 m changed very little during the sampling period (Figure 2a). Below the mixed layer depth there was a cool band of water (<3°C) that fluctuated around the 100 m depth, approximately in phase with fluctuations of the mixed layer depth. Salinities indicated surface water intrusions of more saline water (>33.6‰) at stations 5 and 13 and to a smaller extent at station 10 (Figure 2b). The most notable changes in salinities occurred between the bottom of the mixed layer depth and 150 m at stations 10 and 12, where there was a general increase and decrease in salinity, respectively.

The mixed layer depth (MLD) fluctuated from 33 to 51 m and indicated two cycles with a 12 hour periodicity (Figure 2c, 3a). While these oscillations were mostly regular, it deviated from this pattern twice, once at station 6 and again at station 11. In both cases the MLD was less than expected. It appears tidally generated fluctuations in the mixed layer depth occurred as minima at stations 3 and 9 (12 hours out of phase) and a maximum at station 12.

Ichthyoplankton Abundance

Redfish larvae (Sebastes spp.) were the dominant ichthyoplankton sampled during the 24-h period, on average comprising 97.5% of all fish eggs and larvae sampled. During this period abundance of redfish larvae varied by a factor of 5.2, ranging from 22.4 to 115.6 larvae/m^2, with a mean abundance of 57.0 larvae/m2 (Table 1). During the 24-h period there was a slight increase in larval abundance ($r=0.39$, $n=13$) but this was not

significant. Abundance estimates showed a pattern of 4-6 hour cyclic fluctuations up to station 9, after which estimates for stations 10-12 varied widely (Figure 3b). Two-way analysis of variance on log-transformed data indicated there was a significant difference between station abundances ($P<0.0001$) but not between nets. The degrees of freedom were 12 and 1, respectively, with a F-statistic of 11.6 for station differences. Duncan's multiple range test indicated 5 station groupings, however, no distinct set of contiguous stations formed a single group. Analysis of variance for differences on larvae caught, not standardized for volume filtered, gave similar results.

Correlation analysis of larval redfish abundance with a large array of biological and physical variables indicated an unexpected relationship with volume of water filtered. Abundances of larvae/m2 were negatively correlated with volume filtered ($P<0.05$, $R2=0.382$, Figure 4b) and tow time ($P<0.05$, $R2=0.381$). During the 24-h sampling period volume filtered ranged from 425 to 830 m3 and tow times from 19 to 41 minutes (Table 1). As expected, volume filtered increased significantly in relation to tow time ($P<0.005$, $R2=0.65$). Windmilling of the flow meters as the nets entered and left the water was not observed to occur, nor was there any correlation of volume filtered with wind speed measured at the time of sampling. The only other variable having a significant correlation with tow time and volume filtered was the mixed layer depth ($P<0.1$, $R2=0.295$; Figure 5). This indicates an expansion of the mixed layer (from 30-50 m) was related to increased tow times down to a standard depth of 200 m, and consequently more water being filtered.

The negative relationship of larval redfish abundance to volume of water filtered and tow time was not expected. Normally an increased in volume filtered would be expected to increase the number of larvae caught. However, there was no relationship between the number of larvae caught and volume filtered (Figure 5a). It is apparent, therefore, that the standardized values were largely an artifact of more water being filtered without any increases in larvae captured. Such a situation would occur on Flemish Cap, for example, if redfish larvae were found only in surface waters and there were subsurface currents which varied during sampling.

Ichthyoplankton Vertical Distribution

Results from the vertical sampling series carried out at this location in 1981 indicated larvae were concentrated in the upper 50 m of the water column. Each set of observations is from a series of intergrated tows to one of three depths, therefore, interpretation requires some caution due to unknown variability between tows within each series. Larvae were always caught in the 0-50 m tows indicating larvae were at least in this layer at all times (Table 2). Comparison of sample means indicated no significant differences between depths for number of larvae caught. However, densities (larvae/m3) were significantly higher in the 0-50 m samples than either of the deeper tows ($P<0.05$). Therefore, towing to deeper depths did not significantly increase the number of larvae caught but did have a significant effect on estimates of their densities. Obviously larvae were more abundant in surface waters.

These analyses were done with no correction for larvae captured at shallower depths for the 0-100 m and 0-200 m tows within each station. If the number of larvae caught are corrected in this manner then 4 of 5 samples in the 50-100 m depth range and 2 of 5 in the 100-200 m depth range were computationally zero (Table 2). Only at stations 14, 16 and 17 were larvae 'caught' in the 100-200 m depth range and only at station 16 in the 50-100 m depth range. Comparison of means based on these corrected data has the effect of raising the significance levels but does not change the results.

In spite of the statistical results larvae were abundantly caught in the 0-200 m tows at stations 16 and 17 and were present

at station 14. This indicates larvae may in fact occur abundantly in the 100-200 m depth range some of the time, in addition to larvae occurring at shallower depths. However, it is not clear why they did not occur in the 100-200 m depth range at stations 14 and 17. On the other hand, variability between tows due to patchiness has not been accounted for. It may have been high enough that more larvae happened to occur in surface waters during the 0-200 m tow during these two stations than occurred in tows to the shallower depths. Unfortunately, these alternate explanations cannot be resolved based on these data.

These results indicate redfish larvae were more abundant in the 0-50 m depth range 95% of the time. Given that the MLD ranged to 50 m depth it is reasonable to assume that larvae were in the surface mixed layer. In simultaneous tows done at the surface and at 25-30 m depth Postolaky (1978) found redfish larvae were 4.3 and 2.1 times more abundant at the deeper depth during May and June, respectively. In July densities at each depth were approximately equal. These observations demonstrate larvae were not distributed throughout surface waters but were concentrated near the pycnocline.

