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PLANKTON BLOOMS OF ECONOMIC IMPORTANCE TO FISHERIES IN UK WATERS 1968-1982

by

P A Ayres*†, D D Seaton** and P B Tett***

*MAFF, Fisheries Laboratory, Remembrance Avenue, Burnham-on-Crouch, Essex, England
**DAFS Marine Laboratory, PO Box 101, Victoria Road, Aberdeen AB9 8DB, Scotland
***SMBA, Dunstaffnage Marine Research Laboratory, PO Box 3, Oban, Argyll PA34 1AD, Scotland

ABSTRACT

Three phytoplankton species blooms which have been reported harmful to fisheries in UK waters are discussed:

(1) The armoured dinoflagellate *Gonyaulax tamarensis* has caused harmful levels to humans of paralytic shellfish poison in most years since 1968 in shellfish from sites on the British east coast between 54.5°N and 56.7°N. The months of maximum toxicity are May and June.

(2) Red tides of the naked dinoflagellate *Gyrodinium aureolum* have caused mortalities of wild marine animals in south-west England in 1978 and in North Wales in 1971, and killed farmed salmon in the west of Scotland in 1980. These red tides occurred between August and October. The dinoflagellate occurs all along the west coast of Britain and is often abundant at fronts.

(3) Blooms of 'flagellate X', possibly a species of *Olisthodiscus* or *Chattonella*, have killed farmed fish in sea-lochs on the west coast of Scotland in 1979 and 1982.

†Current address: New South Wales State Fisheries, Brackish Water Fish Culture Research Station, Taylor's Beach, Salamander Bay, NSW 2301, Australia

RÉSUMÉ

Les fleurs correspondant à trois espèces de phytoplancton déclarées nuisibles à la pêche dans les eaux du Royaume-Uni font l'objet de cette étude:

(1) Le dinoflagellé cuirassé Gonyaulax tamarensis a produit des niveaux de poison paralysateur nocifs à l'homme pendant presque toutes les années depuis 1968 chez des testacés ramassés sur la côte orientale de la Grande-Bretagne dans des endroits situés entre 54,5°N et 56,7°N. La toxicité atteint son maximum aux mois de mai et de juin.

(2) Les marées rougeâtres formées par le dinoflagellé nu Gyrodinium aureolum ont provoqué en 1978 la mort d'animaux marins de type sauvage dans le sud-ouest de l'Angleterre et en 1971 dans le nord du pays de Galles et ont tué en 1980 des saumons d'élevage dans l'ouest de l'Ecosse. Les marées rougeâtres se sont produites entre les mois d'août et d'octobre. Ces dinoflagellés apparaissent tout le long de la côte occidentale de la Grande-Bretagne et ils se présentent souvent en grande abondance sur les rivages.

(3) Les fleurs du 'flagellé X', peut-être une espèce d'Olisthodiscus ou de Chattonella, ont fait mourir en 1979 et en 1982 des poissons d'élevage dans des bras de mer faisant partie du littoral occidental de l'Ecosse.

INTRODUCTION

Although blooms of phytoplankton that result in significant harm to fisheries are uncommon in UK waters, they occur sufficiently frequently to cause concern. This concern is evidenced, for example, by the PSP-monitoring programme instituted by the UK government following an epidemic of paralytic shellfish poisoning in 1968, and also by the increased cost to marine fish farmers of insuring against fish death from plankton blooms.

There occur in UK waters at least three algae whose blooms have been associated with marked harmful effects. The organisms involved are the armoured photosynthetic dinoflagellate Gonyaulax tamarensis, which contains a toxin causing paralytic shellfish poisoning (PSP) when shellfish that have injested the dinoflagellate are eaten by higher animals; the naked photosynthetic dinoflagellate Gyrodinium aureolum, associated with late-summer kills of farmed fish and wild fish and invertebrates; and mixed blooms of small flagellates and dinoflagellates which have killed farmed salmonids during early summer in sea farms in western Scotland, the causative organism perhaps being a chloromonad temporarily named 'flagellate X'.

Appendix 1 lists and discusses dinoflagellates to which toxicity or harmful effects have been ascribed, and which occur in UK waters. Appendix 2 reviews information concerning the possible identity of 'flagellate X'.

GONYAULAX TAMARENSIS

The classification of dinoflagellates used here follows the scheme adopted by Dodge (1980) and thus no attempt has been made to distinguish toxic forms of Gonyaulax tamarensis from non-toxic ones as proposed by Balech (1971). The information presented has been derived primarily from a monitoring programme of PSP toxins in shellfish off the NE coast of England which has been conducted annually since 1968 and has been reported in detail elsewhere (Ayres and Cullum 1978; 1981). In view of the mass of data collected during this period only the main points are presented in the current paper.

