International Council for the Exploration of the Sea

C.M. 1993/L:17
Biological Oceanography Committee

Upwelling around the southwest Irish coast : Near-surface dynamics and blooms of the dinoflagellate *Gyrodinium* cf. *aureolum* (Hulbert).

R. Raine, B. Joyce, J.W. Patching, University College Galway, Ireland.
K. Jones, J. Richard, The Dunstaffnage Marine Laboratory, Oban, Scotland.

Abstract

An upwelling system has been described for coastal waters around southwest Ireland. Exceptional blooms, or "red tides", of the dinoflagellate *Gyrodinium aureolum* have frequently occurred in the region which have an origin in the adjacent shelf waters. The advection of these blooms towards the coast is a result of surface wind effects, which are more obvious in the large embayments of southwest Ireland which are axial to the prevailing south-westerly winds. In addition, this organism accumulates at the frontal zones between upwelled water and the adjacent stratified shelf waters, effectively a situation where the pycnocline is forced towards the sea surface.

The role of upwelling in promoting extensive populations of *G. aureolum* is examined. In particular, relationships between surface wind stress and both upwelling and surface advective bloom transport are discussed.

Introduction

Large dinoflagellate blooms have become regular occurrences in western European coastal waters and elsewhere over the past two decades. These blooms, referred to as either "exceptional" blooms due to their very high chlorophyll concentration (Tett, 1987) or as "red tides" due to water discolouration, often occur in late summer and *Gyrodinium* cf. *aureolum* (Hulbert) has been identified as the causative organism on a number of these occasions (Tangen, 1977; Richardson and Kullenburg, 1987).

Several instances now exist associating *Gyrodinium aureolum* with extensive blooms in coastal waters around southwest Ireland. The earliest records go back to August 1978 (Roden *et al.*, 1980) when a bloom was recorded in Roaring Water Bay, inside the Fastnet Rock, and extended some 100 Km eastwards along the south coast (Pybus, 1980). An exceptional bloom of this organism was recorded again in August, 1979 (Roden *et al.*, 1981). Both of these blooms were associated with the death of marine organisms including benthic invertebrates and farmed fish. In 1984, large populations (up to 500,000 cells.l^{-1}) were recorded around the Fastnet Rock and comparable populations were also noted in 1987 in Bantry Bay (Raine *et al.*, 1990a).

The coastal region around southwest Ireland is known to be periodically influenced by upwelling (Raine *et al.*, 1990a). Although it is likely that the upwelling is driven by surface wind speed and direction, this has yet to be confirmed. The influence of geostrophic effects on advective currents alongshore or the propagation of internal waves originating from the shelf-break have yet to be examined. Frontal regions between the upwelling zone and adjacent thermally stratified waters could, however, be a site of bloom formation, as frontal regions such as the tidal fronts in the Irish Sea have frequently been associated with large populations of *G. aureolum* in summer.

This paper examines the combined effect of surface wind stress and upwelling in promoting coastal blooms of *G. aureolum*.

Methods

Studies were carried out in July and August, 1991 in Bantry Bay, southwest Ireland and adjacent coastal waters (Figure 1). Conventional CTD, incorporating a Sea Tech in situ fluorometer, and water bottle casts for nutrients and chlorophyll were made at a series of stations aligned axially to Bantry Bay. The transect was sampled on five occasions between 15th July and 8th August. These measurements were supplemented by the deployment of an instrument buoy at station 3 (Figure 1) over the entire period. The instrument array consisted of a string of four current meters, a thermistor chain and surface meteorological station (wind speed and direction, surface irradiance) In addition an in situ fluorometer (Sea Tech) for recording chlorophyll fluorescence was suspended from the buoy at a depth of 7 m.

Details of all analytical techniques and the moored instrument array may be found in Raine *et al.* (1993a) and Edwards *et al.* (1991) respectively.

