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Changes in the Phytoplankton of the Western English Channel in recent years*

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After completing my Ph.D. in London under Professor Fogg (Boalch, 1958) I was appointed to a fellowship at the Laboratory of the Marine Biological Association of the UK at Plymouth. The fellowship was funded by International Paints and my field of investigation was the action of antifouling paints on seaweeds. In London I had cultured *Ectocarpus* (Boalch, 1961a, b) and one of my interests had been extracellular products (Fogg & Boalch, 1958). In those days when copper and mercury were the main toxins in antifouling paints, the action between these metals and the extracellular products produced by the algae was of considerable interest. At Plymouth I also became interested in the production of extracellular compounds by phytoplankton and with John Armstrong made some early measurements on volatile sulphur compounds, the now famous dimethyl sulphide (Armstrong & Boalch, 1961). However, I had no training in organic chemistry and John was a very good analyst and inorganic chemist but not an organic chemist so we found we were out of our depth and moved into other fields; soon after, John went to Canada.

By the time my fellowship had ended I was interested in marine phytoplankton. Doctor Mary Parke was working on flagellates and did not want to cover the diatoms or dinoflagellates so, on joining the staff of the Association, I moved on to these. At this point I must say how much I owe to Dr Parke. She had built up a remarkable reputation for work on the smaller phytoplankton and she was a great guide to me in so many ways. She passed on what information she had collected on diatoms and dinoflagellates. She also instilled in me taxonomic principles and the need to uphold the International Code of Botanical Nomenclature. Later, when she was the editor of the British Phycological Journal, Dr Parke taught me the basics of editing so that when I became the editor of the British Phycological Journal, in 1975, I already had a good idea of what to do. I should say how much I am also indebted to my colleagues at the Plymouth Laboratory, to my assistant Derek Harbour and to the captains and crews of the Laboratories research vessels. They have all helped in various ways over the last 25 years.

Tow-net samples

In the early 1960s I started looking at regular samples of the local phytoplankton. Wherever the laboratory ships were working they would take a tow-net sample. To identify the material in my samples I first used the two books written by Marie Lebour (Lebour, 1925, 1930)—who was still working on zooplankton at the laboratory and then gradually moved on to the volumes of the Kryptogamen Flora by Hustedt and Schiller (Hustedt, 1930–1962; Schiller, 1933–1937) and to the many other books needed for the identification of phyto-

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plankton (e.g. Hendey, 1964). I was getting a sample most days and sometimes the identification of an unfamiliar species would occupy a lot of time. The system I adopted with the tow-net samples was first to list the dominant species and then note all the other species I could find in the sample in about 15 min. I soon accumulated a pile of note books with lists of species and a seasonal pattern began to emerge. What did worry me was that this pattern did not fit in with that described by Lebour (Lebour, 1925, 1930). The species that she said were common were not really so and the species she listed as rare were often common. I was using a similar sampling technique so there was only one sensible explanation, the species pattern had changed from what it had been when Dr Lebour wrote her books in 1925–1930, i.e. the species pattern in the late 1950s to early 1960s was not the same as it had been before 1930.

The zoologists at the laboratory had been talking about changes in the fish populations for some time (Russell, 1953; Southward, 1963). The herring fishery had declined in the 1930s and there had been some suggestion that this may have been due to overfishing but at the same time there had been a change in the arrow worms (*Sagitta*) and these were certainly not fished. F. S. Russell, who was the Director of the laboratory at that time, had suggested (Russell, 1973) that there might be cyclic changes in the fish populations in the Western English Channel (Russell *et al.*, 1971). I was beginning to wonder if there were similar changes in the phytoplankton.

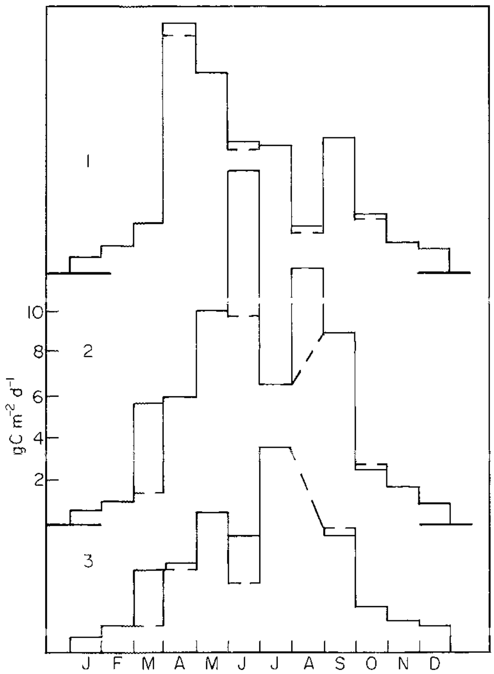

FIG. 1. Mean monthly rates of carbon fixation (g C per under 1 m^2 per d) for three stations in the Western English Channel for the years 1964–1974. If the values for 1966 are omitted then the values are as shown by the broken lines.