The bloom of Gonyaulax tamarensis in waters off the northeast coast of Britain in 1968, and the resulting outbreak of PSP which affected 78 people, has been described by Coulson et al. (1968), Adams et al. (1968), Ingham et al. (1968), Robinson (1968), and Wood (1968). PSP-monitoring was begun in that year, and toxins have been found in molluscs from the same area every year since. Limited sampling of offshore molluscs (eg Pecten maximus) has shown that they may become toxic three to four weeks earlier than mussels in the littoral region and that this is coincident with the appearance of various species of dinoflagellates in offshore waters. Gonyaulax tamarensis has been observed every year in water and in the gut contents of mussels when mussels were toxic but usually in relatively low numbers.

In the initial year 1968, however, up to 74,000 cells/litre of seawater were found during May. The organisms were found to be present in an area extending up to 97 km offshore and 200 km long between the Forth estuary and the Yorkshire coast. In 1969 samples collected from the Scottish North Sea coast showed toxicity extending to Aberdeen (Conn and Farrard, 1970), and in June 1982 900 mouse units/100g were found in mussels from the Montrose basin, south of Aberdeen. In 1970, 8,400/litre Gonyaulax tamarensis occurred off Holy Island in early June. From 1971 examination of mussel gut contents replaced water sampling and so from that year onwards only relative abundance could be measured.

In general mussel toxicity appeared to be associated with an increase in total dinoflagellate numbers rather than the dominance of a single species. Gonyaulax tamarensis has always been seen to be coincident with toxicity though invariably it has been exceeded in numbers by other dinoflagellates, especially Protoperidinium spp. Mussel gut analysis has also shown that dinoflagellate cysts are often very common and dominant during periods of mussel toxicity, occasionally, eg in 1970, when 15,000/litre of water were seen off Holy Island and they actually outnumbered identifiable cells. Samples examined during 1978-1981 tended to confirm a relationship between dinoflagellate cysts and mussel toxicity, with cyst numbers increasing and declining as toxicity appeared and disappeared. The highest numbers of cysts observed were in the gut of a mussel sample which also possessed the highest level of toxin. Although this correlation appears to be sound the relationship between toxicity and vegetative cells is less clear. It is possible that the more fragile vegetative cells were lost prior to examination although a wide variety of species have been observed both in water and mussel gut samples.

The general pattern of species succession and toxicity is that Gonyaulax spp. are normally present when toxicity first appears and Table 1 shows that this is always in the period April to early May. Other species, particularly the

Protoperidinium group tend to be dominant during May and often coincide with the spread of toxicity to other stations. Maximum toxicity values occur in the month between the end of May and end of June, a period when cysts are usually dominant. With the decline in mussel toxicity other dinoflagellates, particularly *Dinophysis* spp., become dominant. Thus there seems to be a spectrum of development, which in terms of dinoflagellates commences with *Gonyaulax* spp. of which *G.tamarensis* is the commonest. Development of toxicity is linked with this organism though maintenance of toxin levels and its spread to other areas away from the locus may be more closely associated with dinoflagellate cysts.

In the years 1968-1970 it appeared that blooms of dinoflagellate originally arose well offshore in the region of the Firth of Forth and that there was a gradual dispersion, north, south and shorewards with a focus in the Holy Island area (see Table 1). Although this clearly has occurred since 1970 it is also evident that more localised blooms, unrelated to the primary source of toxicity also arise further down the coast. References to Table 1 shows that stations in the south such as Sunderland and Hartlepool are now most at risk from toxic dinoflagellate blooms even though toxicity normally still appears first in the Holy Island area. With the appearance of dinoflagellate cysts it is possible that there has been a gradual seeding of other areas, and with the residual southerly current this would account for shift of toxicity to the southern areas.

Ayres and Cullum (1978) reported that a survey of all major commercial shell fisheries in England and Wales failed to demonstrate toxicity in areas other than those referred to above. Parker (1980) reports negative results from assays carried out on shellfish from regions of the Irish Republic affected by *Gyrodinium aureolum* blooms in 1976 to 1978. Parker also reports that the Northern Ireland Department of the Environment carried out surveys of the north-eastern coast of Ireland in 1969 and 1978. Positive results (about 200 mouse units/100 ml) were obtained only in Belfast Lough in 1978. Mussels examined from a few sites on the west coast of Scotland have shown no significant toxicity in 1982. Dodge (1981) shows *Gonyaulax tamarensis* occurring in many places on the British west coast but does not distinguish toxic from non-toxic strains.

GYRODINIUM AUREOLUM

Blooms of *Gyrodinium aureolum* and other dinoflagellates have been associated with fish kills in Scandinavian waters since 1970 (reviewed by Tangen, 1977, 1979) and in Irish waters since 1976 (references in Pybus, 1980, and Wilson, 1982). Well-documented blooms of *Gyrodinium aureolum* causing mortalities in UK coastal waters took place in the eastern Irish Sea in 1971 (Ballantine and Smith, 1973; Helm *et al.*, 1974), on the south coasts of Devon and Cornwall in 1978 (Boalch, 1979; Forster, 1979); Griffiths *et al.*, 1979), and in the Firth of Clyde in 1980 (Jones *et al.*, 1982).