Results

Distributions of temperature and water density along the transect of stations on three sampling occasions are presented in Figure 2. It may be seen that a wedge of cool dense water had intruded into the bay between the 15th and 31st July, and that this had regressed out of the bay by 8th August. Analysis of the current meter record (Figure 3a) confirmed a net overall influx of water along the bottom up to 31st of July, and a rapid efflux over the period 31st July to 2nd August. The effects on water column structure are best illustrated from the thermistor chain record (Figure 3b). It can be noted that the efflux and influx events have a periodicity of the order of a 3-5 days. The events did not therefore correlate with either semi-diurnal or spring-neap tidal effects.

The periodicity was more in phase with meteorological patterns such as the drift of depressions across the study area. This is apparent when the current meter and temperature profile patterns are compared with the component of surface wind speed and direction which is axial to the bay (Figure 3c). Over the sampling period winds were variable but were predominantly cyclonic south to southwesterlies, the prevailing wind direction over the west of Ireland. When the axial component of the wind was southwesterly, i.e. blowing into the bay, there was a net inflow of water at the surface and net outflow at the bottom of the water column. When the axial component was northeasterly, blowing down the bay out to sea, water movements were opposite, out of the bay at the surface and into the bay at the bottom as occurred over 30th July. It should be noted, however, that surface water movements out of the bay also occurred during calm conditions.

Of particular importance is the switch in axial wind direction that occurred during 30th July. This caused a large surface inflow and bottom outflow, with net bottom water current speeds of up to 16 Km d^{-1}. The resultant exchange was equivalent to approximately 65% of the volume of Bantry Bay. The 7 m fluorescence record after 31st July shows a marked increase in signal output (Figure 3d). This was due to an influx of a population of *G. aureolum* which had been associated with the pycnocline in waters outside the bay (Raine *et al.*, 1993a). Concentrations of this organism reached 2,000,000 cells l^{-1} and the water inside Bantry Bay was visually discoloured when the pycnocline had been elevated to within a few meters of the surface.

Discussion

Water column structure around southwest Ireland ranges from an upwelling situation to one that is fully stratified (Raine *et al.*, 1990a; 1990b). Observations taken in the region in late summer have indicated that upwelling does not always reach the sea surface, but can have the effect of shallowing the seasonal pycnocline to within 25-30 m of the sea surface. The pycnocline is thus uplifted to a depth well within the euphotic zone and is associated in late summer with a chlorophyll maxima containing predominantly dinoflagellate communities (Raine *et al.*, 1993b).

Roden *et al.* (1981), reporting on the 1979 *G. aureolum* bloom around Sherkin Island, SW Ireland, demonstrated the association of the organism with a frontal region moving shorewards. Given that the oceanography of southwest Ireland is highly variable and that upwelling occurs there reasonably regularly in summer, it is most likely that the frontal system Roden *et al.* (1981) describe was not a tidal front but a weak coastal front (*sensu* Holligan, 1981), separating upwelled and stratified water, moving shorewards due to surface wind stress effects as described in this paper.

The influx of bottom water observed in this study is a baroclinic wave caused by changes in surface wind stress. The effect is similar to the internal surge or seiche in Loch Ness (Thorpe. 1971; 1977), a long, narrow freshwater lake aligned to the prevailing wind. It is thus highly probable that the events occurring inside Bantry Bay observed in this article also occur in all marine embayments aligned to the prevailing wind direction and which are relatively long and narrow.

The effects of upwelling in promoting dinoflagellate blooms in the southwest of Ireland may be summarised as follows. First, the pycnocline on the adjacent shelf is uplifted into the euphotic zone thereby stimulating phytoplankton growth. The uplift may extend to the sea surface forming a frontal region where dinoflagellates flourish. Secondly, upwelling (or downwelling that occurs after these events) may affect the speed which bottom water flows into and out of Bantry Bay. Attempts to model the water movements with surface wind stress as the driving variable fit the data set presented here very well with the exception of the efflux speed of bottom water noted on 31st July to 2nd August (A. Edwards pers. comm.). This was much higher than predicted by the model and cannot be explained in terms of wind effects alone. A downwelling event on the shelf outside the bay would have accelerated the current speed but the data set does not extend far enough onto the shelf to confirm this effect. Finally, it should be noted that upwelling around southwest Ireland also promotes diatom blooms within the upwelling region. This effect is discussed elsewhere (Raine et al., 1993c).