Ichthyoplankton Mean Length

Mean length of larval redfish ranged form 9.2 to 10.9 mm standard length during the 24-h sampling period, averaging 9.9 mm (Table 1; Figure 2c). Two-way analysis of variance indicated no significant differences between stations or nets. Mean larval length varied irregularly during the sampling period (Figure 3b) and did not meaningfully correlate to variations in other measured variables. There were no significant relationships between larval length and abundance, nor with volume filtered or mixed layer depth.

The 95% CI of the mean larval length was 0.3 mm. Given that redfish were growing at 0.15-0.16 mm/d at this time (Anderson 1984, Penney and Evans 1985) then this length difference would be equivalent to about 2 days growth. This is well within the 6-day period assumed for sampling synopticity. However, both the range and average size measured during the 24-h sampling period were larger than the 8.5 mm larval length sampled at this location during the grid survey two days earlier. Comparison of these observations indicates an increase in mean larval length of 1.4 mm at this location during these two days. Such an increase would represent a growth rate of 0.7 mm/d, which is substantially higher than average growth estimates of 0.15 to 0.16 mm/d for redfish larvae during this period (ibid.). It would appear, then, that the larger sizes measured during the 24-h study represented larger larvae advected into this area during a relatively short time interval.

Invertebrate Zooplankton:

Zooplankton abundance fluctuated by a factor of 3.8, ranging from 1.7×10^4 to 6.3×10^4 plankton/m2 (Table 1, Figure 3d). This falls within the range of 2.6-5.1 reported by Wiebe (1970) and 2-7 by Sameoto (1975, 1978). Abundances tended to increase with time but, as with larval abundance, this was not significant. Neither were there day/night differences in zooplankton abundance. There was a positive relationship between the abundance of larval redfish and zooplankton but this was not significant, accounting for only 14% of explained variation in the data. There was no apparent relationship with mean larval length, nor with volume filtered and mixed layer depth. In summary, total zooplankton abundance appeared to vary independent of any other measured parameter.

Detrended correspondence analysis (DCA) explained 58.9% and 24.4% of the zooplankton species variation along Axes 1 and 2, respectively. Explained variation was calculated as a percent of the eigenvalue total for the first four axes. The gradient length along axis 1 was 1.16 s.d., or about half of a community half-change (Gauch 1982). This analysis indicated a major group

of stations (Figure 6) which were numerically dominated by Calanus finmarchicus, C. hyperboreus and to a lesser extent by the cladocerans Conchoecia obtusata and C. elegans, and the euphausiid Thysanoessa longicaudata (Table 3). Apart from this major group there were five stations which stood apart: stations 5 and 10, stations 8 and 11, and station 12 by itself. Stations 5, 10, 8 and 11 differed from the main group due to an increased abundance of the larvacean Oikopleura sp. and the cyclopoid copepod Oithona sp. Station 12 differed from all other stations sampled due to the numerical dominance of Oithona sp., the only time it was the most abundant species during the 24-h sampling period, and the complete absence of Oikopleura.

There was no overall pattern relating species compositional changes to fluctuations in water masses as measured by T-S data. All of the coincidental changes observed occurred in subsurface waters $\geq$ 50 m depth. The most notable observation was for station 12 where salinity decreased at all depths $\geq$ 50 m and temperatures increased at 50 and 100 m. These values represent maximum changes in salinity of 0.18‰ and temperatures of 1.8°C at 50 m, and maximum changes in salinity of 0.12‰ and temperature of 0.5°C at greater depths. Station 10, lying at the other extreme of axis 1 for species composition (Figure 6), had an increase in salinity at 75 m and an increase in both temperature and salinity at 100 m but no apparent change at 50 m. Station 5, while similar to species composition at station 10, was more similar in T-S characeristics of station 12 at 50 and 100 m but not at 75 m.

Part 2: Sampling Biases

Tidal Currents

Considerable variations in tow times and volumes filtered were experienced during this study, in spite of the fact each bongo tow was done using the same cable payout rates, ship towing speeds and maximum excursion depths. The absence of any relationship between number of redfish larvae caught versus volume filtered, and the surface distribution of these larvae suggests the variation in volumes filtered was due to variable subsurface currents. In model simulations of bongo towing performance it was noted that the presence of subsurface currents can substantially alter tow times (Webster and Anderson 1986). This model is applied here to examine the variability of observed tow times. The model assumes that the current regime in the upper ocean can be modelled as a two-layer system. Within each layer the current velocity is taken to be independent of depth. The ship's towing speed is assumed to be measured relative to the upper layer. The lower layer is allowed to flow at some speed either in the direction of the tow or against it.

In applying the model the division between the upper and lower layers was taken to be the average mixed layer depth (MLD) which was 40 m. The MLD was observed to vary between 33 and 51 m, but varying the upper layer thickness over this range produced little effect in the simulation results. For the simulations the towing speed was taken to be 1.2 m/s and the cable payout rate to be 0.83 m/s. Since there was some uncertainty in the exact cable retrieval rate, simulation results are presented for retrieval rates of 0.25 and 0.33 m/s. Each simulation curve was obtained by allowing the current in the lower layer (v) to vary. Positive v means the current in the lower layer is moving against the direction of tow.