The origin of these blooms is not known for certain. Observations on the phytoplankton of fronts in the coastal seas of the British Isles have however shown that *Gyrodinium aureolum* is abundant at many fronts during summer (eg Pingree *et al.*, 1975, Pingree *et al.*, 1978; Simpson *et al.*, 1982). It thus seems possible that near-shore red tides of *Gyrodinium aureolum* are seeded from offshore fronts as a result of wind-induced currents. Near-shore conditions such as estuarine convergences may favour local concentration of *Gyrodinium* *aureolum*, and local nutrient enrichment may favour its growth.

Ballantine and Smith (1973) and Helm *et al.* (1974) describe the effects of a bloom of *Gyrodinium aureolum* in the eastern Irish Sea during September and October 1971. Concentrations of the dinoflagellate exceeded 2×10^6 cells/litre along the North Wales coast in October, and there was extensive mortality of lugworms (*Arenicola marina*) and sea-urchins (*Echinocardium cordatum*). Laboratory experiments suggested that the dinoflagellates had some toxicity, but Helm *et al.* concluded that lugworm and urchin mortalities resulted mainly from oxygen depletion in their burrows following the decomposition of the dinoflagellate bloom during calm sunny weather. Lugworms survived experimental exposure to *Gyrodinium aureolum* if adequately aerated.

A late summer/autumn bloom of *Gyrodinium aureolum* in the eastern Irish Sea in 1975 was described by Evans (1976). The peak density was 9.2×10^5 cells/litre and there were associated mortalities of lugworms.

A bloom of *Gyrodinium aureolum* during August and September 1978 caused mortalities of wild fish and benthic invertebrates, notably lugworms, in bays along the south coast of Cornwall between Plymouth and Penzance (Boalch, 1979; Forster, 1979; Griffiths *et al.*, 1979). Experiments carried out by Widdows *et al.* (1979) suggested that *Gyrodinium aureolum* either produced or contained a substance cytotoxic to mussels (*Mytilus edulis*) causing reduction in the mussels' clearance rate and damage to their gut. The Cornish mortalities were however attributed mainly to the decay of the dinoflagellate bloom, causing deoxygenation in near-bottom waters and perhaps also physical clogging of benthic animals.

In Loch Fyne, in western Scotland, in September 1980, water containing about 20 million *Gyrodinium aureolum* per litre was taken into 12 shore tanks containing salmon (*Salmo salar*). In one tank all the salmon died, probably as a result of toxin which damaged the delicate surfaces of their gills and guts (Jones *et al.*, 1982). Some fish in a previously unaffected tank died when water was inadvertently transferred from the affected pond into it. The circumstantial evidence suggests a toxin produced upon the death of *Gyrodinium* and in relatively small amounts per cell compared with *Gonyaulax tamarensis* and 'flagellate X'. Gill-clogging and oxygen depletion might also have been involved, and calculations suggest that the large biomasses involved in a bloom of *Gyrodinium aureolum* should use up oxygen rapidly at night, especially when concentrated into a near-surface layer only a few metres deep.

The occurrence of *Gyrodinium aureolum* in western Scottish coastal waters has been monitored since 1980; little was found in 1981 and, so far (June) in 1982. But its distribution must be taken as potentially coextensive with the western shelf seas of the British Isles, from the mouth of the English Channel to Cape Wrath, including the Celtic, Irish and Hebridean Seas (Holligan *et al.*, 1980; Dodge, 1981). It has also been recorded from the eastern North Sea (Dodge, 1981) although blooms have been reported only from Norwegian coastal waters. At the time of writing (July '82) an extensive bloom of *Gyrodinium aureolum* together with dead fish and invertebrates has been observed in the English Channel off the south-west coast of England.

'FLAGELLATE X'

The investigations of salmon mortalities in sea cages in Loch Striven and in shore based tank systems at Otter Ferry, Loch Fyne in May, 1979 and May, 1982 respectively has produced strong circumstantial evidence that these incidents were caused by blooms of a small (less than 20 µm) flagellate species, the specific identity of which has proven to be extremely difficult to establish but which is thought to be either Olisthodiscus luteus Carter or possibly a Chattonella species. These incidents, and a second mortality in Loch Striven in June 1979 also suggest that in some Scottish sea lochs the spring assemblage of small phytoplankton species may include other small flagellate/ dinoflagellate species which, if they bloom, are potentially toxic to fish. For a brief discussion of the Loch Striven incidents see Tett, ed. (1980). Both Olisthodiscus luteus, a member of the Chrysophyceae (Gibbs et al., 1980) and Chattonella subsala Biecheler, a member of the Chloromonadophyceae have been indicted as bloom forming species which cause fish kills and other Chattonella species are also known to form extensive blooms in Japanese waters (Iwasaki, 1979). However a literature search indicates that there are still problems of specific identity and of taxonomy to be resolved; some of these are discussed in Appendix 2.