Acknowledgements

The authors would like to thank the crew of the R/V Lough Beltra for their invaluable assistance. This work arose from a study sponsored by the European Commission (DG XII : Marine Science and Technology).

References

Edwards, A., Graham, J., Jones, K, and MacDougall, N. 1991. Specifications of the DML mooring, Ria de Vigo, 1990. Marine Physics Group Report No. 75, Dunstaffnage Marine Laboratory, Oban, Scotland. 16pp.

Holligan, P.M. 1981. Biological implications of fronts on the northwest European continental shelf. Phil. Trans. R. Soc. Lond., A302: 547-562.

Pybus, C. 1980. Observations on a *Gyrodinium aureolum* (Dinophyta) bloom off the south coast of Ireland. J. mar. biol. Ass. UK, 60: 661-674.

Raine, R., O'Mahony, J., McMahon, T. and Roden C. 1990a. Hydrography and phytoplankton of waters off southwest Ireland. Estuarine, Coastal and Shelf Sci., 30: 579-592.

Raine, R., McMahon, T., O'Mahony, J., Moloney, M. and Roden, C. 1990b. Water Circulation and Phytoplankton populations in two estuaries on the west coast of Ireland. In Estuarine Ecotoxicology. pp.19-28. Ed. by

P.L. Chambers and C.M. Chambers. JAPAGA, Ashford, Wicklow, Ireland. 161 pp.

Raine, R., Joyce, B., Richard, J., Pazos, Y., Moloney, M., Jones, K., and J.W. Patching. 1993a. The development of a large bloom of the dinoflagellate Gyrodinium aureolum on the south west Irish coast. ICES J. mar. Sci., in the press.

Raine, R., McMahon, T. and Roden, C. 1993b. A review of the summer phytoplankton distribution in Irish coastal waters : a biogeography related to physical oceanography. Occ. Publ. Ir. biogeog. Soc. 2, in the press.

Raine, R., McMahon, T., Roden, C., and J.W. Patching. 1993c. Upwelling and the phytoplankton ecology of southwest Irish coastal waters. ICES CM 1992/L:18.

Richardson, K. and G. Kullenberg. 1987. Physical and biological interactions leading to plankton blooms: A review of *Gyrodinium aureolum* blooms in Scandinavian waters. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 187: 19-26.

Roden, C.M., Ryan, T., and Lennon, H.J. 1980. Observations on the 1978 red tide in Roaring Water Bay, Co. Cork. J. Sherkin Island, 1: 105-118.

Roden, C.M., Lennon, H.J., Mooney, E., Leahy, P. and Lart, W. 1981. Red tides, water stratification and phytoplankton species succession around Sherkin Island, south-west Ireland, in 1979. J. Sherkin Island, 1: 50-68.

Tangen, K. 1977. Blooms of *Gyrodinium aureolum* (Dinophyceae) in north European waters, accompanied by mortality in marine organisms. Sarsia, 63: 123-133.

Tett, P. 1987. The ecophysiology of exceptional blooms. Rapp. P-v. Reun. Cons. int. Explor. Mer, 187, 47-60.

Thorpe, S.A. 1971. Asymmetry of the internal seiche in Loch Ness. Nature, 231, 306-308.

