

DYNAMIC OF TOXIC DINOFLAGELLATES DURING AN UPWELLING EVENT AT THE NORTHWEST COAST OFF PORTUGAL

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Abstract

The dynamics of *Gymnodinium catenatum* and *Dinophysis acuta* was studied during the development of a weak upwelling event observed in a repeated coverage of a combined CTD/plankton transect at 41°05'N, off the coast of Portugal. Both species were mainly distributed in the surface wind driven layer within the region of the equatorward coastal jet. Wind induced mixing, offshore transport and vertical motions were reflected in the distribution and the number of cells. It was generally observed that wind relaxation was associated with blooming conditions and shellfish toxicity, while active winds gave rise to dispersion of cells, reduction of their number and detoxification of bivalves.

INTRODUCTION

Since 1985 blooms of *Gymnodinium catenatum* and of species of the genus *Dinophysis*, like *D. acuta*, *D. sacculus* and *D. acuminata*, along the western coast of Iberian Peninsula have been associated with recurrent toxicity problems involving, respectively, paralytic shellfish poisoning (PSP) and diarrhetic shellfish poisoning (DSP) (Fraga, Anderson, Bravo, Reguera, Steidinger and Yentsch, 1988; Reguera, Mariño, Campos, Bravo, Fraga and Carbonell, 1993; Sampayo, 1989; Sampayo, Alvito, Franca and Sousa, 1990). Off Rías Baixas (NW Galicia), these dinoflagellates belong to phytoplankton assemblages characteristic of late stages of succession in the coastal upwelling ecosystem (Figueiras and Rios, 1993). Proliferations of these species in several pulses are also a common feature during summer and autumn in the rias (Fraga, Reguera and Bravo, 1990) as well as in Portuguese coastal lagoons (Sampayo *et al.*, 1990).

In the Iberian area, significant development of *G. catenatum* has never been referred to occur north of cape Finisterre. Until 1990 blooms of this species occurred mainly north of Lisbon during summer and autumn (Moita, 1993), while in 1992-93 large cell numbers have been observed south of Lisbon even during winter (Sampayo and Vilarinho, personal communication). In 1985-87 the major outbreaks in the Galician rias took place during autumn, associated with southerly wind events that caused shoreward advection of coastal waters, eventually penetrating into the rias (Reguera, Campos, Fraga, Mariño and Bravo, 1991). Maximum cell counts were observed in the upper 5 m in the outer parts of the rias. The same authors mention that, since 1988, weak summer outbreaks of this species have also occurred

in stratified conditions during moderate upwelling. In such cases surface counts were very low, the cell maxima being observed in the thermocline.

Reguera *et al.* (1993) relate the growth of *D. acuta* and other species of *Dinophysis* to the establishment of a thermocline (10-15 m) under which the maximum concentrations are found, in the temperature range 15-17.5 °C, at salinities above 35. These authors suggest that extremely dry, hot summers combined with moderate upwelling pulses, which allow thermoclines to persist at suitable depths, may give rise to suitable conditions for unusual summer blooms of *D. acuta* in the Galician rias.

Blooms of flagellates have been associated with different hydrodynamical conditions within and between water masses. In particular, coastal currents and coastal trapped buoyant plumes have been referred as playing a major role in the development and advection of the blooms and the associated toxicity (Franks and Anderson, 1992; Lindahl, 1993). During spring and summer the Portuguese shelf north of the Nazaré canyon (ca. 39°30'N, Figure 1) tends to be occupied by a shallow lens of reduced salinity, roughly limited below by the seasonal pycnocline. The lens must be the result of the combined contributions of water from the NE Atlantic and the Bay of Biscay, being modified by local river runoff and interaction with Central Water upwelled near the coast (Jorge da Silva, 1992a). Upwelling events have been observed to disrupt the structure of this lens near the coast (Jorge da Silva, 1992a,b) or to push its coastal limit offshore (Jorge da Silva, 1992b), mainly depending on wind strength and persistence (Jorge da Silva, 1992c).

In this paper the cross-shelf and vertical distributions of *D. acuta* and *G. catenatum* during their nearly simultaneous blooming in the northwest coast of Portugal is discussed in relation to the development of an upwelling event and the associated dynamics, as well as with the presence of near-surface stratification conditions.