^{14}C experiments

In 1964 we joined a NATO marine productivity project that was to involve a number of European countries in measuring primary production and sea water chemistry on a unified system (Boalch, Armstrong & Butler, 1969). By this it was meant that all the countries taking part were to use exactly the same methods so that the results would all be comparable. The programme was not a success as some groups found that they could not work with methods with which they were unfamiliar and they resorted to previous methods. Also, the use of the *in situ* ^{14}C method to measure primary production from dawn to mid-day or mid-day to sunset was not always practicable, for instance we found it was too expensive to keep our ship on station for half a day while the experiment was in progress so that we had to develop a simulated *in situ* method. We calibrated this against the true *in situ* method and found a correction factor to apply to our simulator. The NATO project lasted for three years but at the MBA we continued the survey for 10 years and have continued using the same techniques at our International Station E1 ever since and now have more than 20 years of data for this station. Figure 1 shows the mean monthly ^{14}C fixation over the 10-year period 1964–1974 at three stations (Fig. 2) in the English Channel (Boalch, Harbour & Butler,

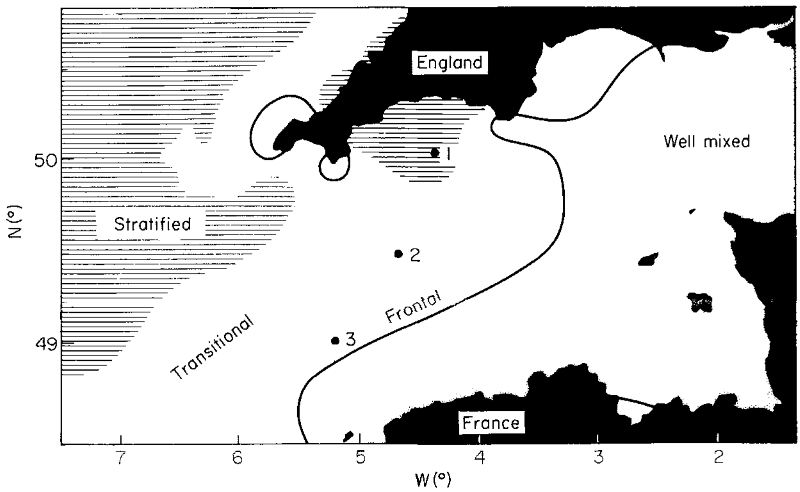

FIG. 2. Map of the Western English Channel to show the positions of the three sampling stations. (After Maddock *et al.*, 1974.)

1978). At station 1 (International Hydrographic Station E1) there is a double peak with high production early in the spring and again in the autumn. At the stations further out into the Channel the two peaks come closer together until at the third station it is difficult to consider them as two peaks but rather as a period of summer production (Fig. 1). This indicates that the classical studies that were carried out at Plymouth in the 1930s, showing production peaks in the early spring and again in the autumn, were accurate for waters close to Plymouth but certainly did not give a true picture of the English Channel as a whole (Harvey *et al.*, 1935).

Long-term changes

During my period of observations there have been a number of changes in the phytoplankton. The first change occurred in the winter of 1965–1966 (Fig. 3). That winter there was some very peculiar plankton off Ushant, in fact we had traces of freshwater plankton in the area and low-salinity water appeared to be entering the Channel both in February and March (Armstrong, Butler & Boalch, 1974). In the spring and again in the late summer there was very high production at our mid-channel station (Fig. 2) and even at station 1 the production was higher than it had been previously (Fig. 3) (Boalch, Harbour & Butler, 1978). At the same time I had noticed changes in the species of phytoplankton off Plymouth. It was not that a large number of species had completely disappeared or many new ones arrived but there was a change in the balance. A change was also noticed in the zooplankton in that there was a marked increase in the catch made by a standard net towed under standard conditions (Russell *et al.*, 1971; Southward, 1980). This was indicating a return to the pre-1930 conditions when the standing crop of zooplankton had been much greater than it was in the period 1935–1965 (Russell *et al.*, 1971). At the same time the numbers of pilchard eggs off Plymouth began to decline indicating a decline of the mature pilchard population. If this was a return to the pre-1935 conditions it might be expected that herring would return to the Plymouth area. They did not, but there was a great increase in mackerel and a large winter fishery developed off South Devon and Cornwall; there were soon allegations of overfishing, especially after the purse seine was introduced in the area in the early 1970s. In 1983–1984 there was another change (Fig. 4). At this time we were only carrying out measurements of production by

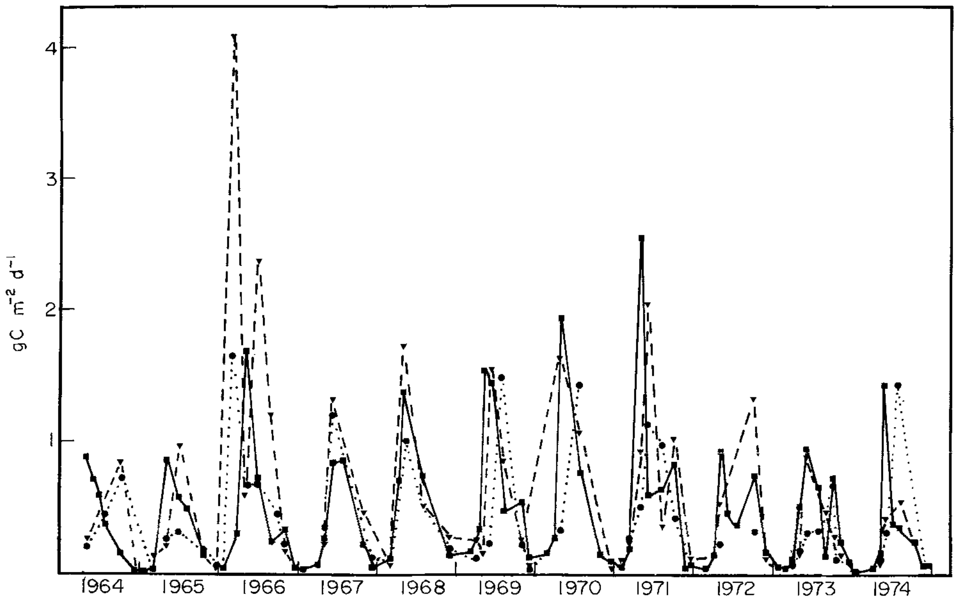

FIG. 3. Carbon fixation (g C under 1 m^2 per d) for three stations in the Western English Channel, 1964–1974. ■——■, station 1; ▼– – –▼, station 2; ●· · · ·●, station 3.