Thorpe, S.A. 1977. Turbulence and mixing in a Scottish loch. Phil. Trans. R. Soc. Lond. A., 386,125-181

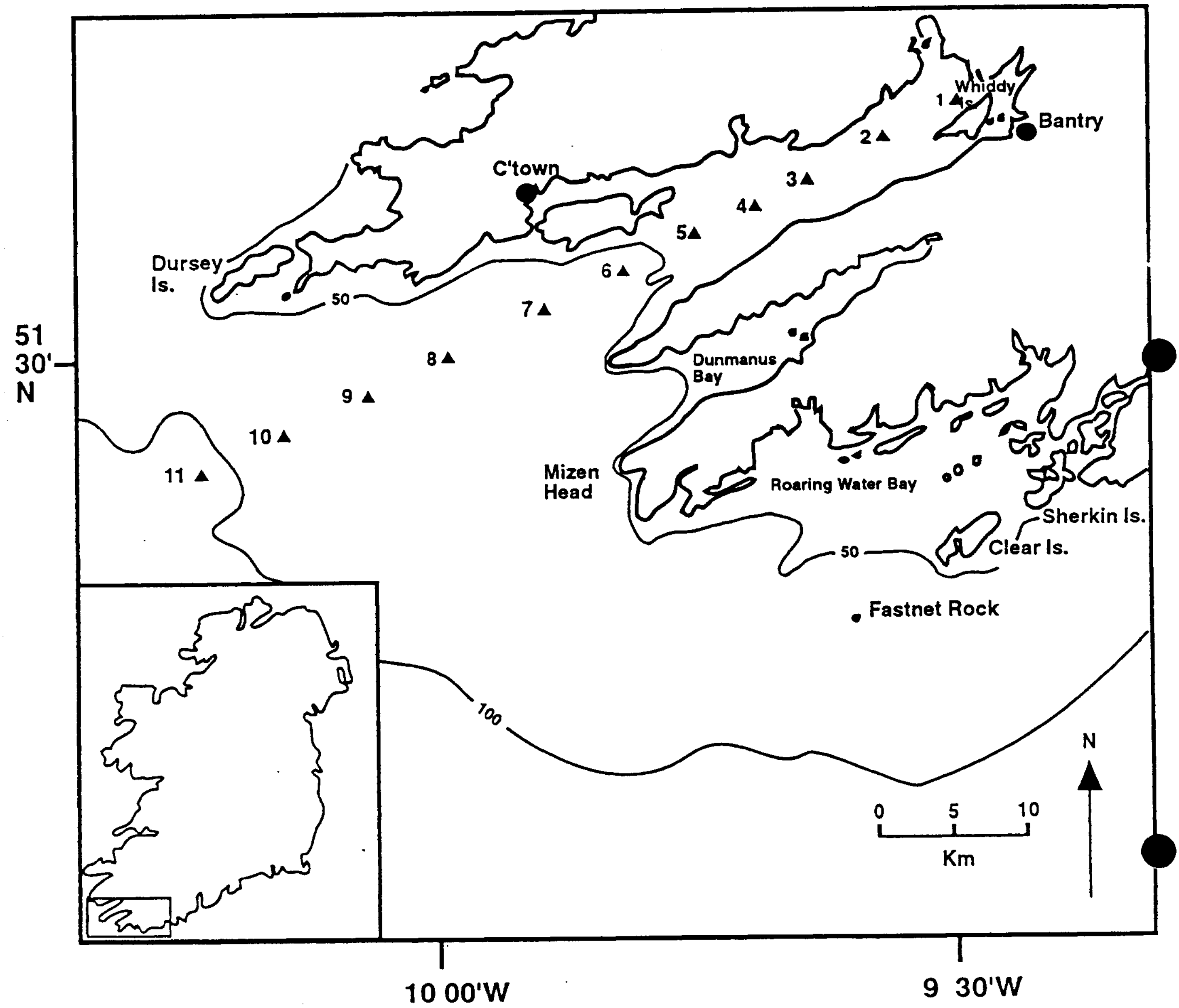

Figure 1. Sampling station positions, Bantry Bay and SW Ireland, July-August, 1991.