The bloom of 'flagellate X' differed in several aspects from those of Gyrodinium aureolum. Firstly, there was no evidence that 'flagellate X' was seeded from offshore waters; the bloom appeared to arise locally, perhaps as a result of wind-driven upwelling of nutrient-rich water in the sea-lochs in question. Secondly, the blooms occurred in May and June; most Gyrodinium aureolum red tides take place in August or later. Thirdly, the 'flagellate X' blooms developed very quickly, probably in less than a week; although Gyrodinium aureolum may appear quickly at a site this is probably due to its being carried there from elsewhere, and then concentrated, not to rapid local growth. Fourthly, 'flagellate X' toxin affected the gut and liver of farmed salmon, not the gills as in the case of Gyrodinium aureolum, and not the nervous system as in the case of other dinoflagellate toxins. Finally, 'flagellate X' was toxic at much lower biomasses than Gyrodinium aureolum (5-20 mg chlorophyll a/m^3 during the Loch Striven 'flagellate X' blooms in 1979 compared with >200 mg chlorophyll a/m^3 during the Loch Fyne Gyrodinium aureolum red tide in 1980). In May 1979 mortalities in Loch Striven exceeded two thirds of all farmed salmon other than smolts, chlorophyll concentrations probably not exceeding 20 mg/m^3 - only a part of which was due to 'flagellate X'; whereas in September 1979 Gyrodinium aureolum in excess of 2000 mg/chlorophyll-a/m^3 killed only about one-tenth of farmed salmon.

At the time of writing (July 1982) a bloom of 'flagellate X' reaching about 3×10^5 cells/litre was reported as occurring in June near Ullapool (at 57.9°N on the west coast of Scotland) but has so far killed only a very few caged salmon.

DISCUSSION

Although investigatory effort has not been uniformly applied, the observations presented above suggest that three sorts of phytoplankton bloom are a source of concern in UK waters.

(1) Gonyaulax tamarensis (motile cell and cysts) is responsible for PSP-toxin found each year between April and August in shellfish collected from the North Sea coast of England and Scotland. Toxin has not been found further north than Rosehearty (57.4°N) and only traces have been measured at Bridlington (54.1°N). The highest

levels of toxin have been found between 2 May and 25 June each year, in shellfish taken between Whitby (54.5°N) and Pittenweem (56.2°N) substantially exceeding safe levels for human consumption in every year except 1971-73 and 1980. Gonyaulax tamarensis has been recorded from elsewhere in the British Isles, but the problem of toxicity is largely confined to the North Sea coast between the Humber and the Forth estuaries.

(2) Gyrodinium aureolum occurs along the entire western seaboard of Britain; it has been found dominating phytoplankton in frontal regions from Ushant to Islay; its near-shore blooms, which might have been seeded from fronts, have caused mortalities of marine organisms in S.W. England in 1978 (50°N) and 1982, North Wales and Lancashire in 1971 (53-54°N), and have killed farmed salmon in the Firth of Clyde in 1980 (56°N).

(3) Serious blooms of 'flagellate X' have so far been reported in the UK only from the sea-lochs of the Firth of Clyde (at 56°N), where they have caused three major kills amongst farmed salmonids since 1979. The organism occurs, however, as far as 58°N.

In addition to these serious problems, blooms of other kinds of phytoplankton have sometime caused nuisances. In particular foaming associated with phytoplankton blooms in the Firth of Clyde (at 55.3°N) has interfered with the operation of shore-based farms, and in April or May of some years the foam has proven toxic to farmed turbot and eels. The toxicity might have come from blue-green algae (Oscillatoria ≡ Trichodesmium species) which perhaps originated the foam, or from the remains of 'flagellate X' embedded in it.

All these blooms have implications for shellfish harvesting and farming, and the recurrence of blooms of Gyrodinium aureolum or 'flagellate X' is a cause of some concern amongst farmers of salmonids in the sea-lochs of western Scotland.

Scientific aspects of the problem include identifying the responsible organisms; identifying the toxins and specific effects on fish and shellfish, and discovering the circumstances that give rise to harmful blooms. Problems of identification are discussed in Appendices 1 and 2. The toxins and effects of Gonyaulax tamarensis has been well investigated in North America (see Lo Cicero, ed. 1975, and Taylor and Seliger, eds.; 1979) and the Japanese have investigated the toxins of other dinoflagellates and some small flagellates. Thus the identification in the dinoflagellate Prorocentrum lima (Ehrenberg) Dodge, of okadaic acid (Murakami, 1982) - a new polyether C_{38} fatty acid - as an icthyotoxin has far reaching implications for the study of toxicity in dinoflagellate species. The 'brevis' toxin isolated from the bloom forming dinoflagellate species Ptychodiscus brevis (Davis) Steidinger has many ether rings and there is also evidence that a toxin extracted from Prorocentrum lima (PL Toxin 1), and another toxin produced by Dinophysis forti Pavillard, a species responsible for diarrhetic shellfish poisoning (Yasumoto et al., 1980) are also derivatives of okadaic acid. It would therefore seem probable that toxins of similar molecular structure are widespread in dinoflagellate species.