Tow times versus volumes filtered for the actual tows compared well with those predicted by simulation (Figure 7). The simulations demonstrate the effect of increasing v is to increase both the tow times and volumes filtered, as expected. Overall, the actual tow times also show an increase with volumes filtered. In fact, with the exception of two tows (1 and 5) the actual data fell close to one or the other of the simulation curves. To account for the maximum values of volumes filtered it is necessary to postulate currents up to 0.3 m/s in magnitude in the lower layer. This assumes the variation is due entirely to

currents and ignores any variation in ship's speed, which is unknown. The data for tows 1 and 5 are considerably above the simulation curves. To model their behaviours it is necessary to postulate a cable retrieval rate as low as 0.15 m/s, which is substantially less than the retrieval rates necessary to simulate the other eleven tows.

We can ask whether a 0.3 m/s differential between the upper and lower layers is reasonable. The presence of strong internal tides have been recorded on Flemish Cap (Hill et al. 1974, Ross 1980). The internal tide would manifest itself by a heaving of the pycnocline and by velocities in opposite directions above and below the pycnocline (LeBlond and Mysak 1978). Over the sampling period the pycnocline was observed to oscillate in depth suggesting the presence of an internal tide. It is straitforward to show, provided the depth of the lower layer is much greater than that of the upper layer, that the amplitude of the velocity differential between the layers is given by:

$$V = 0.5\sqrt{\frac{g'}{h}}\Delta z$$

where g' is the reduced gravitational acceleration related to the difference in water density above and below the pycnocline, h is the thickness of the upper layer, and Δz is the vertical range of the pycnocline excursion (taken to be the MLD excursion). For g' = 0.01 m/s^2, h = 40 m, and Δz = 18 m, determined from observations, V is calculated as 0.14 m/s.

Results from a current meter mooring placed near our study location in April 1972 demonstrated a clear diurnal periodicity in the tidal stream and velocities (Hill et al. 1975). These velocities formed distinct sinusoidal waves, especially at the near-bottom current meter position. Peak velocities of 0.46 m/s were measured at the near-bottom meter and 0.34 m/s at the near-surface meter, although the velocities usually did not exceed 0.3 and 0.2 m/s, respectively. Velocities of this magnitude exceed those estimated in this study as being necessary to produce the observed extremes in volume filtered. This suggests that sub-surface tidal velocities in this area of Flemish Cap are great enough to produce the variations in tow times and volumes filtered predicted by this study.

The relative velocity between layers in the direction of tow will clearly depend on the phase of the internal tide and the ship's heading. If it is assumed that the ship's speed with respect to the surface layer remains the same for all tows, then the towing characteristics of the net within the surface layer would remain the same. The volume sampled within the surface layer would depend only on the MLD and would be quite independent of the relative movement between the surface and lower layers. If our hypothesis is correct that larvae occur only in the surface layer and the variation in tow times is due to relative layer movements, then standardizing larval densties using the total sampling volumes would bias results since total volumes vary due to conditions in the lower layer.

Correcting Abundance Estimates

The sampling bias outlined here indicates the standard abundance estimates for redfish larvae were too low. Assuming larvae were distributed only in the surface mixed layer then a corrected abundance estimate could be made as a funtion of the MLD. Assuming a constant ship's speed of 1.2 m/s and payout and retrieval rates of 0.83 and 0.33 m/s, respectively, sample volumes for the MLD were estimated based on the simulation model of Webster and Anderson (1986) and corrected abundance estimates made (Table 1). Corrected estimates of abundance averaged 81.8 larvae/m2 which was higher than the original estimates by a factor of 1.4 but was not significantly different. This correction also had the effect of decreasing the CV from 45.3% to 29.2%, which is expected as the corrected estimates of abundance would not be directly affected by sampling bias due to subsurface currents and whould be, therefore, mostly a function of

patchiness. Corrected estimates of density were higher by a factor of 7.2.

Comparison of data collected in 1980 at 47N 46W and the vertical sampling series in 1981 at 4720N 46W is of interest. Data collected during June 1981 was one month later than in 1980 and abundances were an order of magnitude lower. Mean length, however, was similar (10.5 and 9.9 mm, respectively) due in part to lower growth rates in 1981 (Anderson 1984, Penney and Evans 1985). In 1981 the same sampling gear and procedures were used as in 1980, however, volumes filtered for the 0-200 m tows only ranged from 365 to 545 m3. The average volume filtered was 442 m3 which was significantly less than during 1980 ($P<0.05$). The bongo simulation model of Webster and Anderson (1986) indicates an ideal volume filtered with no current effects is 480 m3, assuming a ship's speed of 1.2 m/s and payout and retrieval rates of 0.83 and 0.33 m/s, respectively. This suggest samples collected in 1981 were not subjected to the same conditions as in 1980. Either layer differences in tidal currents did not occur (i.e. there were no subsurface currents) or the tow direction was such that any effects of subsurface currents were minimized by towing in the same direction.

Even with larval distribution limited to surface waters it is only when tow volumes are very high that a significant bias occurs in estimating larval abundance. Densities, of course, will be substantially underestimated. Assuming the average volume filtered in 1981 of 442 m3 represented non-biased conditions, then at what increasing volume of water filtered are abundance estimates significantly underestimated? Standardizing abundance estimates of larvae caught in 1980, assuming a constant volume of 442 m3, compared to abundances standardized using increasing values of volume filtered indicated that volumes $\geq$ 605 m3 result in significantly lower abundance estimates of larvae/m2 ($P<0.05$, $n=13$). The volume filtered which significantly biases results will vary based on what, in fact, represents a 'true' volume filtered. For example, the simulation indicates volume filtered in the absence of any currents would be 480 m3, in which case volumes filtered $\geq$ 655 m3 would result in significantly low estimates of abundance.