the ^{14}C method at station 1 but the change was very evident in the winter phytoplankton. This became dominated by large centric diatoms as it had been in the period prior to 1965. At the same time the zooplankton catches decreased and pilchard eggs became more abundant in the samples (Southward & Boalch, 1987). It looked as if the system was turning once again. If this was so, the change had come after only 18 years whereas the previous change had taken place after about 30 years. These periodic changes have been called the Russell Cycle (Cushing & Dickson, 1976; Cushing, 1982; Southward, 1983) after the late Sir Frederick Russell who first noticed the pattern, though it seems not to be a cyclic system but one which undergoes comparatively sudden switches which may not occur at exactly regular intervals.

Now to examine some of the changes in more detail. The measurements of ^{14}C at the

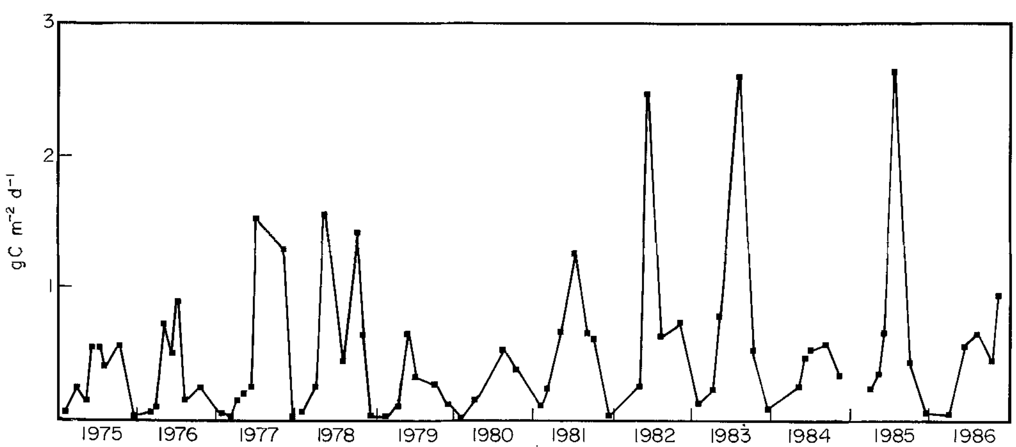

FIG. 4. Carbon fixation (g C under 1 m^2 per d) for station 1 (1975–1986).

three stations for the 10-year period 1964–1974 (Boalch *et al.*, 1978 and Fig. 2) show considerable fluctuations from year to year. The high values at all three stations in 1966 stand out from the rest. These were followed by a period of increasing spring production and then at station 1 a period of low spring production. In 1982 (Fig. 4), there were high values again but this time later in the spring and in 1983 a high summer production (Fig. 4). Clearly the changes in phytoplankton I have referred to earlier came at the time of unusual fluctuations in primary production but fluctuations in primary production also occurred in 1971–1972 (Fig. 3) and 1977–1978 (Fig. 4) but without such marked changes in phytoplankton. The 1977–1978 fluctuations were during a period of fine summers when *Gyrodinium aureolum* Hulburt was particularly abundant in the waters offshore from Plymouth (Holligan, 1979).

Immigrant species

The mention of *Gyrodinium aureolum* brings me on to another topic and this time we are thinking at the species level and not at the population level. During the period of my observations I have listed a number of new records for the area. Some of these were sporadic occurrences such as *Ptychodiscus noctiluca* Stein (Boalch, 1969) and *Ceratium inflatum* (Kof.) Jorg. (Marine Biological Association, 1972) -species that were previously recorded for areas adjacent to the Western Approaches. Clearly these were species that were carried into the area by abnormal conditions of weather or water movement. Then there are the records of the new species *Halosphaera parkeae* Boalch et Mommaerts (Boalch & Mommaerts, 1969) and the new species of *Pterosperma* (Parke *et al.*, 1978). These have probably been in the area for a long time but because the species or even the genera had not been critically studied the species limits were not recognized and hence it is likely that these species were included in related ones in previous investigations.

However there are also a number of new records for species that are quite new to the area and were most certainly not here earlier. In most cases these have arrived in the area, made some sort of impact on the ecosystem and then settled down to occupy a rather insignificant part in the ecosystem. The first of these species was *Pleurosigma planctonicum* Simonsen (Boalch & Harbour, 1977a). We first noticed this off Ushant in 1966 and within a few years it was abundant in the Western English Channel but it had no harmful effects and did not cause an upset in the ecosystem and then settled down to a minor part; it has now almost disappeared. The next was *Thalassiosira angstii* (Gran in Gran et Angst) Markarova which we first noticed in 1978 (Marine Biological Association, 1979) and was very abundant in the period 1980–1981 but this also had no marked effect on the ecosystem and now has an insignificant role. In 1968 I made a note that I had seen what I thought was a new dinoflagellate but as it was a *Gymnodinium* or *Gyrodinium* and members of these two genera are extremely difficult to identify, especially if one only sees a few isolated cells, I did not attempt to give it a name. A little later I had a letter from Dr Vagn Hansen in Denmark saying there was a *Gymnodinium*-like organism off the Danish coast which was forming red tides and killing fish (Hansen & Sarma, 1969; Hansen, Albrechtsen & Frandsen, 1969). He sent me details and some samples and I told him I could not identify the organism with any certainty but it looked like the few cells I had seen in my samples. Similar toxic blooms had also occurred on the Norwegian coast (Braarud & Heimdal, 1970) and the plankton workers there contacted Dr Hulburt of Woods Hole, USA as they thought this new arrival looked like a species that Hulburt had described (Hulburt, 1957). It was decided that the organism that was causing all the problems in Europe fitted the description of *Gyrodinium aureolum* and Dr Hulburt agreed that the European material looked like the material that he had described and this name was applied to the