Gyrodinium aureolum is probably the most serious phytoplantonic threat to marine fish farming (and perhaps also to wild fish and invertebrates) in North-

Western European waters, and we know very little about its toxicity (if any) or its growth requirements. Its investigation in pure culture is urgently needed, and a proper study of its effects will require co-operation amongst several disciplines.

The ecological problems posed by toxic blooms are part of a more general problem of phytoplankton ecology: what factors determine the growth of a particular species? A hypothesis concerning the origin of *Gyrodinium aureolum* red tides at fronts has been mentioned above; testing it will however require much work in European shelf seas. The explanation of the distribution and seasonal cycle of *Gonyaulax tamarensis* may involve study of its life cycle and especially of its costs.

Recent American investigations by Yentsch *et al*. (1981) have, for instance, shown that motile cells of *Gonyaulax tamarensis* which produce and contain the toxins can have a long life span when non-dividing (months as opposed to days for diatom phytoplankton). A comparison of several cell types including actively growing cells, persistent non-dividing cells, temporary cysts and resting cysts is currently underway at the Bigelow Laboratory for Ocean Science.

Predicting blooms of 'flagellate X' requires an understanding of the hydrography and ecology of the deep, nutrient-rich, sea-lochs of the Firth of Clyde.

Current awareness of incidents involving harmful phytoplankton blooms is at a very high level in many countries and the investigation of these incidents requires the participation of marine scientists of varied disciplines. The wide dissemination of information from involved institutes and from the media has obviously highlighted the problem. However even taking account of these factors there does seem to be an accumulation of evidence to suggest that incidents of this nature are increasing in many parts of the world. In addition the growth of commercial salmon farming projects in Scotland and other European areas coupled with the re-occurrence of salmon mortalities caused by phytoplankton blooms in previously affected areas strongly reinforces the need for long term programmes of research into phytoplankton ecology.

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APPENDIX 1

DINOFLAGELLATE SPECIES OCCURRING IN UK WATERS WHICH HAVE BEEN REPORTED AS TOXIC IN LABORATORY OR FIELD TESTS AND WHICH HAVE BEEN ASSOCIATED WITH FISH KILLS OR INVERTEBRATE MORTALITIES IN VARIOUS PARTS OF THE WORLD

The species covered in this list may be provisionally placed in one or other of the following categories. The evidence for these categorisations is, in a number of instances, very circumstantial. In many reported fish kill incidents there is no unequivocal evidence of the toxicity of the implicated dinoflagellate species and the associated deaths of fish and other organisms have been attributed to other mechanisms eg gill clogging, to low oxygen levels resulting from the high overnight respiratory demand of such concentrations of cells or to oxygen depletion arising from the death and decay of these blooms. It does seem a tenable hypothesis that oxygen depletion is, at least, a contributory stress factor in such situations. In addition, stress of one type or another may cause dinoflagellate cells to secrete organics which could act as growth substrates for pathogenic bacteria and the death and subsequent lysing of cells may liberate toxins into the sea with fatal results for fish and invertebrates. The further possibility exists that assay techniques currently in use do not detect toxins which are chemically dissimilar to those already characterised.

CATEGORY I   Toxic to marine organisms and indirectly to man

Gonyaulax phoneus (Woloszynska & Conrad) L. Loeblich & Loeblich III

≡ Pyrodinium phoneus Woloszynska & Conrad

Gonyaulax tamarensis Lebour var excavata Braarud

≡ Gonyaulax excavata (Braarud) Balech

Prorocentrum minimum Ehrenberg

≡ Exuviaella marie-lebouriae Parke & Ballantine

Ptychodiscus brevis (Davis) Steidinger

≡ Gymnodinium breve Davis

Gonyaulax phoneus is probably conspecific with Gonyaulax tamarensis var excavata. Studies of the 'Tamarensis complex' have highlighted the taxonomic problems associated with this group of dinoflagellates. The systematics of Gonyaulax are presently under review; Dodge (1982) includes G.phoneus and G.excavata in G.tamarensis.

Gonyaulax tamarensis var excavata is a source of toxin(s) in shellfish which cause paralytic shellfish poisoning in man. These toxins can also be transmitted through herbivorous copepods to animals at a higher trophic level and toxin can reach sufficient level in zooplankters to cause fish kills (White, 1982). G.tamarensis also renders Buccinum undatum toxic to man as a result of its predation on toxic bivalues (Caddy, J.F. and Chandler, R.A., 1968).

