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HARMFUL PHYTOPLANKTON EVENTS CAUSED BY VARIABILITY IN THE IRISH COASTAL CURRENT ALONG THE WEST OF IRELAND

Shane O'Boyle, Glenn Nolan and Robin Raine

The Martin Ryan Institute for Marine Science, National University of Ireland, Galway, Ireland.

ABSTRACT

Frequent sampling in summer along the western and northwestern coasts of Ireland showed the rapid onshore development of blooms of potentially harmful phytoplankton species. In both 1998 and 1999, concentrations of *Gyrodinium* cf. *aureolum* rose by four orders of magnitude to over one million cells per litre in Donegal Bay (northwestern Ireland) in less than 10 days. The rapid development of these populations was linked to advection resulting from unfavourable wind-forcing of the Irish Coastal Current (ICC) which runs northwards along the western Irish coast. Current measurements showed that after a particular sequence of changes in wind direction phytoplankton populations could be rapidly advected from areas of slack circulation on the shelf via the ICC into aquaculturally sensitive coastal zones such as Donegal Bay. The model presented is similar to one already demonstrated for the occurrence of toxic events in the bays of southwestern Ireland. Other historical harmful events along the west and northwest coasts relating to substantial losses in both finfish and shellfish culture could also be explained using the model. These include the *G. aureolum* bloom of 1992, the *Prorocentrum balticum* bloom in 1997.

INTRODUCTION

It is now accepted that potentially harmful phytoplankton blooms can arise at coastal sites through physical advection of a community which has developed elsewhere [1,2,3]. Wind-forcing can result in advection of dinoflagellate blooms from the shelf off the south coast of Ireland around the southwest Irish coast and into coastal embayments [4]. This has been demonstrated directly for both *Gyrodinium aureolum* blooms [5], and the advection of a *Dinophysis acuta* community resulting in an accumulation of DSP toxins in farmed mussels [6]. The significance of these events is witnessed by the fact that approximately 80% of the national edible mussel (*Mytilus edulis*) and 60% for the Pacific oyster (*Crassostrea gigas*) production currently come from aquaculture operations along the southwestern Irish coast. A further 25% of national farmed salmon production comes from this region.

More recent development of aquaculture along the northwestern Irish coast has not been without problems. For example, an exceptional bloom (<3 x 10^6 cells l^{-1}) of *G. aureolum* in Donegal Bay in September 1992 was directly linked to mass (80%) mortalities of farmed clams (*Tapes semidecussatta*). A bloom of *Prorocentrum balticum* of over 16 x 10^6 cells l^{-1} was observed in the same region in November 1997 (Irish Dept. of Marine, unpublished records). Both of these events occurred over a time scale smaller than the sampling frequency (<3 days for the *G. aureolum* and < 1 week for *P. balticum*) with the implication that they have arisen via advection.

This paper presents results of physical and biological studies carried out since 1997 in Donegal Bay, NW Ireland and demonstrates the role of wind forcing on the Irish Coastal Current (ICC) in the advection of potentially harmful phytoplankton populations into the region.

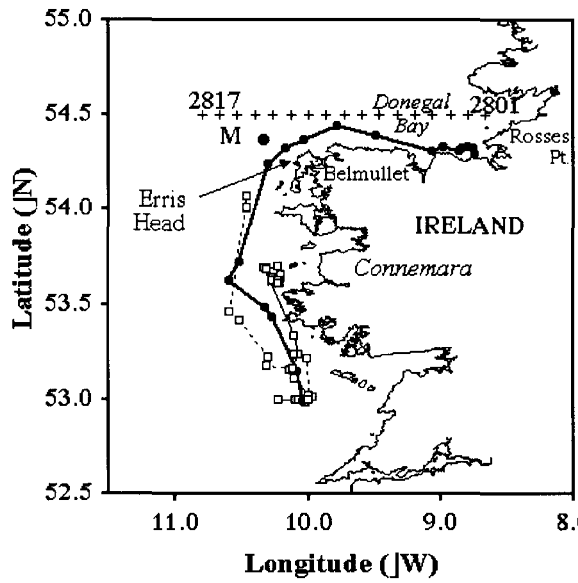

Figure 1: Map of study area. M indicates the position of the current meter mooring PBF-3; the line of crosses refers to the transect of 17 stations sampled on 12-13 August 1999. Included are the tracks of Drogues A (open squares, solid line), B (open squares, dashed line) and C (filled circles). See text for details.

