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AT A SINGLE LOCATION NEAR CABO NAZCA, PERU

MASTER

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ABSTRACT

Temporal variations in the biomass and species composition of zooplankton at a single midshelf station in an upwelling area off Peru can be explained to a large extent by onshore-offshore advection in the upper 20 m of the water column. During periods of strong or sustained near-surface onshore flow, peaks in biomass of zooplankton were observed at midshelf and typically oceanic species of copepod were collected. In periods of offshore flow at the surface, a copepod capable of migrating into oxygen-depleted layers deeper than 30 m was collected. A simple translocation model of advection applied to the cross-shelf distribution of Paracalanus parvus suggests that the fluctuations in P. parvus observed in the midshelf time-series were closely related to onshore-offshore flow in the upper 20 m.

Fluctuations in abundance of the numerically dominant copepod, Acartia tonsa, were apparently affected by near surface flow also. The population age-structure suggests that A. tonsa was growing at maximal rates, due in part to its positive feeding response to the dinoflagellate/diatom assemblage of phytoplankton.

INTRODUCTION

Temporal variations in zooplankton at a given location in an upwelling region can occur as a result of both biological and physical processes. Biologically, variations occur on a time scale of weeks associated with the life cycle of the organisms, and on a diurnal time scale associated with vertical migration. Physically, variations may occur as a result of on-shore-offshore and alongshore advection which generally have a dominant time-scale of several days, intermediate to the two dominant biological time scales. We shall examine the temporal variability of zooplankton observed during a 15-day period of daily observations at a single location in the coastal upwelling region off Peru.

The observations of zooplankton were obtained from vertical net hauls made primarily at a single midshelf location, called C-3, at about 15°07'S, 75°31'W over the shelf just south of Cabo Nazca (Figure 1). These net hauls were made from R. V. Alpha Helix daily from 28 March to 11 April 1976, at about the same time each morning, between 0900 and 1100 LST, to avoid possible aliasing from the diurnal cycle of vertical migration. Live specimens of the dominant species, Acartia tonsa, were collected from the net hauls and maintained in the laboratory to study their grazing habits. The off-shore distributions of zooplankton were inferred from occasional observations between April 1 and April 5 at other locations along the C-line (Figure 1). No direct information is available about the alongshore distribution of zooplankton, but alongshore variation in biological variables are believed to be much less than offshore variations (Dugdale et al., 1977). Our observations have been made during an atypical period in the upwelling regime off Peru. Dinoflagellates dominated the phytoplankton along much of

the coast (Dugdale et al., 1977; Rojas de Mendiola, 1979), and denitrification was taking place (Packard et al., 1978). The prevailing conditions in 1976 have been characterized both as an aguaje (Rojas de Mendiola, 1979) and an El Niño (Wyrtki, 1977).

Observations on currents were made during this period at two locations over the shelf: at Mila, alongside C-3, and at Agave, inshore of C-3 (Figure 1). The current meters at Mila were all at depths greater than 25 m, but at Agave one of the current meters was at 10 m, which is usually well within the surface Ekman-like layer. Wind observations were made at a coastal station at San Juan (Figure 1). Preliminary analysis indicated that the zooplankton data were not correlated with either the alongshore wind or the alongshore currents at Mila or Agave. However, the onshore component of the near-surface current seemed to account for some of the variability in the zooplankton samples. Some of the variability, particularly in the dominant species Acartia tonsa and hence in the biomass, can also be explained in terms of in situ growth. We shall demonstrate that onshore-offshore advection alone accounts for the occurrence of most of the species of zooplankton at C-3, while both growth and advection affect the occurrence of the dominant species, Acartia tonsa.

METHODS

Zooplankton were collected in vertical hauls of 60 cm diameter "Bongo" frames fitted with 102 μ m mesh nets (S. Smith, 1978) and in vertical hauls of 70 cm diameter Hensen net fitted with a 300 μ m mesh net and a 10 mm mesh prefilter in the net mouth. At stations with depths less than 100 m, hauls of the Hensen net were from bottom to surface and 50 m to surface, while at deeper stations two hauls were from 200 m to surface and one was from 50 m

to surface. One of the deeper hauls at each station was frozen and returned to the laboratory where it was washed with distilled water onto a preweighed filter, dried at 60°C for 48 h, and weighed. All other samples were preserved in formalin for determination of displacement volume and the quantitative analysis of species composition. The hauls of the "Bongo" nets were from 100 m or 200 m to surface depending on station depth. The collection from one net was poured through sieves of 102, 223, 505, and 1050 μ m mesh, dried at 60°C, weighed and corrected for phytoplankton (see S. Smith, 1979, for details). Net hauls at C-3 and C-5 were taken during daylight in order to remove the effects of diurnal migration.