Prorocentrum minimum has been shown by Japanese investigators to contain or produce two toxic substances and this species is assumed to be a causative agent of a major shellfish poisoning incident, at Lake Hamana in Japan, where 114 people died after eating clams and oysters. Recent tests did not detect the presence of the toxin(s) responsible for PSP.

Ptychodiscus brevis produces a potent neurotoxic endotoxin(s) lethal to fish, man and other mammals. There are no reports of blooms of this species in UK waters.

CATEGORY II Associated with gastro-enteric disorders in man

Dinophysis fortii Pavillard

Prorocentrum micans Ehrenberg

Prorocentrum triestinum J. Schiller

≡ Prorocentrum redfeldii Bursa

Recent Japanese investigations have shown that Dinophysis fortii transmits a fat soluble toxin (dinophystoxin) to shellfish which causes diarrhetic shellfish poisoning in man.

Both Prorocentrum micans and Prorocentrum triestinum have been associated with gastro-enteric disorders in man in Dutch coastal areas.

It should be borne in mind that there are three types of shellfish poisoning which may sometimes be concurrent in people who have consumed mussels. They are (1) Gastrointestinal shellfish poisoning (2) Erythrematous shellfish poisoning and (3) Paralytic shellfish poisoning.

CATEGORY III Toxic to marine organisms or to mice in laboratory tests

Amphidinium carterae Hulbert

Gonyaulax polyedra Stein

Gymondinium veneficum Ballantine

Noctiluca scintillans (MacCartney) Ehrenberg

Prorocentrum lima (Ehrenberg) Dodge

Amphidinium carterae is known to produce, in culture, a substance which is toxic to marine organisms. Recent tests did not detect the presence of the toxin(s) responsible for P.S.P. Japanese investigators have demonstrated the presence of a haemolytic toxin in one benthic Amphidinium species.

Gonyaulax polyedra, a bloom forming species occasionally occurring in high numbers in Irish coastal waters has been shown to contain or produce a substance which is toxic to mice. Recent tests did not detect the presence of the toxin(s) responsible for P.S.P.

Gymnodinium veneficum, in laboratory tests this species had lethal effects on a wide range of marine fish, other marine organisms and mice. It is not known to form blooms.

Noctiluca scintillans, in laboratory tests acidic extracts of this species were lethal to killifish and to mice. The toxic substance was identified as ammonia.

Prorocentrum lima, the major toxin, one of three present in this species has been identified as okadaic acid. All three toxins are lethal to mice.

CATEGORY IV Associated with mass mortalities of fish and/or inverebrates although unequivocal evidence of toxicity is generally lacking

Ceratium furca (Ehrenberg) Claparède et Lachman

Ceratium tripos O.F. Muller

Glenodinium foliaceum Stein

≡ Peridinium foliaceum (Stein) Biecheler

Gonyaulax grindleyi Rienecke

Gonyaulax polygramma Stein

Gymnodinium splendens Lebour

Gyrodinium aureolum Hulbert

Heterocapsa triquetra (Ehrenberg) Stein

Polykrikos schwarzii Bütschli

Prorocentrum balticum (Lohman) Loeblich III

≡ Exuviaella baltica Lohman

Protoperidinium depressum (Bailey) Balech

≡ Peridinium depressum Bailey

Scrippsiella trochoidea (Stein) Loeblich III

≡ Peridinium trochoideum (Stein) Lemmerman

Glenodinium foliaceum, Gonyaulax grindleyi, Gonyaulax polygramma, recent tests did not detect the presence of the toxin(s) responsible for P.S.P. in any of these species.

Gyrodinium aureolum, a dinoflagellate species first recorded in European waters in 1966 and now the most common bloom forming dinoflagellate in UK sea areas has been responsible for kills of marine fish, invertebrates and farmed salmon in British, Irish and Norwegian waters. Although this species has been shown to produce a substance which is cytotoxic to the mussel Mytilus edulis and histological observations on killed fish indicate gill damage the toxic element of Gyrodinium aureolum, if one exists, remains unknown.

Ceratium tripos, Heterocapsa triquetra and Scrippsiella trochoidea are during some seasons common members of the phytoplankton of western Scottish coastal waters, and cause only nuisance effects, if any, to fish farms there.

APPENDIX 2

THE IDENTITY OF 'FLAGELLATE X'

There are two related questions. What is 'flagellate x'? Did it kill fish in Loch Striven in 1979 and Loch Fyne in 1982? Droop et al. (1980) described an Olisthodiscus-like flagellate temporarily named 'flagellate x' as dominant amongst the small flagellate component of a mixed diatom-small flagellate bloom responsible for fish deaths in May 1979. This flagellate could not be reported present with certainty in June 1979, when further fish died, but a similar alga was found in Loch Fyne during fish kills in May 1982. 'Flagellate x' possessed 2 flagella and multiple chloroplasts; it was 15-20 µm in size. It was very fragile often collapsing under the microscope and then showing exploded 'nematocysts'; and it preserved badly in Lugol's iodine. Material from the 1982 bloom has been preserved for electron-microscopy and this may help in identification when complete.

