# 5. THE OCEANOGRAPHY OF SOUTHWEST IRELAND: CURRENT RESEARCH ACTIVITIES

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## 5.1 Abstract

The coastal waters of Ireland are rich in physical features affecting both chemistry and biology. Amongst these are the tidal fronts of the Irish Sea (Le Fevre, 1986) and the Irish Shelf Front on the Atlantic coast lying along the 200 m isobath (Huang *et al.*, 1991). Recently, an upwelling system has been described in the vicinity of the Fastnet Rock (Roden, 1986; Raine et al., 1990). Coastal upwelling systems are ecologically very important and are generally extremely productive, as nutrients brought up to the sea surface can stimulate extensive phytoplankton growth. This paper describes further satellite and ship-based investigations which are currently being carried out to examine the mechanisms driving the upwelling system and its effect on local ecology.

## 5.2 Satellite Studies

### 5.2.1 Background

The use of thermal infra-red satellite imagery for the study of marine phenomena was established in the 1970s via the NOAA series of satellites. The development of advanced very high resolution radiometry (AVHRR) permitted images with a 1 $km^2$ resolution that is more appropriate to marine systems. In the context of Irish coastal waters AVHRR images have been used as a technique in the study of the Irish Sea tidal fronts (Simpson and Pingree, 1978), the southwest Ireland upwelling system (Raine et al., 1990) and the Irish Shelf front (Huang et al., 1991).

The Coastal Zone Color Scanner, used by previous researchers to plot chlorophyll levels, has reached the end of its life, having been in operation longer than scheduled. For the immediate future there are no provisions to launch into orbit a platform carrying a colour scanner specifically designed to sense water bodies. Thus, it is of considerable interest to investigate whether the data produced by existing colour sensors designed for other purposes can be satisfactorily used to retrieve characteristic water parameters such as phytoplankton (chlorophyll) and suspended sediment concentrations.

### 5.2.2 Relative Chlorophyll Concentration Mapping and its Limitation

The technique of detecting chlorophyll using satellite colour imagery depends on the absorption spectra of pure water and of chlorophyll. The radiation absorption curve of chlorophyll is such that chlorophyll can be detected by comparing two image bands, one in the blue and one in the floating quadrants of a LandSat 188 km wide scene. Each quadrant is therefore approximately 62 x 62 km in earth area and the quadrant images are approximately 3072 x 3072 pixels which is equivalent to 9 Mb per image band.

For microcomputer application processing, i.e. chlorophyll retrieval, only the two relevant bands (blue and green) were extracted from the original LandSat interleaved data format. These extracted bands were then network transferred to micro-computer disk. In order to store the LandSat quadrants on microdisk, it was necessary to divide each into nine sectors, each being 1024 x 1024 pixels requiring just 1 Mb of storage per band. Chlorophyll retrieval processing of an image sector, including final median filtering, takes approximately 20 minutes on a 386/387 25 MHz PS/2.

### 5.2.4 LANDSAT TM-5 Chlorophyll images

Chlorophyll images for sectors of the southeast and southwest coasts taken in the summer of 1990 are shown in Figures 5.1 and 5.2. Although some detail has been lost due to the white-black shading used for this article, several features are evident.

#### 5.2.4.1 Southeast Ireland (Figure 5.1)

The Celtic Sea Front, running southeast from the Saltee Islands over to South Wales, supports enhanced, sometimes extensive, phytoplankton growth. High levels of chlorophyll may be seen in Figure 5.1 at the location of the northwestern end of the front. Both Waterford and Wexford Harbour contain increased nutrient levels due to land run-off and industrial and domestic effluent, and like many estuaries contain high levels of phytoplankton (chlorophyll). The estuary plumes are quite visible on the images, moving to the right emanating from the mouths as might be expected from geostrophic considerations, although this could also be due to tidal movements.

