angles and density of the krill, and sound-speed contrasts between krill and seawater. Density and sound-speed contrasts are known to show annual cycles. In this study, seasonal variations of the specific density and sound-speed contrasts of *Euphausia pacifica* are presented. Biological sampling was carried out during twilight, when the sound-scattering layer migrates up to the surface. The specific densities of *E. pacifica* were measured, using a series of variable density glycerol solutions, within 48 h of net sampling. Sound-speed measurements were performed 2 hours after net sampling, using a T-shaped velocimeter with two transducers mounted on the ends of a horizontal tube. In 1999, the seasonal changes in specific densities and sound speed contrasts were ca. 1% and 3%, respectively. When calculated using Stanton's straight cylinder model, these seasonal changes yielded a difference of approximately 5 dB in the target strength of *E. pacifica*.

3:15–3:30 Break

3:30

1pAO5. Broadband echo spectra from euphausiids and copepods. Kenneth G. Foote (Woods Hole Oceanogr. Inst., Woods Hole, MA 02543, kfoote@whoi.edu), Tor Knutsen (Inst. of Marine Res., N-5024 Bergen, Norway), Philip R. Atkins, Claire Bongiovanni, David T. I. Francis (Univ. of Birmingham, Birmingham B15 2TT, UK), Peter K. Eriksen, Mette Torp Larsen, and Tom Mortensen (RESON A/S, DK-3550 Slangerup, Denmark)

A seven-octave-bandwidth echo sounding system [J. Acoust. Soc. Am. **105**, 994 (1999)] was used to observe diverse zooplankton along the coast of western Norway during the period 28 April–9 May 1999. Echo spectra were obtained from freshly caught, swimming specimens of the euphausiid *Meganyctiphanes norvegica* and copepod *Calanus finmarchicus ex situ* in a tank mounted on the stern deck of R/V JOHAN HJORT. Echo spectra were also obtained from scatterers *in situ* at 15-m depth in the same sea areas where the experimental animals were caught. Pulse compression was used to reduce the risk of analyzing overlapping echoes. All echo spectra were absolute, as the system was calibrated by the standard-target method using a 10-mm-diameter sphere of tungsten carbide with 6% cobalt binder. Comparison of echo spectra over the nominal bandwidth 1600–2600 kHz supports the claim of acoustic classification. Additional evidence is provided by reference to modeling computations [J. Acoust. Soc. Am. **105**, 1050 (1999); **105**, 1111 (1999)] where the bodies were assumed to be weakly scattering and fluid-like, with representative morphometries and assumed or measured properties of mass density and longitudinal-wave sound speed. [Work supported by the EU through RTD Contract No. MAS3-CT95-0031 during the project.]

3:45

1pAO6. *In situ* target tracking of individual krill (*Meganyctiphanes norvegica*) in the Oslo fjord. Anders Røstad (Oregon State Univ., Hatfield Marine Sci. Ctr., 2030 SE Marine Science Dr., Newport, OR 97365, anders.roestad@noaa.gov) and Stein Kaartvedt (Univ. of Oslo, Blindern, N-0316 Oslo, Norway)

Krill (*Meganyctiphanes norvegica*) were studied during and after their diel vertical migration to near-surface water using a Simrad EK500 echosounder with a split-beam 120-kHz hull mounted transducer. Target tracking of individual krill provided information on target strength, swimming velocity, and 3-D swimming patterns through the acoustical beam. Both prospects and limitations of the split-beam target tracking technique in behavioral studies are discussed.

4:00

1pAO7. Three-dimensional acoustic tracking of krill with a multibeam sonar. Alex De Robertis, Chad Schell, and Jules S. Jaffe (Scripps Inst. of Oceanogr., La Jolla, CA 92093, aderobertis@ucsd.edu)

The swimming behavior of individual zooplankton mediates how the animals experience their spatially heterogeneous environment, and consequently, has an important effect on population dynamics. However, current understanding of zooplankton swimming behavior is limited by conventional zooplankton sampling techniques. Here, we describe the use of a high-resolution multibeam sonar [Jaffe *et al.*, Deep Sea Res. **42**, 1495–1512 (1995)] to reconstruct the swimming trajectories of individual krill (*Euphausia pacifica*) in Saanich Inlet, British Columbia. The instrument was deployed in the deep scattering layer at depth during the day, and in near-surface strata during twilight periods of vertical migration and at night. Successive acoustically determined animal positions from these records are linked using a simple target tracking algorithm resulting in $>10^4$ trajectories of several seconds duration. The spatial positions of the tracked targets are improved by applying an algorithm [J. S. Jaffe, J. Acoust. Soc. Am. **105**, 3168–3176 (1999)] developed to localize targets within the acoustic beams. These methods permit quantitative analyses of swimming behavior of undisturbed krill in their natural environment for the first time.

4:15

1pAO8. Experimental verification of an algorithm for animal localization using a multibeam sonar system. Jules S. Jaffe, Chad Schell, and Alex De Robertis (Scripps Inst. of Oceanogr., La Jolla, CA 92093)

Behavioral inferences of zooplankton activity from data generated with active multibeam sonar systems require high precision in localization due to the small extent of the animal movements. If target localization is limited to whether a target is within one beam or another, sonars with many beams and high complexity are required. Sonars which have multiple beams with measurable side lobes have the capability of achieving adequate resolution in situations of high signal to noise. In Jaffe [J. Acoust. Soc. Am. **105**, 3168–3175 (1999)], a maximum likelihood estimator for position was proposed. The algorithm utilizes a minimum mean square estimator in amplitude in order to estimate target position to a resolution smaller than the sonar's beamwidth. Experimental verification of the application of this algorithm to data aquired in a test tank with simultaneous verification of position with an optical imaging system is presented. The methodology employed uses a pair of cameras in order to simultaneously estimate the three-dimensional location of a target which is simultaneously being observed with a three-dimensional multibeam acoustical system [Jaffe *et al.*, Deep Sea Res. **42**, 1495–1512 (1995)]. The results indicate that the algorithm can produce an accurate estimate of three-dimensional target positional information providing accurate calibration is performed.

4:30–5:00

Panel Discussion