Direction of Tow During Sampling

The effect of varying tidal currents on tow time and volume filtered will vary with orientation of the tow paths to the current (Schnack 1974). The tidal data collected by Hill et al. (1975) demonstrated the tidal streams rotated through 360° in a 24 hour period most of the time. Our sampling procedure was to deploy and retrieve the bongo sampler into the wind and, therefore, we have a measure of the tow direction. In this way sampling for the first station was southeast at 130° and progressed counterclockwise as sampling proceeded, with the final samples being taken due west at 270°. Unfortunately there is no easy method to predict the direction of baroclinic tidal flow. Any correspondence of our tow direction with changes in subsurface tidal currents must be viewed as fortuitous.

Conclusions

There are three sources of error in plankton sampling, those due to net avoidance and extrusion, and that due to the patchy distribution of plankton (Wiebe and Holland 1968). We assume there was little error associated with net avoidance or extrusion of the redfish larvae. There were no day/night differences indicative of avoidance in the samples from this study, nor from the grid area surveyed immediately prior to this study. Larvae averaging 10 mm standard length are readily retained by 0.333 mm mesh nets. What we sampled was variation due to the patchy distribution of fish larvae plus that due to changing currents.

The high variation in plankton abundances sampled during this study demonstrated the integrated plankton tows were variable on time scales much less than 24 hours. In fact, data from this study indicated extreme differences in values from

samples taken only 2 hours apart. The fact that larval abundances were significantly different demonstrated the survey assumption of homogeneity at a particular station, representative of a grid area, is not always valid. This was observed on a time scale of one day, let alone the 6-day period of assumed sampling synopticiy for this area. While there was a measured bias in standardized larval abundances, the fact total larvae caught were also significantly different within the 24-h period indicates this variation was not strictly a function of sampling bias associated with variations in volume filtered. Brought into question is what constitutes a representative estimate of abundance at each sampling location. This will have a profound effect on fish egg and larval surveys which attempt to estimate comparatively small differences in survival that subsequently result in large differences in recruitment.

Variation in plankton abundance estimates are typically high. Coefficients of variation for ichthyoplankton range from 15-70%, as measured in a number of studies (Conte et al. 1979, Houde and Lovdal 1985, Ware and Lambert 1985) and can exceed 100% (Fortier and Leggett 1982). Such fluctuations in abundance are attributed to horizontal transport of plankton patches into and out of a sampling area (station), and often related to tidal oscillations (Wiebe 1970, Sameoto 1975, 1978, Lee and McAlice 1979, Fortier and Leggett 1982). While marked changes in plankton abundances, mean larval length and zooplankton community changes were observed in this study, there was no clear indication from this short time series of simple back and forth tidally generated oscillations.

Our observations suggest that changes were depth-specific. This was certainly the case in terms of T-S data indicating not only were surface changes completely uncoupled from those below, but that changes within the subsurface layer were also very depth-specific. When interpreting data from an integrated plankton tow to 200 m depth this would help to explain why changes in redfish larval abundances and mean length, living in surface waters, were not easily related to zooplankton abundance and species changes that appeared to be more dependent on subsurface oceanographic events.

The sampling bias measured in this study was strictly a function of the surface distribution of redfish larvae. Had they been distributed throughout the water column this bias in standardizing abundance estimates would not occur. Knowing the depth distribution of a species and their prey, and how this changes with development, is obviously critical to accurately estimate abundance and in understanding growth and survival dynamics.

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Table 1. Summary of data collected during the 24-h station, May 1980. Standard estimates of abundance and density are based on volumes sampled to 200 m, and corrected estimates based on volumes of simulated tows to the bottom of the mixed layer depth (MLD). Larvae caught are expressed as an average of the left and right nets.

Station	Larvae Caught	Standard Estimates Abundance (#/m2)	Density (#/10m3)	Corrected Estimates Abundance (#/m2)	Density (#/10m3)	Larval Length (mm)	Invertebrate Zooplankton (#/m2)	Tow Time for 200m (min)	Volume for 200m (m3)	Volume for MLD (m3)
1	88.0	22.4	1.11	40.5	9.89	9.2	30929	41	790	89
2	111.5	33.7	1.68	51.8	14.67	9.8	33090	28	664	76
3	139.5	66.9	3.35	63.9	19.38	9.9	16743	19	416	72
4	245.0	70.4	3.54	111.8	27.53	9.5	37112	30	692	89
5	120.0	39.2	1.96	55.8	11.76	10.9	52775	38	613	102
6	176.0	42.8	2.12	81.7	19.78	10.1	22159	35	831	89
7	236.5	57.2	2.86	108.2	24.64	9.7	34826	38	828	96
8	216.0	81.9	4.08	99.5	23.74	9.8	62823	28	529	91
9	216.0	75.0	3.75	99.9	30.00	10.5	44721	28	576	72
10	86.5	24.6	1.23	39.5	9.94	10.1	45233	35	706	87
11	285.5	115.6	5.79	131.4	36.60	9.9	60320	26	493	78
12	201.5	51.2	2.65	92.4	18.15	9.3	48004	32	759	111
13	187.0	59.9	2.99	86.2	22.00	10.1	45254	28	625	85
Mean	177.6	57.0	2.86	81.7	20.62	9.9	41076	31.2	655.5	87.5
sd	63.7	25.8	1.30	29.2	8.01	0.46	13686	6.0	129.8	11.4
CV (%)	35.9	45.3	45.4	35.8	38.9	4.7	33.3	19.3	19.8	3.1
Range	3.3	5.2	5.2	3.3	3.7	1.2	3.8	2.2	2.0	1.5

Table 2. Summary of data collected during the vertical sampling program, June 1981.