#### 5.2.4.2 Southwest Ireland (Figure 5.2)

Enhanced chlorophyll levels can be observed around Whiddy Island. This is probably a direct result of nutrient inputs from Bantry town into sheltered waters with restricted circulation. Aberrations due to reflection from the sea bed could be the cause of the highest (white) patches in shallow inlets. Enhanced levels inside Roaring Water Bay are most likely the result of a previous upwelling event inside the bay stimulating plant growth. A front known to exist at the mouth of Bantry Bay south-east of Bear Island (see Raine et al., 1990) can be discerned from the image, as these fronts tend to support increased levels of chlorophyll.

A contrast in levels of chlorophyll can be made between waters to the west and east of the Fastnet Rock lighthouse. Although direct interpretation from the image would indicate that this is a result of increased headland mixing (around Mizen Head), ground truth studies (Lough Beltra cruise 20/90) indicate this to be a consequence of an upwelling event. Ground truth data from Lough Beltra cruise 20/90 which companion these images, together with further image analysis may be found in Hoey (1991).

Fig 5.1

Fig. 5.2

## 5.3 Studies involving R.V. Lough Beltra

Lough Beltra cruise 9/91 was the focus of a collaborative exercise in Bantry Bay funded under an EC MAST programme involving scientists from UCG, Vigo (Spain), Scotland and N. Ireland which has the overall aim of elucidating environmental factors which govern phytoplankton class dominance in marine systems. The study area and location of stations sampled is shown in Figure 5.3. Methodology may be found in Raine et al. (1990). In addition a WS Ocean Systems conductivity-temperature-depth probe was employed, to which was attached a SeaTech in situ fluorometer for the measurement of chlorophyll, used in profiling mode with a host micro-computer acting as a data logger on deck. Only those results pertinent to the effect of an upwelling event on water circulation in Bantry Bay are presented here, with notes on the causative mechanisms leading to an exceptional bloom of the red tide organism *Gyrodinium aureolum* in the area (see McMahon *et al.*, this volume).

The entire transect of stations along Bantry Bay were sampled periodically between 15 July and 8 August. Temperature distributions along the transect are shown in Figure 5.4; distributions of density closely resembled those of temperature. Between 15 and 31 July an intrusion of cold water came into the bay reaching the innermost end at Whiddy Island (Station 1). This was presumably a result of an upwelling event offshore. Between 31 July and the 8 August this sub-surface cold water layer had retreated back down the bay, probably a density-driven current caused by relaxation of the upwelling mechanism. Note that the inflow of cold water along the bottom is accompanied by an outflow of the surface layers.

Station 3 (Figure 5.3) was the site used for additional experimental work during the cruise, and a high frequency of temperature-salinity profiles was obtained there. Results have been synthesised into a depth-time plot and are shown in Figure 5.5. After the 31 July the retreat of the cooler subsurface layer was remarkably rapid, resulting in an exchange of water equivalent to 70% of the volume of the inner section between Whiddy Island and Sheeps Head within a period of 3-4 days. Contemporaneous current meter measurements made by personnel from the Dunstaffnage Marine Laboratory, Oban show the bottom layer residual outflow was in the order 5-10 $cm.sec^{-1}$.

The bottom outflow observed between 31 July and 3 August was accompanied by an equally strong inflow of the surface layers. On this occasion the warm surface water flowing into the bay contained a large population of the dinoflagellate *Gyrodinium aureolum*, resulting in surface or near-surface concentrations of several hundred thousand per litre ($10^5$-$10^6$ $cells.l^{-1}$). The highest concentration observed was $5.2 \times 10^6 . l^{-1}$ at station 11. The increase in concentration of this organism in the surface layers of Bantry Bay is evident in the counts from samples taken from Station 3 (Figure 5.6). The concentrations recorded from this and other stations taken over the cruise were large enough to cause discoloration of surface water, or "red tide", which was observed between Shot Head and Roancarrig on 5th August.