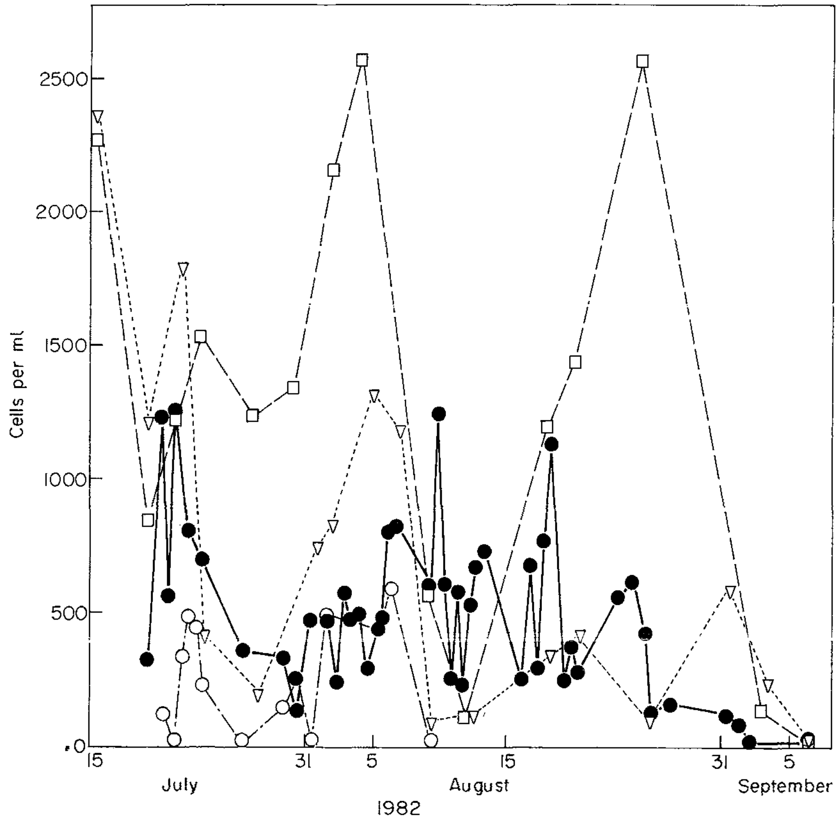

FIG. 5. Cell counts of *Gyrodinium aureolum* at various sites in Plymouth Sound in 1982. Sutton Pool (□- - -□); Western end of the Breakwater (▽···▽); laboratory circulation (○——○); intake for laboratory supply (●——●).

dinoflagellate in Europe. Since then *Gyrodinium aureolum* has been widely recorded in European waters and is still spreading (Tangen, 1977). In a number of areas fish kills have been reported and it has proved very troublesome in areas where there are fish farms. In the Plymouth area we had fish kills along the Cornish coast in 1978 (Boalch, 1979; Forster, 1979; Griffiths, Dennis & Potts, 1979; Widdows *et al.*, 1979). Because of the potential danger of this organism we keep a very close watch when it becomes abundant in Plymouth Sound. If it were to be taken in with the water for the Aquarium we could loose fish, including specimens we have kept for more than 15 years. Each summer, as soon as we find the numbers of *Gyrodinium aureolum* building up near the Aquarium intake, Mr Frettsome takes regular samples and counts the number of cells. In 1982 we did quite an extensive survey and counted samples from around the Sound, at the intake and in the Aquarium circulation. Figure 5 shows that the numbers fluctuated wildly in Sutton Pool and at the Breakwater. At first these large fluctuations appeared to fit in with the spring tides but then they got out of sequence so I am not certain what causes them. There is no obvious link with tides or weather. The widely fluctuating numbers at the sea-water intake at different times of the day (Fig. 6) are a little easier to explain as they are related to the depth of the water above the intake at the time the sample is taken. The main population of the dinoflagellate during the hours of daylight is in the slightly sub-surface layer and as this rises and falls above the intake so the main population is sampled to a different extent.