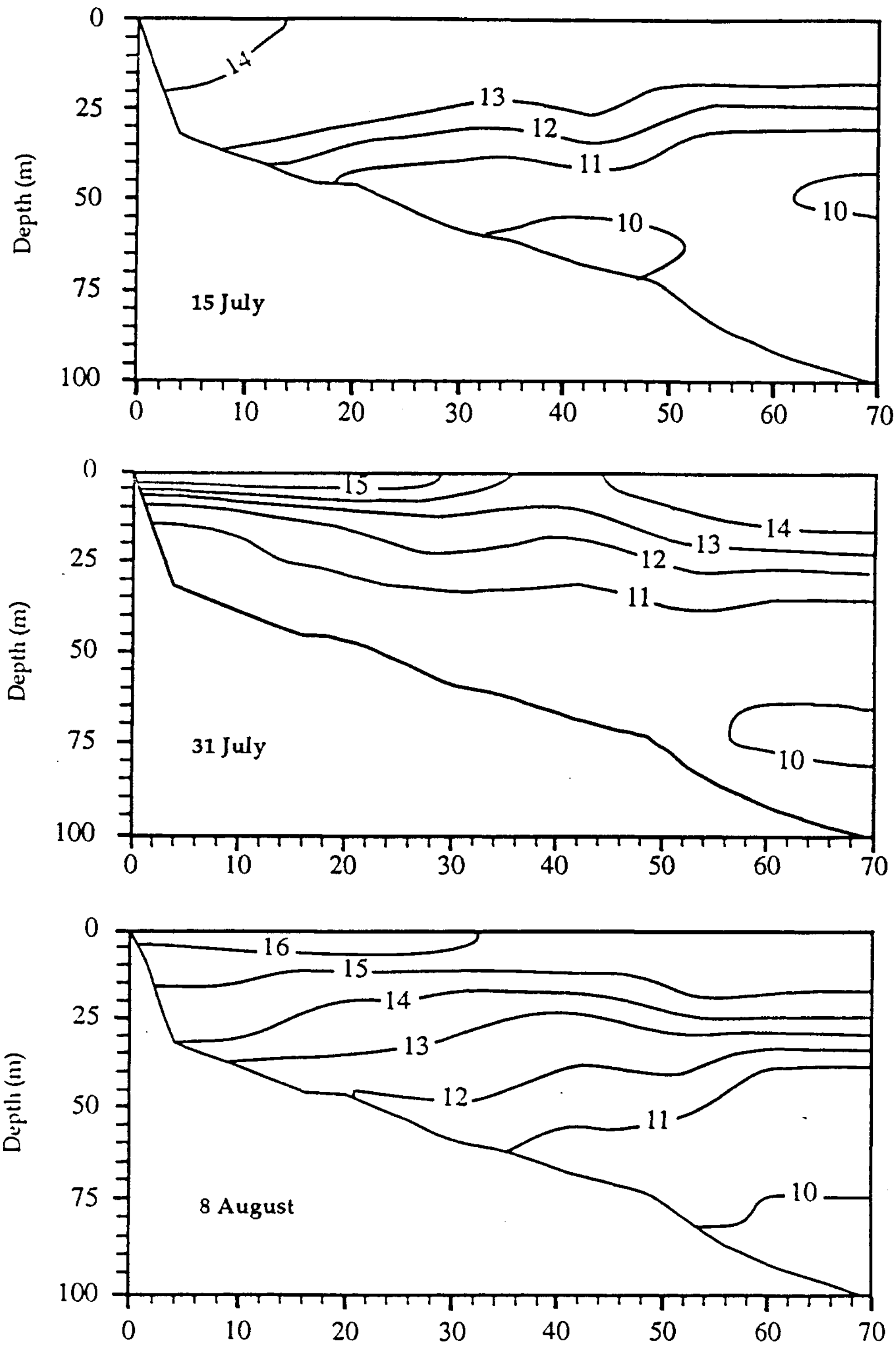

Figure 2(a). Isotherms (C) along transect of eleven sampling stations in Bantry Bay on three occasions during July and August 1991. See Figure 1 for sampling locations.