Observation	Larvae Caught 0-50m	0-100m	0-200m	Larval Density 0-50m	0-100m	0-200m
1	24	15	31	1.22	0.41	0.38
2	33	30	24	1.34	0.61	0.32
3	11	20	59	0.51	0.44	0.58
4	13	11	55	0.81	0.29	0.50
5	29	29	13	1.29	0.62	0.18
Mean	22.00	20.40	36.40	1.04	0.47	0.39
sd	9.70	7.76	19.92	0.36	0.14	0.16
CV (%)	44.07	38.07	54.72	34.89	29.79	40.25
Range	3.0	2.73	4.54	2.63	2.14	3.25

Table 3. Percent abundance of dominant zooplankton species/groups for a 24-h sampling period on Flemish Cap (47°N, 46°W).

Species/Group	Station 1	2	3	4	5	6	7	8	9	10	11	12	13
Calanus finmarchicus	36.9	30.5	41.9	51.2	42.1	45.2	42.3	32.2	41.7	28.7	30.8	26.9	40.2
C. hyperboreus	12.2	10.4	9.7	7.1	2.7	5.3	7.4	4.8	8.5	4.2	4.6	4.7	4.0
Conchoecia spp.*	9.6	8.8	10.1	7.7	4.5	9.7	9.0	2.4	4.8	5.8	5.4	5.2	5.3
Thysanoessa longicaudata	5.1	3.8	6.9	5.3	4.0	5.1	5.1	6.4	4.6	2.9	4.3	2.8	6.4
Oithona spp.**	2.4	16.8	1.3	9.2	12.3	13.4	5.3	29.7	23.3	12.5	27.7	40.8	24.4
Oikopleura sp.***	3.9	6.7	0.6	0.2	13.7	0.4	1.0	6.9	0.6	22.0	8.8	0.0	0.0

*Includes C. obtusata and C. elegans.