Grazing rates of Acartia tonsa were measured in late April 1976. Adult A. tonsa were sorted from samples collected by vertical net tows (1 - 100 m) into beakers containing unfiltered surface seawater. Experimental food conditions were established from ambient chlorophyll a concentrations at selected euphotic zone depths. Ambient concentrations were occasionally diluted with filtered seawater to create a range of food concentrations. Two adult A. tonsa were placed into 250 ml experimental bottles, each experiment having at least two replicates plus a control. Bottles were held in a light-tight water bath for 24 hours. Surface sea water circulated through the bath, keeping temperatures within 1°C of "catch" temperatures, and also gently rolling the polyethylene bottles such that the particulate food remained in suspension. Since a Coulter counter was not available on this cruise, grazing rates have been calculated based on initial and final chlorophyll a concentrations in the control and experimental bottles. The equations of Frost (1972) were used to calculate rates. Data are presented in terms of carbon, assuming a carbon chlorophyll ratio of 50 (see Cowles, 1977, for details).

The current and temperature observations were obtained from Aanderaa current meters on subsurface moorings with instruments at 10 and 29 m at Agave, at 28, 53, and 78 m at Mila, and with additional instruments at more distant locations. The time-series were low-pass filtered with a half-power point of 47 hours to remove tidal and other variations of shorter period. Details of installation and data treatment can be found in Enfield, Smith, and Huyer (1978), and data are discussed more fully in Brink, Allen and R. Smith (1978) and R. Smith (1978). The San Juan wind data were obtained from a land-mounted anemometer with good exposure to the coastal winds (Stuart et al., 1976).

RESULTS

The Flow Field

The mean currents (Table 1) for 39.5 days from 28 March to 6 May 1976, including the period of daily observations of zooplankton show that the flow is equatorward and weakly offshore near the surface at Agave, and poleward and onshore at each of the deeper current meters at both locations. The equatorward flow at 10 m Agave is part of the wind-driven surface current, while the poleward flow elsewhere is part of the undercurrent (Brink, Allen and Smith, 1978). The mean onshore flow at depth and offshore flow at the surface are consistent with an upwelling circulation pattern driven by the mean equatorward alongshore wind stress of $0.82 \text{ dynes cm}^{-2}$. The mean flow at 10 m Agave is probably representative of the mean near-surface currents across the whole shelf in this region. Direct observations of both near-surface and subsurface currents with better vertical resolution at nearby locations in 1977 (Brink, Smith and Halpern, 1978) substantiate this conclusion.

Fluctuations in the currents in this region are associated with fluctuations in the local wind stress and with remotely generated disturbances that appear to propagate as low frequency, coastally trapped waves (R. Smith, 1978). At both Agave and Mila, fluctuations in the alongshore current are not significantly correlated with the local wind stress (Brink, Allen and R. Smith, 1978). The alongshore current fluctuations at all current meters are significantly correlated with each other, and with current observations off Callao (375 km north of Mila and Agave) but with a lag of 2 days due to the wave propagation (R. Smith, 1978). Fluctuations in the onshore flow at the deeper current meters are significantly but weakly correlated with the alongshore wind stress, with stronger onshore flow when the equatorward wind stress is stronger. Simple Ekman dynamics would lead us to expect that the surface offshore flow is also stronger when the wind stress is stronger, but the onshore component of the current at 10 m Agave is not significantly correlated with the local wind stress (Brink, Allen and Smith, 1978). Part of the variance in the onshore flow might be due to propagating disturbances. In either process, variations in the onshore current at 10 m Agave are probably representative of the near-surface flow across the whole shelf in this region.

Biomass of Zooplankton

Net hauls at C-3 were made from both 50 m and 100 m with the 300 m Hensen net. The time-series of settled volume from both hauls (Figure 2) shows that they captured similar amounts of zooplankton. On 2 and 8 April, jellyfish fragments were abundant; these probably account for the higher volume from 50 m than 100 m on April 8. Except on 28 March and 1 April, when the 100 m haul had significantly greater volume than the 50 m haul, the zooplankton at C-3 were concentrated in the upper 50 m.

