

Transport of toxin producing dinoflagellate populations along the coast of Ireland within a seasonal coastal jet.

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Abstract

During an investigation into the distribution of *Dinophysis* spp. in coastal waters off the south coast of Ireland, a thin layer of *Dinophysis acuta* was observed as a sub surface thin layer containing up to 55,000 cells l⁻¹. The layer did not coincide with the fluorescence maximum, and was found to be a patch of maximum dimensions ~10 km x 7 km. The patch was observed to move westwards within a seasonal coastal jet previously recorded in the area, and also evident due to the aggregation of isopycnals at the seafloor. The patch was followed for 6 days, and shown to be moving within the coastal jet at a speed of ca. 6.5 km d⁻¹ towards a nationally important shellfish production area. These observations have substantial implications for regional monitoring of toxic blooms in that they document how harmful populations may be transported in coastal jets along coasts to aquaculture sites.

Introduction

The southwest of Ireland is an important national shellfish aquaculture area where 80% of the Irish blue mussel (*Mytilus edulis*) rope cultivation and 50% of the national pacific oyster (*Crassostrea gigas*) production occurs (Parsons, 2005). There is a history of harmful algal events here, notably contamination of shellfish with diarrhetic shellfish toxins (McMahon *et al.*, 1995) or exceptional blooms of *Karenia mikimotoi* (Roden *et al.*, 1980; Roden *et al.*, 1981; Raine *et al.*, 1993; Raine *et al.*, 2001; Silke *et al.*, 2005). Wind is important in the region as it

determines exchange of water between the bays and the adjacent shelf waters (Edwards *et al.*, 1996). Harmful phytoplankton from shelf waters can enter the bays via this mechanism. However, the origin of these harmful shelf populations has to date been ill-defined.

Jet-like flows have been observed at bottom density fronts located at the boundaries of seasonally stratified water along the northwest European continental shelf. These flows are seasonal phenomena occurring from May to October. They are narrow (10-20 km) jet-like flows and reach speeds up to 30 cm s^{-1} (Brown *et al.*, 2003; Hill *et al.*, 2008). Observations of these coastal jets around northwest Europe have been summarised by Hill *et al.*, 2008. The significant feature in this paper refers to the alongshore flow which runs along the south coast and then the west coast of Ireland (Figure 1). Whilst coastal jets have been implicated in the transport of harmful algae over the near coastal shelf towards aquaculture sites, no direct evidence has yet been made available.

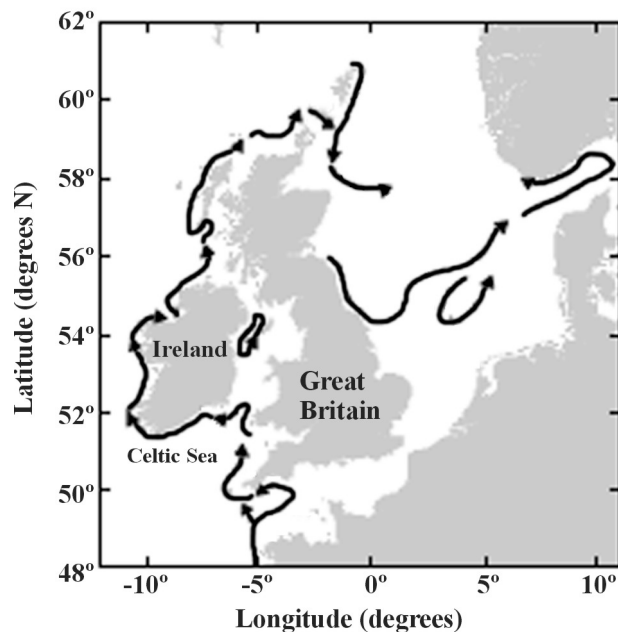


Figure 1. A summary of the density driven coastal jets along the coastlines of northwest Europe, modified from Hill *et al.* (2008).