**Includes Oithena spp., O. spinirostris and O. similis.

***Includes Oikopleura sp. and O. labradoriensis.

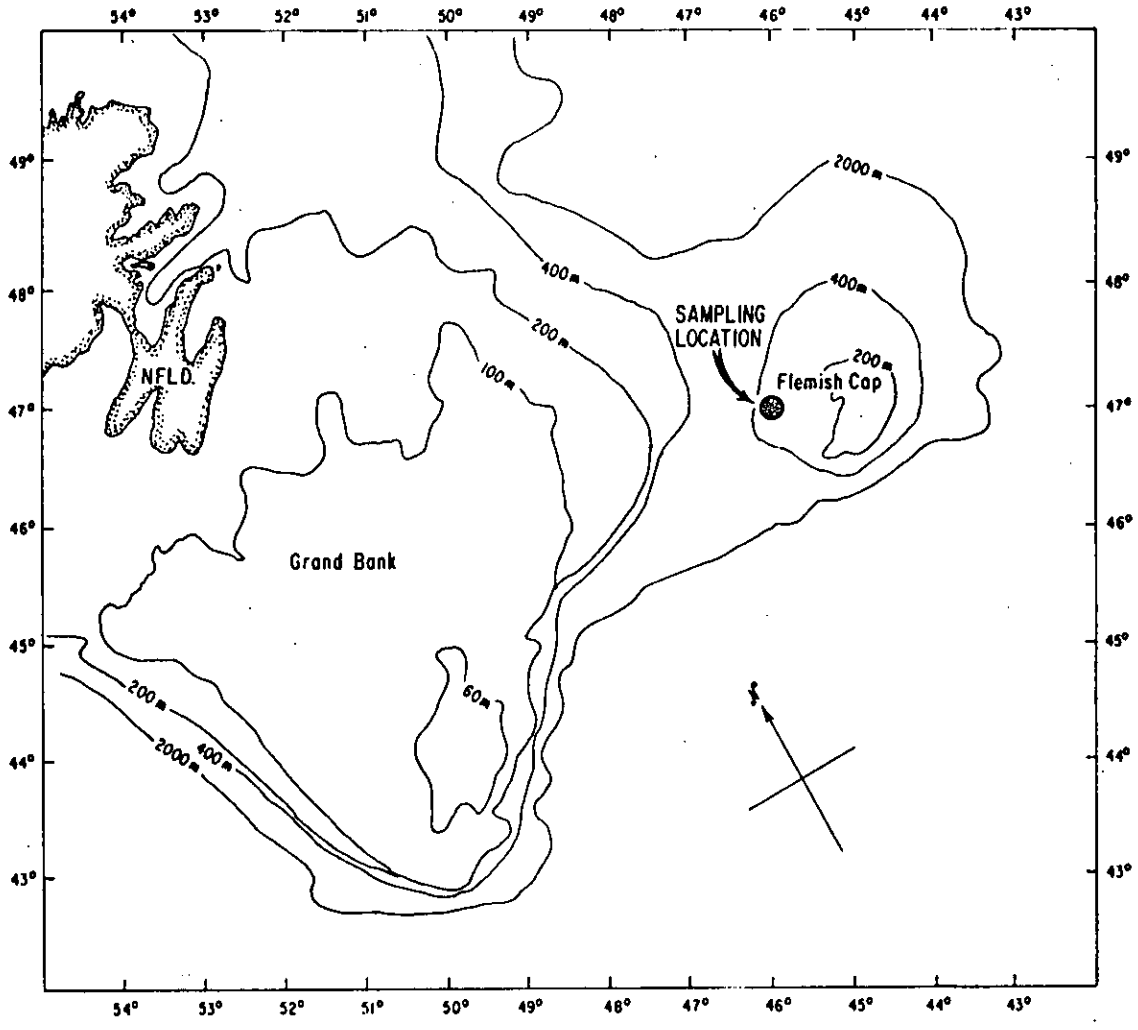

Figure 1: Flemish Cap bank east of the Grand Bank of Newfoundland showing the study location (47N, 46W).

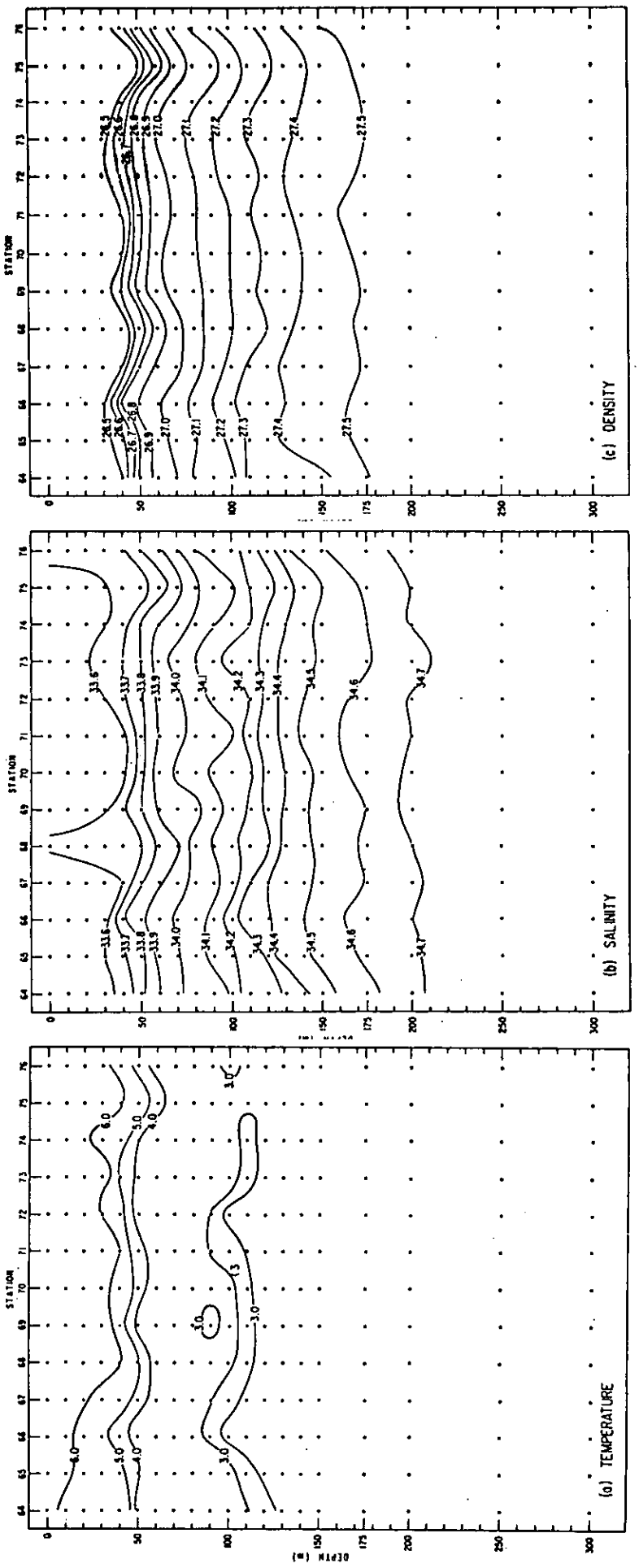

Figure 2: Temperature (C), salinity ( ) and density ( ) data collected during the 24-h sampling period.

