COMPARISON OF CROSS-SHELF TRENDS IN ACOUSTIC DOPPLER CURRENT PROFILER AMPLITUDE AND ZOOPLANKTON DISPLACEMENT VOLUME IN SOUTHERN CALIFORNIA

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ABSTRACT

Simultaneous insonification and net sampling of the plankton in a discrete volume of water is the preferred field method for calibrating acoustic devices. The problem with this technique for the acoustic Doppler current profiler (ADCP) is that the volume insonified is too large for any plankton net. This causes error because of small-scale patchiness. The ADCP may be calibrated over large spatial scales by comparing the cross-shelf gradient in zooplankton volume to the cross-shelf gradient in the ADCP amplitude. We accomplished this by comparing ADCP amplitude data from transects off southern California in spring and summer during 1991 with zooplankton volumes from oblique net tows taken in the same seasons and area during 1991. The cross-shelf trends are similar, showing that measuring zooplankton with ADCP is possible. Although the ADCP may not be accurate for estimating the integrated zooplankton volume, it does describe the vertical distribution of the zooplankton and the scale and intensity of mesoscale patchiness as well as the amount of zooplankton, furnishing information not available from integrated net tows.

RESUMEN

El método preferido para calibrar aparatos acústicos en el campo es obtener simultáneamente muestras de plancton con redes y la respuesta sónica en un volumen aislado de agua. Para el Medidor de Perfiles Acústicos de Corrientes Doppler (MPACD), esta técnica tiene la desventaja de que el volumen de donde se obtiene la respuesta sónica es demasiado grande para las redes. Esto causa error debido as los patrones de agregación a pequeña escala. El MPACD podría calibrarse a escalas mayores comparando los gradientes perpendiculares a la línea de costa de volumen de zooplancton con los de la amplitud del MPACD. Comparamos datos de la amplitud del MPACD en transectos efectuados frente a las costas de California en primavera y verano de 1991 con datos de volumen de zooplancton colectado por arrastres oblicuos en las mismas estaciones y en la misma zona, en 1991. Las tendencias de los datos en dirección perpendicular a la costa son similares, lo que mostró que es factible medir el zooplancton con el MPACD. A pesar de que el MPACD no estima con exactitud el volumen integrado de zooplancton, sí describe la distribución vertical del zooplancton, la escala e intensidad de los patrones de agregación en la meso-escala, y la cantidad de zooplancton; esta información no puede obtenerse a partir de arrastres integrales de la columna de agua hechos con redes.

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INTRODUCTION

The 50-year zooplankton time series of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) has produced many advances in our knowledge of zooplankton distribution, ecology, and life history (e.g., Roesler and Chelton 1987 and references therein). One use of this large base of knowledge is to calibrate new methods of studying zooplankton distribution and ecology. One of the newest methods is the acoustic Doppler current profiler (ADCP).

The ADCP improves on traditional methods of studying zooplankton pattern because in addition to detecting patches, it also relates them to currents in the sea. Standard net tows show only the intensity of patchiness; they do not show the scale of patches or their location. Echo sounders can find the patches and define their vertical distribution, but they do not measure the currents along with the zooplankton. The ADCP does both (Smith et al. 1989).

Previous studies have calibrated the ADCP by comparing net tows directly to the backscattering intensity examined by the ADCP. Flagg and Smith (1989a, b) compared the results of moored and ship-mounted ADCPs against the results of MOCNESS tows and found very high correlations, but they took few net samples. They suggested several techniques for increasing the accuracy of the zooplankton index: calibrating the transducers' signal in a temperature bath, changing the geometric average to an arithmetic average, and measuring the initial signal intensity along with the returned sound (Flagg and Smith 1989a). Plueddemann and Pinkel (1989) used an acoustic Doppler system, similar to an ADCP, to describe and measure the speed of zooplankton vertical migration. Heywood (et al. 1991) used an ADCP without Flagg and Smith's corrections, like the one we used for this study, to measure the amount of zooplankton

