and with a sampling volume for each beam of 133 m^3 with a 3-m bin size (Gilboy et al., 2000). ADCP measurements made from August 21, 1996 (BTM Deployment 6) to November 29, 2000 (BTM Deployment 14) and from May 10 to November 13, 2003 (BTM Deployment 18) are used in this study. Specific BTM deployments used for the present time-series measurements are summarized by deployment period in Table 1. The time series are not continuous for several reasons: (1) new instruments were added during the program, (2) data gaps of several days exist between mooring recoveries and redeployments, and (3) occasional delays in mooring redeployments were caused by weather and sea-state conditions and ship-related problems.

To our knowledge, most previous ADCP zooplankton estimates have relied upon narrowband ADCPs to measure acoustic backscatter. The narrowband system's automatic gain control (AGC) output is strongly temperature dependent and many studies have been unable to determine absolute backscatter intensity since output signal strength was unknown. Broadband ADCPs (BBADCPs) have an advantage over narrowband ADCPs of having much lower random fluctuations for both current and backscatter data (Deines, 1999). The received signal strength indicator (RSSI) outputs of BBADCPs are not temperature dependent; moreover, the ADCP manufacturer, RDI, provides transmit power data for the BBADCP, which are required for absolute backscatter estimations. The BBADCP also enables higher resolution along the profile with little reduction of velocity precision (Gilboy et al., 2000).

An important aspect of the present study is the collection of zooplankton samples, which were obtained at the BATS site (31°50′N, 64°10′W) near the BTM site with a 1-m^2 rectangular, 202-μm mesh net beginning in 1994 (Madin et al., 2001). Size-fractionated biomass (wet and dry weight (DW)) was determined from each tow by wet sieving through nested sieves with mesh sizes of 5.0, 2.0, 1.0, 0.5 and 0.2 mm. Two replicate double oblique tows were made from the surface to approximately 200 m during the day (between about 0900 and 1500 h) and at night (between about 2000 and 0200 h) during BATS cruises (Madin et al., 2001).

2.3. Estimation of zooplankton biomass from acoustic backscatter data

The echo intensity (counts) recorded by the BBADCP was converted to a backscatter coefficient, S_v, by use of the following equation given by Deines (1999):

$$S_v = C + 10\log_{10}((T_x + 273.16)R^2) - L_{DBM} - P_{DBW} + 2\alpha R + K_c(E - E_r), \qquad (1)$$

where S_v is the backscattering strength in dB re $(4\pi\,m)^{-1}$. C is an empirical constant required to account for some of the relevant phenomena affecting echo intensity that cannot be measured independently. T_x is temperature of the transducer (°C) and R is range along the beam (slant range) to the scatterers (m). L_{DBW} is $10\log_{10}$ (transmit pulse length, meters) and P_{DBW} is $10\log_{10}$ (transmit power, Watts). α is the sound absorption coefficient of water (dB m^{-1}), as calculated using the method of Francois and Garrison (1982), and the factor $2\alpha R$ is calculated by the method given by Deines (1999). K_c is the conversion factor for echo intensity (dB $count^{-1}$) and the values of C, P_{DBW} and K_c are provided by the manufacturer. Echo intensity (E) is derived from the RSSI of the receivers; its real-time reference level is denoted E_r and a typical value is 40 counts. In practice, we assume that E_r is equivalent to the lowest value of E measured in the water column during the entire data collection period. There is no laboratory calibration for E_r; instead, we use the minimum of counts for each beam when the ADCP is sampling in the ocean. The E_r values we used for each beam were 39, 37, 43, and 33 for beams 1 through 4, respectively.

To obtain absolute backscatter data, transmit power must be estimated. In general, this power is proportional to the input voltage (Deines, 1999). Our 153-kHz Broadband ADCP has a high power module (with constant power) that removes this dependence upon input voltage. If backscatter intensity of one specified beam exceeded the mean value of the other three beams by 5 db for a given bin, then data for that bin were discarded for averaging purposes. This process eliminates large scatterers (such as fish) from the data. A minimum 'percent good' of 25% was selected for quality control. The low RSSI values for bin 1 in Deployments 6, 7, 10, 11, 12, 13 and 14 may be due to the hardware's Low Pass Filter time constant, which may be too long. The high bin 1 (deepest bin, closest to BBADCP) RSSI values for Deployments 8 and 9 may be due to ringing or a hard target in front of the transducer (Steve Maier, personal communication). Thus, bin 1 ADCP backscatter intensity data for all deployments were omitted. The acoustic