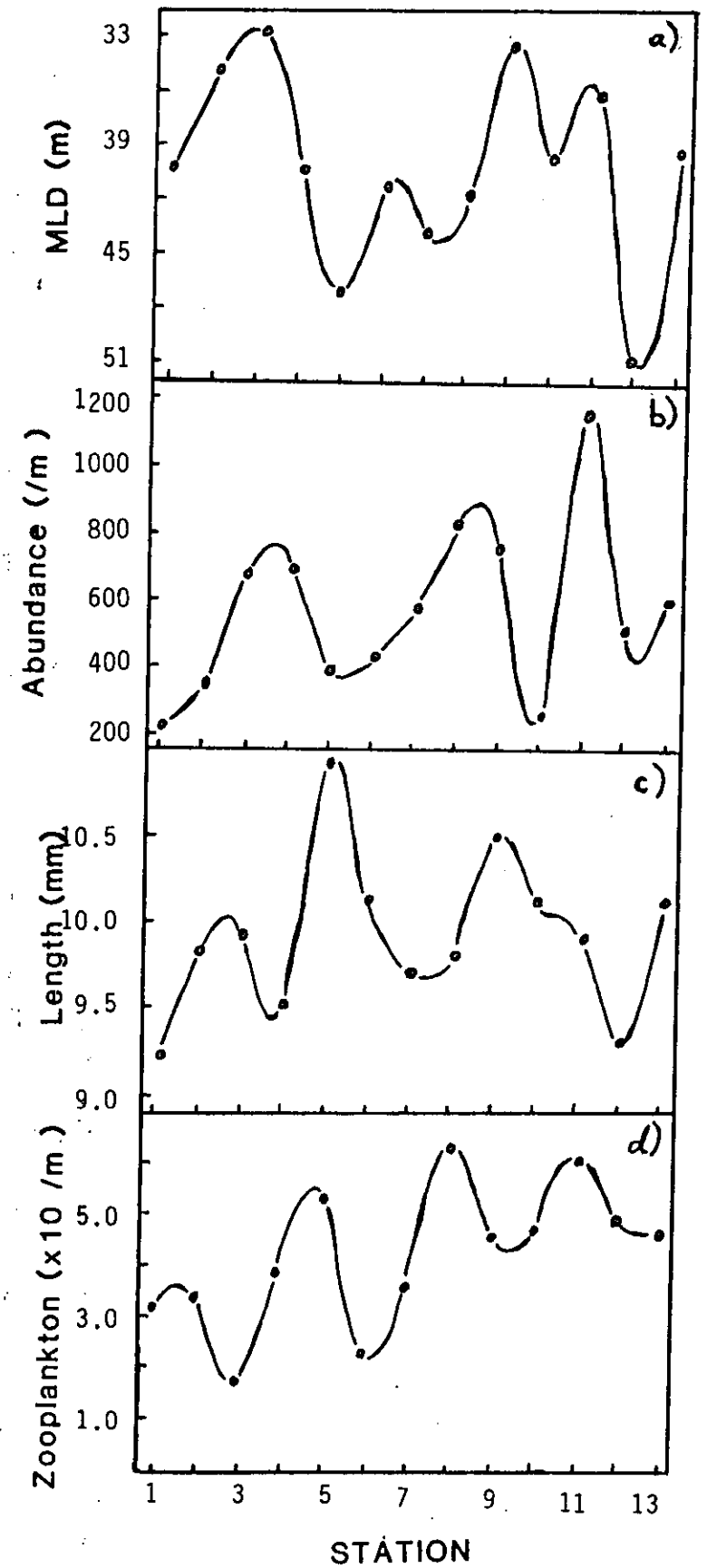

Figure 3: Fluctuations during the 24-h sampling period in: a) mixed layer depth (m), b) redfish (Sebastes spp.) abundance (larvae/m2), c) mean larval length (mm standard length), d) invertebrate zooplankton abundance (numbers/m2).

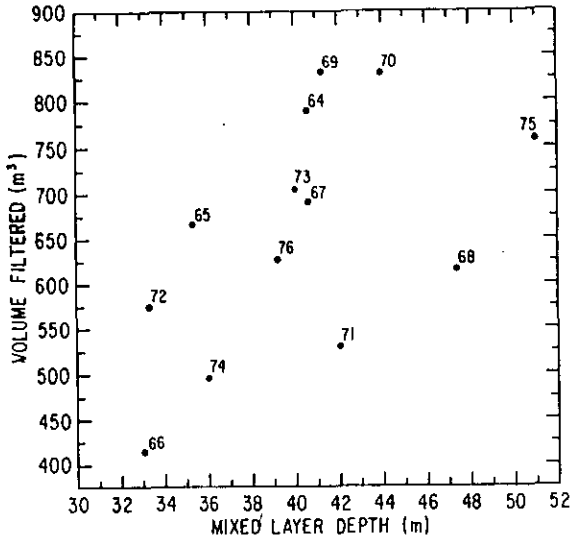

Figure 4: Scatter plot of volume of water filtered per bongo net (m3) versus the depth of the mixed surface layer (m).

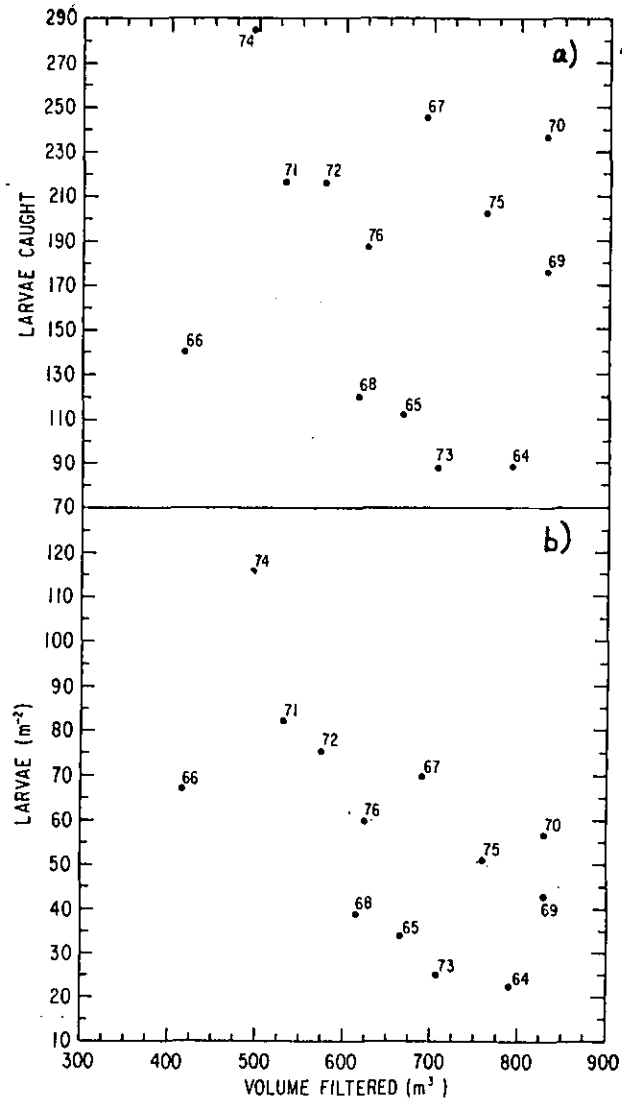

Figure 5: Relationships between a) total larvae caught by the bongo sampler at each station and b) standardized estimates of abundance (larvae/m2) at each station, versus the volume of water filtered (m3).

