Three-Dimensional Acoustic Measurements of Zooplankton Swimming Behavior in the Red Sea

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Abstract: The three-dimensional swimming trajectories of several hundred thousand individual zooplankters were measured using the 445 kHz acoustical imaging system FishTV during a three night moored deployment in the Gulf of Eilat, Israel. The sonar examined a five cubic meter volume of water at 26 m depth, in water 280 m deep. The image rate was 4 images/s. Multiple targets were tracked from image to image using an automatic three-dimensional tracking algorithm developed for the project. Over 14,000 of the targets remained in the field-of-view for over 5 seconds (with the longest lasting over 97 seconds), and the trajectories of these targets were used in subsequent analysis. Ancillary data from net tows indicated that most of the targets were euphausiids. The tracks of the targets with target strengths below -82 dB re 1 m² were highly correlated with the horizontal flow measured simultaneously by an S4 current meter. These targets also exhibited strong vertical motions, apparently due to internal waves. In order to judge the swimming speeds of the animals themselves, the estimated mean flow was subtracted from each trajectory. Statistical analysis of the “flow-removed” tracks indicated that the variance in the vertical direction was much greater than the variance in the horizontal throughout the night. However the variance became more isotropic as dawn approached. A hop-and-sink swimming behavior, previously observed for some forms of crustacean zooplankton, is one possible explanation for the high variance in the vertical direction.

METHOD

FishTV is a 445 kHz three-dimensional acoustical imaging system designed to examine very fine scale distributions of zooplankton (1-3). The system has also been used to measure the three-dimensional tracks of individual zooplankters (3). In July 1994, a large FishTV data set was collected in the Red Sea over two nights. The data set was composed of 28 3-D image sequences. These were collected at 4 images per second for 8 minutes each. The FishTV transducer was attached at 26 m depth to the top float of a taut mooring line, anchored at a bottom depth of 280 m approximately 1.2 km from the shore. A large vane kept the transducer aimed up-current. The ensonified animals were thought to be undisturbed by the presence of the hardware. The volume of water ensonified was approximately 5 m³. The measurements were supplemented by simultaneous measurements of flow with an S4 current meter attached to the mooring line approximately 4 m below the transducer. Two BONGO net tows made during the experiment indicate that euphausiids (Euphausia diomedae, E. sanzoi, Stylocheiron abbreviatum, and S. affine) were well represented in the fauna (10's to 100's per m³).

Multiple targets were tracked from image to image using an automatic tracking algorithm developed for the project. Over 14,000 individuals were tracked for at least five seconds, with one target remaining in FishTV’s field-of-view for over 97 seconds. The smallest targets (< -82 dB re 1 m²) were treated as passive tracers of water motion. Their movement in the horizontal plane agreed well with the data from the S4 current meter (R² = 0.84). The average vertical component of velocity for these tracers varied approximately sinusoidally with a period of 4 hrs, suggesting the presence of internal waves. Superimposed on this bulk motion were the movements of the animals themselves. These were estimated by subtracting the bulk movement from the movement of all acoustic targets, large and small.
RESULTS AND DISCUSSION

After flow removal, there was little evidence of upward vertical migration in the evening data, but it is likely that the periods of sampling did not coincide with the main part of the migration. Also, with the sensor at 26 m depth, it is likely that the animals observed were not “passing through” as much as “arriving on location”. The energy allocated to vertical vs. horizontal “random” movement was compared by examining the variances in those two components of the target trajectories. These were compared for three times of day: early evening, midnight, and dawn. Data from evening and night indicated a much greater variance in the vertical component of motion than in the horizontal component, whereas at dawn the two variances were almost identical. One interpretation of this observation is that in the evening and at night, the euphausiids employed a “hop-and-sink” swimming style. Hop-and-sink swimming is commonly associated with copepods, possibly as a way of obtaining food (4), although Haury and Weihs (5) have shown that for any zooplankter that is heavier than water, hop and sink swimming in the vertical dimension is a more efficient method for maintaining depth than is continuous swimming. Either of these two explanations (foraging vs. station-keeping) is consistent with the observed activity in the evening and at night, and with its cessation in the early morning (end of feeding vs. end of station keeping and start of the dawn descent).

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REFERENCES