Materials and methods

During July 2007, a research cruise took place in the Celtic Sea. Real-time vertical profiles of temperature, salinity, chlorophyll *a* fluorescence and particle size analysis (Gentien *et al.*, 1995) were used to determine sampling depths. Seawater was sampled via a pump which was attached to the profiler frame. Two litres of seawater from each depth were concentrated to 30 ml and sub samples of 3 ml were immediately processed to give near real-time estimations of *Dinophysis* spp. cell concentrations. In addition, a conventional CTD (Seabird SBE 19) with an integrated fluorometer and transmissometer (both Sea Tech USA) and with a rosette of 10 l Niskin type

water bottles was used at selected stations. Samples were also preserved in Lugol's Iodine for subsequent analysis in the laboratory (McDermott and Raine, 2010). Vertical phytoplankton net hauls were taken at each station by lowering and raising a 25 μm mesh net, with a mouth diameter of 25 cm, at a speed of 0.5 m s^{-1} from the sea surface to 50 m depth (at shallower stations to within 5 m of the sea bed) and back.

Results

A sub-surface thin layer of *Dinophysis acuta* was observed in the region (Figure 2). Cell densities of up to 55 000 cells l^{-1} were observed in a layer of 5 m thickness close to the pycnocline. This layer was not, however, coincident with the chlorophyll fluorescence maximum, but approximately 5 m above it (Figure 2). The phytoplankton within the fluorescence maximum at the pycnocline was dominated by diatoms of the genus *Pseudo-nitzschia*.

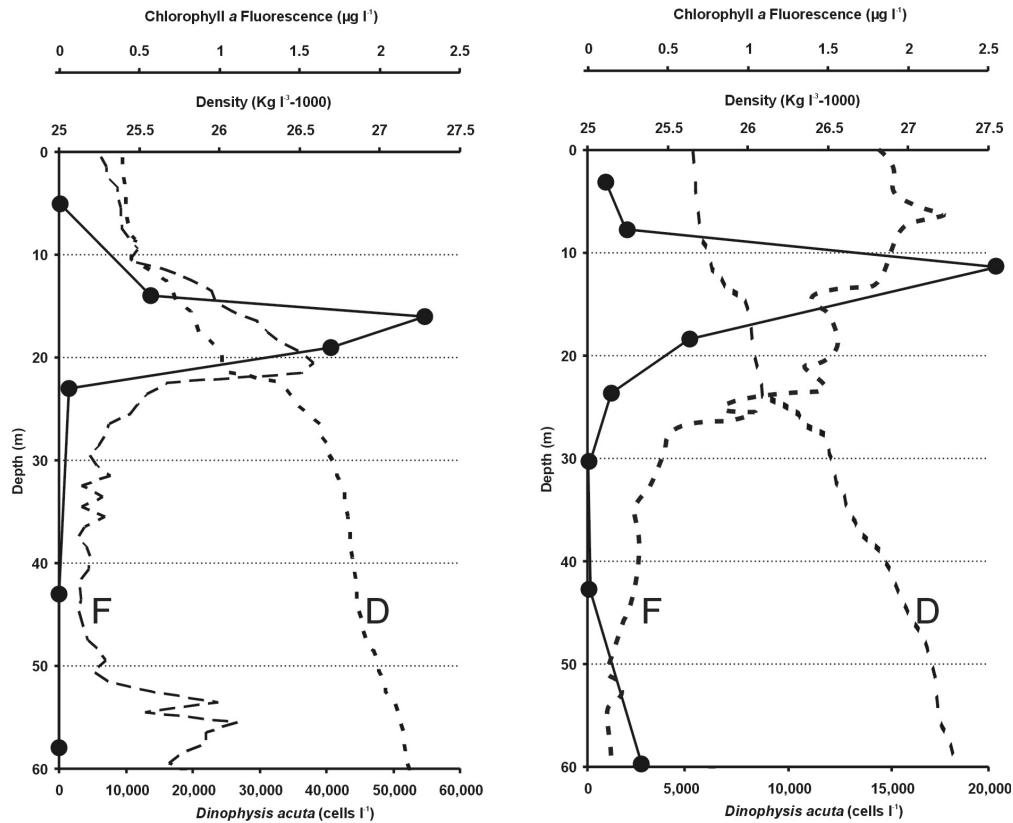


Figure 2. Vertical profiles of density (D), chlorophyll fluorescence (F) and *D. acuta* cell densities (filled circles) at stations 3 ($51^{\circ} 29' \text{ N}$, $08^{\circ} 45' \text{ W}$; 23 July 2007) and 36 ($51^{\circ} 24' \text{ N}$, $09^{\circ} 08' \text{ W}$; 26 July 2007) off the south coast of Ireland. Note the high density sub-surface thin layer of *D. acuta*.

