THE MEASUREMENT OF OCEANIC PARTICLE FLUX - ARE "SWIMMERS" A PROBLEM?

By Cindy Lee, Stuart G. Wakeham and John I. Hedges

ABOUT 10 years ago, the use of sediment traps to measure oceanic particle fluxes and composition began to proliferate (Honjo, 1978; Rowe and Gardner, 1979; Knauer *et al.*, 1979; Honjo, 1980; Deuser *et al.*, 1981). This technique has now become widespread. Research on particle composition and flux using sediment-trap and other large-particle sampling technologies has clearly shown the importance of particulate matter in global biogeochemical cycles. It has become a major goal within the oceanographic community to understand the processes controlling particle production, transport and destruction on both small and large scales (National Academy of Sciences, 1984; Alldredge and Hartwig, 1986). Particularly important to these studies is an accurate estimate of particle production and flux in surface waters.

Initially, sediment traps were used to collect particles without careful regard to *in-situ* bacterial decay of material in the traps. As it became clear that organic material in particles could be significantly degraded during the two-week and longer periods over which traps were deployed (Gardner *et al.*, 1983; Lee *et al.*, 1983; Knauer *et al.*, 1984), poisons and preservatives became more commonly used to prevent decomposition. Typical poisons currently used are $HgCl_2$ and NaN_3, while common preservatives are formalin and salt. We are currently investigating the effectiveness of these and other compounds in preventing decomposition and alteration of particulate organic compounds collected in sediment traps. However, with the use of poisons and preservatives, another potentially more significant bias is introduced to sediment trap collections. This is the collection of "swimmers" (see Fig. 1, p. 35): zooplankton and other marine animals that swim into the trap and die (Knauer *et al.*, 1979, 1984; Harbison and Gilmer, 1986; Martin *et al.*, 1987). Under some circumstances, particularly in shallow traps placed in coastal areas, much of the material collected can be swimmers. We observed this in trap samples collected in the California Current during the VERTEX V experiments. (VERTEX was a multidisciplinary study of VERtical Transport and EXchange of material in the upper ocean.) Even in deeper or less productive waters, swimmers can be present in trap samples.

Attempts have been made to decrease the influence of swimmers. Coale and Bruland designed a swimmer trap (unpublished design) that was used in the collection of amino acid flux data during the VERTEX III and IV experiments (Lee, unpublished). These traps used a series of funnels to exclude swimmers from a central collection tube. Although material which sank into the central tube was not free of swimmers, the area outside the central tube almost exclusively collected swimmers. Results from the VERTEX experiments showed the strong influence of swimmers down to 1500m, the greatest depth at which traps were deployed (Fig. 2, p. 35). Fluxes calculated from analyses of the euphotic zone traps suggest that at least 40-50% of the amino acids in material collected there may be due to swimmers. Since amino acids make up about 10-25% of the organic carbon in sinking particles in surface waters, estimates of carbon flux, and therefore estimates of new production based on vertical flux measurements, would be in error by 5-10% due to the swimmer contribution from carbon in amino acids alone. Other organic compounds present in the swimmers, such as lipids and carbohydrates, would raise the amount of this error, possibly to 40-50%. This estimate is conservative since much of the material collected in the inner tube was also swimmers.

Analyses of lipid compounds present in sediment trap material indicate that swimmers may also be present in trap samples deeper in the water column. Wakeham *et al.* (1984) found that, for the most part, the flux of particulate organic carbon and fatty acids decreases regularly with depth at five sites studied in the Atlantic and Pacific Oceans. However, fluxes of wax esters and triacylglycerols, compounds that are lipid-storage products in zooplankton, do not decrease regularly and sometimes show deep-water maxima (Fig. 3 shows data for fatty acids and wax esters). Furthermore, the molecular composition of these lipids provides strong evidence for a deep-

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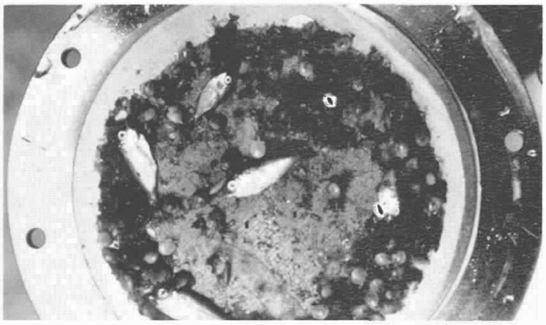