METHODS

The study area is shown in Figure 1. Currents along the west and northwestern shelf off Ireland were measured using both Lagrangian and Eulerian techniques. Vector averaging current meters (Aanderraa Instruments, Bergen) located 45 and 100 m above the seabed were deployed on a mooring on 4 May 1997 at position PBF-3 (54°22'N; 10°20'W) off Erris Head in a water depth of 125 m. On recovery, the data length was 138 days, with a time interval of 20 minutes. In 1999, three Argos satellite-tracked drifters were deployed off the west coast of Ireland at 53°N. The drogues were of a "holey-sock" design, with dimensions 7 m long and 1.5 m in

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diameter, set at 35 m depth in order to be located close to or within the seasonal thermocline where maximum cell densities are known to occur. An average of 2 to 3 fixes per day were obtained for each drifter. Wind data for all years were supplied by the nearest Irish Meteorological Office station located at Belmullet, Co. Mayo (Fig. 1).

In 1998 and 1999, water samples were collected off Rosses Point (Co. Sligo; Fig. 1) at least twice per week from July to September. A 1.3 l NIO water sampling bottle was used to collect discrete water samples from near the surface and at 3 m depth for the determination of phytoplankton and salinity. Phytoplankton samples were enumerated with an inverted microscope after sedimentation using a modified Utermohls technique [7]. *TS* profiles at the location were obtained with a calibrated WTW LF 191 temperature-salinity probe. A transect of 17 stations (Fig. 1) along 54°30'N was sampled on 12-13 August 1999 when a Seabird CTD rosette system linked to an *in situ* fluorometer was used to sample water from the sub-surface chlorophyll maximum.

RESULTS

The mean residual current over the period 5 May to 20 September 1997 was 7.5 cm s^{-1} in direction 003° (T). A more northeastards flow (013°; 13.5 cm s^{-1}) was evident from the record, interspersed with occasional southwestward flow, as occurred between 4-11 May and during the second half of June. These reversals were a direct consequence of wind-forcing from northerly winds (Fig. 2).

G. aureolum counts observed at Rosses Point in 1998 and 1999 are shown in Figure 3. Both data sets show rapid increases of approximately two orders of magnitude within 3 days occurring around 19 August 1998 (Fig. 3a) and 26 July 1999 (Fig. 3b). In both instances cell concentrations reached over 10^6 cells l^{-1}. These increases are faster than known growth rates for this organism [5]. Two other features are apparent in the results. First, the blooms disappeared equally as quickly as they appeared, suggesting physical transport in and out of the sampling location. Secondly, they were both accompanied by an increase in salinity (Fig. 3c,d) indicating physical control of these events. Stick plots for daily wind speeds and direction recorded at Belmullet for the periods covering the 1998 (not shown) and 1999 (Fig. 4) blooms showed that the blooms occurred when winds were from the east.

Phytoplankton counts on samples taken from the surface and from within the sub-surface chlorophyll maximum along the transect of stations at 54° 30'N on the 12 August 1999 did not reveal any measurable *G. aureolum* populations within Donegal Bay until 9°40' W. where a population of 5-10 x 10^4 cells l^{-1} existed (Table 1). These samples were taken 10 days after peak concentrations were observed at Rosses Point, and the results are indicative of the speed of dispersion of the blooms out of Donegal Bay. Furthermore, winds at the time (12-13 August) were westerly, which might favour entrapment of phytoplankton populations within the bay.

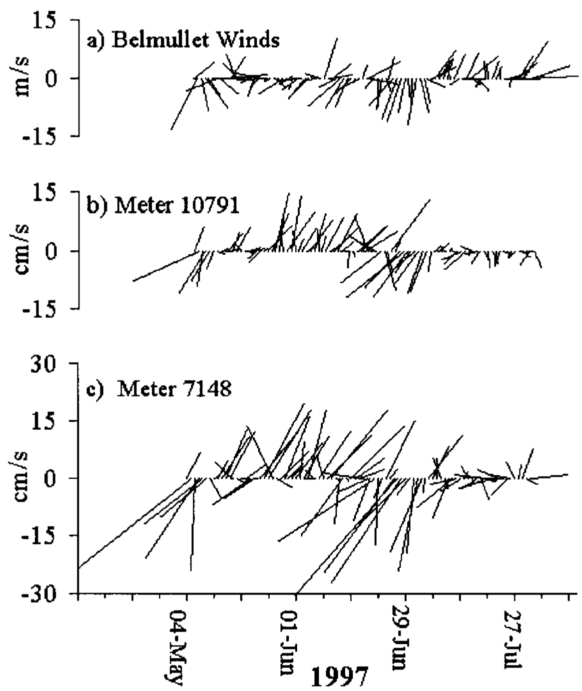

Figure 2: Stick plots of a) winds measured at Belmullet (m s^{-1}) and residual (non-tidal) currents (cm s^{-1}) measured by the current meters b) 10791 located 95 m above the sea bed and c) 7148 located 43 m above the sea bed. Vectors are all scaled to show true direction

The tracks of the drogues deployed at 53° N are shown in Figure 1. All drogues moved north along the shelf. Drogue A halted in its northward track at 53°37'N on 8 August, apparently being caught in a coastal eddy. Drogue B stopped transmitting its location on 7 August. Drogue C, however tracked into Donegal Bay on 23 August, ending up close to the Rosses Point sampling station at the beginning of September. Measured northwards velocities between 53° and 54° north were of 6.8 cm s^{-1} (Drogue A; 28 July to 7 August), 8 cm s^{-1} (Drogue B; 28 July to 7 August) and 22.3 cm s^{-1} (Drogue C; 19 to 22 August). Comparison with wind data shows that these maximal rates occurred when winds were from the northwest.