The thin layer of *Dinophysis* was initially observed at 8° 45'W. At those stations where an extended station time was involved (> 2 hrs), it became apparent that the population covered a small geographic area (~ 3 km) as maximum cell densities quickly declined with time (Figure 3). This, taken in conjunction with ship's ADCP measurements, suggested an alongshore dimension of the extent of the *Dinophysis* population smaller than the tidal excursion (7 km). Tidal currents here run parallel to the coastline (Carillo et al., 2005). Transects of stations normal to the coastline showed that the layer was confined to a narrow band in the direction offshore-onshore of similar dimension to its alongshore length (Figure 4). These observations indicated that the *D. acuta* population was present as a sub-surface thin layer within a patch of dimensions smaller than 7 km x 10 km.

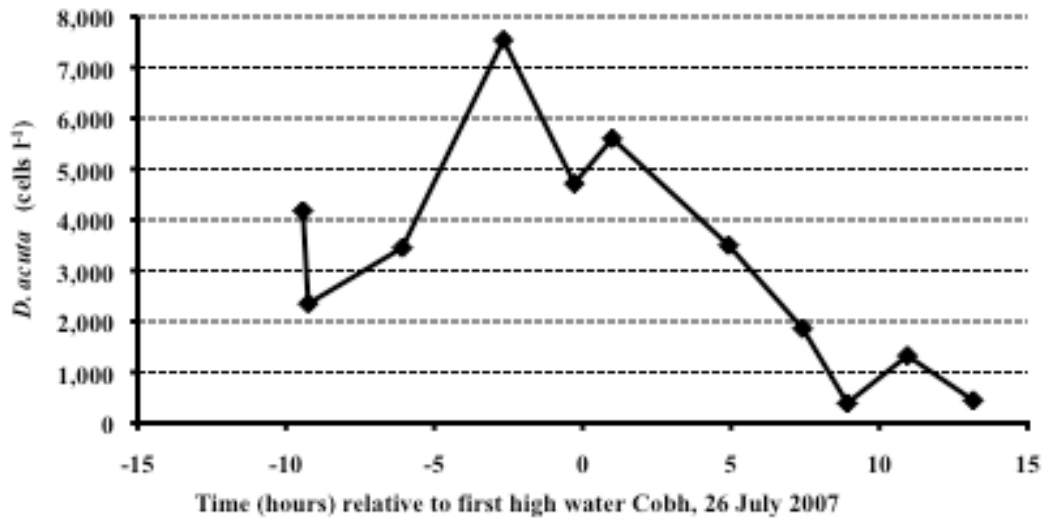


Figure 3. Change in sub-surface maximum cell density with time at station 28 (51° 27' 8° 57' W) sampled over 25-26 July 2007.