THE DATA

From 19 to 27 August 1987 a combined hydrographic/plankton section was repeated daily over the western Portuguese shelf and slope roughly off the city of Oporto (Figure 1). CTD data, using a *NBIS Mk IIIB* instrument, were collected along the section from on board *R/V Almeida Carvalho*. When the third repetition had just begun the CTD hit the bottom and the temperature sensor was damaged. The observations were, therefore, concluded using *Nansen* bottles equipped with reversing thermometers.

A *General Oceanics* 101512 rosette sampler (or *Nansen* bottles from the third repetition on) was used to collect samples for nutrients and phytoplankton studies at every other CTD station over the shelf and every third station over the slope, starting at the coastalmost one. Sampling levels were 5, 10, 20, 30, 40, 50 and 75 dbar (or near bottom in shallow areas).

During the whole study, coastal winds were measured at an *Aanderaa* automatic weather station installed near Ferrel, at an altitude of 17 m in a well exposed area with no distinct topographic features, some 200 km to the south of the section (Figure 1).

Phytoplankton samples were preserved with hexamethylenetetramine buffered formalin to a final concentration of 2% (Thronsdon, 1978). Subsamples of 100 ml were allowed to settle for 3 days. Cells were identified and counted by the Utermohl technique (Hasle, 1978). In this paper the authors' concern will essentially be related to two dinoflagellate species, namely *Dinophysis acuta* and *Gymnodinium catenatum*.

CTD data were processed as described in Jorge da Silva, Marreiros and Almeida (1992). The wind time series, collected at 30-min intervals, was filtered to produce hourly values, and subsequently low-pass filtered ($f_c = 0.028$ cph) with a third order *Butterworth* filter that preserves 95% of the signals with 50-hour periods and 5% of signals with 20-hour periods. Prior to low-pass filtering, the eastward and northward wind stress components (τ_E, τ_N) were calculated using the quadratic drag law

$$(\tau_E, \tau_N) = \rho_a C_D |\vec{v}| (u, v)$$

where \vec{v} is the wind vector, (u, v) are, respectively, the eastward and northward wind components, ρ_a is the air density (1.22 kg m^{-3}) and C_D is the drag coefficient (0.0012).

RESULTS

The summer upwelling season of 1987 was rather weak, the main favorable wind events having occurred in mid May to mid June (Vitorino, 1989) and intermittency being the main characteristic of the remaining months (Jorge da Silva, 1992c). Somehow reflecting this situation, at the beginning of the observations, on 19 August, blooms of large autotrophic dinoflagellates, in particular *Ceratium fusus* (1.3×10^6 cells l^{-1}), dominated a characteristic late summer / early autumn plankton community. At the same time, *G. catenatum* and *D. acuta* reached, respectively, 36×10^3 cells l^{-1} and 69×10^3 cells l^{-1} .

The wind was weak to moderate from an upwelling favorable direction during the investigations (Figure 2). The near surface response of the ocean, clearly revealed by the offshore displacement of the isotherms over the shelf (Figure 3), occurred within 1 day of the onset of a significant forcing. The effect of the weak wind pulse of 17-19 August could still be noticed as inshore temperature values lower than 15°C . In the water column the induced vertical motion near the coast was quite obvious as an uplifting of isohalines and isopycnals, with surface outcropping at the innermost 20 km (Figure 6).

Dinophysis acuta was basically distributed over the inner and mid shelf, the largest mean values being observed inshore during periods of wind relaxation (Figure 4), with water column maxima being found in association with the largest inshore vertical density gradients (Figure 7). *Gymnodinium catenatum* was distributed over the whole shelf. Mean values tended to reflect the cross-shelf water transport associated with wind pulses both as an offshore displacement of the maximum and as a reduction of the average number of cells (Figure 5).

During the relaxation of the short wind event that peaked on 18 August the maximum number of cells of *D. acuta* occurred inshore in the upper 10 or 20 dbar (Figure 7), usually in water with salinity above 35.4 and density anomaly greater than 26.0 kg m^{-3} (Figure 6).

G. catenatum showed a similar behaviour but significant cell numbers were also found at mid shelf, extending vertically down to the basis of the seasonal pycnocline.

On 22 August the surface water was less saline and less dense, particularly at the innermost 10 km (Figure 6). Maximum cell numbers of *G. catenatum* on that day extended over deeper levels and greater distance from the coast than 2 days before, significant values still being found close to the bottom of the pycnocline (Figure 7). On the other hand, maxima of *D. acuta* were absent from the near surface, in an apparent indication that the lighter inshore water contained no cells of this species although it was rich in *G. catenatum* (Figure 7).