## 5.4 Discussion

The events recorded during Lough Beltra cruise 9/91 have shown that the red tide of 1991, recorded not only in Bantry but also in neighbouring Dunmanus Bay (see McMahon *et al.*, this volume), was initiated by a relaxation of an upwelling event resulting in import of warm surface waters from offshore containing extensive populations of *Gyrodinium aureolum*. This

Fig. 5.3

Fig. 5.4

Fig. 5.5 & 5.6

mechanism of water mass exchange is likely to be that causing the inshore red tides in Roaring Water Bay in 1978 and 1979 reported by Roden and others (Roden *et al*, 1980;1981; Jenkinson and Connors, 1980). The area inside the Fastnet Rock is known to be greatly affected by periodic upwelling events (Roden, 1986; Raine et al., 1990) and landward transport of surface water containing established populations of *G. aureolum* during upwelling relaxation would, in the light of results from the present study, appear to be the operative mechanism. Roden et al. (1981) pointed out that landward transport of offshore communities was likely to be the cause of the red tide of 1979, but were not able to establish a suitable physical mechanism.

With respect to the developing aquaculture industry in the area, two crucial questions remain. First, why *G. aureolum* and not other bloom-forming dinoflagellates, and secondly how do the physical mechanisms described above affect the ecology of the dinoflagellates *Dinophysis acuta* and *D. acuminata* which are implicated in toxin production and shellfish contamination in the area?

*Gyrodinium aureolum* is a dinoflagellate which is associated with fronts, for example the Celtic Sea front which meanders from Waterford across to South Wales. Implicit in its continued occurrence around southwest Ireland is the existence of a frontal system offshore which can be suitably stable to encourage extensive *G. aureolum* populations. The existence of the Irish Shelf front approximately 60 km southwest of Dursey Island is one possible location, although as this is a coastal salinity front it is difficult to postulate an adequate nutrient supply for the formation of a bloom. Alternatively, upwelling conditions will produce fronts between the upwelling and adjacent stratified shelf water. The existence of this type of front is indicated by the data of Roden *et al.* (1981) a few miles to the south of Sherkin Island. It seems most likely that this is the source of the advected blooms. The situation is further complicated by the area being the location of the boundary between Atlantic shelf and Celtic Sea water.

The high flushing rate in Bantry Bay caused by upwelling events, where 70% of the Bay water may be exchanged with that offshore in about 4 days, has many implications for the marine ecology of the area. Amongst these is the occurrence of *D. acuta* and *D acuminata*. It is unfortunate that we still do not know enough of the ecology of these organisms, particularly in the offshore realms, to assess the effect of flushing. Further microscopic examinations of samples taken in 1991 may yield some insight, but as yet no definitive conclusions may be made concerning the effect of upwelling on *Dinophysis* spp.

A final comment should be made concerning the periodicity of upwelling/deep water intrusion events into Bantry and the adjacent bays. As yet, we do not know what mechanisms cause upwelling around southwest Ireland. Data obtained near Whiddy Island by Queens University personnel (R. Goward, pers. comm.) show that four cold water intrusions occurred between May and September 1991. Long-term deployment of current meter and/or thermistor chains in Bantry Bay would establish the regularity or irregularity of these events. If subsequent correlations of their frequency with either meteorological or physical phenomena can be derived, then at last a predictive capability with respect to exceptional blooms of *G. aureolum* in late summer around southwest Ireland may be established. There can be no doubt, however, that the combined use of satellite imagery with field studies will prove an important technique in elucidating physical and biological mechanisms in the area.

green. The two bands used for this project were Bands 1 and 2 of the LandSat Thematic Mapper (TM-5) imagery (Tassan, 1987). The resultant chlorophyll image maps are segmented to show distinct relative concentration levels. Statistical techniques have been developed to interrogate, through image windows, sections of the image to give values for the mean pixel intensity, the mean deviation of pixel intensities, and the standard deviation of pixel intensities.