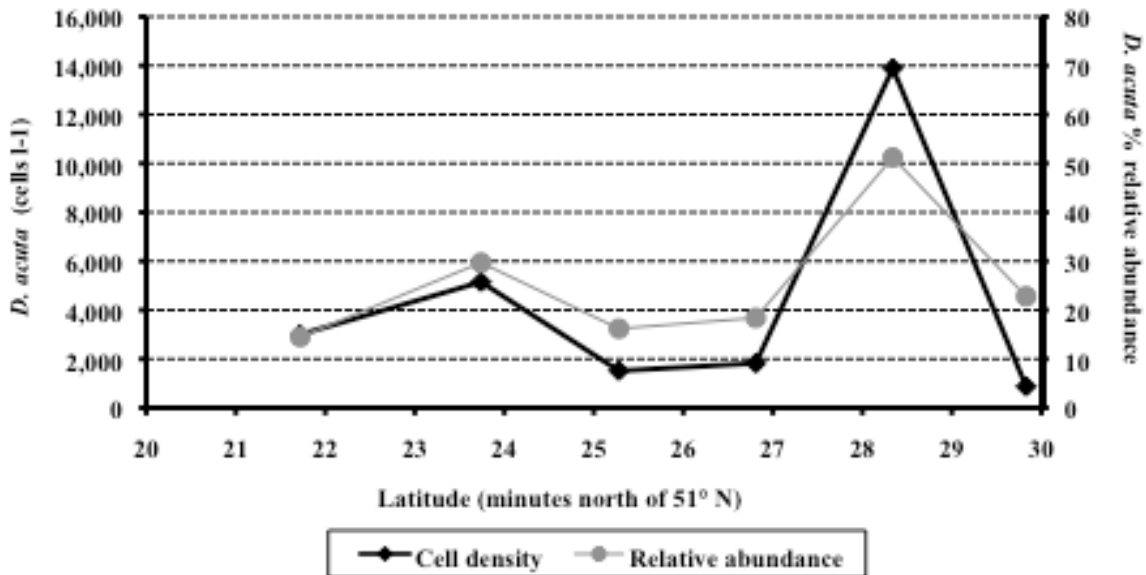


Figure 4. Variation in *D. acuta* maximum cell densities and relative abundance of *D. acuta* in net hauls with latitude at 8° 56'W.

Subsequent sampling of a series of CTD and profiler transects repeatedly showed an absence of the population at longitudes where it had previously been observed, and appearance (generally westwards) at locations where it had been absent. For example, the population was located at 9° 8.1' W on 26 July 2007 (stations 36) and 9° 16.5'W on 29 July 2007. This information was reinforced by examinations of vertical phytoplankton net hauls, in which small relative abundance values of <20% *D. acuta* correlated extremely well with an absence or low (<5000 cells l⁻¹) cell density of *D. acuta* at the vertical cell maximum.

The observations of the location of the patch of *D. acuta* are presented pictorially in Figure 5. This shows that the population travelled generally westwards, and also that it followed the path of the bottom density front which is associated with coastal jet-like flows. Importantly it can be calculated from the sequence of positions of the patch that it was travelling alongshore westwards at a speed of 6-7 km d⁻¹, virtually identical to the speed of the coastal jet recorded in the area.