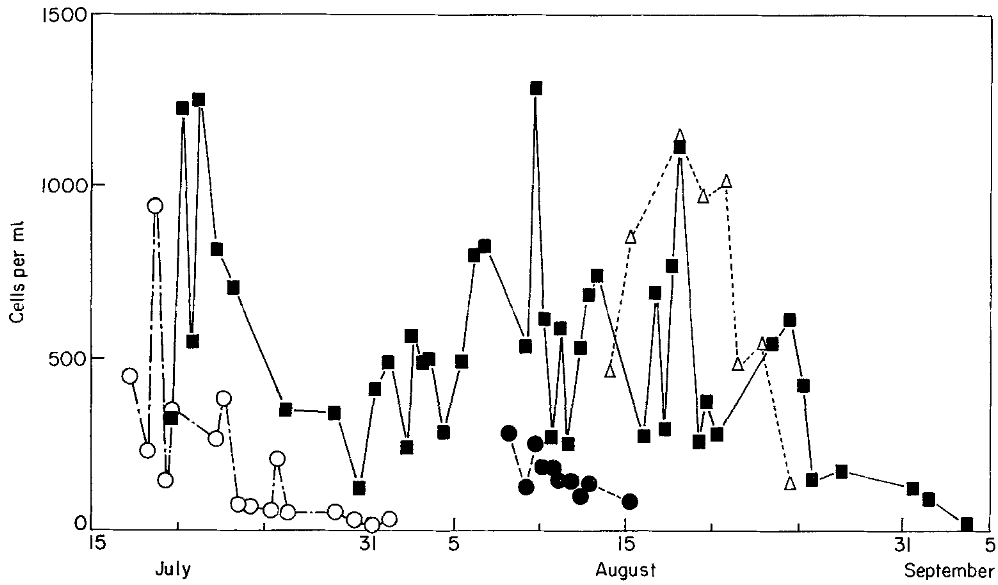

FIG. 6. Cell counts of *Gyrodinium aureolum* at the intake for the Laboratory supply in 1982 (■——■), 1983 (△···△), 1985 (● ●) and 1986 (○ · · ○).

Nineteen eighty-two was rather an abnormal year as is shown in Fig. 6. In 1982 the *Gyrodinium* bloom extended from July to September. In other years the bloom in the Sound has only lasted for about 3 weeks and in 1985 there was no bloom at all.

Coscinodiscus wailesii Gran et Angst (Boalch & Harbour, 1977b) was another new arrival. We first noticed it in the Plymouth area in 1977 and I erroneously identified it as *Coscinodiscus nobilis* Grun. Soon after we had first seen it in our samples Mr Harbour isolated it into culture for me and as soon as the culture started growing he commented that it was producing an abnormal amount of mucilage. Soon we began to get reports from the local fishermen that their nets were becoming clogged with a heavy slime. We began to suspect that this slime had originated from our diatom which was now becoming abundant in the local waters. We sent samples of the mucilage from a culture and the slime from the nets to Dr Elizabeth Percival at Royal Holloway College and she confirmed that the structure of the two samples was so similar that it was very likely that the slime from the nets had originated from the diatom (Percival, Rahman & Weigel, 1980). It looked as if the mucilage from the diatom was sinking to the sea-bed where it was collecting a lot of sand and mud and becoming much heavier and then causing problems with the fishing nets. As we knew the number of diatom cells in the water over the fishing grounds and we could measure the amount of mucilage produced by cells in culture we were able to calculate the amount of mucilage settling on a unit area of sea-bed. It was then quite simple to calculate the area of sea-bed swept during a standard trawl and we found that the trawl would sweep up enough slime to twice fill its volume (Boalch & Harbour, 1977b). One fisherman had actually lost his trawl due to the weight of the slime in it. Of course there was nothing we could do to stop the diatoms producing the slime and there was no way we could eliminate the diatom, but we could tell the fishermen which areas were not dominated by the diatom and hence where it was safe to fish. *Coscinodiscus wailesii* is still present in the Plymouth area and in recent years has formed the major constituent of the winter centric diatom population but there have not been any reports of problems with the

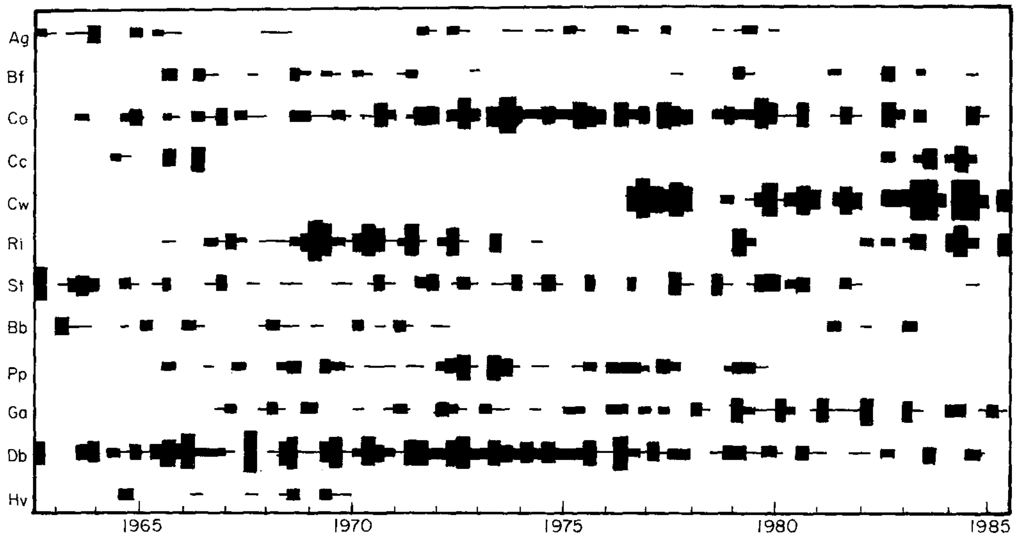

FIG. 7. Occurrence of selected species of phytoplankton taken off Plymouth in the period 1963–1985. Ag, *Asterionella glacialis*; Bf, *Bacteriastrum furcatum*; Co, *Corethron criophyllum*; Cc, *Ceratium candelabrum*; Cw, *Coscinodiscus wailesii*; Ri, *Rhizosolenia alata* fo. *indica*; St, *Streptotheca thamensis*; Bb, *Braarudosphaera bigelowii*; Pp, *Pleurosigma planctonicum*; Ga, *Gyrodinium aureolum*; Db, *Ditylum brightwellii*; Hv, *Halosphaera viridis*.

fishing nets. Perhaps the mucilage is only produced under certain conditions. Incidentally this species was first described from the west coast of America in 1920 by Gran and Angst. How it came to the Channel is a mystery but now it is widely distributed in European waters. In some ways it is repeating the story of the arrival of *Odontella* (formerly *Biddulphia*) *sinensis* (Grev.) Grun. which came to Europe from the Far East in 1889 and spread throughout European waters (Ostenfeld, 1908) and is now an important constituent of the winter and spring diatom flora.