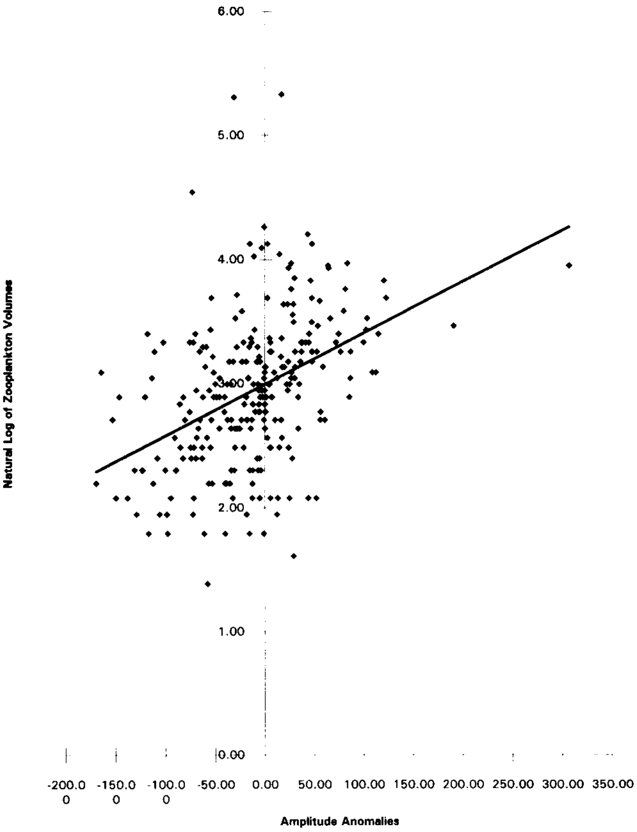

Figure 1. Correlation of MOCNESS net samples and ADCP results (R = 0.26, N = 255, p < 0.001). From Lyons, poster presented at CalCOFI meeting, 1992.

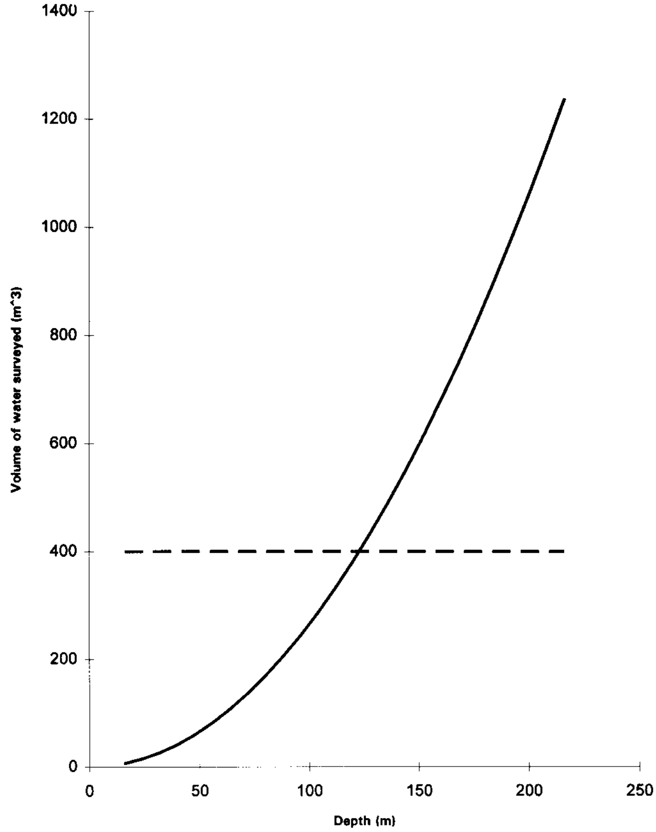

Figure 2. Comparison of volume surveyed by ADCP with volume from CalCOFI standard oblique tow. The *straight line* represents ADCP survey volumes at each depth; the *dashed line* represents the total volume surveyed by one whole net tow.

around an island in the Indian Ocean. Calibrations for the Heywood study came from 200-meter integrated net tows.

Previous research done by the first author compared ADCP data from off central California with zooplankton volumes from MOCNESS tows done simultaneously (figure 1). For each depth range, an anomaly was calculated. The anomaly was the difference between the raw ADCP data and an average for each depth. The average corrected for spherical spreading and attenuation. The anomalies were summed up over the volume the net sampled. The correlation between the MOCNESS tows and the ADCP results was significant (R = 0.26, N = 255). The low variance explained by this relationship may have been caused by the presence of several outliers, but there was no evidence that any should be removed.