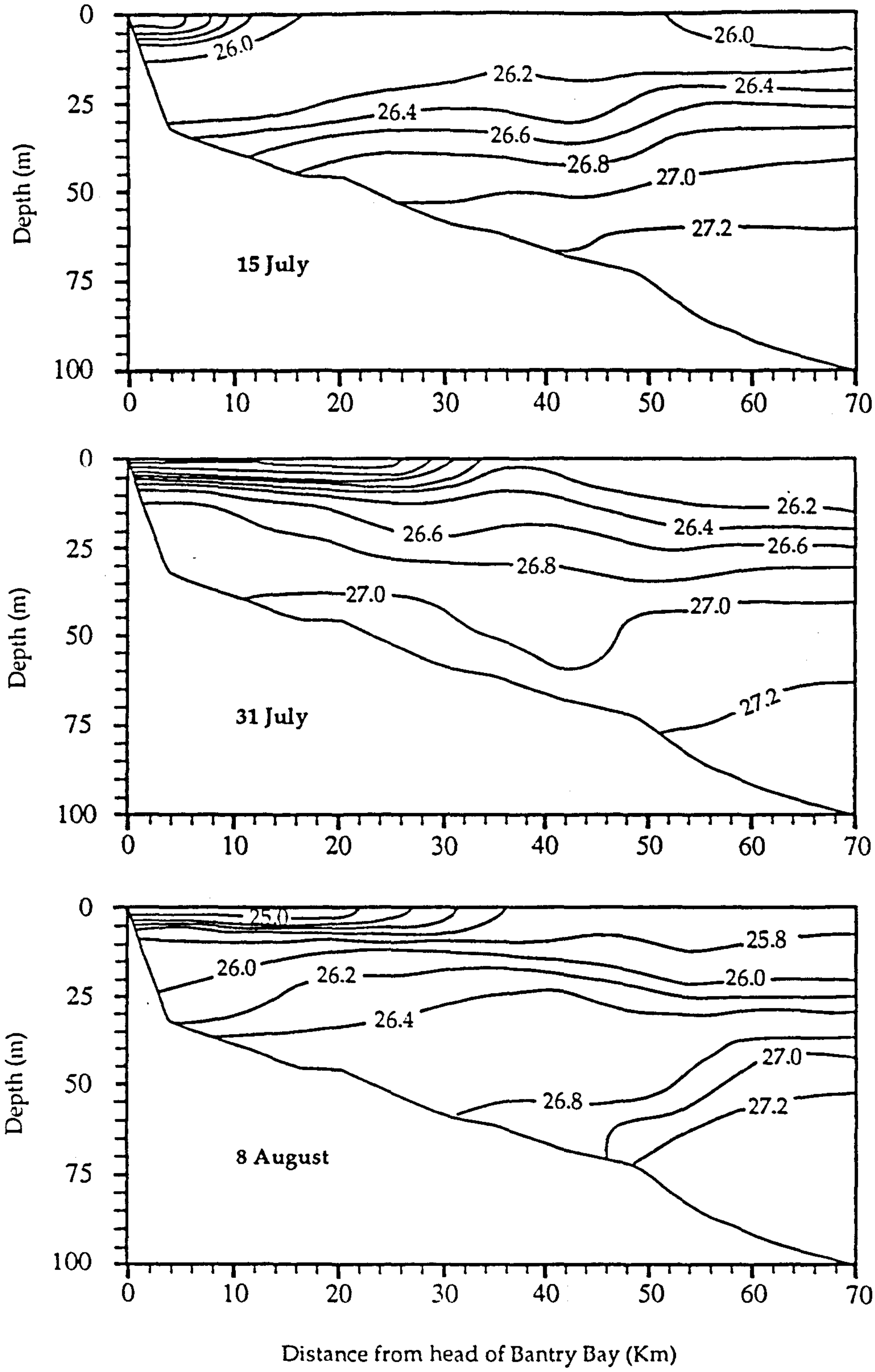

Figure 2(b). Isopycnals (sigma-t) along transect of eleven sampling stations in Bantry Bay, SW Ireland on three occasions during July and August 1991. See Figure 1 for sampling locations.