Figure 1. Fish and pteropods in 300-μm *Nitex-screened VERTEX V sediment-trap samples from the California Current (100m). The top entrance to the conical Soutar traps was covered by 1-cm baffles. For scale, the filter is 14.2cm in diameter. The fish were alive when the trap was recovered. Photo credit: Mary Silver.*

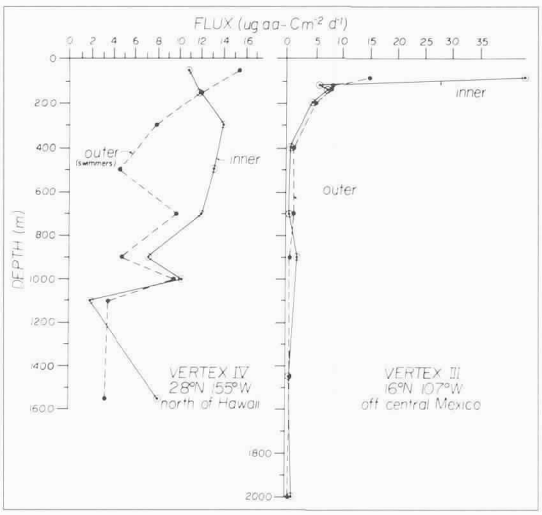

Figure 2. Fluxes of total hydrolyzed amino acids in VERTEX III and IV samples. The material was collected with a swimmer trap designed by Coale and Bruland (unpublished) which collected both sinking material and some swimmers in an inner cylinder, but mostly swimmers in the outer collection area. Data for VERTEX III are from Lee (unpublished) and VERTEX IV from Wakeham and Lee (1988).

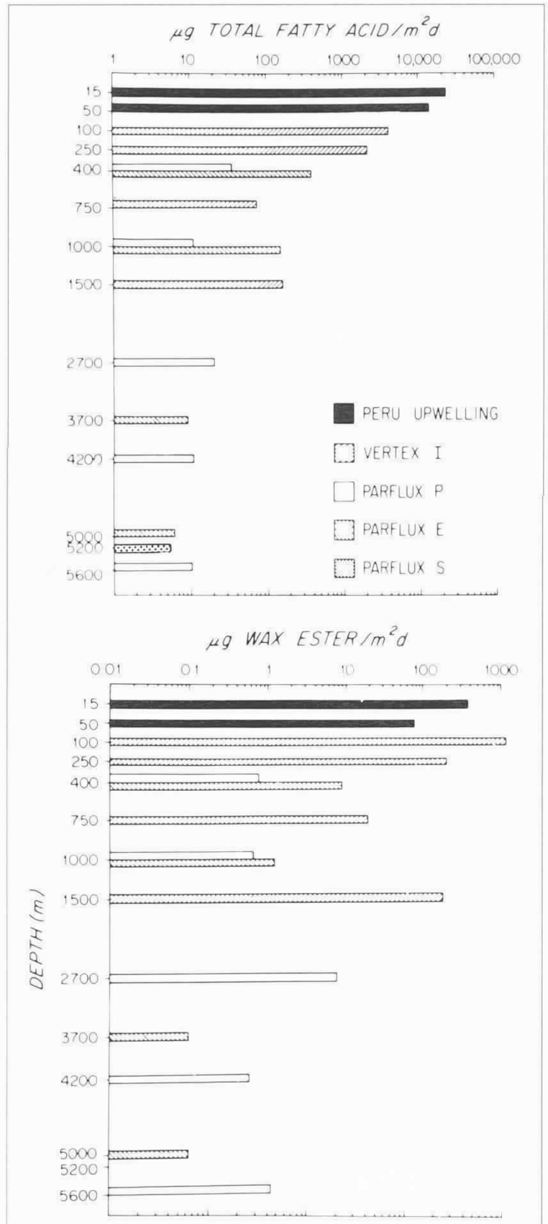

Figure 3. Fluxes of total fatty acids and wax esters at five sites in the Atlantic Ocean (PARFLUX S and E) and Pacific Ocean (VERTEX I, PARFLUX P, and Peru); after Wakeham et al., *(1984).*

water source. For example, the wax ester distribution at 2770m at the PARFLUX P site in the North Pacific Gyre is dominated by compounds which are almost certainly biosynthesized by mesopelagic zooplankton, rather than by surface-dwelling animals (Wakeham *et al.*, 1984). Flux measurements of these lipid-storage compounds are particularly subject to bias caused by the presence of zooplankton swimmers.