The problem with calibrating the ADCP at this small scale is that an ADCP samples far more water than nets sample (figure 2). At 125 meters, an ADCP samples more water in each 8-meter bin than a net would in its entire 200-meter deep tow. In a region of small-scale patchiness, an ADCP will estimate an amount of zooplankton that will differ from that estimated by nets, even though both are correct.

In this paper we calibrated the ADCP at a large scale by using a comparison of the 650 km inshore-offshore trend in zooplankton abundance. Every parameter in the California Current, including zooplankton biomass, changes as one measures it farther offshore. The rate of this change may be expressed as the inshore-offshore slope. Comparing the slopes of ADCP amplitude data and zooplankton net tows makes it possible to calibrate the ADCP on a much larger scale than can be done when each tow is compared to each ADCP amplitude. This calibration against nets will allow the ADCP to provide absolute zooplankton volumes rather than the relative measure that is all that is available when there is no comparison with nets.

METHODS

The ADCP uses sound to measure current speeds. The one we used, manufactured by RDInstruments, emits 150 kHz sound pulses from a hull-mounted transmitter (figure 3). A ping is transmitted in four beams, each pointing into the water at an angle of 30 degrees

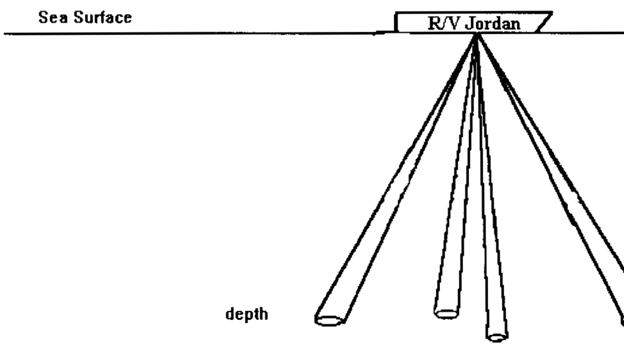

Figure 3. Diagram showing the arrangement of ADCP beams under the research vessel. One beam is directed toward the bow, one toward the stern, and two toward the sides of the ship.

off vertical. These pulses scatter off particles in the water. The frequency of the reflected sound is related to the current speed. The amount of reflected sound (the amplitude) that returns to the transmitter is proportional to the amount of particles in the water and their target strength. After the raw amplitude has been received by the ADCP, the amplitudes are averaged into minute-long (60-ping) ensembles. The data are also grouped by depth into 8-meter-deep bins. The amplitude, proportional to the amount of zooplankton in that volume of water, is recorded as "counts." The counts are related to decibels by a temperature-dependent conversion factor. Converting to decibels did not seem necessary for this work. The four bins closest to 50 m, 100 m, 150 m, and 200 m were chosen from two CalCOFI survey cruises conducted in March and August 1991 (table 1). The areas from which we obtained data are shown in figure 4.

Zooplankton were collected by CalCOFI standard oblique tows (Smith and Richardson 1977). A paired bongo net with 505-micron mesh was towed approximately 200 meters to the surface. We present only the volume of small plankton (no organisms larger than 5 ml), not the total plankton displacement volume, although the results were similar for both. We transformed the data by using logarithms to match the ADCP data, which were already log-transformed. The zooplankton volume from the same cruises as the ADCP were used for this study (table 1).

Because of net avoidance, the zooplankton volumes from the nets were very different between day and night.