Data from tow-net samples

I will now refer to some of the data produced by the computer analysis of my lists from the tow-net samples. First of all, the records were analysed to give the percentage occurrences of each species in the samples from 3-monthly periods. The year was divided up to fit the biological cycles into December, January and February (winter) March, April and May (spring) June, July and August (summer) September, October and November (autumn). Using this system the distribution of the species was examined over the period 1962–1985 and the results for some of the interesting species are shown in Fig. 7.

First of all *Asterionella glacialis* Castr. (formerly *A. japonica* Cleve et Gran) shows a very broken distribution as does *Bacteriastrum furcatum* Shadbolt (Boalch, 1974). In fact the two show almost a reciprocal distribution. This is not surprising when it is realized that *Asterionella* is common in the North Sea and to some extent in the Irish Sea whereas *Bacteriastrum* is more common in the Bay of Biscay (Maddock, Boalch & Harbour, 1981). *Corethron criophyllum* Castr. obviously did well in the period 1965–1983—what we term the cold-water period. This is the period when the cold-water species of fish were most in evidence and *Corethron* is a cold-water species (Maddock *et al.*, 1981). Perhaps the most interesting distribution is that of *Ceratium candelabrum* (Ehrenb.) Stein which only comes into our area at the times of changes in the system i.e. 1965–1966 and 1983–1985. This again is a species from the Bay of Biscay so there may be a considerable movement of water from

Biscay around Ushant, up the Channel and across towards Plymouth when the system changes. It also seems that this may be a plant indicator species. I have already spoken about *Coscinodiscus wailesii* and its arrival in the Channel. *Rhizosolenia alata* fo. *indica* (H.Perag.) Gran is very interesting, it is not a distinct species but a form of *Rh. alata* which is produced under certain conditions. These conditions are normally found to the south-west of the English Channel but clearly they are occasionally found near Plymouth. An investigation of the conditions that control the form would be worthwhile. We can cause it to revert to the *alata* form in culture but not vice versa as yet. Professor von Stosch used our culture material of the *indica* and the *alata* form to which it gave rise when he was studying the structure of the girdle in *Rhizosolenia* (Stosch, 1975). *Streptotheca thamensis* Shrubs. is another species which probably has its centre of origin in the North Sea and spreads down the Channel in winter under the influence of easterly winds but in recent years it has become less abundant. *Braarudosphaera bigelowii* (Gran et Braarud) Defl.—a wonderful name combining the names of two of the people that have contributed so much to the study of phytoplankton—is a coccolithophorid with an unknown life cycle but it shows an interesting cyclic behaviour. *Pleurosigma planctonicum* I have already mentioned but it is interesting to see that it has disappeared from our area since 1980. *Gyrodinium aureolum* has also been mentioned earlier. In this case I am not very happy about the record prior to 1969. It happened that we recorded a small dinoflagellate and when the records were put into the computer they were all entered under the one name. The points of interest here are that around 1980 it was predominantly an autumn species but was recorded throughout most of the year. *Ditylum brightwellii* (T.West) Grun. was a very common species, present all the year round, but in recent years it has been much less abundant. *Halosphaera viridis* Schm. (Parke & den Hartog-Adams, 1965) has its main centre of distribution in the Mediterranean but it also occurs to the west of Ushant and although we can still find it there it has not occurred in the Plymouth area for some time.

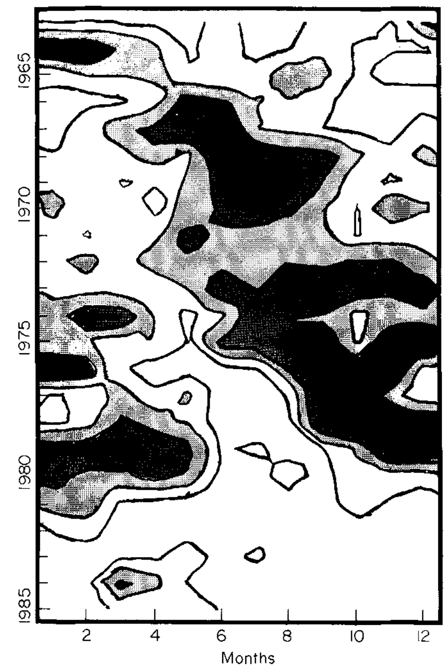

FIG. 8. Occurrence of the diatom *Skeletonema costatum* off Plymouth (percentage occurrence in all samples) for the period 1963–1985.

One other interesting species which I have illustrated in a different way (Fig. 8) is *Skeletonema costatum* (Grev.) Cleve. This used to be considered the weed of the phytoplankton and certainly in the 1970s it was around in our samples right through the year. This figure shows an interesting drift in the peak occurrence of the species from summer to autumn and then a new spring occurrence. In recent years it has almost disappeared. It used to be so abundant in Plymouth Sound that it was difficult to isolate any species without getting *Skeletonema* growing instead. Now we cannot find it in the Sound. There has been a publication reporting that this species is particularly sensitive to the poison tributyl tin which is used in antifouling paints (Walsh *et al.*, 1985) and tributyl tin has also been shown to be having a marked effect on the common dog whelks around the coast of the UK, especially in areas where high concentrations of the toxin are present (Bryan *et al.*, 1986). Are we recording the demise of a species of phytoplankton due to poisoning from TBT?