The northerly wind event that peaked on 22 August (Figure 2) gave rise to coastal upwelling and surface mixing. On 24 August the density anomaly in the surface layer was greater than 26.0 kg m^{-3} all over the mid and inner shelf and the salinity was above 35.6 everywhere but at the surface in the innermost station (Figure 6). Cell numbers of *D. acuta* had the same order of magnitude from the near surface to 20 dbar at the innermost 10-15 km (Figure 7). Below that level the number of cells was drastically reduced, in contrast with the situation of 22 August.

On 23 August (not shown) cell numbers of *G. catenatum* were maximum in a band extending from 10 dbar at 10 km to 30 dbar at 30 km, roughly following the 26.8 kg m^{-3} isopycnal. On 24 August, however, the values were lower, evidencing greater vertical homogeneity with the exception of the innermost station where no cells were found below 10 dbar (Figure 7).

Wind relaxation occurred again on 25 August (Figure 2) and the average cell number of *D. acuta* was seen to increase near the coast (Figure 4). This contrasts with the distribution of *G. catenatum* which showed a minimum close to the coast (Figure 5). On 26 August, *D. acuta* was basically confined to the upper 20 dbar, with maximum values at 5 dbar in the innermost 10 km. Instead, the largest cell counts of *G. catenatum* were obtained in the upper 10 dbar at 20 km from the coast (Figure 7).

On 27 August the number of cells of both species decreased again (Figures 4 and 5), in an apparent association with the wind peak the day before (Figure 2).

DISCUSSION

Based on direct current measurements conducted at three mooring positions covering the whole shelf along the CTD/plankton section, Jorge da Silva (1992c) described the shelf circulation associated with the upwelling process in the area. Matching his interpretations of the current system on 19 August, just after the short northerly wind peak (Figure 2), with the present vertical distributions (Figures 6 and 7) on 20 August, it is possible to arrive at the following:

- The wind driven surface (Ekman) layer was roughly limited below by the isopycnal of 26.8 kg m^{-3} ;
- The offshore extension of the equatorward coastal jet was likely to coincide approximately with the 35.7 isohaline;

- The poleward undercurrent had its core at 50-60 km from the coast, along and below the coastal limit of the offshore salinity maximum;
- The onshore subsurface motion was most important beneath the offshore salinity maximum;
- Near bottom onshore motion was likely to bring deeper water to pressure levels above 100 dbar at mid shelf;
- Both dinoflagellate species were mainly distributed in the wind driven layer within the coastal equatorward jet;
- A secondary maximum of *G. catenatum* was present near the bottom within the coastal salinity maximum, where the motion tended to be generally poleward and onshore.

As a consequence of the wind event that began on 22 August, the coastal equatorward jet intensified and underwent offshore displacement, with an inshore counter-current being noticeable on 25-26 August (Jorge da Silva, 1992c). The wind driven surface layer was, however, restricted to the upper 30 m or less, at least over the inner and mid shelf (Figure 6). The water column remained two-layered after the upwelling event, which Jorge da Silva (1992c) attributed to the relatively mild wind conditions.

Positive cell counts were essentially found in the wind driven surface layer, and reflected the vertical oscillations of its base. This was particularly evident on 26 August in the distributions of both dinoflagellate species (Figures 6 and 7). It is interesting to compare the distributions of cells on that day with those on 20 August, also obtained after wind relaxation (Figure 2) and when surface salinities were similar close to the coast. It is tempting to interpret the differences in cell distributions as due to either totally different stratification conditions, resulting from the different strength of the upwelling events, or different longshore dynamics close to the coast: equatorward jet on 20 August, and poleward counter-current on 26 August (Jorge da Silva, 1992c).

Toxicity by both DSP and PSP was observed during the cruise in the mussel *Mytilus edulis* (intertidal) and the clam *Spisula solida* (caught at the bottom inshore of the 35 m isobath). The samples were collected on 24 August in the area off Oporto, and a ban was imposed on shellfish harvest. It seems reasonable to link the shellfish toxification with the high numbers of both *D. acuta* and *G. catenatum* observed inshore at the beginning of the cruise. Conversely, the lower abundance of both dinoflagellates after 23 August, particularly in inshore near-bottom waters (Figure 7), is likely to be the main reason of the confirmed absence of shellfish toxicity after 31 August.