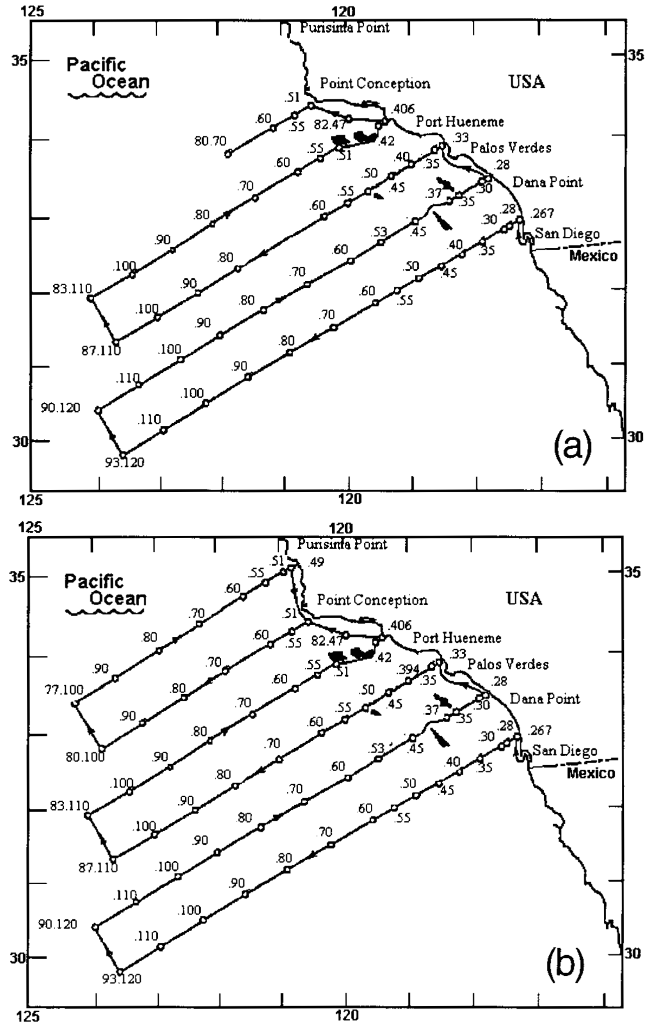

Figure 4. CalCOFI survey station pattern with area sampled in this study outlined for the March (*a*) and August (*b*) cruises in 1991.

The average volume for a nighttime tow was more than twice that of a daytime tow. This was not aliased into the spatial trend because each cross-shelf transect took at least two days to complete. The difference between the nighttime and the daytime zooplankton volumes for the nets would contribute to the variability around the slope, but would not contribute systematically to the trend itself.

These data were examined three ways—the averages in each 50 or 100 km block from shore were compared;

TABLE 1
Source of Data

Cruise	Ship	Date	Number of net tows	ADCP ensembles*
9103JD	R/V *David Starr Jordan*	26 Feb.–11 Mar. 1991	48	5173
9108JD	R/V *David Starr Jordan*	24 Jul.–9 Aug. 1991	58	3007

*Units are minutes of data gathered (ensembles) at each of the four different depths.