The taxonomy of Chattonella-like algae is confused. Loeblich and Fine (1977) have proposed that species of Heterosigma, Horniella and Olisthodiscus are members of genus Chattonella, a biflagellate multi-plastid containing alga of the division Chloromonadophyta. Fine-structure studies described by Leadbetter (1969) and Loeblich and Fine (1977) show that Chattonella contains 'mucocysts', perhaps the same as the 'nematocysts' seen by Droop et al. (1980). Loebich and Fine consider that the algae identified as Eutreptiella-like euglenoids, and as the dinoflagellate Exuviella, by Iwasaki (1971), Matusato and Kobayashi (1974) and Yoshikawa (1974) were probably Chattonella. These algae formed red tides associated with fish kills.

According to Aquaculture Magazine March/April 1982 Olisthodiscus luteus was identified as the major phytoplankton species during a fish kill near the Lummi Indian Reservation, Bellingham, Washington. It has also been identified in algal blooms in Lower New York Bay on the east coast of America and in Japan where Adachi (1972) lists it as a toxic species. Tomas and Deason (1981) state that various authors report that Olisthodiscus is a poor food source for a variety of marine organisms, viz several prosobranch larval species, juvenile oysters, Ostrea edulis Linnaeus, clams, Mercenaria mercenaria Linnaeus and sardine larvae, Sardina pilchardus (Walbaum). Some of this evidence is not really very supportive as for instance the sardine larvae (Blaxter, 1969) fared just as poorly on several other phytoplankton species.

However it is significant that Tomas and Deason's data do suggest that low filtration rates on Olisthodiscus luteus by Acartia species might well reflect a selection based on the chemical detection of food by these copepods and this could explain the apparent contradiction of the development of major blooms in the late spring during a period of maximum grazing. It is also interesting, in relation to the re-occurrence of Olisthodiscus blooms in affected areas, that the benthoic or palmelloid stage of this species can survive for extended periods in the dark and at low temperatures.

Again in Aquaculture Magazine, Cattolico and Anderson, University of Washington and University of British Columbia respectively who are currently working on a project, funded by Washington Sea Grant, to study Olisthodiscus *luteus* are quoted as saying that this organism "could have potentially disastrous results on fishing and shellfish industries" in the USA. Their preliminary findings indicate that if *Olisthodiscus* becomes stressed by slight changes in temperature, for instance, it secretes organic substances which appear to act as growth substrates for bacteria such as *Vibrio* and *Pseudomonas* which are lethal to oyster larvae.

Chattonella subsala, first described by Biecheler from brackish water from the Étang de Thau in 1936, has been recorded by Hollande et Enjumet 1956 as having toxic effects on fish, molluscs and crustaceans in Algiers Harbour. Subrahmanyan (1954) reports marine animal kills by this species (Synonym. *Horneilia marina*) on the Malabar coast of India. Bernard (1967) states that "the mucous given out by the decomposing individuals has an action similar to that of curare and animals killed by it are toxic or lethal to human beings". In addition it is reported by Okaichi (in Sieburth 1979) that he has isolated normal (50 µm) and large (100 µm) strains of *Chattonella* from the Seto Inland Sea that were associated with massive fish kills. The flagellate attaches to the gills, apparently with its trichocysts, and the toxic factor has been identified as palmitic acid which presumably prevents the passage of oxygen and suffocates the fish. A *Chattonella* species has also been reported as "contributing" to fish kills off Puerto Rico (Juhl and Weidner, 1981).

FIGURE LEGENDS

Figure 1A The British Isles, showing the location of harmful phytoplankton blooms referred to in this paper.

Figure 1B The Firth of Clyde, showing the location of fish kills referred to in this paper.

TABLE 1

PSP TOXIN IN SHELLFISH FROM THE NE ENGLAND/E SCOTLAND AREA 1968-1981

	FIRST RECORDED TOXICITY		MAXIMUM TOXICITY RECORDED		
Year	Date	Location	Date	Location	Toxin*
1968	Not known	Present late May Holy Island	5 June	Holy Island/Bundle Bay	50,000
1969	9 March	Offshore - Farne Islands	12 June	Blyth	6,305
	30 April	Inshore - Holy Island			
1970	14 April	Holy Island	18 June	Blyth	4,100
1971	19 May	Berwick/Holy Island	24 May	Whitby	488
1972	3 May	Holy Island	2 May	Hartlepool	212
1973	25 June	Hartlepool	25 June	Hartlepool	218
1974	13 May	Berwick	23 June	Hartlepool	2,730
1975	6 May	Berwick	28 May	Berwick	6,146
1976	26 April	Hartlepool	29 June	Sunderland	869
1977	4 May	Bundle Bay	20 June	Sunderland	5,350
1978	24 April	Bundle Bay/Berwick	12 June	Saltburn	1,659
1979	30 April	Bundle Bay/Berwick	27 May	Pittenweem (Scotland)	905
1980	15 April	Bundle Bay/Berwick	3 June	South Shields	504
1981	5 May	Bundle Bay	9 June	Sunderland	1,674