The concentration of the zooplankton within the upper 50 m may be due in part to the presence of water with very low oxygen concentrations. The vertical profile (Figure 3) of dissolved oxygen data collected during this period (MacIsaac et al., 1979) shows values less than $1 \text{ ml} \cdot \text{l}^{-1}$ at depths greater than 30 m. These values may be overestimates, since this water showed evidence of denitrification (Packard et al., 1978). If most species of zooplankton avoid this oxygen-depleted water, and there is evidence that some do (Boyd et al., 1980) most of them would be concentrated in the upper 30 m. Furthermore, the surface mixed layer was less than 15 m throughout this study (MacIsaac et al., 1979). If such near-surface concentration occurred, we would expect the near-surface currents, represented by 10 m Agave, to have a significant effect on the distribution of zooplankton.

Time-series of the biomass of zooplankton at C-3 (Figure 2) were obtained from the 100 m hauls of each net; estimates from the 300 μm Hensen net are smaller by about a factor of five than those from the 102 μm Bongo net, indicating that much of the biomass is made up of zooplankton smaller than 300 μm . Dry weights from two size fractions collected in the 102 μm Bongo net (Figure 4) also show that over the shelf most of the biomass of zooplankton is in the smaller ($<505 \mu\text{m}$) size category. Variations in the two biomass estimates are qualitatively similar, except for a large discrepancy on April 5, for which the Bongo net estimate is questionable. Comparing day-to-day fluctuations in biomass with the cross-shelf flow measured at 10 m Agave shows that peaks in biomass generally occurred during onshore flow and that biomass was least during offshore flow (Figure 2). The largest biomass appeared near the end of the period of sustained onshore flow between 2 and 6 April (Figure 2).

The qualitative similarity between biomass and the onshore flow can be explained by the offshore distribution of zooplankton biomass: For each size range, the biomass increases near the shelf break (Figure 4). The total biomass of zooplankton smaller than 505 μ m has a maximum at the shelf edge, with lower biomass farther offshore. As an additional comparison between the cross-shelf flow and the biomass, we computed a "predicted" time-series by assuming that the offshore profile of Figure 4 is representative for a particular date, and that this profile is passively displaced onshore or offshore without distortion. We assumed the offshore profile of total biomass (both $>102 \mu$ m and $>300 \mu$ m) was representative for 3 April, the date on which the net hauls at C-5 shelf break were made. The displacement for each date before and after 3 April was computed from the time integral of the cross-shelf current at 10 m Agave. The resulting time-series of "predicted" biomass (Figure 5) does not agree very well with the observed biomass, but it does pick up the two major peaks in biomass that occurred on 31 March and 4-6 April. We repeated the calculation of "predicted" biomass using crossshelf currents averaged over several depths but all other combinations failed to pick up the March 31 peak in biomass. We also used the offshore profiles of biomass for different size fractions, but found no improvement in the "predicted" biomass. Although agreement is not good, the coincidence of peaks for the two different series of net hauls suggests that the zooplanktonic community as a whole was sensitive to currents in the uppermost part of the water column. The implication is that for the most part zooplankton were restricted to the layer influenced by surface currents. Any agreement is encouraging since there was bound to be distortion in the pattern, the cross-shelf profile (Figure 4) was not synoptic, and in situ processes were ignored.

Species Composition

Patterns of the abundance and diversity show three groups of copepod species associated with the continental shelf, continental slope, and deep ocean. The shelf group, composed of Acartia tonsa Dana and Centropages brachiatus Dana, decreased sharply in abundance offshore of the shelf break (Figure 6). The continental slope group, containing Paracalanus parvus Claus, Eucalanus spp. and Oncaea spp., increased gradually in abundance from midshelf to 110 km offshore (Figure 6). The deep water or oceanic group contained seventeen species which were abundant between 80 and 110 km offshore; four are shown in Figure 6.

Day-to-day fluctuations in the abundances of each group of species at C-3 (Figure 7) show the effects of onshore-offshore advection more clearly than does biomass. The numerically dominant copepod during this study was Acartia tonsa, a cosmopolitan and opportunistic species often found associated with dinoflagellate blooms (Conover, 1956; Seki et al., 1974; S. Smith, 1978; Morey-Gaines, 1979; Walsh et al., 1974). This species is regularly present in coastal waters off northern Chile (Vidal, 1968) and off Peru (Heinrich, 1973), but it is not abundant in normal oceanographic periods (Heinrich, 1973). The maximum abundance of A. tonsa occurred during the period of sustained onshore flow (2-6 April) with a secondary peak during the relatively brief but strong onshore flow of 30-31 March (Figure 7). Lowest numbers were associated with periods of offshore flow. The next most abundant species, the shelf copepod Centropages brachiatus, also had maxima during periods of onshore flow (Figure 7), suggesting that shelf species accumulate at C-3, and probably inshore of C-3 during onshore flow.