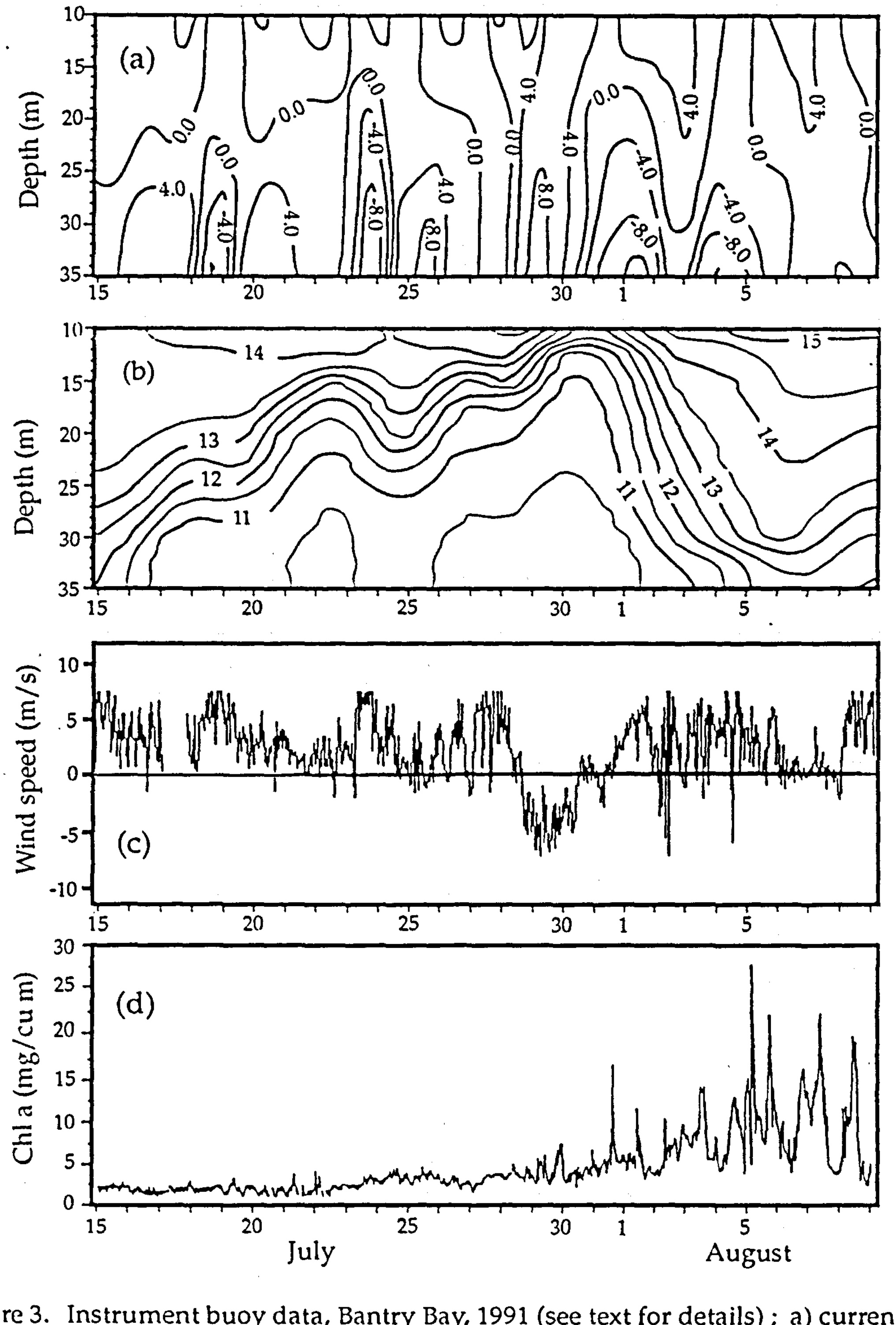

Figure 3. Instrument buoy data, Bantry Bay, 1991 (see text for details) ; a) current speeds axial to the bay (negative denotes outflow), b) thermistor chain (degrees C) data, c) wind speeds axial to the bay (positive denotes blowing into the bay from offshore and c) in situ fluorometer output (7m depth).