Several investigators have used screens to try to eliminate swimmers. Screens may be effective under certain conditions, particularly when used to exclude large zooplankton (Karl *et al.*, 1988). However, some large particles may also be excluded from the sample when screens are used. In our work in the shallow waters of Dabob Bay during the spring of 1988, we placed polyvinyl-chloride screens with a 2-mm mesh in the lower quarter of the trap, above the poison level. Considerable detrital material was collected on the screens and thus was not subject to the preservation treatment. In some cases, such screened material may be resuspended and lost.

The accuracy of the bulk flux measurements can be significantly improved by "picking" swimmers out of material caught in sediment traps. However, the picking procedure is subjective, and certain elemental and organic compound fluxes may be significantly biased by errors in the picker's judgment. It is not always possible to determine which zooplankton swam into the trap and died (swimmers) and which died first and fell into the trap (sinkers). In samples which are predominantly composed of swimmers, it is probably not possible to remove the swimmers without removing some of the organic detritus adhering to them. In the VERTEX V samples mentioned earlier, for example, the mucus coating of the swimmers (doliolids?) confounded efforts to separate swimmers from detritus. If microscopic swimmers are present, they would be almost impossible to remove. In addition, recent evidence (Peterson and Dam, personal communication) shows that some copepods can herniate upon entering traps containing salt (60 ppt) as a preservative, spilling gut contents into the trap. Significant bias in pigment flux (10-50%) can be due to this phenomenon.

Various poison treatments may attract swimmers to different extents. In our Dabob Bay sediment-trap work, visual observation upon recovery of the sediment traps suggested that brine solutions collect more swimmers than other commonly used poisons or preservatives. Preliminary laboratory experiments using Long Island Sound copepods also support this observation (Lee and Dam, unpublished data). Lee and Cronin (1984) found substantial differences in amino acid fluxes between formalin- and chloroform-treated traps, which they attributed to differences in the number of swimmers collected.

Zooplankton can bias measurement of particle flux and composition even in the absence of poisons. They appear to be capable of swimming into traps and consuming sedimented material. Some material may be returned to the trap reprocessed as fecal matter, while some may be completely removed if the zooplankton leave the trap. In sediment trap studies in Lake Greifen (Lee *et al.*, 1987) and Lake Lucerne (Sturm, Lee and Wakeham, unpublished), Switzerland, unpoisoned traps were allowed to collect material; for comparison, some were then covered and some left uncovered, and the traps were left in place. A markedly decreased flux was observed in the uncovered relative to the covered traps. The decrease was attributed to consumption of material by zooplankton that later swam out of the traps. In the Dabob Bay studies, we found large numbers of euphausiids clinging to the trap mooring line during recovery, possibly attracted by the motion of the line in the water. The presence of swimmers in the traps was obvious, but whether fecal pellet concentration in the traps increased due to unusually high numbers of zooplankton in the vicinity of the traps is more difficult to judge.

Much of what we have reported here is observational and incidental. Few rigorous studies of the effect of swimmers on trap fluxes have been carried out. Swimmers may be a significant problem in the use of sediment traps to estimate the particulate flux of certain elements and compounds even at depths greater than 1km, and swimmers certainly are a critical problem for the use of traps in the very important surface waters. However, very little quantitative data are available on how significant the problem is. One approach to the question is to try to determine what the effect of the swimmers is on flux and correct for it; a better approach would be to design a trap system to eliminate the problem. In a November 1988 workshop sponsored by the National Science Foundation as part of the Global Ocean Flux Study, some of these problems will be discussed. We believe that it is critical to improve trap technology and hope that this workshop and increased awareness of the problem will spur further research in this area. A positive step toward solving this problem would be for geochemists interested in flux measurements to cooperate with ecologists having a knowledge of zooplankton behavior.

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