Two of the slope species, Paracalanus parvus and Oncaea spp., also have peak abundances during periods of onshore flow; during the period of sustained onshore flow (3-6 April) they lag the shelf species by a day. The oceanic species do not appear during or after the short burst of strong onshore flow on 31 March, but they were observed during and immediately after the period of sustained onshore flow (Figure 7). In addition, other organisms such as Euphausia mucronata (Euphausiacea), Muggiaea atlantica (Siphonophora) and doliolids which generally occur seaward of the shelf break were captured at C-3 during periods of onshore flow. Figure 7 suggests a lag in abundances of the three groups following onshore flow beginning on 3 April: Acartia tonsa peaks on 4 April, the slope species' peak on 5 April, and the oceanic species peak on 6 April.

One of the species in the continental slope group, Eucalanus inermis Giesbrecht, was most abundant at C-3 on 2 April, in a period of offshore flow at Agave 10 m (Figure 7). This species was not confined to the upper layer (<30m) over the shelf in this area in 1977 (Boyd et al., 1980): It had the ability to migrate deeper than 30 m where oxygen concentrations were generally less than $0.1 \text{ ml} \cdot \text{l}^{-1}$. Thus Eucalanus inermis was probably not restricted to the near-surface layer and is likely indicative of freshly upwelled water being advected offshore.

Since there was a cross-shelf pattern in the species of zooplankton, we computed "predicted" abundances from the offshore abundance profile and the onshore current data, in the same way as we computed "predicted" biomass described above. In particular, we computed the "predicted" abundance of Paracalanus parvus, one member of the continental slope group of species. We assumed that the offshore distribution of P. parvus shown in Figure 6 was

valid for 3 April; its onshore or offshore displacement from this date was determined from the time-integral of the cross-shelf current at 10 m Agave (other estimates of the cross-shelf current were also used, but the 10 m Agave data again gave the best prediction). The overall agreement of the observed and "predicted" curves (Figure 8) is startling considering how simplistic the calculation is: ignoring the effect of the nearby coast, assuming onshore currents are the same in all space, neglecting alongshore effects and assuming that zooplankton are conservative, passive tracers. We conclude that advective effects are extremely important in determining the distribution of Paracalanus parvus, and that since shallow currents give by far the best prediction, its population is concentrated in the upper 10-20 m of the water column. The second conclusion is supported by the observation that generally 0-50 m and 0-100 m casts show similar patterns in Paracalanus parvus counts. On 7 and 8 April large numbers of P. parvus were collected below 50 m while few were collected above 50 m, resulting in an over prediction of the Paracalanus parvus population. Similar calculations for Centropages brachiatus and Acartia tonsa show general agreement between observed and predicted abundances at C-3 as well (Figure 8) though both patterns have over predictions on 28 and 29 March and 7 and 8 April. The over prediction on 7 and 8 April suggests that on those days much of the zooplanktonic community may have been distributed deeper in the water column than on other days of the time-series.

The dominant species: *Acartia tonsa*

Until this point we have been presenting evidence that mass and species composition of zooplankton passing our fixed point (C-3) on the continental shelf off Peru in 1976 were associated with the onshore flow measured at 10

m depth nearshore. That advection was not the only factor determining the abundance of zooplankton at C-3 becomes clear when we consider the biological characteristics of A. tonsa, the numerically dominant copepod during this study (Figure 7). Analysis of daily collections with the 102 m mesh nets from C-3 for the percent composition of nauplii and copepodids show three peaks in copepodid proportions and two in the proportion of nauplii (Figure 9). Using the laboratory data of Heinle (1966) and the sea-surface temperatures prevailing during this time-series, a maximal growth rate of Acartia tonsa could produce an egg-to-egg cycle of 11 to 13 days with the age-structure shown in Figure 9. Comparing the age-structure of an A. tonsa population resulting from the maximum growth rate calculated from laboratory data with the observed population age-structure suggests that most of the observed proportions of nauplii and copepodids in the A. tonsa population could result from the introduction of new nauplii and copepodids on two different days followed by maximum growth (Figure 9). The days on which new nauplii would have to have been advected into the C-3 area are 27 March and 4 April 1976, days which are near the end of periods of onshore flow.