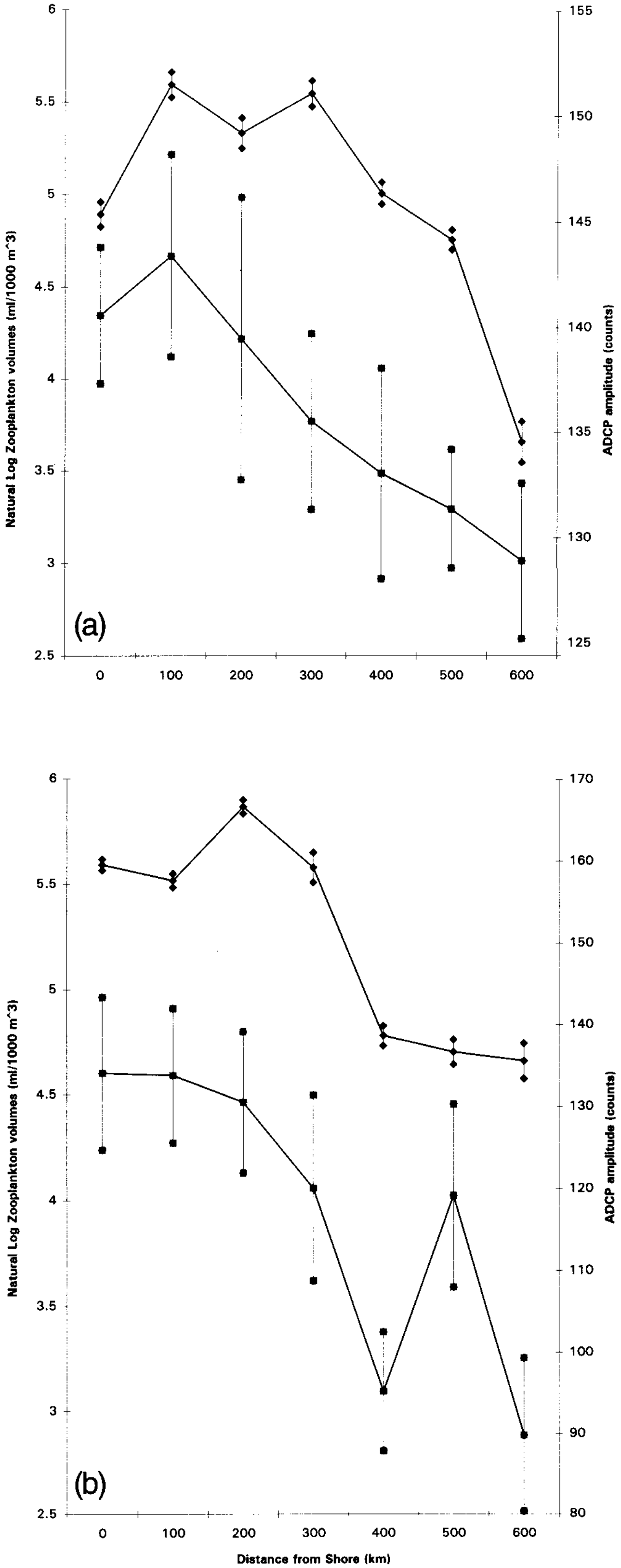

Figure 5. Inshore/offshore trends of the ADCP data (*diamonds*) at 50 m depth, and the net tow results (*squares*) for spring (*a*) and summer (*b*). The lines connect the means; confidence limits (± 2 SE) are shown by symbols above and below each mean.

the data were regressed with the distance from shore (Zar 1984); and the averages of the 50 m ADCP were compared to the net tow averages. We chose to average over 50 km for the ADCP to compare the different depths to show the greater detail that the ADCP can provide. We had to use the 100 km block for the net tows because the smaller block was imprecise. Figures 5 and 6 present the averages of the data for blocks 50 or 100 km from shore, graphed against distance from shore, with confidence intervals of two standard errors.

To simplify the calculations and avoid dealing with the irregularities of the California coastline, we calculated the distance from shore by changing the latitude and longitude, recorded from the Global Positioning System for the ADCP for each ensemble, to CalCOFI line and station (Eber and Hewitt 1979). The station for each line corresponding to the shore is known. Using this information, we calculated the number of stations between the study point and shore for the ADCP and the net data. The number of stations was translated into the distance offshore for each data point.

As an additional confirmation, we graphed the averages over the 100 km blocks for the ADCP versus the net tows. Correspondent averages would show that the ADCP agrees with the net tows over a large range of zooplankton abundances.

RESULTS

The main trend in zooplankton abundance across the shelf declines (figure 5). Both the ADCP and the net results show the same major trend. The spring patterns show a peak at 100 km and a relatively gradual decline to 600 km for the net data. The ADCP results show a broader maximum, from 100 to 300 km offshore before the decrease. The summer pattern shows a shallower slope.

Comparing the trend across shelf for the four different depths of the ADCP shows that the trend is constant between depths in summer, but not in spring (figure 6). Because the signal amplitude decays with depth, the return from zooplankton diminishes as the signal goes deeper. This reduction in signal amplitude explains the large decrease between depths. The reduced amplitude can be corrected by calculating spherical spreading and attenuation. We did not make such corrections because our emphasis was on comparing different trends, not comparing the absolute value of different depths together.

The spring patterns for each depth are not similar (figure 6a). The placement of the fluctuations in the trend varies between the depths. All depths do show the same general declining trend.

The summer profiles for the separate depths are very similar (figure 6b). All four depths show a broad maximum before a decrease. They also show a minimum at