The lower cell counts obtained after 23 August, and the subsequent absence of shellfish toxicity, may be due to replacement of the inshore bottom water, in a direct consequence of the upwelling event. Alternatively, one may think that the offshore displacement of the equatorward jet, as well as of the upwelling source region (Jorge da Silva, 1992c), may have replaced the water in the coastalmost 10 km, when the inshore counter-current was established in the last days of the cruise.

Whenever the observations happened to have extended to the bottom at mid shelf they tended to reveal a weak maximum in cell number of (at least) *G. catenatum* (20, 22 August, Figure 7). The development of upwelling, giving rise to a shoreward compensation current at depth, may have carried this maximum inshore (26 August). Actually, the intensification of the equatorward jet may have originated, through bottom friction, onshore motion in the near

bottom layer (Jorge da Silva, 1992c). It may, thus, be hypothesized that cyst re-suspension and germination is likely to underlie the presence of this maximum, although the possibility of offshore sinking in a vertical circulation cell should not be excluded as a possible cause of its presence.

CONCLUSIONS

At the mid-term of a weak summer upwelling season off Oporto (Portugal), dinoflagellates dominated a plankton community characteristic of early autumn in which *Gymnodinium catenatum* and *Dinophysis acuta* represented, at most, 5% of the most abundant species. These two species were distributed over the shelf, *D. acuta* being absent from its outer part. They were mainly present in the surface layer within the region of the equatorward jet characteristic of coastal upwelling. During a short lasting wind induced upwelling event of moderate intensity, the water column remained two-layered and the distribution of those dinoflagellates reflected the vertical displacement of the pycnocline.

Upwelling and the associated wind mixing apparently caused offshore transport, dispersion and reduction in the number of cells, which was particularly evident with *G. catenatum* due to its wider distribution area. It is suggested that stronger stratification conditions favor the development of both dinoflagellate species, but it is not clear whether the nearshore dynamics plays also a relevant role.

Shellfish toxicity was positively linked to blooming of both dinoflagellates in inshore waters. Subsequent detoxification was associated to the decline of the blooms which appeared to be caused by development of coastal upwelling.

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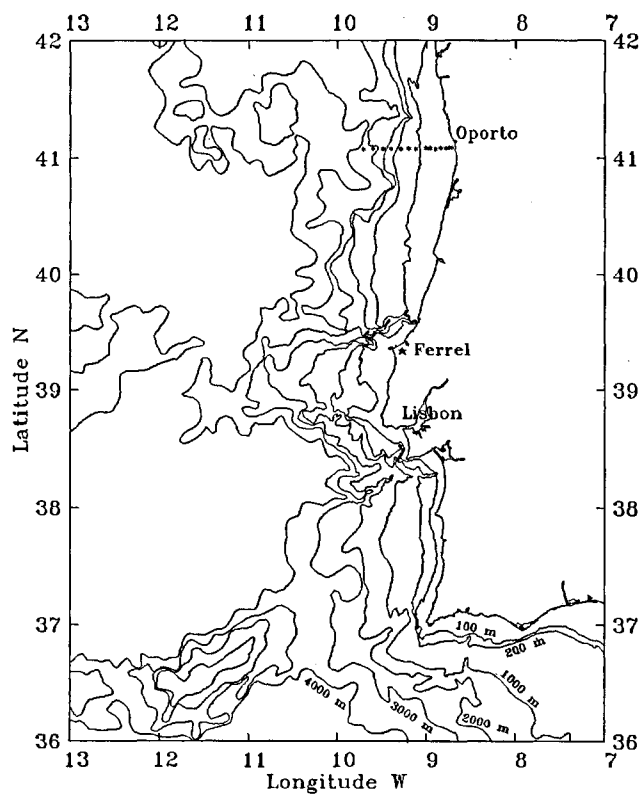


Figure 1. Bathymetric chart of the coast of Portugal (isobaths in metres), position of the repeated section and approximate location of the coastal automatic weather station of Ferrel.