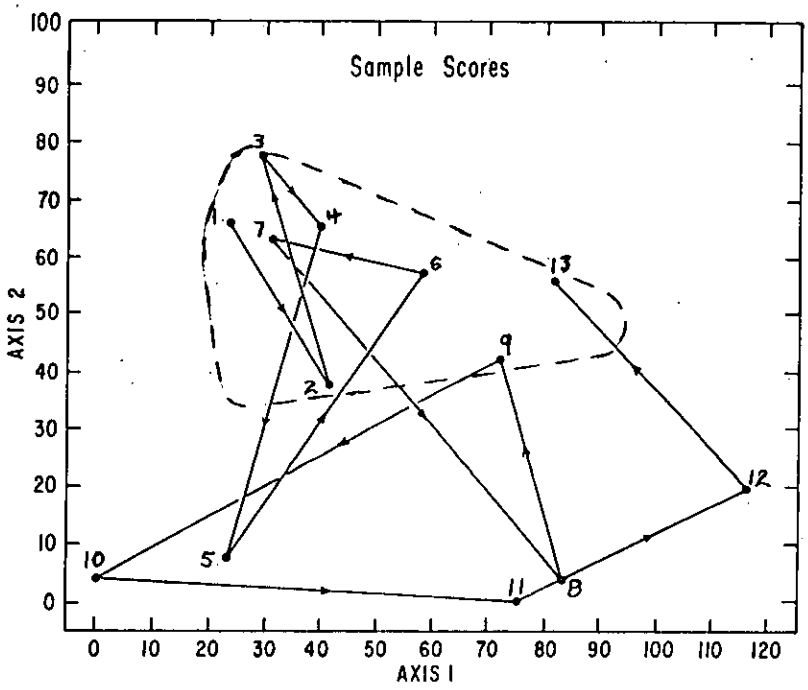

Figure 6: Invertebrate zooplankton sample scores for Axes 1 and 2 from the detrended correspondence analysis.

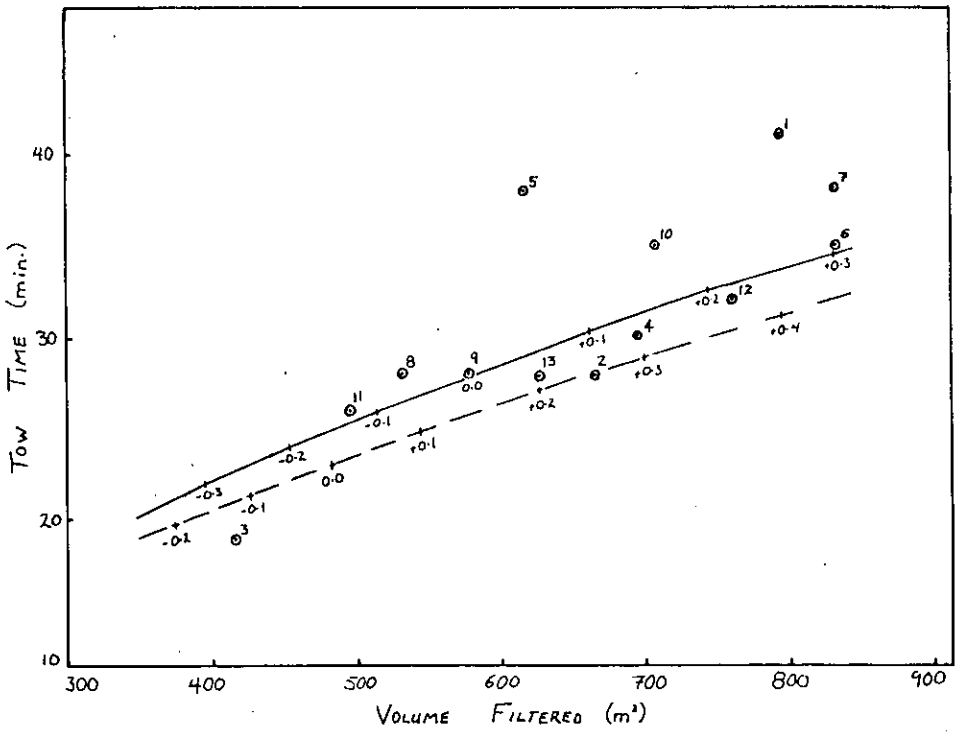

Figure 7: Comparison of tow time versus volume filtered for actual tow data and for simulated data. The tow data is indicated for each sampling station. The simulations were done using a ship's speed of 1.2 m/s, a payout rate of 0.83 m/s and retrieval rates of 0.25 m/s ( ) and 0.33 m/s ( ). Relative layer velocity set for each simulation is marked on the respective lines.