*Mouse units of toxin/100 g of tissue; maximum safe level = 400

Figure 1A

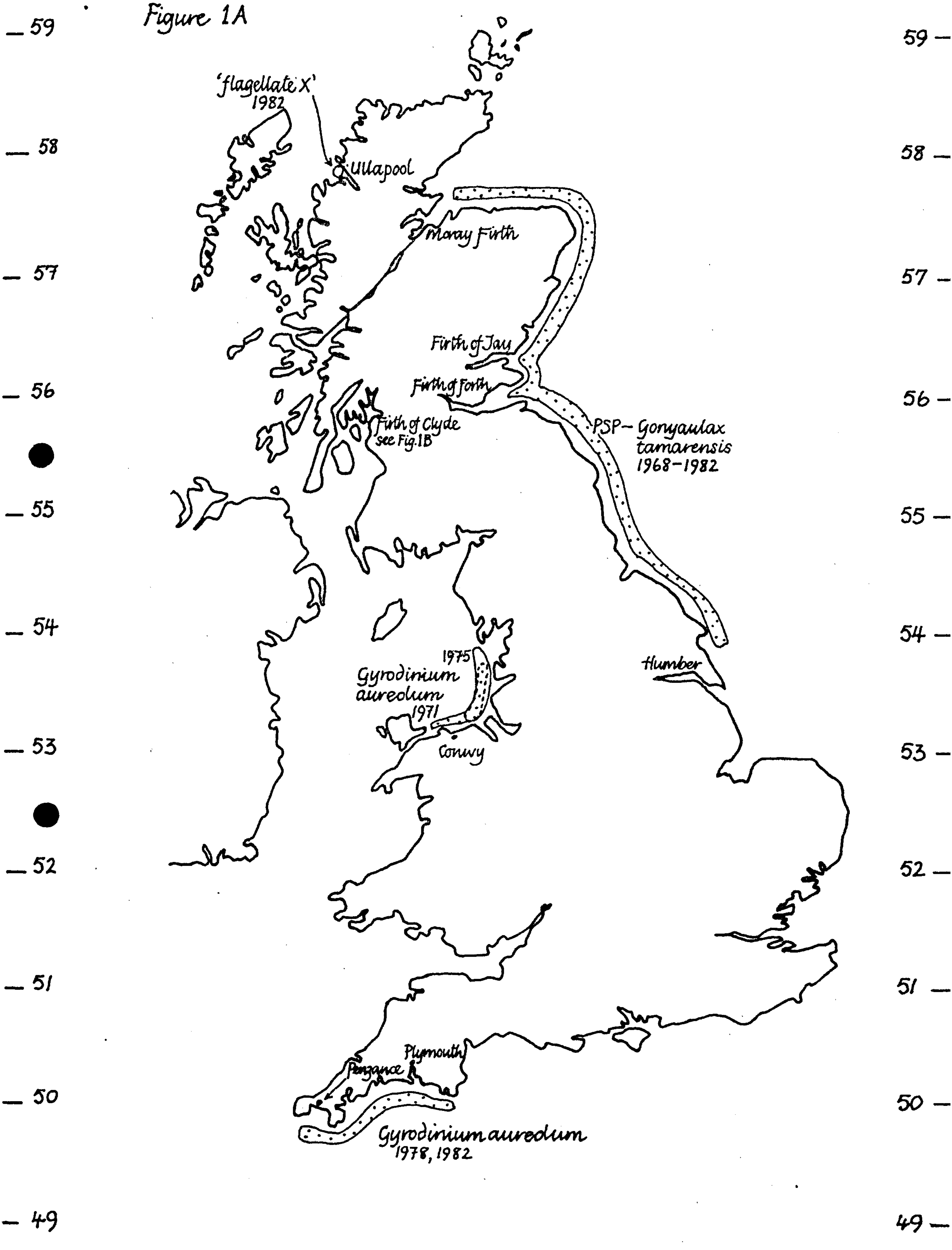
'flagellate X'
1982
Ullapool
Moray Firth
Firth of Tay
Firth of Forth
Firth of Clyde
see Fig.1B
PSP- Gonyaulax
tamarensis
1968-1982
Humber
1975
Gyrodinium
aureolum
1971
Conwy
Plymouth
Penzance
Gyrodinium aureolum
1978, 1982
59
58
57
56
55
54
53
52
51
50
49

Figure 1B

Firth of Clyde,

Scotland