DISCUSSION

The Irish Coastal Current (ICC) runs along the continental shelf roughly parallel to the western Irish coast [8,9]. Current speeds of the ICC have been estimated to be approximately 7 cm s^{-1} [8], in close agreement to the velocity (7.5 cm s^{-1}) calculated from the extended current meter record (138 days) obtained in the present study. The higher velocity measured from drogue C of 20-25 cm s^{-1} is quite similar to the larger

Table 1. *Gyrodinium* cf. *aureolum* counts at the chlorophyll maximum measured along a transect of stations at 54° 30'N on 12-13 August 1999.

Station	Latitude (deg)	Latitude (min)	Depth (m)	Cells l^{-1}
2801	8	40	22	7600
2802	8	48	30	8900
2803	8	56	24	10100
2804	9	04	20	8900
2805	9	12	28	5000
2806	9	20	16	1200
2807	9	28	23	11400
2808	9	36	23	29000
2809	9	44	23	84000
2810	9	52	25	47000
2811	10	00	25	103000
2812	10	08	30	26000
2813	10	16	25	43000
2814	10	24	0	16500
2815	10	32	30	0
2816	10	40	27	5000
2817	10	48	15	2500

northwards velocities measured at PBF-3 when winds were from the southwest (Fig. 4). It should be noted that the track shown by this drogue is consistent with the hypothesis that phytoplankton blooms can be rapidly imported into Donegal Bay from the continental shelf.

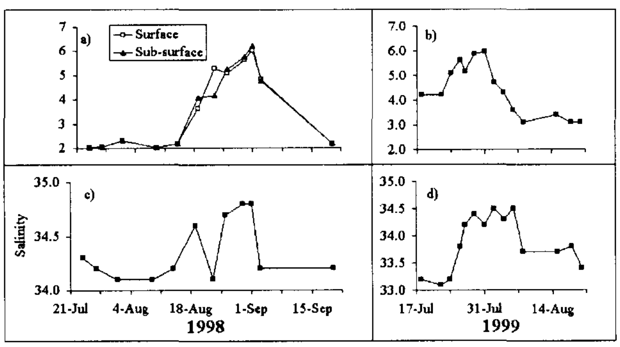

Figure 3: a, b ; *Gyrodinium aureolum* densities (cells l^{-1}) and c, d ; Salinity (PSU) measured at Rosses Point, Co. Sligo during the summers of 1998 and 1999.

Wind-forced water exchange between coastal embayments and outlying water is a well understood phenomenon. In an Irish context, a model has been developed which shows water exchanges to occur as a result of shifts in the axial component of the wind-stress along Bantry Bay, SW Ireland [10]. This process has been directly related to ingress of phytoplankton blooms within the bay [5]. The origin of these blooms were subsequently shown to be a region of slack residual circulation on the adjoining shelf [4].

The results presented here are consistent with a similar advective mechanism occurring in Donegal Bay. Measurements of the local currents demonstrate that phytoplankton can be transported northwards along the western Irish shelf with speeds of up to 20-25 cm s^{-1} and subsequently into Donegal Bay.

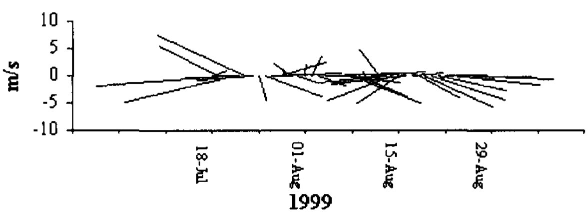

Figure 4: Stick plot of winds (m s^{-1}) measured at Belmullet during July and August, 1999.

Further inferences can be drawn from phytoplankton observations carried out in October 1997, when a bloom of *P. balticum* was observed off west Connemara [11]] Samples containing 10^5-10^6 cells l^{-1} were observed at aquaculture sites, and the presence of this organism was associated with mortalities, starvation, and abnormal behaviour of farmed salmon. Subsequently, the population was noted within Donegal Bay. Again, these observations are consistent with the advective mechanism proposed here, which highlights the importance of wind forcing in transporting potentially harmful phytoplankton populations into aquaculturally sensitive regions.

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