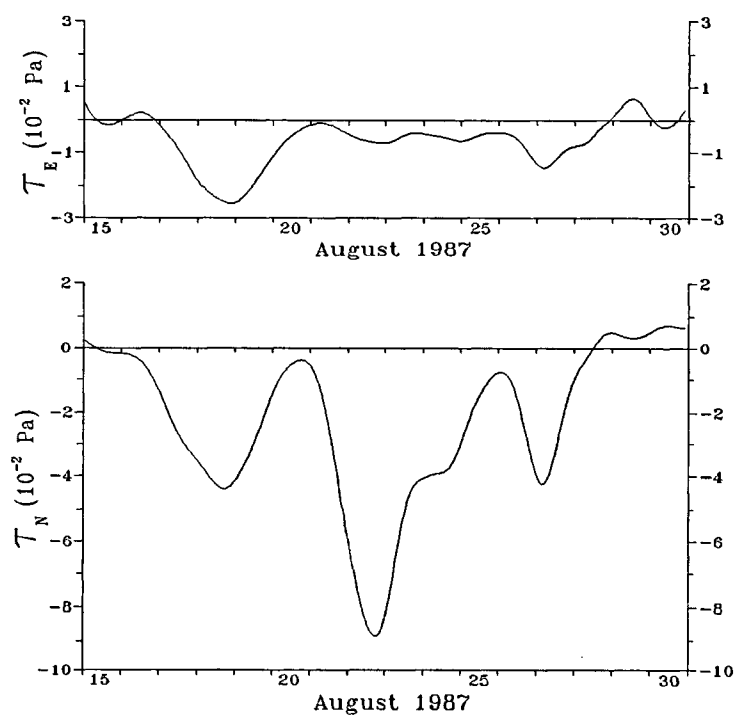


Figure 2. Coastal wind stress at Ferrel, August 1987.

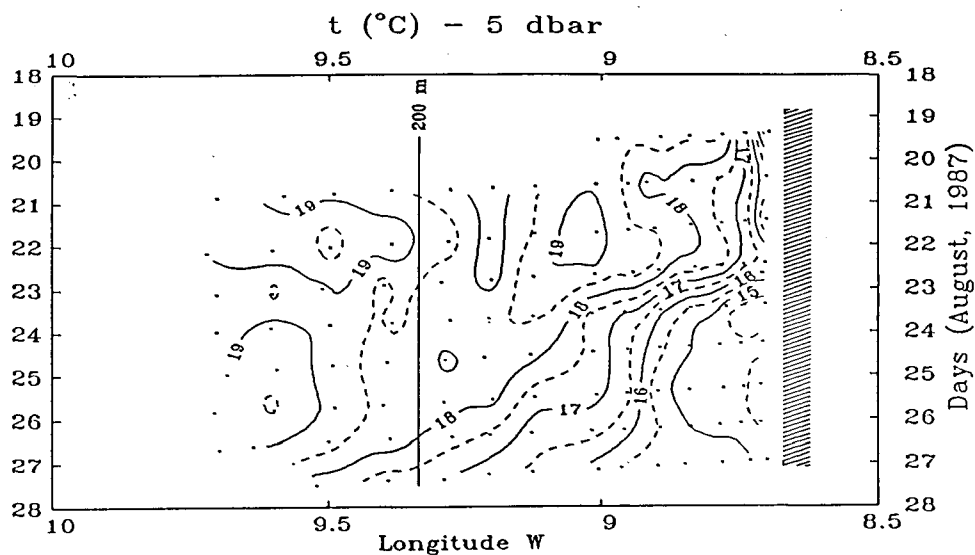


Figure 3. Space-time representation of temperature at 5 dbar. The vertical line indicates the position of the 200 m isobath.

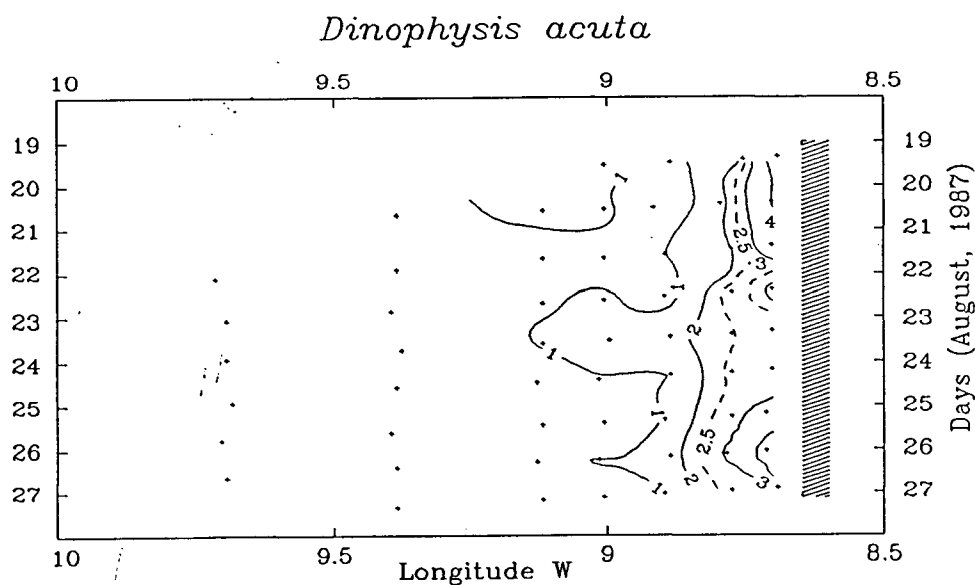


Figure 4. Space-time representation of the mean cell count of *D. acuta* in the water column (log no. cells l⁻¹).