Important errors may be introduced by instrument noise and by the relatively low number of the available signal quantisation levels. Instrument noise is usually expressed by the signal-to-noise ratio. A low signal-to-noise ratio such as is present in the low luminance winter scenes severely restricts the application of the technique. The analogue radiometric signals from TM-5 are converted to a 256 level digital number for transmission from the satellite to the ground stations. In practice, however, the dynamic range of the signals is such that, when digitised, the numbers range from a level of zero to only about 50. This results in a much-reduced signal-to-noise ratio and therefore reduces the quality of the chlorophyll retrieval algorithm.

For low radiance scenes, the value of the gain can be increased by using pixel clustering with digital scale factors higher than unity. For example, a 4x4 cluster admits a maximum gain increase by a factor of 16. This procedure is effective in reducing the contribution of the error source resulting from the relatively few signal quantisation levels, but has no effect on the error induced by the bias level.

TM images suffer from narrow striping and wide banding that are exaggerated by the chlorophyll algorithms. In practice, this means the winter scenes retrieved from the UCD archive do not produce relative chlorophyll mapping of usable quality. For Irish coastal waters, this is due to the low illumination density and the resultant low signal-to-noise ratio producing the evident narrow and broad image horizontal striping. Several pixel-by-pixel tests were executed to quantify this effect. For low luminance image scenes it was therefore necessary to develop and incorporate a localised destriping algorithm. Further, it has been found useful to apply a median smoothing filter to the resultant chlorophyll map. The median filter produces more even contours of equal chlorophyll concentration and this aids visual interpretation,

The excellent TM-5 ground resolution allows one to distinguish details of particular interest in coastal waters. As a LandSat quadrant contains approximately 3072 x 3072 pixels at 30 x 30 m per pixel, which equates to a land area of 90 x 90 km. This allows one to distinguish details of particular interest in coastal waters, for example headland mixing and river outflows.

The relatively long TM-5 repetition cycle of 16 days represents a significant limit to its range of application for water sensing. In particular this causes difficulty in the exact matching of ground truth data gathered on scheduled research vessel cruise dates to image data obtained from the closest satellite cloud-free overpass. For example, in the case of the two 1990 floating quadrants specially purchased to match the Lough Beltra cruise dates the satellite overpasses were 21 July 1990 and 4 August 1990 respectively whereas the corresponding cruise dates were the 23 July 1990 (Southeast Ireland) and 25, 28 and 30 July and 1 August 1990 (Southwest Ireland).

### 5.2.3 Outline of Typical Methodology

The LandSat images were sourced from the earth station located in Sweden on 9-track tapes that were loaded onto a VAX workstation. LandSat source images are supplied as fixed or

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## References

Hoey, M.J. 1991. The mapping of relative chlorophyll concentration in Irish waters from LandSat TM satellite imagery. Final Report for Department of the Marine, Leeson Lane, Dublin. 83pp.

Huang, W.G., Cracknell, A.P., Vaughan, R.A. and P.A. Davies. 1991. A satellite and field view of the Irish Shelf front. Cont. Shelf. Res., 11, 543-562.

Jenkinson, I. and Connors, P. 1980. The occurrence of the red tide causing organism, *Gyrodinium aureolum* Hulbert (Dinophyceae), round the south and west of Ireland in August and September, 1979. J. Sherkin Island, 1, 127-146.

Le Fevre, J. 1986. Aspects of the biology of frontal systems. Advances in Marine Biology, 23, 163-299.

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

Roden, C.M. 1986. An upwelling zone around the Fastnet Rock. Proc. 2nd annual Lough Beltra workshop, G. O'Sullivan, ed., NBST, Dublin.

Roden, C.M., Ryan, T and Lennon, H.J. 1980. Observations on the 1978 red tide in Roaringwater 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 species succession around Sherkin Island, SW. Ireland. J. Sherkin Island, 1, 50-68.

Simpson, J. and R. Pingree. 1978. Shallow sea tidal fronts produced by tidal stirring. In Oceanic Fronts in Coastal Processes, M.J. Bowman and W.E. Esaias, eds., Springer-Verlag, New York. pp 29-42.

Tassan, S. 1987. Evaluation of the potential of the Thematic Mapper for marine applications. Int. J. Remote Sensing, 8, 122-150.