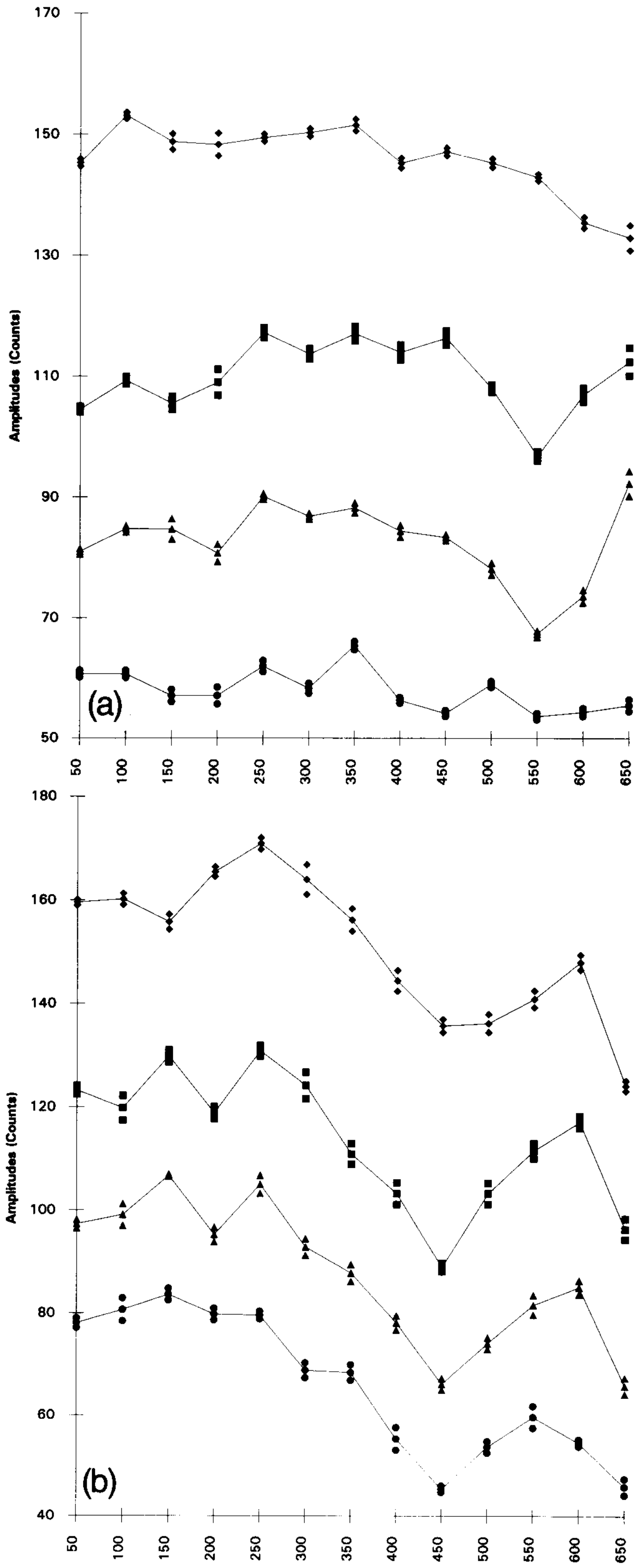

Figure 6. Depth-stratified ADCP results for spring (*a*) and summer (*b*) divided into 50 m (*diamonds*), 100 m (*squares*), 150 m (*triangles*), and 200 m (*circles*) depth intervals. Means and confidence limits are the same as those described for figure 5.

TABLE 2
Results of Regression

	Spring			Summer		
	Slope	N	r^2	Slope	N	r^2
CalBOBL data						
	−2.4	48	32.8%	−2.2	58	30.2%
ADCP data						
50 meters	−13.7	5173	7.6%	−47.4	3007	25.2%
100 meters	4.7	5173	0.8%	−47.9	3007	23.7%
150 meters	−7.8	5173	2.4%	−54.3	3007	36.0%
200 meters	−10.1	5173	6.0%	−61.0	3007	42.3%

450 km with a secondary maximum at 550–600 km. This pattern is reflected in the net tow trend for this season as well (figure 5b).

The slope calculated from the regression of the net tows generally agrees with the slope from the ADCP (table 2). The complicated patterns in figures 5 and 6 are not easily reduced into one number. The spring ADCP trend varies between depths and between the ADCP and the net tows. The low variability explained by the ADCP's slope shows that the spring trend was much more variable than the summer one. The summer ADCP trends are all similar and compare well with the slope of the net tow.

There is a strong relationship between the averages of the ADCP and the net tows for the 100 km blocks from shore (figure 7). Both the spring and the summer averages appear to fall onto the same line. There is less variance in the ADCP average in spring. Unfortunately, we do not have enough net tow data to use smaller averaging blocks, and thus more points in this figure.

DISCUSSION

The trends exhibited by the ADCP and the zooplankton data for both spring and summer demonstrate the extreme variability in the California Current. It is difficult to apply only one meaningful number to the slope. Thus, the most valid means of comparing the two instruments across the shelf is to compare the pattern of the ADCP across-shelf trend to the trend of the net tows (figure 5).