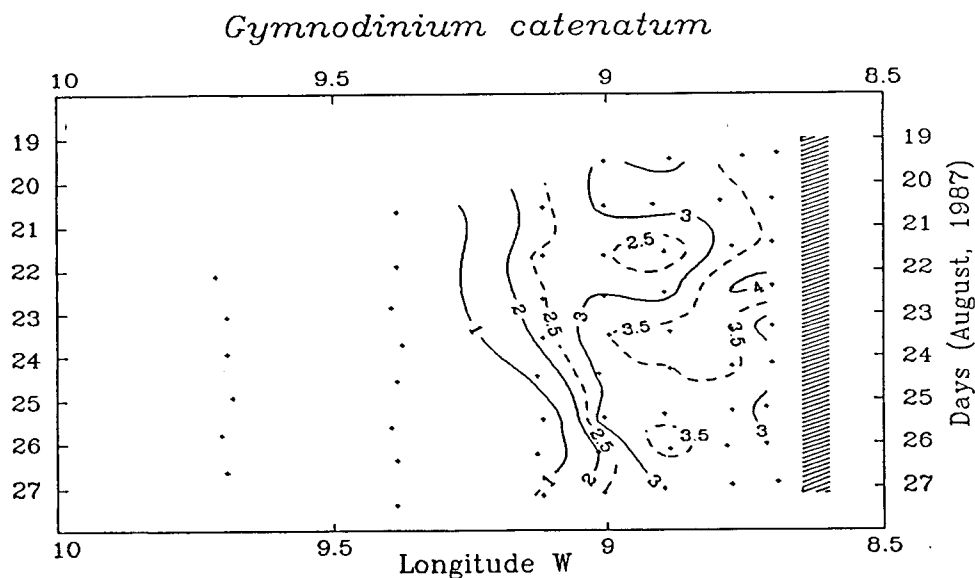


Figure 5. Space-time representation of the mean cell count of *G. catenatum* in the water column (log no. cells l⁻¹).