The ingestion rate of Acartia tonsa increased linearly with food concentrations (Figure 10). The ingestion experiments were done over a period of 7 days (22-28 April 1976) when the composition of phytoplankton was changing from about 50% diatoms to about 85% diatoms (Blasco, personal communication). Comparison of the results in Figure 10 with phytoplankton composition data indicate that shifts in the relative abundance of diatoms and dinoflagellates had little or no effect on the measured ingestion rate of A. tonsa. The phytoplankton were dominated by diatoms and/or Gymnodinium splendens throughout March and April 1976 (Blasco, personal communication),

and mean chlorophyll a for the euphotic zone between 28 March and 11 April 1976 ranged from $2.5 \text{ mg} \cdot \text{m}^{-3}$ to $50.5 \text{ mg} \cdot \text{m}^{-3}$ (MacIsaac et al., 1979), indicating that adequate plant food was available throughout the time-series. Since food for Acartia tonsa was abundant and of appropriate size (Morey-Gaines, 1979), and our estimates of the dates of new introductions of nauplii have a reasonable foundation, we conclude that advection and a potentially maximal growth rate operate together to create the large numbers of Acartia tonsa observed.

DISCUSSION

Previous studies of advection and zooplankton in areas of upwelling have not demonstrated explicitly the relationship of daily fluctuations in the cross-shelf patterns in species of zooplankton and onshore-offshore advection (Longhurst, 1967; Peterson et al., 1979). The combination of current meters moored at midshelf and nearshore at 15°S , cross-shelf sampling of zooplankton, and daily biological measurements of the entire midshelf water column have allowed us to demonstrate that the species composition and biomass of zooplankton at midshelf were closely related on a daily basis to onshore-offshore displacement of roughly the upper 20 m of the water column. We have been able to separate short-term advective effects on the zooplankton at midshelf and to separate that effect from the effect of in situ growth by the numerically dominant copepod in the area. The considerable variability on short time-scales (daily) observed during this study in the Peruvian upwelling system suggests that studies of seasonal means, such as that of Peterson et al. (1979), neglect a time-scale which may be important in understanding the dynamics of upwelling systems.

We did not observe any effects that we can attribute to alongshore flow, although the alongshore current is much stronger than the cross-shelf

current over the Peruvian shelf (Brink, Allen and Smith, 1978). At Mila, adjacent C-3, the alongshore flow is stronger than the cross-shelf flow by a factor of at least three for the mean, and a factor of two for the standard deviation. Nearer shore, at Agave, the differences are even greater: A factor of four or more for the means, and a factor of three for the standard deviations. If alongshore gradients were weaker than offshore gradients by a factor of two or three, alongshore currents still would have about as great an effect in producing local results at C-3 as cross-shelf currents, since the advective effect due to a component is proportional to velocity times the gradient in the given direction. Because our results can be explained by cross-shelf currents and cross-shelf biological profiles, we conclude that the alongshore gradients are even weaker. The presence of the dinoflagellate Gymnodinium splendens along the entire coast of Peru during this period (Rojas de Mendiola, 1979; Dugdale et al., 1977) also suggests that alongshore biological gradients were weak.

We would not expect our results to be found in regions where alongshore gradients are as sharp as offshore gradients, or for zooplankton species which undergo extensive diurnal vertical migration. In upwelling regions, the cross-shelf component of flow is strongly depth-dependent, with offshore flow limited to a rather thin surface layer; the compensating onshore flow may occur along the bottom as it appears to off northwest Africa (Mittelstaedt, Pillsbury and Smith, 1975) or in the interior as it does off Oregon (Huyer, 1976). Thus lateral advection of a migrating organism would depend upon the vertical structure of the currents. The upwelling circulation off Peru was generally three-layered: The surface offshore flow was confined to roughly the upper 20 m, the compensating onshore flow was maximum at mid-depth (about 60 m at C-3) and there was very weak offshore flow along the

bottom (Brink, Allen and Smith, 1978). Even though an upwelling circulation did not dominate the cross-shelf currents during the period of our study, there was significant vertical structure in the cross-shelf currents (Figure 11) which would subject migrating zooplankton to opposing lateral flows during a daily cycle. Our result that the abundance of zooplankton at C-3 is strongly affected by the near-surface current indicates that there was little or no vertical migration and that the zooplankton were concentrated in the upper layer. The conclusion that there was little vertical migration is consistent with the dominance of Acartia tonsa and the presence of oxygen-depleted water below 30 m: Acartia tonsa seldom exhibits diurnal migratory behavior (Conover, 1956) and the lack of sufficient oxygen probably also inhibits any tendency of other species to migrate downward.