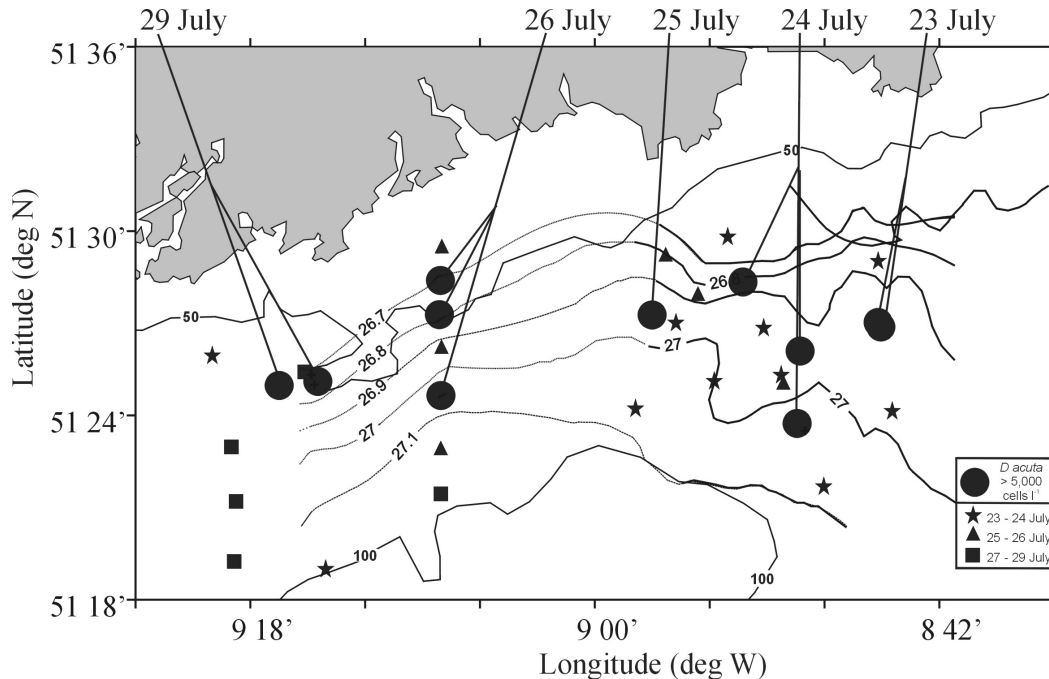


Figure 5. Daily observations of *D. acuta* population maxima during the survey. The location of population maxima (> 5,000 cells L⁻¹) for each day is highlighted (black circles) and other samples. Smaller symbols indicate absence of *D. acuta*, results which also include phytoplankton net relative abundance data for *D. acuta* within the dinoflagellate community when < 20 %, indicative of an absence of sub surface maxima of this density. Bottom density contours derived from CTD data are also included.

The magnitude of the maximum observed cell density of *D. acuta* declined over time from 55,000 cells l⁻¹ (23 July 2007) to 8,000 cells l⁻¹ (29 July 2007). Intermediate between these,

maximum cell densities of 19,000 cells l⁻¹ were observed at 9° 08'W on 26 July 2007 (Figure 5). It is difficult to assign a sampling error to these figures, as small variations in actual sampling depth could have a large effect on the cell density observed when sampling within layers. Nevertheless they still indicate a dispersal of cells from the layer, particularly when taken in conjunction with the magnitude of the initial observation, which appeared to be due to wind mixing (Farrell 2009).

Discussion

Jet-like flows are found around the eastern and northern boundary of the Celtic Sea, and continue northwards along the west coast of Ireland. The flow follows strong discontinuities in the bottom density contours, referred to as bottom fronts, and is relatively fast with a speed of the order 6.5 km d⁻¹ (Brown et al 2003).

Implications of seasonal jet-like flows in the transport of potentially harmful plankton populations have been considered for *K. mikimotoi* (O' Boyle & Raine, 2007) and toxic *Alexandrium* spp (Brown et al., 2001). Historically, blooms of *Karenia mikimotoi* along the continental shelf of northwest Europe (Partensky & Sournia, 1986) have occurred co-incident with the coastal jet pathway. Results presented here suggest the transport of a harmful population of *D. acuta* within this coastal jet towards an economically important shellfish aquaculture area.

The dispersal of the population has implications for both the source and persistence of the population. The relatively fast decrease in population density, most likely due to an increase in vertical diffusion linked to a change in wind, could also be a result of viral or parasite attack, an increase in the patch size, or the dispersion which would accompany a weakening of the jet, but there was no evidence to suggest any of these phenomena. The patch size was probably contained by horizontal shear associated with the jet. If *Dinophysis* blooms occupy the same time window, of the order 10 days, as most other phytoplankton (Parsons et al. 1984; Mann and Lazier 1996) then a local origin has to be considered. Given the hydrodynamics of southwest Ireland coastal waters, this points to an origin within a radius of 70 km. High cell densities of *Dinophysis* have only been regularly recorded in Irish coastal waters off the southwest (McMahon et al. 1998) which also supports the hypothesis for a local origin.

The implications of these results as regards monitoring of harmful phytoplankton are significant. In the first instance, the population was present as a sub-surface thin layer, which means that in order to maximise the chances of sampling them integrated water column samples (Lindahl, 1986) need to be taken. This sampling method can, however, become impractical if the layer is very deep (>20 m). Secondly, in order to allow a satisfactory length of time for mitigation measures to be put in place, once a harmful population has been detected, monitoring would have to be performed several kilometres upstream from the place of impact. This would best be done through the deployment of offshore observatories in their predicted path, i.e. the coastal jet.

It is concluded that hydrodynamic controls are very important in the development of *Dinophysis* populations. Xie et al. (2007) also concluded that the dispersal of a population of *Dinophysis* was limited by the retentive structure (eddy) in which it was retained during its transport onto the coast in the Baie de Vilaine, France. At a similar scale, the results presented here show retention and transport of a population in a coastal jet. The physical component of any biological-physical coupled model must be of suitable resolution if HAB events, linked to *Dinophysis*, are to be predicted with realism. This study has indicated the horizontal scale necessary which should be included in such models. Mesh sizes of the order 1 km or less in the horizontal and 0.5 m (or possibly less) vertical resolution must be applied.

Acknowledgements

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