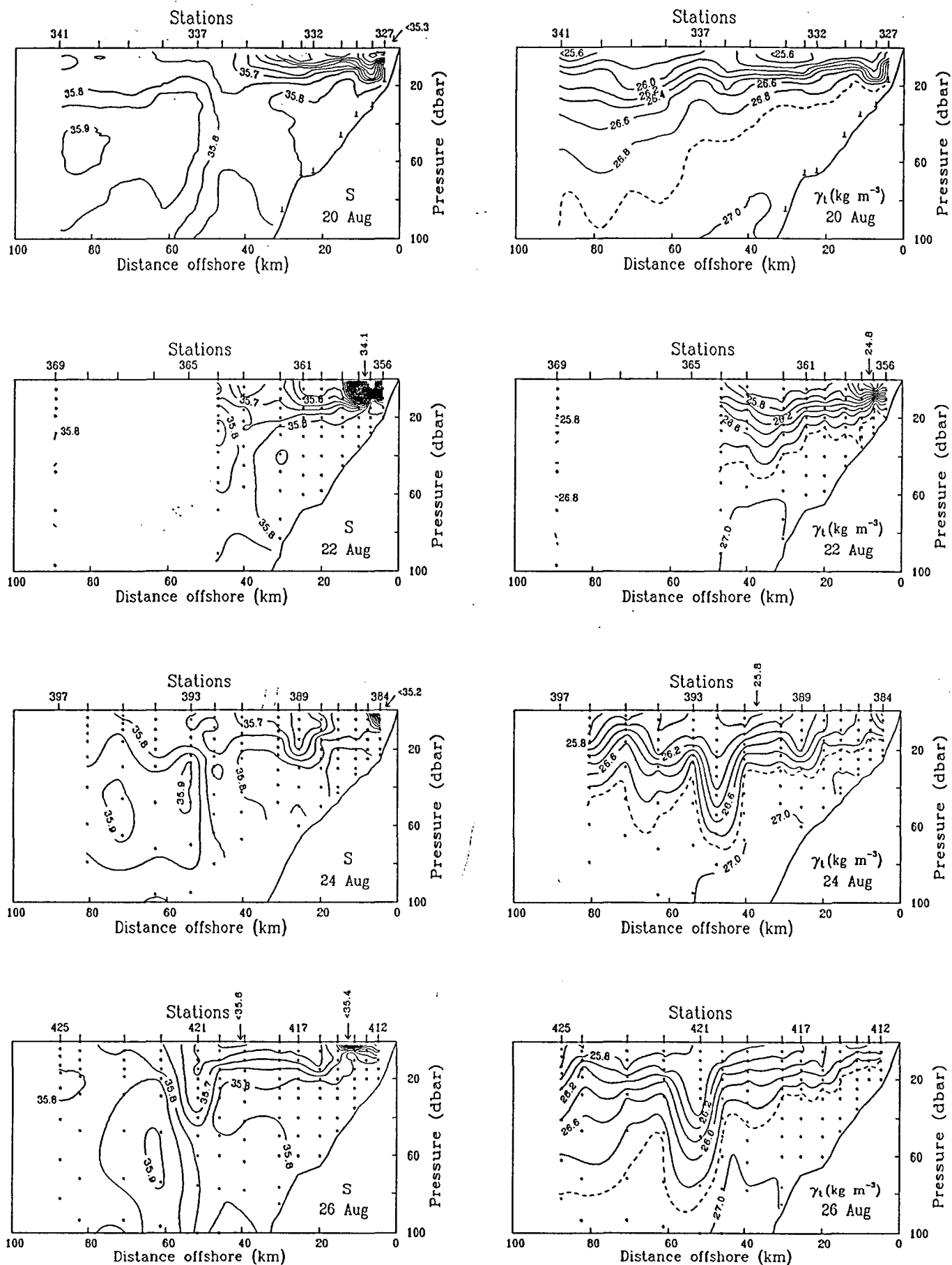


Figure 6. Vertical distributions of salinity and density anomaly at the repeated section (Lat 41°05'N), August 1987.