The spring pattern shows an offshore maximum for both instruments (figure 5a). The offshore maximum is broader for the ADCP, perhaps because of the greater resolution of the ADCP in detecting changes in the trend. Nets do not sample these changes because they reflect single points along the trend. The ADCP continuously measures the trend. Thus it detects the whole trend, including any fluctuations. This is apparent in figure 6a. Each depth has its own significant peaks and valleys, some of which, such as the peak at 250 km, cross depths. Some of the peaks and valleys are only on one depth, like the decrease at 650 km for the 50 m depth.

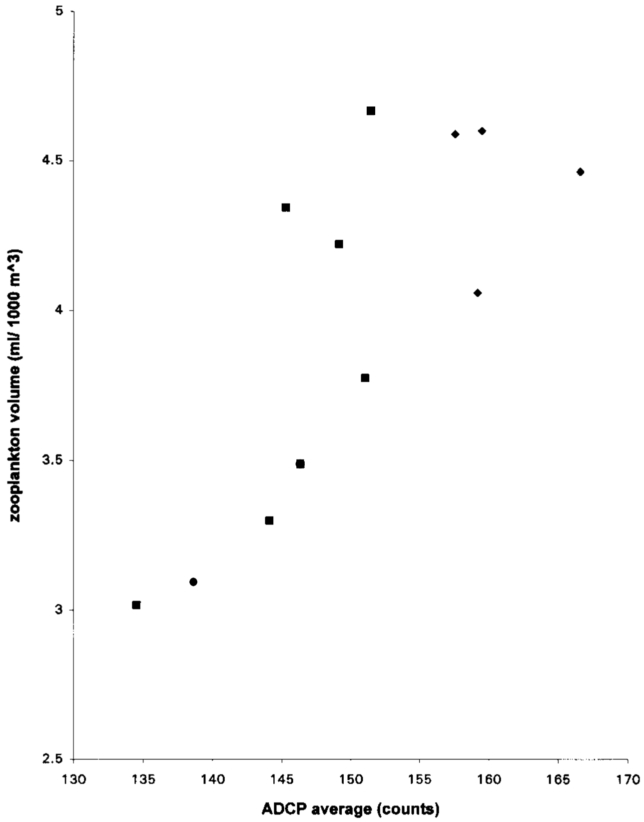

Figure 7. The averages of the 100-kilometer blocks from shore for spring (*diamonds*) and summer (*squares*) for the net tows against the ADCP averages at 50 meters.

The nets provide an overall estimate of the trend, but the ADCP follows the trend more precisely.

The summer pattern compares even better between different depths of the ADCP (figures 5b, 6b). When the ADCP is averaged over the same scale as the net tows, the patterns are not similar. When the ADCP is averaged less, over 50 km blocks, the patterns at each depth match each other and the trend of the net tows as well. This better match shows how averaging smooths fluctuations in the trend.

The slopes from the regression of the onshore-offshore trends of the ADCP and the net tows match to within an order of magnitude (table 2). This small correlation is adequate, considering the amount of error in each number. The net results present problems because of net avoidance by zooplankton and because the net samples all depths. The ADCP is not an exact measure of zooplankton volume and summarizes over a larger volume of water. Thus this agreement, weak though it is, supports the hypothesis that ADCP amplitude offers a means of measuring the absolute zooplankton volume in the ocean.

In fact, the ADCP's precision is probably higher than that of a net. Thousands of ADCP profiles can be recorded in one cruise (table 1). But time constraints on four cruises do not even allow 100 net tows. The smaller standard error for the ADCP curves is a result of averaging many more values together (figure 5). Given the results of a normal cruise, the ADCP will give more precise data than net tows. Further research will ascertain the ADCP's accuracy compared to nets.

ADCP data can augment standard plankton data by estimating, continuously and relatively accurately, the scale, intensity, and depth of plankton patches. The CalCOFI standard oblique tow provides one number for the whole water column; the ADCP furnishes a result every 8 meters. It also makes it possible to map zooplankton, a great benefit to investigations of zooplankton. These advantages demonstrate why the ADCP will help us understand the distribution of zooplankton in the California Current.

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