Blooms

These days there is a lot of talk about blooms as if they are something new. Of course blooms have always occurred and the blooms of the coccolithophorids in the Cretaceous Period would have been a wonderful sight. Whether blooms are more frequent now than previously is very difficult to ascertain (Boalch, 1984). We are now very much more environmentally aware and as soon as there is any discoloration of the sea someone reports it as possible pollution and so scientists are alerted. It should be remembered that many blooms are natural phenomena and often they have no ill effects whatsoever, even if a bloom is very dense. In 1982 there was a very spectacular red tide of the pink, non-photosynthetic dinoflagellate *Noctiluca scintillans* (Macartney) Ehrenb. Cells of this organism had been growing for some time, feeding on the photosynthetic phytoplankton and dispersed through the water column. There was then a spell of very fine weather and all the cells rose to the surface. This occurred in most of the Western English Channel so that the surface of the Channel from Plymouth to Roscoff was red. A pilot who was flying from Cork to France told me that it looked as if the whole of the Channel had turned into tomato soup (Boalch, 1984). Some people get very worked up about such blooms but in this case it was a perfectly natural happening brought about by a combination of conditions. The cells floating on the surface of the sea were killed off by the ultra-violet light and a week or so later there was a storm which brought about mixing and the dead cells were dispersed through the water column. The bloom was soon gone and left no after-effects.

For those who think my studies of phytoplankton have taken me too far away from the seaweeds that I started collecting when I was nine—*Gigartina* and *Chondrus* used for the production of an agar substitute during the 1939–1945 war (Marshall, Newton & Orr, 1949)—I must add that I still have a love of the seaweeds and I am always grateful when we have a visitor at Plymouth who needs to be taken out onto the shore to look at or collect seaweeds.

REFERENCES

Armstrong, F. A. J. & Boalch, G. T. (1961). Ultraviolet absorption of seawater and its volatile components. *Int. Ass. phys. oceanogr.*, Monograph **10:** 63–66.

Armstrong, F. A. J., Butler, E. I. & Boalch, G. T. (1974). Hydrographic and nutrient chemistry surveys in the Western English Channel during 1965 and 1966. *J. mar. biol. Ass. UK*, **54:** 895–914.

Boalch, G. T. (1958). Studies on *Ectocarpus* in culture. *Ph.D. thesis*, University of London.

Boalch, G. T. (1961a). Studies on *Ectocarpus* in culture. I Introduction and methods of obtaining uni-algal and bacteria-free cultures. *J. mar. biol. Ass. UK*, **41:** 279–286.

Boalch, G. T. (1961b). Studies on *Ectocarpus* in culture. II Growth and nutrition of a bacteria-free culture. *J. mar. biol. Ass. UK*, **41:** 287–304.

Boalch, G. T. (1969). The dinoflagellate genus *Ptychodiscus* Stein. *J. mar. biol. Ass. UK*, **49:** 781–784.

Boalch, G. T. (1974). The type material of the diatom genus *Bacteriastrum* Shadbolt. *Nova Hedwigia*, Beih. **45:** 159–163.

Boalch, G. T. (1979). The dinoflagellate bloom on the coast of south-west England, August–September 1978. *J. mar. biol. Ass. UK*, **59:** 515–528.

Boalch, G. T. (1984). Algal blooms and their effects on fishing in the English Channel. *Hydrobiologia*, **116/117:** 449–452.

Boalch, G. T. & Harbour, D. S. (1977a). Observations on the structure of a planktonic *Pleurosigma*. *Nova Hedwigia*, Beih. **54:** 275–280.

Boalch, G. T. & Harbour, D. S. (1977b). Unusual diatom off the coast of south-west England and its effect on fishing. *Nature, Lond.*, **269:** 687–688.

Boalch, G. T. & Mommaerts, J.-P. (1969). A new punctate species of *Halosphaera*. *J. mar. biol. Ass. UK*, **49:** 129–139.

Boalch, G. T., Armstrong, F. A. J. & Butler, E. I. (1969). Mediterranean Productivity Project, Plymouth Report. *NATO Subcommittee on Oceanographic Research, Technical Report* **47:** 96–102.

Boalch, G. T., Harbour, D. S. & Butler, E. I. (1978). Seasonal phytoplankton production in the western English Channel, 1964–1974. *J. mar. biol. Ass. UK*, **58:** 943–953.

BRAARUD, T. & HEIMDAL, B. (1970). Brown water on the Norwegian coast in autumn 1966. *Nytt. Mag. Bot.*, **17**: 91–97.

BRYAN, G. W., GIBB, P. E., HUMMERSTONE, L. G. & BURT, G. R. (1986). The decline of the gastopod *Nucella lapillus* around south-west England; evidence for the effect of tri-butyltin from antifouling paints. *J. mar. biol. Ass. UK*, **66**: 611–640.

CUSHING, D. H. (1982). *Climate and Fisheries.* Academic Press, London.

CUSHING, D. H. & DICKSON, R. R. (1976). The biological response in the sea to climatic change. *Adv. Mar. Biol.*, **14**: 1–122.

FOGG, G. E. & BOALCH, G. T. (1958). Extracellular products in pure cultures of a brown alga. *Nature, Lond.*, **181**, 789–790.

FORSTER, G. R. (1979). Mortality of the bottom fauna and fish in St Austell Bay and neighbouring areas. *J. mar. biol. Ass. UK*, **59**: 517–520.

GRIFFITHS, A. B., DENNIS, R. & POTTS, G. W. (1979). Mortality associated with a phytoplankton bloom off Penzance in Mounts Bay. *J. mar. biol. Ass. UK*, **59**: 520–521.