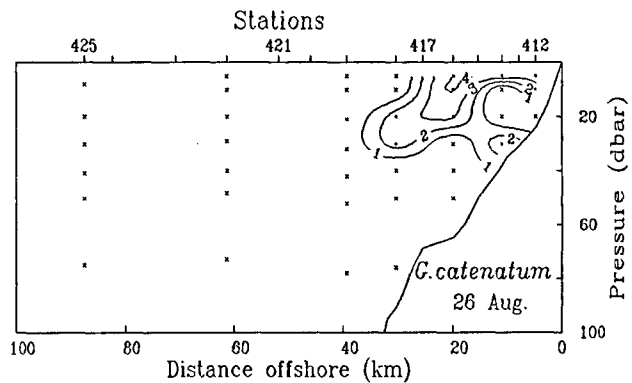
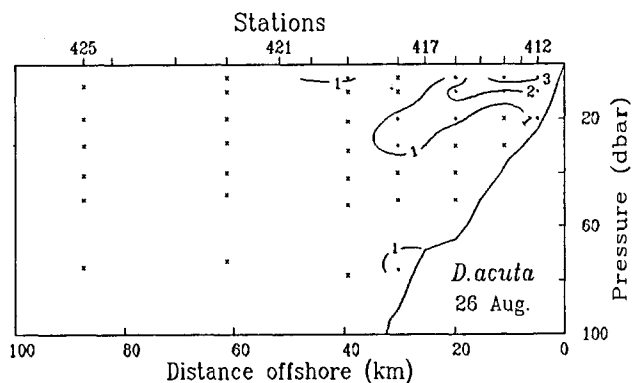
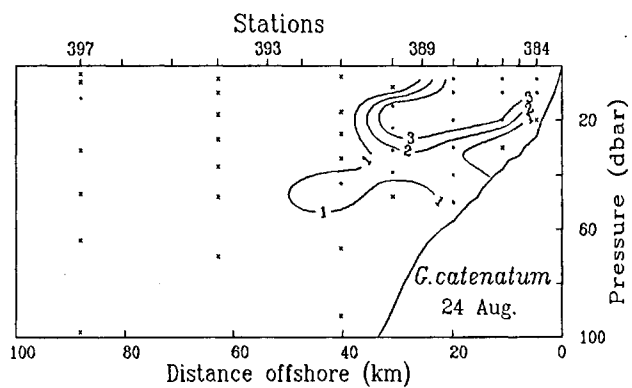
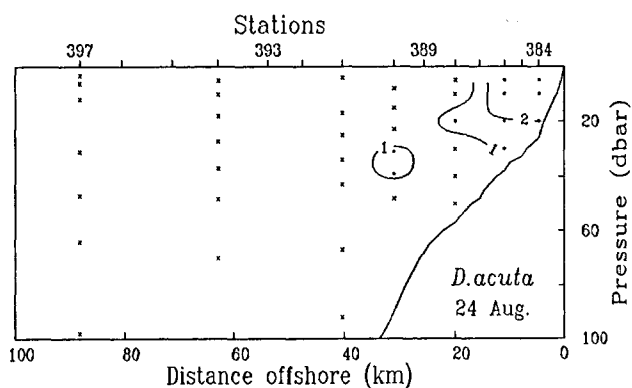
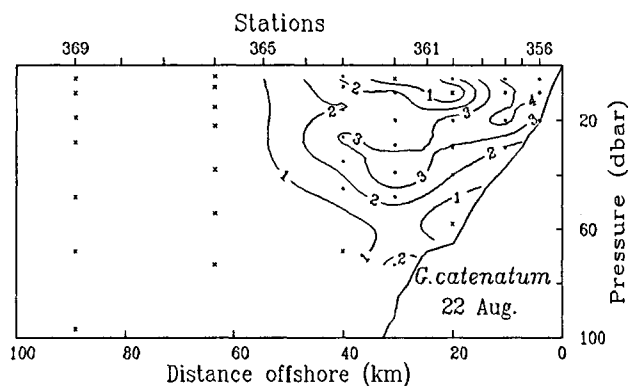
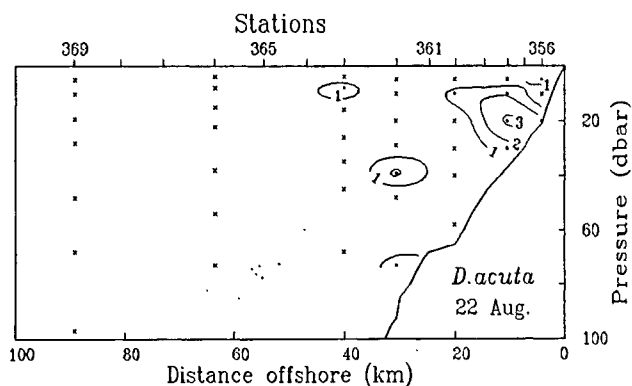
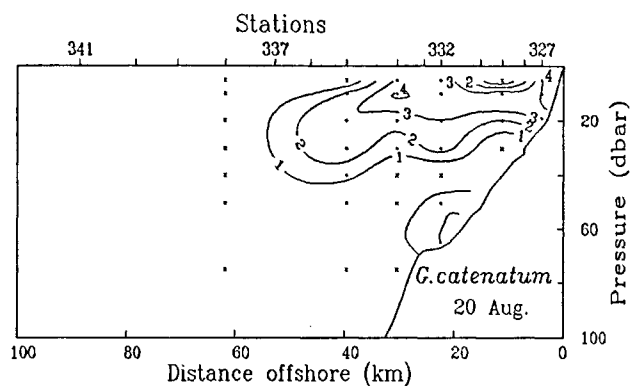
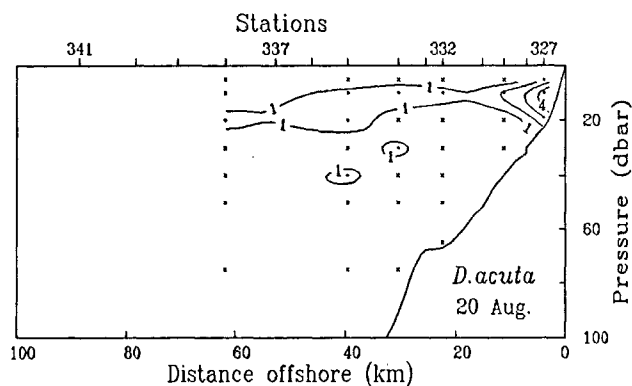


Figure 7. Vertical distributions of *D. acuta* and *G. catenatum* (Log no. cells l^{-1}) at the repeated section (Lat $41^{\circ}05'N$), August 1987 (station levels with positive cell counts are represented by dots and those with zero cell counts by crosses).