In many coastal upwelling regions, the currents fluctuate with a time-scale of several days, while most species of zooplankton have a life cycle lasting several weeks. The numerical dominance of Acartia tonsa in this study may be related to the unusual temporal scales for processes affecting A. tonsa. The dominant period of onshore advection was about six days, while that for maximum reproduction and growth of A. tonsa was about thirteen days (Helzlsouer, 1966). Thus, the advective time-scale and the time-scale for maximum rates of production for Acartia tonsa are of the same order, suggesting comparable importance for the two processes. The suitability of dinoflagellates as food, observed as ingestion, may be taken to indicate the likelihood of enhanced egg production (Morey-Gaines, 1979). The numerical dominance of A. tonsa was apparently the result of its ability to grow and reproduce rapidly on a diet of dinoflagellates, its tendency not to undergo diurnal vertical migration into deeper oxygen depleted water, and conceivably to a favorable advective regime.

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Robert L. Smith provided the 1976 current meter data, and David Stuart provided data on winds. Susan A. Huntsman and Dolores Blasco participated in early discussions of data which led to this paper.

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- Figure 1. Location of zooplankton observations from R/V Alpha Helix, 28 March - 11 April 1976. C-3 is the location of the daily time series. Currents were measured at 10 and 29 m at Agave (Δ) and at 28, 53 and 78 m at Mila (O). The wind was measured at a coastal station at Punta San Juan.
- Figure 2. Settled volume and biomass of the zooplankton at C-3, cross-shelf current at Agave and wind at San Juan. Settled volume is shown for 50 and 100 m net hauls of the 300 μ m Hensen net; biomass as dry weight is shown for 100 m hauls of both 102 μ m Bongo net and the 300 μ m Hensen net. The cross-shelf current at 10 m Agave is shown (—) with its time integral (---) depicting displacement of a water mass from its position on 3 April if the currents were homogeneous in space.
- Figure 3. Vertical profile of the concentration of dissolved oxygen at C-3, from Alpha-Helix stations 20, 22, 24, 27-29, 31 and 33, made daily 3 April to 11 April 1976. Values were determined with a polarographic oxygen electrode (MacIsaac et al., 1979).
- Figure 4. The offshore distribution of biomass collected in vertical hauls of the 300 μ m Hensen and 102 μ m Bongo nets between 1 and 5 April, 1976. All hauls except the Hensen net haul at 110 km offshore were made during daylight. Within 5 km of shore, net hauls were made to 50 m; between 5 and 25 km, net hauls were made to 100 m; farther offshore, net hauls were made to 200 m.

- Figure 5. Time-series of the observed and "predicted" biomass at C-3 for the 102 μ m Bongo net and the 300 μ m Hensen net. "Predicted" biomass is computed from the onshore (positive) or offshore (negative) displacement of the offshore profile of biomass from its assumed position of 3 April (Figure 4).
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- Figure 7. Time-series of the abundance of various species of zooplankton in the continental shelf, continental slope and oceanic groups, with the cross-shelf component of the current at 10 m Agave (—) and its time integral(---). All abundances are from the 50 m haul of the Hensen net.
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Figure 11. Observed midshelf, onshore (positive) and offshore (negative) flow at C-3, 28 March - 11 April 1976. Data are from 10 m at Agave and 28, 53, and 78 m at Mila.

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Table I. Mean Current Meter Data

Position and Instrument Depth	$\bar{u}(\text{cm s}^{-1})^1$	$\bar{v}(\text{cm s}^{-1})^2$	$\bar{T}(^{\circ}\text{C})$
Agave 10 m	-0.7	9.8	15.59
29 m	1.8	-3.5	15.12
Mila 28 m	6.3	-19.9	15.50
53 m	3.6	-22.6	14.65
78 m	2.3	-19.0	14.36

¹Positive (negative) values are for onshore (offshore) flow.

²Positive (negative values) are for equatorward (poleward) flow.

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Fig 4

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fig 5

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fig. 6

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Fig 7

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Fig 8

Fig 2
continued

Fig 11
depth