HANSEN, V. K. & SARMA, A. H. V. (1969). On a *Gymnodinium* red water in the eastern North Sea during autumn 1968 and accompanying fish mortality with notes on the oceanographic conditions. *ICES* (Copenhagen) **CM21**.

HANSEN, V. K., ALBRECHTSEN, L. & FRANDSEN, C. (1969). De dode fisk og planteplanktonet i Nordsoen i 1968. *Skr. Danm. Fisk. Havunders.*, **29**: 36–53.

HARVEY, H. W., COOPER, L. H. N., LEBOUR, M. V. & RUSSELL, F. S. (1935). Plankton production and its control. *J. mar. biol. Ass. UK*, **20**: 407–442.

HENDEY, N. I. (1964). An introductory account of the smaller algae of British coastal waters. PartV Bacillariophyceae (Diatoms). *Fishery Investigations*, Series **IV**, HMSO.

HOLLIGAN, P. M. (1979). Dinoflagellate blooms associated with tidal fronts around the British Isles. In *Toxic Dinoflagellate Blooms* (Taylor, D. L. & Seliger, H. H., editors), 249–256. Elsevier.

HULBURT, E. M. (1957). The taxonomy of unarmored Dinophyceae of shallow embayments on Cape Cod, Massachussets. *Biol. Bull., Woods Hole*, **112**: 196–219.

HUSTEDT, F. (1930–1962). Die Kieselalgen. In *Rabenhorsts' Kryptogamen-Flora*, Bd **7**, 1–3.

LEBOUR, M. V. (1925). *The Dinoflagellates of Northern Seas.* The Marine Biological Association, Plymouth.

LEBOUR, M. V. (1930). *The Planktonic Diatoms of Northern Seas.* The Ray Society, London.

MADDOCK, L., BOALCH, G. T. & HARBOUR, D. S. (1981). Populations of phytoplankton in the Western English Channel between 1964 and 1974. *J. mar. biol. Ass. UK*, **61**: 565–583.

MARINE BIOLOGICAL ASSOCIATION (1972). Report of the Council for 1971–1972. *J. mar. biol. Ass. UK*, **52**: 1067–1102.

MARINE BIOLOGICAL ASSOCIATION (1979). Report of the Council for 1978–1979. *J. mar. biol. Ass. UK*, **59**: 1033–1074.

MARSHALL, S. M., NEWTON, L. & ORR, A. P. (1949). *A Study of Certain British Seaweeds and their Utilization in the Preparation of Agar* (Newton, L., editor). HMSO.

OSTENFELD, C. H. (1908). On the immigration of *Biddulphia sinensis* Grev. and its occurrence in the North Sea during 1903–1907. *Medd. Konm. Hav. S. Plankton* **1**. Copenhagen.

PARKE, M. & DEN HARTOG-ADAMS, I. (1965). Three species of *Halosphaera. J. mar. biol. Ass. UK*, **45**: 537–557.

PARKE, M., BOALCH, G. T., JOWETT, R. & HARBOUR, D. S. (1978). The genus *Pterosperma* (Prasinophyceae): species with a single equatorial ala. *J. mar. biol. Ass. UK*, **58**: 239–276.

PERCIVAL, E., RAHMAN, M. A. & WEIGEL, H. (1980). Chemistry of the polysaccharide of the diatom *Coscinodiscus nobilis. Phytochemistry*, **19**: 809–811.

RUSSELL, F. S. (1953). The English Channel. *Rep. Trans. Devon. Ass. Advmt Sci.*, **85**: 1–17.

RUSSELL, F. S. (1973). A summary of the observations on the occurrence of the planktonic stages of fish off Plymouth 1924–1972. *J. mar. biol. Ass. UK*, **53**: 347–355.

RUSSELL, F. S., SOUTHWARD, A. J., BOALCH, G. T. & BUTLER, E. I. (1971). Changes in biological conditions in the English Channel off Plymouth during the last half-century. *Nature, Lond.*, **234**: 468–470.

SCHILLER, J. (1933–1937). Dinoflagellatae (Peridineae). In *Rabenhorst's Kryptogamen-Flora* Bd **10**, Ab **3**, Teil 1 & 2.

SOUTHWARD, A. J. (1963). The distribution of some plankton animals in the English Channel and approaches. III. Theories about long-term biological changes including fish. *J. mar. biol. Ass. UK*, **43**: 1–27.

SOUTHWARD, A. J. (1980). The Western English Channel—an inconstant ecosystem? *Nature, Lond.*, **285**: 361–366.

SOUTHWARD, A. J. (1983). Fluctuations in the ecosystem of the western Channel: a summary of studies on progress. *Actes 17e Symp. Euro. Biol. Mar. Brest 1982, Oceanologica Acts No. Sp.*, 187–189.

SOUTHWARD, A. J. & BOALCH, G. T. (1987). Aspects of long term changes in the ecosystem of the Western English Channel in relation to fish populations. *Invest. Pesq.* (in press).

STOSCH, H. A. VON (1975). An amended terminology of the diatom girdle. *Nova Hedwigia*, **53**: 1–28.

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

WALSH, G. E., MCLAUGHLAN, L. L., LORES, E. M., LOUIE, M. K. & DEANS, C. H. (1985). Effects of organotins on growth and survival of two marine diatoms, *Skeletonema costatum* and *Thalassiosira pseudonana. Chemosphere*, **14**: 383–392.

WIDDOWS, J., MOORE, M. N., LOWE, D. M. & SALKED, P. N. (1979). Some effects of a dinoflagellate bloom (*Gyrodinium aureolum*) on the mussel *Mytilus edulis. J. mar. biol. Ass. UK*, **59**: 522–524.

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